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AGRICULTURAL SECTOR

CISTERNS FOR RURAL LOW INCOME COMMUNITIES IN NORTHEAST BRAZIL

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Abstract:

Access and use of water for low income communities in the Northeast Brazilian semi-arid tropics is complicated by climatic (long dry season and spotty rains), social and political factors (dependency and exploitation), leading in many cases to rural exodus.

But rainwater storage is feasible as a result of sufficient even if irregular annual rainfall (about 500 mm). Traditional ways of storage are clay-pits, pot-holes and hand-dug rock-cisterns. There exist also experiences of cement tanks and failed experiments with PVC sheet cisterns.

IRPAA (the Regional Institute of Appropriate Smallholder Farming), a non-governmental organization, works on the improvement of the hand-dug rock-cisterns, spreading cement-plate and ferrocement cisterns and developing brick and lime-mortar cisterns of an average size of 20 000 liters.

The paper shows especially how to construct hand-dug rock-cisterns and cisterns made of bricks and lime-mortar. In addition, some results of the research about capillary absorption and imperviousness of lime mortar are described.

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1. INTRODUCTION

Brazil is a big country with a surface of 8 511 965 square kilometers and 155 million people (In comparison, China has 9 560 900 square kilometers and 1 200 million people). There are several different types of climate and vegetation.

This paper deals with the semi-arid region of Brazil. About 12 % of Brazil's surface is semi-arid land. It is mostly covered with tree and shrub vegetation, called "Caatinga", and located in the Northeast of the country, an area of nearly one million square kilometers and a population of 17 million. Annual rainfall is below 1000 mm with less than 500 mm in the central part of the semi-arid region (in years with the El Niño phenomenon as in 1981-83, 1993 and 1995 the rainfall is as low as 200 mm). The region is subject to irregular rainfall with great variations both within and between seasons. Even in seasons of good rainfall there are prolonged droughts, which make crop production very risky. Potential annual evaporation rate is above 2500 mm. For these reasons the region is called "the polygon of droughts".

Figure 1: *Map of the semi-arid land in Northeast Brazil.*
Hatched: rainfall below 1000 mm; crosshatched: rainfall below 650 mm.

This semi-arid region has been inhabited for at least fifty thousand years. Unfortunately almost all of the indigenous people were wiped out after the arrival of the Portuguese. From the 16th to the 19th century it was exploited for slave-labor based sugar-cane production and big-scale cattle-breeding. Today the government focuses upon big irrigation projects on the São Francisco River, where the local people are employed as day laborers. Most of the land with easy access to water from rivers or wells is occupied by irrigation-farmers or cattle-breeders. The peasants in the semi-arid region frequently farm in a way not adapted to the climate, especially to the annual dry season and they have not resolved the problem of water-supply. More than that the people suffer from social and political dependence and exploitation; as a consequence there is an exodus from rural to urban areas.

2. WORKING WITHIN THE ENVIRONMENTAL AND LIVING CONDITIONS OF THE RURAL POPULATION

We work at the Regional Institute for Appropriate Smallholder Farming (IRPAA), a non-governmental organization, with its headquarters in Juazeiro, Bahia, in the center of the Brazilian semi-arid region. Its strategy is to promote the understanding of Brazil's Northeast not as a disaster area - as it is usually described - , but as a viable land on which to live and work, using the existing rainfall and ground water and other natural resources in a sustainable way.

We deal with three areas of interest to the peasants:

a - How to conserve water and what must be done to have water during the six to eight months long dry season.

b - How to raise small farm animals, especially goats and sheep well adapted to semi-arid climate and Caatinga-vegetation, and how to feed them throughout the dry season.

c - How to plant avoiding land erosion and how to harvest crops appropriate to the dry climate.

Our principal concern is in sharing the knowledge that the peasants will use to transform reality. We work with base communities, peasant associations and rural workers' unions, all of which send members to our seminars. These members try to share their acquired knowledge with their colleagues at home. There are also seminars for decision making persons like fieldworkers, technicians, community educators, church people, etc. In the long term it is hoped that this work will help change the unjust social structures by showing peasants a secure possibility of life on their land.

3. WATER CONSERVATION FOR THE DRY SEASON

To resolve the problem of water supply in Northeast Brazil, cultural, sociological, political environmental, technological and economic aspects must be taken into account. Therefore IRPAA tries to lead peasants to an appropriate understanding of the semi-arid climate, rainfall, drought, the provisions that can be taken to prevent drought disasters, the occurrence of ground water in the subsoil, etc. IRPAA teaches practical ways (construction of cisterns, shallow wells, small dams, modified ponds, boreholes thrust in by iron tube chisels, how to locate groundwater by dowsing, etc.) to resolve the problem of water.

We understand that the water problem has to be managed in three directions together with the rural people, using all the available kinds of water supply (ground, surface and rainwater). It is necessary to have:

a - drinking water for every family (supplied by cisterns, thrust wells, etc.);

b - community water for washing, bathing and for animals (supplied by ponds, rock-cisterns, shallow wells, etc.);

c - emergency water for drought years (supplied by deep wells and small dams).

Rainwater storage in the Northeast of Brazil is feasible as a result of normally sufficient annual rainfall. Traditional ways of storage are clay-pits, pot-holes and hand-dug rock cisterns.

In some areas, e. g. at Pintadas, Bahia, there exist 15 000 to 50 000 liter cisterns made of cement plates (50 cm x 60 cm x long and 3 cm thick), 14-gauge binding wire and plastered in and outside. The technical know-how probably came from local bricklayers who built this type of cisterns in São Paulo, where they worked during the dry seasons. Certainly these cement cisterns would be a good solution for a government subsidized program to resolve the water supply of families in rural areas, because they can be constructed rapidly, are waterproof, if exactly executed, and the water is of good quality. The problem is that the Brazilian government is not interested in resolving the water problem and the rural people don't have the money to build them.

The government-run Agricultural Research Center of the Semi- arid Tropics (CPATSA) at Petrolina, Pernambuco, made some interesting experiments with different types of truncate pyramidal rural cisterns made of PVC sheets, bricks, polyethylene and cement (Silva, 1988). But unfortunately these experiments were not shared with the rural population by the governmental rural extension service.

Using cisterns to collect rainwater from the roofs of the houses or from ground areas is probably the most viable option to provide drinking water for families in rural areas. For these reasons IRPAA built ferrocement cisterns between 2 000 and 20 000 liters, using pre-fabricated molds and will spread the know-how among the rural communities because it is easier to construct them than cement plates cisterns. Moreover IRPAA works on the improvement of the hand-dug rock-cisterns and developed brick and lime- mortar cisterns up to 40 000 liters. The average size is 20 000 liters. We deal with these two types of cisterns in the following part of the paper.

4. HAND-DUG ROCK-CISTERNS ("CAXIOS")

In some parts of the central Northeast region of Brazil (like Casa Nova, Bahia; Remanso, Bahia; and Petrolina, Pernambuco), there is a subsoil of micaceous rock, and so it is possible to dig into this rock with mattocks and pickaxes, because the hardness degree of mica is only number two. During the big drought of 1981-83 the peasants of Casa Nova remembered that in former times the people dug "caxios" to collect rainwater. "Caxios" are deep rectangular holes dug vertically into this micaceous rock, which receive the rainwater from a nearby ground catchment area or a diverted small seasonal stream. The measurements are 3 m (width), 6 m (length) and 4 m (depth), or bigger. Often there are dug two "caxios" together, one for drinking water and the other for water for the animals. Frequently the "caxio" is protected by a wooden fence. There are more than 1000 "caxios" in the rural area of the county of Casa Nova.

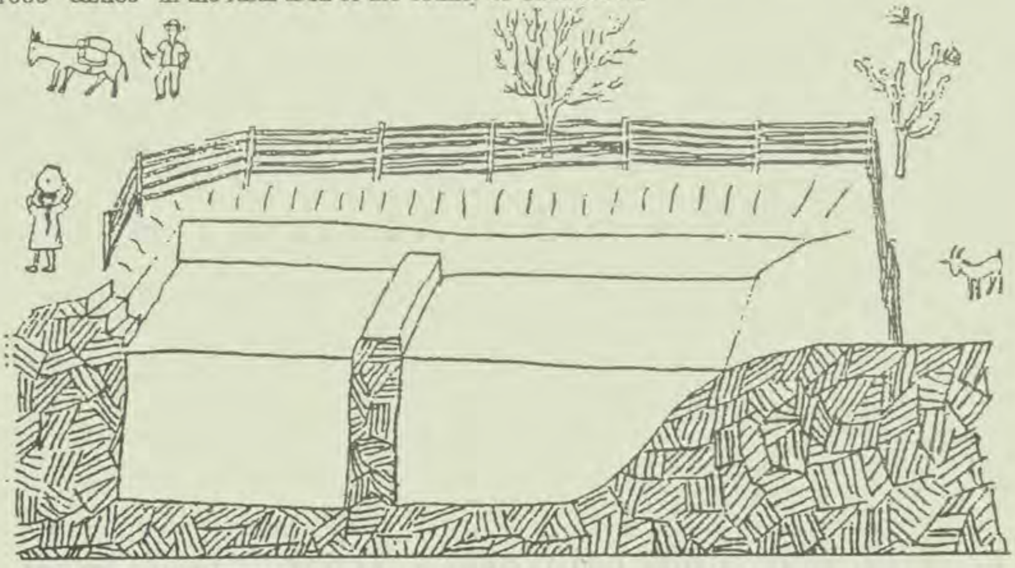

Figure 2: ***Hand-dug rock cistern ("caxio")***

The advantages of this type of rainwater collection system are:

- the "caxio" is an invention of the local rural people and the construction can be administrated totally by rural communities;

- it is only labor-intensive, but not cost-intensive in construction (only digging equipment must be bought);

- the evaporation rate of a "caxio" is low because of the 4 m depth and the vertical walls;

- even in the droughts of 1993 and 1995, with only 200 mm rainfall, the "caxios" were full of water, without water shortage for people and animals.

The only disadvantage is that the occurrence of this type of rock is limited. But there are various places with micaceous subsoil in Northeast Brazil, where this way of water-harvesting has still to be applied.

5. BRICK AND LIME-MORTAR CISTERNS

IRPAA has reinvented a technique for making cisterns from bricks and lime-mortar. The technique of using lime for constructions was introduced in Northeast Brazil by the Portuguese and commonly used until thirty or forty years ago, when lime was replaced by cement.

The brick and lime-mortar cistern is a cylindrical underground tank with a hemispherical bottom (Gnadlinger, 1993 and 1994). The cistern has the shape of the "thick half of an eggshell" and it is important to dig it at once in this shape to facilitate the construction of the wall. The use of a plummet, when the cylindrical part of the hole is dug, is opportune.

The size of the cisterns is adapted to the needs of drinking water of each family. We suppose the necessity of 14 liters of water per person a day (Silva, 1988), i. e. 3 360 liters per person in the eight months long dry season. The size of the cistern depends on the number of people in the house: the sum of the number of people in the house times 3 360 indicates the volume of the needed cistern. For example a family of six people needs 20 160 liters of water (3 360 x 6 = 20 160). To have a catchment area big enough, it is necessary to calculate the probable rainfall on the roof too.

The construction materials are burnt loam bricks (20 cm x 10 cm x 5 cm), mostly fabricated in rural communities, sand and lime (Table 1). Lime is burnt in some rural communities too.

5.1. Why use lime instead of cement or what are the advantages of lime?

We cite some advantages of lime compared with cement here (Intermediate Technology Group, 1991):

- Lime as building material needs less energy in production than cement.

- Lime is fabricated and sold by small rural communities and not by international concerns like cement.

- Lime is cheaper than cement.

- Using lime you dispense with steel and wire which are expensive.

- Lime-mortar dries slower than cement-mortar. For this reason it is not necessary to hurry during the construction of a cistern.

- Lime is more elastic and does not crack so easily like cement.

- It is easier to repair a lime-cistern than a cement-cistern.

- Using lime, local communities can assume construction and maintenance.

You can argue that a disadvantage of lime is that it is a more labor-intensive technique, but on the other hand it can improve the employment situation for the rural population in the dry season.

5.2. How to work with lime?

a - In our region old bricklayers still know how to work with lime and in several regions of Northeast Brazil limestone is still burnt in community owned limekilns and lime powder is available in almost all places. For cisterns this lime powder is mixed with well graded angular sand: Three 18 liter cans of sand with one 18 liter can of lime powder (sand lime ratio 3 : 1). Before this, it is necessary to sift both lime powder and sand. You must mix well the mortar and add some water. Then you have to "beat" the mortar with a wooden stick during 30 minutes. Then you must mix the mortar again. This process has to be made three times running for dissolving small lime lumps in the mortar. Then the mortar has to cure ("rest") for at least three days before using it.

If you want to build a brick and lime-mortar cistern, you must first have dug the eggshell shaped hole according to the size you want the cistern (Table 1). When you construct the cistern wall, it is necessary to make it 20 cm thick. You must begin the construction of the wall in the middle of the hemispherical bottom, placing the bricks standing (The bricks accompany the curve of the bottom). When you come to the cylindrical part of the cistern, you must use the bricks in one row lengthwise and in the other row crosswise and lean them against the soil, because only in this way the wall is later able to support the weight of the water. Exactly for this reason you must not build the wall more than 0.5 m above the ground. During the wall-raising you must not use a plummet (like in cement constructions). When the construction is finished you must wait two month for drying before you can plaster the cistern.

This method is the traditional Brazilian way to work with lime and it is relatively easy to learn. It is rather labor-intensive. But in the dry season many non-employed peasants are at hand. An advantage for a semi-arid region is that very little water is needed for construction.

b - There was used a second method to work with lime too, a method used in Europe (Warth, 1903; Induni, 1988). It is less labor-intensive, but more water is needed. In this case you need quick lime burnt in some rural communities, and you must slake it. Lime is slaked in an empty metal oil barrel and then run through a sieve (to remove unslaked lumps) into a pit or tank, where it is allowed to settle and to slake fully during at least four weeks. Slaked lime will keep indefinitely if kept covered with water. Therefore it is necessary to put water into the lime tank from time to time before it dries out.

After four weeks you can use the slaked lime for building cisterns. You can make this mortar with a sand lime ratio 4 : 1 and use it as in the first method. If there are still some lumps in the slaked lime, we recommend to "beat" the mortar at least once.

5.3. Plastering the cistern from inside

The major problem of brick and lime-mortar cisterns is how to hold the water because lime and bricks are not waterproof for themselves. You must add additives to the plaster mortar which make the plaster impervious. Thereby carefulness is necessary when you plaster the tank from inside in order to obtain an actually waterproof cistern. We give here a summary of our experience made in the last three years with several kinds of plaster. We include here the results of the research made together with the Federal University of Bahia in Salvador, Bahia (Santiago, 1995).

a - Using lime without additives does not make the cistern waterproof because of the capillary absorption of lime and bricks.

b - To obtain waterproofness, we applied successfully "Vedacit - Revestimento OBE 207", an impervious and semi-flexible coating, based on acrylic modifiers, available on the Brazilian market, but too expensive for low income communities.

c - In former times in Brazil there was used whale oil to get lime constructions waterproof (Santiago, 1992). But whale oil is not available any more today.

d - In place of whale oil we experimented different types of plant oils. At first we used castor oil produced by the rural population. We mixed 2 per cent of oil, according to the weight of lime, with the mortar (sand lime ratio 3 : 1 or 4 : 1) and made plasters. Castor oil does not hold water. It gets washed out when you put water into the tank.

e - Then we used soybean oil in the same way. Soybean oil is the cheapest oil available in Brazil. Soybean oil holds water very well because it gets a resin with time. There is a problem that the plaster with oil diminishes its compression strength and it can produce cracks.

f - Oil has already been used by the Romans to make tanks waterproof (Vitruvius, 1960). Based on their experience, we found out another possibility to obtain waterproofness with soybean oil. Firstly we plastered the inside of the cistern with a 1.5 cm thick layer of lime-mortar without additives. Then we painted the lime-mortar plastered cistern with this oil three times always at intervals of a month. It is necessary to wait some months until the soybean oil painting becomes a waterproof resin before putting in water. If you did not yet obtain imperviousness you must repeat the painting. This method works very well.

g - Extracting juice from the smashed leaves of a common cactus in Northeast Brazil (Opuntia spp.) and adding it to the plaster mortar did not give satisfactory results until now.

h - We also used a thin layer of cement-slurry above the plaster of lime-mortar for waterproofing. We plastered the cistern inside 1.0 to 1.5 cm thick with lime-mortar (sand lime ratio 4 : 1) with 5 per cent of cement, according to the weight of lime. We waited two month for drying. Then we put a layer of cement-slurry with a brush above the lime plaster. As a result we obtained a waterproof cistern. You must wet the plaster before and keep it wet some days after applying the cement-slurry and you must cover the cistern to avoid cracks.

i .- A faster process is to use cement-slurry together with the lime plaster. We plastered the cistern with a 0.5 cm thick layer of lime-mortar (sand lime ratio 4 : 1, with 5 per cent of cement, according to the weight of lime). Then we put a layer of cement-slurry with a brush. Above the cement-slurry we put another 0.5 cm thick layer of lime-mortar. You must moisten the plaster every two days and cover the cistern. The plaster must dry for two month, than you have a waterproof tank. IRPAA recommends to use this type of plaster. The cistern gets waterproof and the costs of the little cement that is needed are low.

Annotation: To make the cement-slurry you have to fill a bucket halfway with water and pour dry cement in small amounts while stirring constantly, until you achieve a soupy consistency. Then apply the cement-slurry with a brush to the wall of the cistern. The slurry must be used within half an hour (Hasse, 1989).

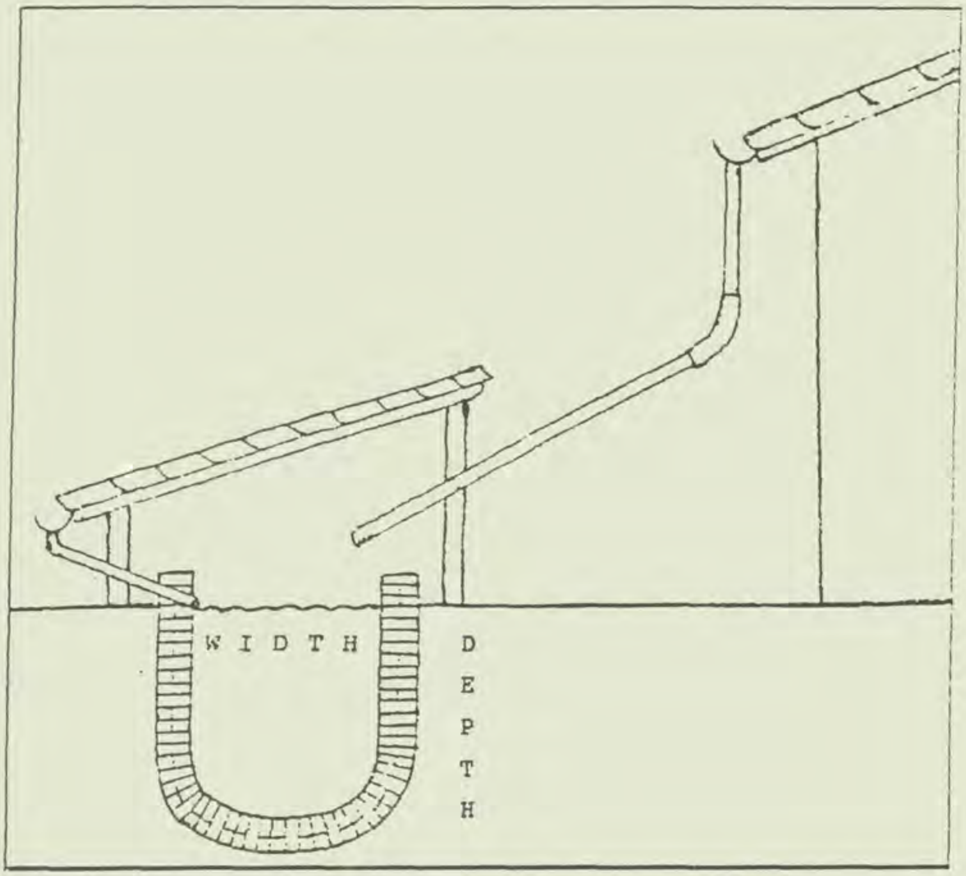

Figure 3: *Side view of a brick and lime-mortar cistern with roof-house*

5.4. Covering the cistern

We recommend to cover the cistern already before it is plastered inside. You can cover the cistern with a low rectangular roofhouse, its walls made of lime-mortar and bricks and the roof covered with laths and tiles. The advantage of this cover is that you can harvest the rainwater from this single pitch roof besides the rainwater harvested from the dwelling-house roof. Other peasants who have enough wood at their disposal cover the cisterns with timber boards. The gutters and downpipes that channel the rainwater from the dwelling-house and from the cistern roof are made of PVC tubes or zinc-sheets, but sometimes gutters made of stems of sisal, palm-trees or empty tin-cans are used.

6. CONCLUSION

We know that the construction of brick and lime-mortar cisterns is a long-term program. We are pleased that we achieved a plaster impervious to water for the lime-mortar cistern during the last three years. Until now we treated several types of cisterns in all our water harvesting seminars and there is an increasing consciousness of the possibilities of rainwater collection among the participants who are selected by the rural communities. These people became a type of grass root technicians entrusted with spreading and accompanying water problem solutions.

The idea of resolving the drinking water supply with brick and lime-mortar cisterns is well accepted, because the technical know-how can be managed by the rural people and a big part of the building materials are available in the rural region. There is a good participation of the community members as to the obtaining of construction material and labor participation. Money resources from out of the communities can be reduced. There are already some base communities that are constructing brick and lime-mortar brick cisterns, and we organized a workshop for brick and lime-mortar cisterns in a rural workers' labor union. But until resolving the problem of water supply many further steps have to be made as consciousness and organization of the affected people and sincere governmental involvement.

IRPAA will continue the research. Especially we want to find out how the people in the Ancient Near East have resolved this problem more than 2000 years ago.

We invite the delegates of the 7th IRWCSA who work with this kind of cisterns to join us with their experience.

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Table 1. The size of the cisterns and the necessary quantity of bricks and lime

Number of persons per family	Liters of water in 8 months dry season	Width of the cistern	Depth of the cistern	Number of bricks	Lime powder18 l cans	Quick lime 18 l cans
3	10 080	3,20 m	2,60 m	3 500	55	16
4	13 440	3,40 m	2,80 m	4 200	70	21
5	16 800	3,80 m	2,90 m	5 000	87	26
6	20 160	4,10 m	3,00 m	6 000	107	31
7	23 520	4,20 m	3,20 m	7 000	122	36
8	26 880	4,60 m	3,30 m	8 000	140	42

Notes

1. All the numbers are approximate.

2. The measure of the width of the mouth and the depth indicates the size of the hole to dig.

3. The size of the bricks is 20 cm x 10 cm x 5 cm. If you use bricks of 20 cm x 10 cm x 4 cm, the quantity of bricks will increase 20 %. The bricks are normally fabricated at the rural communities.

4. You have to choose, to use either lime powder or quick lime.

5. It is interesting to make a price comparison (values from January 15,1995, at Juazeiro):

For a cistern of 20 000 liters you need: either: 31 cans of quick lime, U$ 2.00 each can, that is US$ 62.00; or: 105 cans of lime powder, U$ 0.80 each can, that is US$ 84.00; or: 18 bags of cement, U$ 7.50 each bag, that is US$ 135.00.

PERSPECTIVE OF THE RAIN-FED AGRICULTURE IN GUANGTAO COUNTY

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The so called " rain-fed agriculture", should be the agricultural activities that directly which uses the rainwater resources in the local area. There is a long history of rain-fed agriculture in China. The 24 solar terms is just the agricultural scientific legacy that extracted from the long concrete agricultural practice of the people. The achievements of rain-fed agriculture are closely related to the 24 solar terms. This paper just analyze the development of rain-fed agriculture in Guantao county since 1949, and summarize the experiences and lessons for the establishing of new rain-fed irrigation agriculture system, and the long, effective and steady development of agriculture.

I. Introduction to rain-fed agriculture

During the dozens of years in which the conventional rain-fed agriculture, which lasts for thousands of years in China, has been changed into rain-fed irrigation agriculture, the level of agricultural productivity has been changed from being low and unsteady to stable and high productive, and the water resources has been changed from relatively excess to absolute shortage. The exploitation and utilization of water resources have been not in accordance with the regional actual situation, and it is severe out of control.

1. Geographic and Climate Characteristics.

(1) Geography:

The Guantao country is located in the southern part of Hebei Plain, and in the upper reaches of Heilonggang river basin. Its longitude is 115.06' - 115.28'E and the latitude is 36. 27' - 36.47' N. The width from the east to the west of Guantao County is 18km, and the length from the north to the south is more than 40km. The total area of Guantao is 456.3km^2, among which the cultivated land is 485, 000 Mu(667m^2). The land is with high fertility and it can be divided into three soil categories: loam soil, sandy loam and clay soil. Weiyun River, which is the only one seasonal river passing through this County, is with a length of 40.5km from the south to the north, and with a annual run-off of 776 million m^3. In the period from June to August, the amount of run-off is 621 million m^3, which accounts for more than 80% of the total annual amount of run-off. Weixi channel, which links Weiyun

River at the south and flows to the north through the middle part of the county, and with a length of 37.5 km in the territory of Guantao County, is the main channel for both storage and drainage. The main crops are wheat, corn, cotton, millet, coarse cereals and oil-bearing crops. In recent years, the area of farm land for vegetables and fruits is enlarged rapidly.

(2) Climatic Features:

Guantao County is located in the areas of monsoon climate of the warm and semi-arid climate zone. It is under the alternate influences of the continental and ocean air masses and with a obvious seasonal wind system. The normal average of precipitation is 553.77 mm. In spring, the continental air mass is of priority, wind is heavy and the rainfall is small. The days of heavy wind is the most in Spring and wind speed is the highest. Additionally, the increase of air temperature is rapid and the evaporation is strong, so, the rainfall can not make up the evaporation. As a result, the upper layer of soil is dried rapidly, and the seeding and growth of crops are seriously affected by the continuous droughts. In Summer, under the control of ocean masses, the weather is hot and humid, and crops grow fast. In the fall, the weather is steady with weak wind and small cloud.

2. The Stages of rain-fed agriculture Development.

In Guantao County, the transitional period of rain-fed agriculture to rain-fed irrigation agriculture can be divided into following three stages:

(1). Rain-fed agriculture is also called as dry farming agriculture. Before 1950's, there was no irrigating facilities and agriculture completely depends on the natural rainfall. In this period, water was relatively surplus. Based on the 24 solar terms, rainwater was used directly. The main methods which were adopted were: sowing immediately after precipitation, frequent middle ploughing and harrowing for preservation of soil moisture, selecting suitable seeds according to the amount of precipitation and the quality of ground water, harvesting of rainwater for the resistance of drought and applying animal manures etc. There is a saying which has been handed down for many generations: " wheat relies on three rains respectively in August, October and March ", that's to say: the rain in August is the basic soil moisture supply, the rain in October is the important condition for the seeding of wheat, and the rain in March is just in the period for wheat to turn green, it plays an important role for a high wheat yield. Because the level of the social productivity low and the natural disasters of drought, water-logging, salinization exist together, the non-irrigated agriculture is unstable, and the yield is low, the normal average of wheat and cotton yield respectively is 75kg/Mu and 10kg/Mu.

(2). Diversion of River for Irrigation.

In 1960's, the level of agricultural productivity in Guantao County began to go up. Pointing to the problems of frequent water-logging and drought, a series of channels have been digged, and many pumping stations and water storage works have been build up. Along Weiyun River and Weixi main branch channel, 95 pumping stations and 36 channels, which is 237.7km long in total, have been established. They were both favorable for irrigation and for water-logging drainage. However, the groundwater was still shallow, and the salinization was serious. Due to the rapid development of farmland irrigation, drought was mitigated and the yield of wheat and cotton was increased rapidly, they respectively reached 124kg/Mu and 20kg/Mu. That was a historic change.

(3). Exploitation of groundwater.

Since 1970's, a lot of wells were digged and the groundwater was exploited in a large scale. By the year of 1982, 4200 wells were built in Guantao country. Along with the development of well irrigation, river irrigation increased rapidly. The irrigated land was up to 350,000 Mu, among which, irrigated land by wells was about 210,000 Mu, which accounted for 60% of the total irrigated land. The results of the exploitation of groundwater in large scale were:

(1). Much salizationed land were changed into fine farmland. The reason was that the groundwater level has descended from 3.58m in 1973 to 7.18m in 1982, which both prevented evaporation of the under groundwater and provided more capacity for rainwater storage. The combination of river irrigation and well irrigation formed the embryonic form of rain-fed irrigation agriculture.

(2).The exploiting of natural resources was out of control for the single well-irrigation form. Since 1980's, overshadowed by the blind trend that groundwater resources is inexhaustible in supply and always available for use, the development of pump station was ignored. By the year of 1993, motor-pumped wells were more than 5600, and the pump station were merely about 10. The area of irrigated farmland was up to 400,000 Mu, among which the area of well-irrigation accounted for more than 95%. Because of the rapid development of facilities. agricultural production was greatly increased. In the year of 1992, the crop yield of the whole country was 538kg/Mu and the cotton was 52kg/Mu, they were respectively as more as eight and five times of the average yield in the period between 1949-1963.

(3). In the meantime, the cost of well irrigation raised up rapidly, and it was more than 10 yuan per mu for each time of irrigation. The main reason was the over-exploitation of ground water, which resulted in the rapid drop of ground water level. The pumps had to be renewed frequently. Since 1978. motor pump station were renewed for three times, and in addition to the increase in irrigation times of flood irrigation, irrigation had resulted in negative profit.

3. The Situation of Water Resources Utilization.

At present, The exploitation of water resources in Guantao Country is serious out of control. The main manifestations are:

(1). The utilization of rainwater need further developing. In resent years, the construction of water storage works are attached with more importance. However, the using degree of stored water is low. Especially, no attention is paid to the construction of field ridges which can be used for rainwater harvesting. Methods of soil moisture preservation are ineffective and the loss rate of rainwater is high. It not only results in much water waste, but also leads to economic loss directly.

(2). The surface irrigation works are paralysed. At present, 80% of the surface irrigation works are too old. In fact, only six pump stations is working. In the four large irrigated regions, only one is kept operation in a low efficiency. In resent years, the average of annual river diversion is 2.1 millions m3. and the use rate is only 2.7%. It is proved by practice that the usage of surface water resources is not only favorable for crop growth, but also mitigates the pressure of ground water. Therefore, it is in doubtable that the short exploitation of surface water resources is a great loss.

(3). Ground water is overexploited. There are 5670 wells in Guantao County, and each 68 Mu of irrigated farmland is equipped with a well. The permitted tapping amount of ground water is 57 million m3, while the normal average of actual annual exploitation of ground water is 85 million cubic meters. The amount of over tapped ground water is 28 million cubic meter and the ground water level dropped 0.56m every year. As a result, not only the cost of irrigation is raised, the burden of peasants is increased, but also a series of ecological problems are brought about.

II. Agricultural Ecological Environment Problems

In the short period of past dozens of years, because the exploitation of water resources was out of control, the ecological environment deteriorated. The trend of environmental degradation is serious.

1. Rapid Decrease of Run-off

From 1971 to 1982, the normal average of annual run-off of Weiyun River was still up to 1905 million cubic meters and its maximum was 3965 million cubic meters in 1976. Decrease of the rapid decrease of run-off, a series of ecological deterioration and social problems were brought about.

(1). Shipping business was out of work. Before 1960's, water quantity of Weiyun River was fine. and the discharge was high. Guantao town was a good port for water transportation, and ships could reach Tianjing City directly. However, since the later of 1960's, shipping business disappeared. it brought away not only the profit of water transportation, but also the benefits of environment and social economy. In stead of the shipping business, farming irrigation was greatly developed along the both banks of Weiyun River, especially in the upper reaches. Which is more profitable, shipping business or irrigation ? there is no answer ever since.

(2). River Pollution and drying up. According to the data of 1971-1982, the average number of river drying up days was 61, and the maximum was 206 days in 1974. Furthermore, factories along the river, especially the paper factory, poured out large amount of waste water without any water treatment. River pollution not only killed fishes, but also greatly affected human health through food chain.

(3). River irrigation declined. The surface water conservancy facilities and the area of irrigated farm land all decreased. Of course, it had a close relation with the rapid decrease of run-off. In fact, it was not that there even was no water for irrigation, if it was used properly, at least 40, 000-70,000 Mu of farm land can be irrigated. This is undoubtedly an important supplement to rain-fed irrigation agriculture.

2. Soil Aridization

(1). The shallow fresh ground water was exhausted. Exploited for twenty years, wells became deeper and deeper, the shallow fresh ground water was exhausted. Except for the ancient riverbeds in the west part, the water quality are all worsened. The mineral degree was increased from 1.5g/l in the past to 2.5-5.5g/l nowadays. Year by year, much of the salty ground water were used for irrigation, the soils of well irrigated areas were salinized again. It belonged to secondary saliniation. For years of continuous drought, the secondary salinization would appear suddenly. It mainly distributed in the areas where the shallow ground water was exhausted, it is more serious in the single well irrigated areas, but the most serious area was still in the original salinized regions. The degree of salinization was more serious along with the drought became more and more severe. A typical example is the secondary salinization in the Spring of 1993, because of the severe drought in 1992, the total disaster area was 12500 Mu, among which 27000 Mu had no harvest, wheat production reduced by 30 million kg.

(2). Soil fertility declined. Middle-Lager salty ground water and deep-layer alkaline ground water were used for irrigation in salty water areas. In addition to the application of chemical fertilizer in large amount, soil salinization was accelerated in the cultivated layer, soil granular structure was destroyed, it became hardened and its ventilatage became worse. In the meantime, the organic fertilizer was applied less and less and organic matter in soil declined. According to the sampling by agriculture department, the organic matters were all between 0.4% and 0.9%, the contents of N, P, K were also low, they were respectively 0.05-0.1%, 3-15(ppM) and 50-200(PPM). In 1993, some typical peasant families were investigated, and it was found that the production was notably high if organic manure was applied in a large amount. That's to say, crop yield can not be increased only through the improvement of irrigation facilities

(3). Species were restrained. Because the soils become more arid, natural vegetation were decreasing. some species are district. In the arid salinized field. wheat seedling and apple trees are all died. The drought degrades the environment of soil animals and micro- organism the food chain was out of balance, plant disease and insect pests were getting serious. In 1992, boll worm widely spreaded out, it harmed not only cotton, but also wheat and other plants. Meanwhile, many kinds of birds were disappeared after large amount of pesticides was applied.

3. Useful Findings

(1). Precipitation Change in Space and Time

The main characteristics of precipitation in space and time in Guantao County are: Firstly, the annual variation is very large. In 1956-1993, the average of annual precipitation was 553.77mm, In 1964, it was 830 mm, and in 1992, it was only 241mm. rainfall concentrates in the three month June, July and August, and in which the rainfall accounts for about 70% of the whole year. Dry and wet seasons were distinct, and drought alternates with water-logging. It added more difficulty to the use of rainwater. Secondly, the precipitation was gradually decreasing. In 1956-1969. the average of annual precipitation was 586.16mm. In 1976-1982, it was 549.3mm , and it was 517.84mm in 1983-1993. This is a complex problem. Thirdly, the surface run-off was changed obviously. In 1964, rain lasted for seven days from April 13 to 20, the total rainfall reached 206.7mm. The detected rainwater in the flat areas reached 200-300mm. In contrast, in August 15, 1981, a storm, which produced rainfall 100-300mm, didn't bring about water-logging. If the storm took place before 1978, the effect would be extremely serious. The reason was that the capacity of soil water storage ground water reservoir were enlarged by the over exploitation of ground water.

(2).limited ground water and infinite rainwater

The aridization of plain area and drying up of shallow ground water both show the limitation of ground water. Ground water is limited by surface run off and other supply. So, we must base on the hydrogeological data to calculate the amount of tapped ground water in order to keep the balance between supply and utilization. On the contrary, rainwater is relatively infinite. The infinite rainwater is still a relatively stable, it can be used in anywhere according to the local situation.

(3). The Unmatched Cropping System with Water Resources Use

In Guantao County, there is an outstanding contradictory of irrigation: on the one hand, water resources is severe short, the quantity of water resources for per capita is only 250 cubic meters, for per Mu is merely 128 cubic meters; on the other hand, water is wasted seriously. The area of hydrophilous crops was increased, while the area of water saving crops was decreased.

III. Building a New Style Rain-fed Irrigation Agricultural System.

According to the geographic and experiences obtained in the past dozens of years, it is suitable for Guantao Country to build newstyle rain-fed irrigation agricultural system and promote the development of ecological agriculture. Therefore, from now on, we must better the management of water resource and make a good use of rainwater, and establish a good basis for ecological agriculture.

1. Reforming the existing water conservancy works.

(1). Developing small water pumping stations.

Based on the condition of present water resources, the water pumping station should be forward to " small, new, more ". Some large pump stations near Weiyun River should be remade into small stations. In order to make a full use of river, before the year of 2000, twenty new pump stations will be established in the sites where the condition for water pumping is fine, and thirty-five fixed water pumping stations will be built along the both banks of Weixi channel. If one station can effectively irrigate 500-1500 Mu of farm land, this the irrigated area would be increased from current 25000 Mu to 74,000 Mu. If so, the surface water resources can be put into a full utilization and the profit of rain-fed irrigation agriculture can be greatly raised.

(2). Building water storage network.

In recent years, the local government pay much attention to river water use.

The Weixi channel was rebuild and dredged, ditches near villages were digged and linked to channels, and a water storage network was formed. It can store 12 million m3 water in a normal year, 8 million in low water year, and 25 million in a high water year. The water storage projects will not only raise the level of water-logging drainage, promote the capacity of drought resistance, but also replenished ground water, as well as control the salinization. The profits of both ecology and economy are considerable.

(3). Ajusting the distribution of motor wells.

The general principles for the adjustment of motor well distribution are: strictly control the amount of motor wells, ensure the well quality, and strive for a good economic profits. Along the rivers. some wells should be abandoned in view of their poor water quality and low water yield, the well density can be bigger in the single well irrigated regions. In the salty water areas, motor well group should be built from shallow to deep layer, and rotating irrigation should be carried out in order to raise the irrigation efficiency. In recent years, we have already begun to do these jobs, such as, limitation of water resources use by license, proper control by investment, and leading peasants to adjust their irrigation structure by technological and economic assessment.

(4). Irrigation technological innovation

The water saving projects are necessary for these regions where water is short. In recent years, we have built 317,000 meters of water-proof pipes, and 938 wells. 76,000 Mu of farm land can be irrigated. From now on, we plan to enhance the percentage of water-proof pipes by the year of 2000 and make a good basis for irrigation. So that we can save 27,600,000 m3 of water resources each year. In the meantime, spray irrigation and drip irrigation will be applied in rich villages, and the area of spray irrigation and drip irrigation is planed to be increased to 70,000 Mu. The innovation of irrigation will greatly mitigate the problem of water shortage and develop the modernization of agriculture.

2. Building the Economic small Regions of Rain-fed Irrigation Agriculture

According to the distribution of water resources, Guantao County can be divided into four economic regions .

(1). Region along the rivers. There are nine villages along the Weiyun River, and the area is 114,000 Mu. Wells is distributed all over the region except the river beaches. Water resources is abundant, and water quality is good. It is very good for agriculture. In this region, the rainwater should be better used, and river water should be used for irrigation in arid period. The crop species should be wheat, cotton, corn grain, soybean, peanut, and vegetables, and the beaches can planted weeds to develop hunsbandary.

(2). Water storage region. The middle belt from south to north is a salt water region. The area is 127,000 Mu. In this region, the shallow ground water is dried up, water is short and water quality is poor. It greatly affect the development of agriculture. Therefore, storing water in Weixi main channel is an important measure for the mitigation of water shortage crisis, for the control of secondary salinization. Under the condition of full use of rainwater, ponds and channels should be used to store water, the saltwater in middle layer and deep alkany fresh water should be used properly, and the combination irrigation of stored water , middle layer salty water and deep fresh water, and rotating irrigation should be carried out. In this region, hydrophilous crops, such as wheat and corn, should be planted, and intensive management should be carried out in order to promote the crop yield. and in a proper extent, the area for cotton, grain, soybean and orchard etc should be increased. In the heavy salty land, weeds and trees should be planted for the development of husbandry.

(3). Well irrigated region. This region is the typical economic region of rain-fed irrigation agriculture. The area is 159,000 Mu. In this region, it is very important to make a full use of rainwater, and tap the shallow fresh ground water rationally and keep the balance between supply and utilization of ground water.

(4). Dry farming region. It is sporadicly distributed in the whole county. This region is suitable for drought enduring crops, grass land and meadows.

3. Improving the micro-climate of farm land

The micro-climate of farm land can be changed more favorable for agriculture through changing the conditions of the earth surface. It is important for saving water resource and making a full use of rainwater. Furthermore, it plays an important role in this areas where water is short.

(1). Rationally operating the Soil reservoir. As described above, the dry soil layer is favorable for storing rain water. It is reported that a soil lager of two- meter depth can store water as much as 550-600 mm. Therefore, it is suitable to regard the soil layer as a reservoir for water storage. It is important to make a full use of water storage capacity of soil layer, and store the rainwater as more as possible in rainy season for dry season. The soil reservoir is useful for the improvement of farm land micro-climate. The extent of field micro-climate is thought to be 1.5-2 meters above the soil surface. In fact, this space is greatly influenced by the soil moisture two meters under the soil surface.

(2). Making a rational plan of the plain vegetation. Making a rational plan of the plain vegetation is an very important measure for improving field micro-climate and promoting the function of rain-fed irrigation agriculture. Many countryside pay much attention to this work, protect the vegetation in the field so as to lessen the soil evaporation. They have built forest net in the field and carried out the inter-cropping of crops and trees or trees and weeds. Sparse trees in field is favorable for water storage control and water quality improvement. With regard to the cropping system, the traditional experiences and modern techniques should be combined.

(3). Coverage of farmland. Land coverage is very effective for decreasing soil evaporation, ameliorating soil texture and lessening the effective soil radiation. Therefore, under the condition of developing rain-fed irrigation agriculture, land coverage must be established as a rule for cropping system.

(4). Reviving the traditional agricultural techniques. China is one of the countries in the world with an ancient civilization. The legacy of experiences and science about agriculture is very rich. So, it is very useful for agriculture to revive the traditional agricultural techniques. The traditional techniques include: deep ploughing of the farmland; increasing manure fertilizer to change the soil texture; intensive cultivation and management and operation of agriculture strictly according to the 24 solar terms. It is undoutable that rain-fed irrigation agriculture will bring about a considerable economic profit.

COMPREHENSIVE UTILIZATION AND ADMINISTRATION OF WATER RESOURCES OF ZHANG FU HE IRRIGATION AREA

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The designed irrigation area of Zhang Fu He is 3045000 mu. Theeffective irrigation area is 2010000 mu. The irrigation area has 5184 main canals, branch canals and lateral canals. The headwaters is Yue ChengReservoir and Dong Wu Shi Reservoir. In the near future, supplying water is 450 million m3 or so per year. The actual leading water capacity from Yue Cheng Reservoir is 70 m3/s, while the actual leading water capacity of Fu Yang He from Dong Wu Shi Reservoir is 30 m3/s. The administration department not only undertakes to irrigate 1/3 cultivated land of Han Dan plain area, but also supplies water to Han Dan City electric power, iron and steel, chemical fertilizer, spinning and weaving, running water company and urban daily life. Still it undertakes to prevent flood, prevent waterlogging and administratewater engineerings.

I. Make Rational Use of Water Resources, and Bring about a Great Advance in Industrial and Agricultural Production

Adopting measures of broadening sources and reducing expenditure, srengthening administration, utilizing scientificaly, improving dispatchment since we executived new management system in theirrigationarea in 1988, we have led 2376 million m3 effective water fromYue Cheng Reservoir and Dong Wu Shi Reservoir till 1994, and we havealso led 447 million m3 abandoning water of the two reservoirs in theflood season. It has supplied 2870 million m3 water to the industrialand agricultural production for seven years, including 1395 m3 to supplyto urban daily life and industrial production. For seven years, it hasirrigated 12678100 mu land, in other words, 1811000 mu per year. Thecanal system utilization coefficient has improved 10%. Lateral canalirrigation efficiency is 1200 mu, and supply 483 million m3 storingwater and returning irrigated underground water to the storage gateof the plain area. The irrigation area has made a great contribution tocarry out 9000 million yuan per year output value of the eightenterprises of Han Dan City and increase production of cereals andcotton.

II. Establish Consciousness of Saving Water Firmly, and Carry out Supplying Water According to Planning

We have achieved some good results in making rational use of water resouces. It lies in the following:

(1)Establish consciousness of saving water firmly, manage water well and utilize water well.

The area has been short of water resources and hard to supply water to industry and agriculture since 1980s'. So we must realize that we should manage water well and utilize water well. First we should establish consciousness of saving water. The irrigation area can serve industrial and agricultural production better only through mastering adjustable water resources. Since the State Council and the Party Central Committee determined water engineerings to be a fundmental industrial, we have realized that we should save water better. Based on the target of managing water welland utilizing water well, we have organized workers, allocated personnel and monitored water volume. We have set up a water leading group composed of section chief, deputy section chief and senior engineer. Its subordinate are a office only to administrate water volume dispatching, industrial supplying water group and agricultural irrigation group. The central task of all basic administration institutes is water supplying. They should persist in water volume allocating and discharge measuring throughout the year, and they should improve all the institutions of water conveying and water supplying to guarantee normal conduct and information to feedback in time.

(2)Make great efforts to carry out water supplying according to planning. Water supplying according to planning can be classified into 3 types:

(a)Annual planning: First, all industrial units and beneficial counties report plan of using water in the next year to the department before the end of August in the previous year. The department arranges it totally according to forecasting water volume. (b)Quarterly planning:Mainly based on annual plans of the beneficial counties and crop's demanding water in growing period, we check the realization of plans of agricultural irrigation, sign a contract and charge water fees in advnce. (c)Monthly planning: We implement planning to the industrial units monthly to minimize total leading water volume and satisfy demand of production mainly. Industrial using water fees should be paid monthly.

Until now, the differece of planning using water of industrial units does not exceed 5%. Agricultural irrigation should be adjusted on account of weather changing, but total planning supplying water should be consistent with actual suppliable water.

(3)Broaden soures and reduce expenditure, and improve dispatching. We have made great efforts to start water souces and have tried hard to lead Li Shui of the river basin, river underflow, and abandoning water of escape canal to the main river. This increases 209 million m3 water. Besides, we have paid much attention to dispatching of every dam, improving administration in degree, and carrying out "three increase and three reduce" which means that when industry and agriculture fight for water, we increase to transfer water, on the contrary, we reduce to transfer water;when lower reaches reduce to use water, we increase the store water level of the dam, when the water level rises, we reduce to transfer water;when weather is dry and the tempreture is high, we increase to transfer water, otherwise we reduce to transfer water. Having adopted "three increase and three reduce", we have saved 20% transfering water in nonirrigation quarters.

(4)Raise utilization ratio of existing water resources. Because the northen area is short of water resources, our irrigation area should lead 150 million m3 water pre year from Zhang Fu He. So the supplying water volume is constant for all users. This is contradictory to the farmland water demanding in spring and summer. To ensure industrial using water, daily life water and farmland demanding water, it becomes an important task to administrate and utilize water well. We have adopted three measures: First, master transferring water volume accurately, and repeat using water. This can reduce about 15% transferring water. Second, utilize rainwater fully. Third, make good use of existing store water dams in the plain area. This can store industrial abandoning water in the nonirrigation season to take precautions agaist farmland demanding water to irrigate and lower reaches to fight a drought. Industrial abandoning water volume has been 338 million m3 for seven years. It irrigated 2200000 mu farmland and supplied water to lower reaches farmers to fish.

III. Renew and Reform the Irrigation Area, and Improve the Canal System Utilization Coefficient

The main canals, branch canals and lateral canals engineering undamaged ratio does not exceed 40% because of innate insufficiency and engineering ageing of the canal system. The maximum canal system utilization coefficient did not exceed 0.4 1987 ago. So we should renew and reform the irrigation area engineering tachnique. It needs much money. Under the condition that the finanial is in greatdemand, we use most of water fees of the irrigation area to water engineerings basic construction. For seven years, we have used 30060000 yuan to renew and reform engineerings and rebuilt 2762 main canals, branch canals and lateral canals, which are 3983.9 km long. And we have completed 8457000 m3 projects and erected 1713 buildings. We have improved more than 20% engineering completing ratio, and the canal system utilization coefficient also rises to 0.5.

IV. Utilize Existing Water Sources Comprehensively, and Tide over Lean Years

Han Dan City met severe drought from August in 1991 to July in 1993. In this period, annual rainfall was 150 mm, which is only 26% of the average rainfall. From October in 1991 to June in 1992, rainfall was only 87 mm. The drought was more severe than in 1943. To solute this difficult problem, we have done something: First, tap the latent power of water sources. Based on broadening sources and reducing expenditure in the previous years, we have organized workers to develop "a drop of water should be returned to the river". We not only pay attention to underflow of some seasonal flooding river, but also collect scattering water sources in the irrigation area, we also lead permeating shallow underground water from drainage canals of the rice field to the river. We have led 15000000 m3 water to the river. Second, make industrial users save water. To ensure industrial production not influnced by this, we check every factory'swater supplying planning, use microcomputers to monitor, use meter tomeasure, and restrain the exceeding leading water effectively. We also research to increase internal cycles and repeat to use abandoning water with every factory to ensure to save water. Third, make national use of industrial abandoning water. In our irrigation area, utilizing industrial abandoning water to irrigate farmland has been started since 1980s'. But it isn't arranged in the irrigation area's task index until contract management is carried out. Making rational use of industrial abandoning water to increase benefit of the farmland is a complex and risky job. Its complexity lies in dealing with the storing capacity, storing time and change of water quality in the process appropriately. Its risk lies in the following: If we don't know water quality in the storing period well, there may be something wrong with the farmland. If equipment isn't efficacious and water level is controlled wrongly in the flood season, there will be waterlogging partly. Having tried hard, we have used 71000000 m3 industrial water. So it increases to irrigate 700000 mu farmland and promotes agricultural prodction. Having adopted these measures, in the two years we only led 600 million m3 water. This made industrial production in Han Dan City not suffer heave losses.

V. Promote Industrial and Agricultural Production to Save Water

(1)Develop major efforts to reforming water fees. Since the State Council has assigned the 94th document(1985), we have propagated the spirit of the document and importance of paying cost to the water engineering and establish irrigation area. We have investigated the fixed assets in the irrigation area, registered them, compiled them, and found out the real intention. Based on these, according to water volume and the cost of proceeding, maintaining in the irrigation area, we determine the charge criterion of industrial and agricultural supplying water. Abided by province givernment document adjusting water price, according to complementing of transferring water across river basin and industry using the water agricIture planned to use, industrial water price rises to 0.2278 yuan/m3 from 0. 05 yuan/m3, industrial cycling water price rises to 0.0695 yuan/m3 from 0.01 yuan/m3, agricultural water price rises to 0.024 yuan/m3 from 0. 007 yuan/m3. This not only is positive to the good cycle of the irrigation area, but also promotes industrial and agricultural units to save water. (2)Execute water supplying contract strictly, and minimize water losses. After our department makes contracts with every water using unit, we check and monitor the actual using water of every factory monthly to control the differnce not exceeding 5%. We strengthen administration of canal engineering facilities for agriculture, and supply water to it according to planning. Units using water should report to our department in advance to minimize the nonirrigated water losses. (3)Introduce advanced technique to realize measuring accurately To stop wasting water, it is critical to charge industrial and agricultural using water based on volume. Then the volume should be measured accurately. In this respect, we have done the following jobs: First, estalish fixed river and canal water measuring section to measure water 2-3 times daily. Second, register and compile every industrial water supplying point and agricultural pump center, and master its moving time. Third, introduce supersonic flowmeters and microcomputers to estalish information feedback system of river coveying water and water volume computing. This not only ensure us to measure accurately, but also make us discover and deal with the problems occurring in the period of water conveying and supplying at all times. Furthermore, it can reduce the quarrelling between supplier and user. (4)Make science popular, and irrigate for saving water Under the condition that it is short of water, we have developed science popularizing of forecasting irrigation. Since we established 5 soil moisture content forecasting water in 1991, we have developed 1300000 mu farmland which can be forecasted, and we have assigned measurement of soil moisture content of beneficial counties 80 times at regular intervals. This has shortened the period of irrigation and reduced the bear of the masses, and saved much farmland irrigated water. It can be used for reference for pratising saving water agriculture. Pratice makes us realize that governments at all levels paying attention to water engineering and determining water engineering to be a basic industrial is an important guaranty to make a good job of water engineering. Its idea base is to strengthen administration of the irrigation area and set up the consciousness of saving water. Its important measure is to improve engineering technique. To let the irrigation area develop greatly, we should administrate it scientificaly. We determine to innovate boldly, establish modernlizational administration system, liberate productivity and make the irrigation area develop greatly.

The Effect on Rainfall Catchment and Use of Sowing in Furrow (SIF) on Rain Fed Crop

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ABSTRACT

Precipitation is the main source for crop yield in rain fed land or water shortage area. Precipitation is a fixed factor for crop production, but if its distribution on farmland can be changed to concentrate the limit rainfall in rhizosphere, a better water environment can be created to raise crop yield. The sowing in furrow (SIF) technology has developed by using improved sowing machine. Based on the wheat row space, first to open a furrow in 5-8 cm deep, then put seeds into damp soil in the furrow so that the seeds can keep in better water condition for germination. During the wheat growth and development stages, the furrows can catch more rainfall and snow to increase soil moisture in the root zone. The SIF can reduce the drought damage and raise rainfall use efficiency.

Because Yimeng Mountain in southeast obstructs the hot and humid air current, hebei lowland plain becomes the driest region in Yellow River-Huai River-Hai River area with annual average precipitation 540 mm concentrated in July and August. Only 15% of the total annual precipitation contributes to wheat growth period. Water shortage is a major factor to affect wheat production. In order to solve the problem and improve water use efficiency, the SIF study was started for the objective of catching and using more rainfall.

Key words: Rain fed crop, Sowing in furrow, Rainfall and snow concentration, Ecological impacts.

Study Method:

The experiment, demonstration and extension were located in the dry region of Hebei province. The experiment employed large plot comparison method in many locations (sites). The sowing machines for SIF were selected based on field size and local situation. Model 2BZ-6 improved sowing machine was used for large area field demonstration. Small plots use the conventional manual sowing tool to open furrow first and then seeding. The wheat seed used the local recommended varieties.

Experimental Results:

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1. The difference of the wheat yields between SIF and conventional sowing was significant.

The comparison experiment in 67 sites including rain fed land , irrigated land and different soil fertilities was conducted from 1979 to 1983 , 5 different climatic years. The data analysis indicated that wheat yield in SIF increased than conventional sowing. The mean yield in SIF was 2373 Kg/ha, while 1963. 5 Kg/ha in conventional sowing, which increase 409. 5 Kg/ha, in 20. 85%. The yield difference between two sowing methods was significant (Table 1) among 67 sites, there were 12 sites 17. 9% of total sites which the yield in SIF increased less 10% than conventional sowing; there were 19 sites, 28. 4% of total sites, increased 10-20%; there were 16 sites , 23. 9% of total sites increased 20-30%; and there were 19 sites, 28. 4% of total sites, increased over 30%. There were only one site which the yield in SIF reduced 1. 3% than the conventional sowing.

Table 1. Yields of the conventional and SIF comparison in five years

Years	Year type	Sites or Rep.	SIF(kg/ha)	Conventional (kg/ha)	Increase%
1979	warm winter	4	5391	5038. 5	7. 0*
1980	cold winter	8	6364. 5	6105	4. 3*
1981	warm winter	7	2280	1800	26. 7**
1981	warm winter	4	1335	1009. 5	32. 2**
1982	cold winter	3	4434	3871. 5	14. 5*
1982	cold winter	7	2590. 5	2214	17. 0**
1982	cold winter	19	1225. 5	907. 5	35. 0**
1983	warm winter	7	4474. 5	3852	16. 2*
1983	warm winter	14	2490	2118	17. 6*
1983	warm winter	10	1393. 5	885	57. 5**

Table 1 showed whatever field conditions and climatic situations, the wheat yield in SIF was significantly increased, especially in cold damage years. This technology is strongly recommended to use in dry and low yielding land and cold winter regions.

2. The ecological impact of SIF

(1)Store up rainfall and snow, reduce the soil water evaporation and improve soil water distribution.

Soil moisture in plough layer in SIF kept 5. 6% more than that in conventional sowing. It is helpful to wheat in semi-arid region. The investment result analysis in 1981, the serious dry year, indicated the followings:1)The soil moisture in plough layer in SIF kept higher than conventional sowing before wheat spike formation stage; 2) suitable soil moisture (60% of field capacity) of plough layer in SIF could last to jointing stage, 20 days longer than conventional sowing. 3) 0-60cm soil moisture had significant relation with wheat yield. The soil moisture difference in plough layer was mainly shown at surface soil. 0-4cm soil moisture in SIF was 35% higher than conventional sowing, it made the tilling node into the damp soil, which is good for wheat to cultivate the healthy seedlings before winter. The soil moisture difference in early spring mainly shown in 10-20 cm soil.

(2)Improve field microclimate.

In SIF, there are less air current exchange, inside the furrow due to the dyke protection, so the wheat seeded in furrows is less affected from the cold winter. Based on the measurements, the highest temperature in filling stage before winter in SIF decreases 0. 49°C compared with conventional sowing, and the lowest temperature and daily average temperature increase 1. 41°C and 0. 5 to 1°C respectively, and the accumulated temperature in SIF before winter increased 30-50°C . The relatively warm environment of microclimate contributes to the healthy seedling of wheat in winter and early spring. Although the highest and lowest temperature in SIF are higher than conventional sowing, the daily temperature difference is smaller, especially in windy and cold weather. The above measurement result indicates that favourable microclimate is good to winter wheat for safely getting over the winter and returning to growth earlier in early spring.

3. Improve the distribution of soil salt

For SIF, the salty surface soil move to dykes when furrows are opened, and the salt in furrow is concentrated to dykes with the water evaporation. So the soil salt distribution is improved. The data shows that soil salt content below 0-5 cm deep from furrow bottom reduced 14. 5% and 20. 3% compared with conventional sowing and dykes, respectively. This is very important to wheat production in saline soil.

The above ecological impacts are favourable to full stand and healthy seeding formation before winter in dry region. It can raise 12-23% of the rate of emergence. The ecological impacts in SIF is meaningful in surface water shortage but better deep soil water wheat land. Improved water and climate conditions can increase 0. 83 tillers and 0. 35 three-leave tillers, 1. 38 roots, 12. 85 cm^2 leaf area and 12. 45g biomass per seeding. It lays a good foundation to safety over winter and heading formation. In cold winter and salty soil wheat land, Sowing in furrow technology is effective to cold ressistance, salt avoiding and seedling damage in spring.

In conclusion, sowing in furrow technology can effectively catch the limited rainfall and increase wheat yield in salty soil and cold winter region.

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Agriculture Rainwater Catchment Systems in Mudstone Areas of Kaohsiung, Taiwan

S.C. Chu*, C.H. Liaw* and W.L. Houng**

ABSTRACT

The mudstone areas in the southwestern part of Taiwan are characterized by high temperature and rainfall. However, rainfall is not evenly distributed. Ninety percent of the annual rainfall is concentrated on summer and typhoon seasons. Water shortage periods usually last more than six months. Groundwater is limited due to the impermeability of mudstone layer. Agricultural development in these areas is rather difficult because of insufficient irrigation water sources. Therefore, the rainfall catchment system becomes the only solution in these area for providing more water for agriculture.

The objective of this study is to evaluate the feasibility and the limiting conditions of utilizing rainwater catchment systems in Kaohsiung Hsien. This study also explores the advantages and disadvantages of using different methods of rainwater catchment. The hydrological and meteorological conditions, current land use and rainwater catchment systems at Neimen, Yenchao, and Tienliao Counties were initially surveyed and provided for regional rainfall characteristic analysis, agricultural water use estimation, and optimum rainwater catchment systems storage design. Results from the survey indicate that the hydrological and meteorological conditions favor the establishment of rainwater catchment system in mudstone areas of southwestern Taiwan. The ground surface is the most effective method. The design curve of storage-release failure for rainwater catchment system in these three counties can be represented by the following regression equations:

Neimen	$H = 0.367 \times P_d^{1.805} \times P_f^{-0.220}$	$(r = 0.95)$
Yenchao	$H = 0.991 \times P_d^{1.704} \times P_f^{-0.452}$	$(r = 0.98)$
Tienliao	$H = 1.081 \times P_d^{1.649} \times P_f^{-0.368}$	$(r = 0.91)$

where, H = rainwater catchment system storage capacity given in depth units,

P_d = rainwater catchment system monthly release, and

P_f = rainwater catchment system supply failure percentage.

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INTRODUCTION

The southwestern mudstone areas in Taiwan are steep. Streams are short and swift and usually completely dry during drought seasons. Water for irrigation is always in short supply. Farmers have to rely solely on rainfall. All of these have brought agriculture development prohibited. Reasons for the water shortage can be summarized as follows:

1. The average annual rainfall is about 2,100 mm in this region. Although it is plentiful but not well distributed in time and space. More than 90% of the rain is concentrated on summer and typhoon seasons.
2. The soil erosion is serious in this region. The average soil depth is less than 50 cm. The soil water retention and holding capacity is very low. Therefore, available water supply is rather limited.
3. In most mudstone slopeland, gully formation is quite common and steep. Rainwater cannot percolate and recharge underneath the ground.

Therefore, the soil and water conservation research become a very important topic in this region. Therefore, the rainwater cistern becomes the only alternative to alleviate the water shortage problemin these areas.

The objective of this study is to evaluate the rainwater catchment system in Kaohsiung Hsien. Therefore, the initial step is to focus in field survey and basic data collection. The data will then be processed and analysed afterward.

This study uses the monthly rainfall to describe the rainfall characteristics at three mudstone hillslope counties. The sequent- peak analysis, in addition to local hydrological and meteorological conditions, land use and the usual agriculture water use pattern, would be used to estimate the agricultural water demand for these regions. Finally, the hydrologic continuity equation will be used to simulate the storage capacity of the rainwater catchment system, and to compute the supply failure percentage. The established storage-release-supply failure percentage curves can be used as a tool for designing and selecting the capacity of ponds.

THEORETICAL ANALYSIS

Statistical Analysis of Monthly Rainfall

The extreme value type III distribution will be selected to describe the monthly minimum rainfall and the chi-square distibution to test the goodness-of-fit. The goodness-of-fit test determines the probability distribution of the hydrologic event. Different return periods of monthly rainfall will then be obtained through the probability distribution.

Estimation of Water Demand

The long-term average monthly precipitation, evaporation, farm area, and the irrigation requirement of dryland crops in the southern region (Table 1)have been used to determine the agricultural water demand for the three slopeland counties. The sequent-peak analysis method is then used to determine the required rainwater catchment system storage capacity.

The sequent-peak analysis method can be expressed as the eq.:

$$K_t = \begin{cases} R_t - Q_t + K_{t-1} & \text{if positive} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

$$K_a = \mathrm{Max}\{K_t\}$$

where,

K_t : storage capacity at period t

R_t : water release at period t(irrigation requirement of dryland crops)

Q_t : inflow (rain - evaporation) at period t

K_a : maximum desired storage capacity

when $t = 0$, $K_a = 0$.

If the historic inflow is repeated many times while considering the release (R_t) is constant, the maximum value of K_t is the largest desired storage capacity. In reality, evaporation and seepage loss should be included in designing pond storage capacity. However, the infiltration rate of mudstone areas is relatively low. Therefore, it doesn't have significant difference without considering this factor.

Pond Storage Design and Release Simulation Analysis

The continuity equation for simulating the pond storage capacity and release amount is as follows:

$$S_{t+1} = S_t + Q_t - R_t \qquad 0 < S_{t+1} < K \tag{2}$$

where,

S_{t+1} : storage volume at period t+1

S_t : storage volume at period t

Q_t : inflow at period t

R_t : release at period t

K : maximum storage capacity

Assuming the farm pond is full at the beginning of the time period, the continuity equation can simulate changes of the pond storage volume for any given value of K and at different release R_t. Failure occurs when the water demand is not met, ie. $S_{t+1} < 0$. The failure percentage can then be computed. Repeating the same procedures, the relationship of pond storage volume and failure percentage can be determined for other water demands. Hence, a set of pond storage-release-supply failure percentage curves can be developed.

CHARACTERISTICS MUDSTONE AREAS

Extent of Study Area

The total area of mudstone region in southwestern Taiwan is about 1,014 km^2. A complete survey of this large area is not feasible with limited available sources and time. Therefore, this study selected only three counties, Neimen, Yenchao, and Tienliao in Kaohsiung Hsien for further detailed survey and analysis.

Geographical Conditions

The mudstone region in the southwestern Taiwan covers an area that extends north to Kangkuo in the Tainan Hsien, south to Fuyeng Shan in Kaohsiung Hsien, west to Tingshanchao in Tainan Hsien, and east to the hilly area of Hsinhualiao in Tainan Hsien. The composition of mudstone varies a lot in different areas. The entire area is covered with undulating hills. The elevation is between 50 to 200 m and most of them are below 100 m.

Precipitation Pattern

Based on the rainfall records of Taiwan, Neimen County has the highest average annual rainfall of 2325.4 mm, followed by Yenchao County with 1994.5 mm. Tienliao County has the lowest average annual rainfall of 1911.4 mm. Precipitation is not evenly distributed in this region. Almost 90% of the precipitation is concentrated on summer and typhoon seasons. From October to April (the drought season), the freqency of water shortage increases as evaporation rate exceeds rainfall.The annual rainfall variation and mean monthly rainfall of Neimen, Yenchao and Tienliao are shown in Fig.s 1 and 2 respectively.

RESULTS AND DISCUSSIONS

Regional Rainfall Characteristic Analysis

The main objective of this study is to examine the feasibility of the rainwater catchment systems in the mudstone area of Kaohsiung Hsien. Therefore, the major initial effort is to analyse the rainfall characteristic at the three selected hillslope counties. Results obtained from such analyses are as follows:

1. The average rainfall in all three mudstone hillslope counties exceeds 1900 mm per year. Among them, Neimen has the highest, reaching 2325.4 mm. All three counties obtain 93% of the average annual rainfall of the entire Taiwan island. Their statistical characteristics are shown in Table 2.
2. As shown in Figs. 1 and 2, the monthly records indicate that rainfall is concentrated on the period of May and September. It comprises about 90% of the total rainfall amount. Rainfall from October to the following year April only occuries to 10% of the total yearly rainfall.
3. Using the chi-square test, the minimum monthly rainfall at the three counties follows the extreme value type III distribution. This type of probability distribution was used to estimate the hydrologic events in drought period for different return period (Table 3).

Simulation of Irrigation Water Use

The Sequent-Peak Analysis was used to simulate agricultural water use. Assuming dryland crop irrigation scheme as the crop water requirement at the three mudstone slopeland counties and taking rainfall and evaporation into considerations. the simulated results are shown in Figs. 3 to 5. The peak demand at Neimen and Yenchao counties is about 1068.5 mm and 1469.5 mm, respectively. Tienliao County requires 2495 mm which is about 1.7 times higher than that of other two counties. These results are for unit cropping area. Therefore, the total irrigational water demand for each county can be obtained by multiplying with the total cultivated land area.

Pond Storage Capacity Design

The topography of the three mudstone villages is mostly undulating hills. The ground surface collection method is commonly used to collect rainfall. Although the shape and size differs quite a bit, the water depth can still be used to represent the rainwater catchment storage capacity. Assuming different release based on the various irrigation schemes, the continuity equation used to simulate farm pond storage volume can obtain the farm pond storage-release-demand failure percentage curves on many demand failure conditions. The computed results are shown in Figs. 6 to 8. Their relationships can also be represented by the following regression equations:

Neimen $H = 0.367 \times P_d^{1.805} \times P_f^{-0.220}$ $(r = 0.95)$ (3)

Yenchao $H = 0.991 \times P_d^{1.704} \times P_f^{-0.452}$ $(r = 0.98)$ (4)

Tienliao $H = 1.081 \times P_d^{1.649} \times P_f^{-0.368}$ $(r = 0.91)$ (5)

where, H = rainwater catchment storage capacity given in depth,

P_d = rainwater catchment monthly release, and

P_f = rainwater catchment supply failure percentage.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Reports have that groundwater is not enough to sustain agriculture. Therefore, the water supply in this region rely heavily on the construction of rainwater catchment systems.
2. The elevation of the mudstone region usually falls below 100 m. The impervious nature of the mudstone material is very suitable for building dams. Hence, surface collection is the best method for building rainwater catchment.
3. The rainwater catchment system storage-release-supply failure percentage curves and their regression equations can provide useful information for pond design in the mudstone region.
4. Although the inital cost of rainwater catchment system is relatively high as compared to the other water supply systems, it is still considered the best water supply alternative in areas with limited available water resource. It will become more attractive if environmental impact is involved.

Recommendations

1. From the field study, the operation expreience of most of the large ponds has lost. It would be very useful for planning and improvement of slopeland water use in mudstone regions, if these ponds can be actually re- measured and information be re-constructed.
2. The rainwater catchment system utilization in the arid mudstone region is restricted by economic considerations and land use. The storage volume is very limited. The water collected currently is used only for pesticide and insecticide spraying for disease control, limited irrigation, and drought relief . Construction of large ponds would effectively alleviate the water shortage problem in this area.
3. The rainwater catchment systems currently operated in the arid mudstone region are either subsidized by goverment or owned by farmers according to their needs. Therefore, an integrated planning and/or operating strategy needs to be investigated throughtly to improve the water use efficiency.

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Table 1. The water requirements for dryland crops
unit:mm

crops / region	short time period crops		long time period crops	remark
	spring crops	autumn crops		
north	286	514	1028	the numbers are the amount of water consumed. considering evporation, seepage, transport loss, and rainfall,etc.
center	321	476	1189	
south	338	295	990	
east	297	349	1014	

Table 2. The statistical characteristics of annual rainfall for three different stations (from 1952 to 1991)
unit:mm

station / item	Neimen	Yenchao	Tienliao
annual average	2325.4	1994.5	1911.4
standard deviation	567.7	537.1	517.0
potential monthly water utilization	193.8	166.2	159.3

Table 3. The amount of rainfall for three different stations for different return period in drought analysis

	return period (year) unit : mm					
station	1.1	1.5	2	5	10	50
Neimen	6.2	2.1	1.3	0	0	0
Yenchao	7.6	2.3	1.1	0	0	0
Tienliao	5.8	1.7	0.8	0	0	0

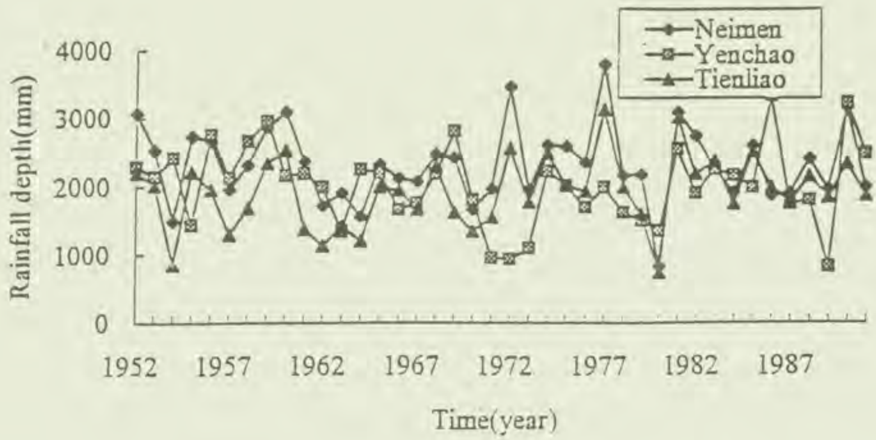

Fig 1. The annual rainfall variation at Neimen, Yenchao and Tienliao stations

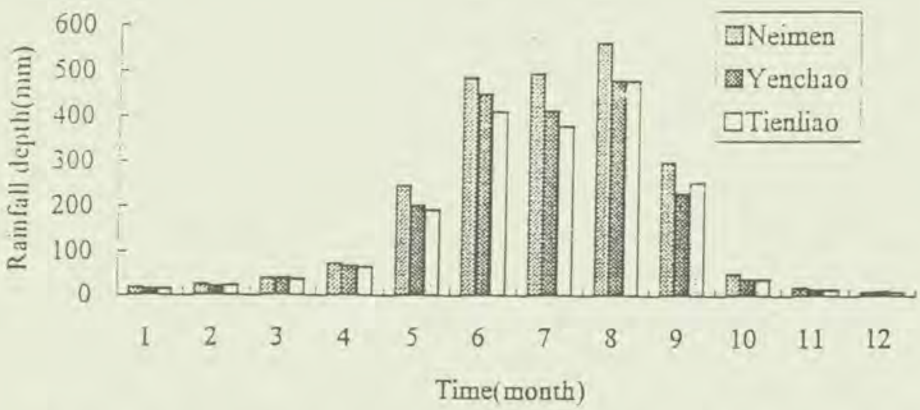

Fig 2. The average monthly rainfall for Neimen, Yenchao and Tienliao stations

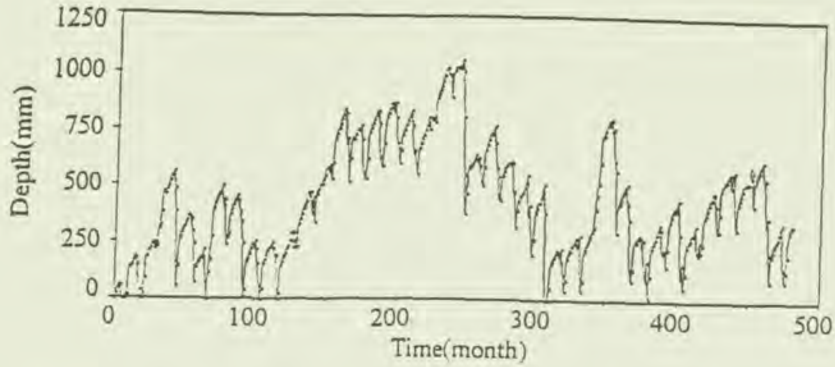

Fig 3. The simulated results of irrigation water use in Neimen

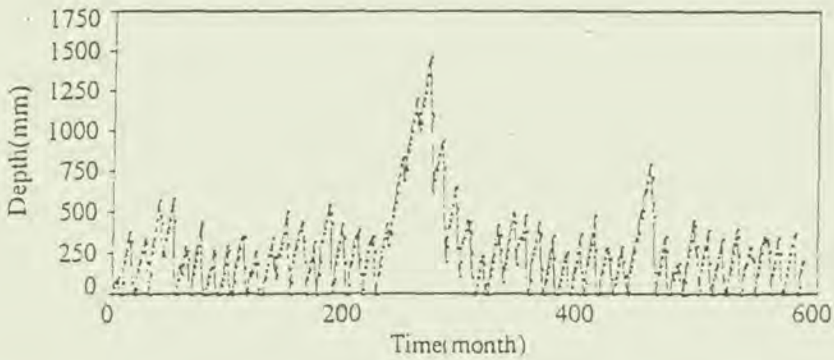

Fig 4. The simulated results of irrigation water use in Yenchao

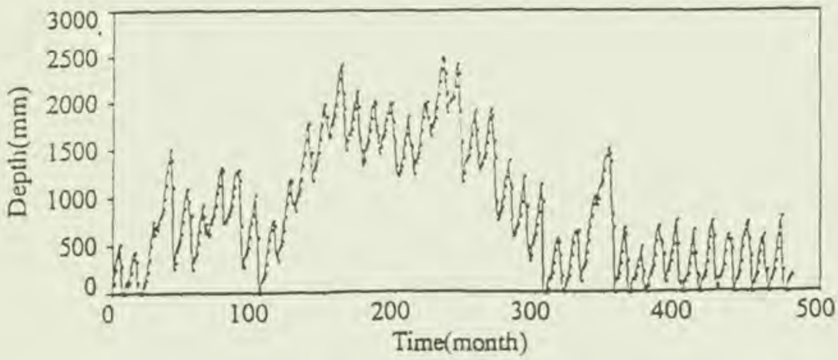

Fig 5. The simulated results of irrigation water use in Tienliao

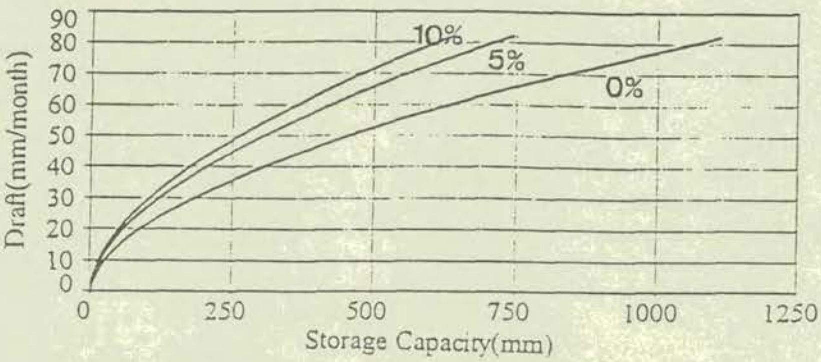

Fig 6. The established storage-draft-supply failure percentage curves for Neimen station using historical data

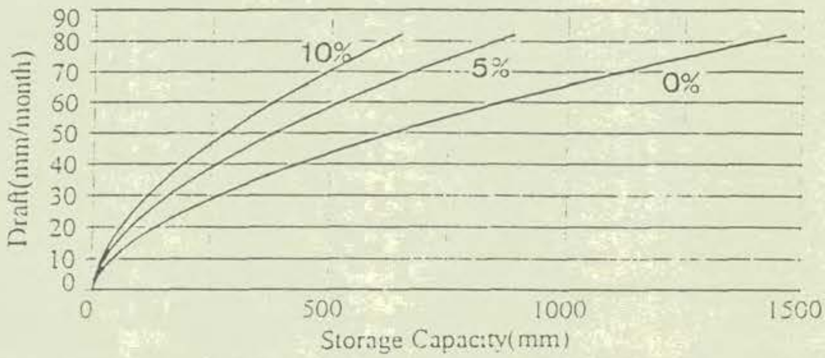

Fig 7. The established storage-draft-supply failure percentage curves for Yenchao station using historical data

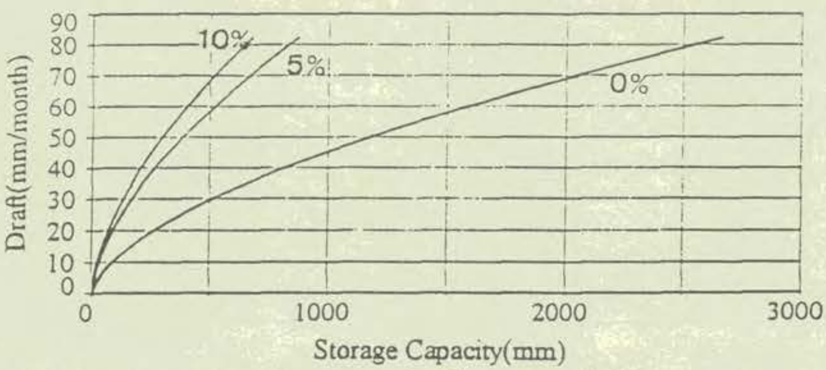

Fig 8. The established storage-draft-supply failure percentage curves for Tienliao station using historical data

THE REPETITIVE IRRIGATION SYSTEM USED IN OUCHI, ISHIKAWA PREFECTURE, JAPAN

Kunihiko KITAMURA* and Ichiro KITA**

ABSTRACT

Ouchi area is located around in the center of Ishikawa Prefecture. Now, the irrigation system covers around 1.400 ha of this area. In 1974, 250 ha of new farm land was reclaimed from Ouchi lagoon. Before the reclamation, water resources in this area were four rivers flowing into the lagoon and "Tameike" in the mountain area near the farm land. However, because of shallow river basin and the old custom of the use of water, it was difficult to supply sufficient irrigation water for the new farm land. In order to solve this problem, the outlet of the lagoon was closed by a gate so that the lagoon might have a function as a reservoir. Moreover, return water from the farm land was stored in catch canals constructed along the lagoon. And, by 18 pumps settled in the catch canals, the used water is repeatedly supplied for irrigation.

This paper shows the repetitive use system of irrigation water of this area, and the volume of pumped up water in each.

1. INTRODUCTION

Ouchi area (Ishikawa Prefecture 1986) is located in the central region of Ishikawa Prefecture. Today, the area's irrigation system covers around 1,400 ha. In 1974, 250 ha of new farm land was reclaimed from Ouchi lagoon. Before the reclamation, water resources in this area were four rivers flowing into the lagoon and "Tameike" (Japanese word for small reservoirs or cistern) located in the mountain area near the farm land. However, because of the shallow river basin and the traditional ways of using water, it was difficult to supply sufficient irrigation water for the new farm land. In order to solve this problem, new irrigation system was planned for this area by using the lagoon in this area.

This paper shows the repetitive irrigation water system of this area, and as well, the volume of water pumped at each pump site.

2. IRRIGATION SYSTEM

Fig. 1 shows a ground map of the study area. As shown in

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this Figure, the lagoon is located at the lowest part of the area, and the farm land surrounds the lagoon, forming an elliptical shape. The water source comes from the 20 or so "Tameike" which are on sides of two mountainous areas. The capacity of these "Tameike" in total is 500,000 to 600,000 tons. This information was obtained from an interview with the section head of the land improvement district, because data for all "Tameike" are not described in books on this topic which have been printed by the government.

The outline of these "Tameike" is shown in Table 1. The capacity of the largest "Tameike" is 270,000 tons, while the smallest is 17,000 tons. Bases on this information, it is clear that other "Tameike" which are not listed in this book have only several thousand tons.

In the study area, four rivers flow into the center and both sides of the farm land. The river water is divided at series of diversion works and supplied to pre-decided irrigation area of the farm land. River water not channeled into the farm land flows directly into the lagoon.

The lagoon's surface area is 200 ha, and its average depth is 1.2m. Its maximum capacity is 2.4 million tons. The lagoon's outlet is closed off by an adjustment gate so that it has a function as a reservoir

Many small ditches for irrigation and drainage are connected to catch canals constructed along the lagoon. Then, water drawn from the farm land through these ditches flows into the catch canals and is stored in it. From the catch canals, water coming from the lagoon through gate and drawn from the farm land is pumped back to the farmland using 18 pumps installed in the catch canals. However, some pumps are in the middle of farm land to assist the lack of ability of the pumps in the catch canals. In addition, as a countermeasure to flooding, an additional 8 pumps installed in the catch canals can pump water into the lagoon.

3. THE MODEL OF IRRIGATION SYSTEM

The model of irrigation system mentioned in the last section is shown in Fig. 2. It is clear that the catch canals play an important role in carrying out a high level of repetitive water use.

4. THE VOLUME OF WATER PUMPED

Table 2 shows the volume of water pumped from 5 pump stations to irrigation areas during the irrigation season (5/1~8/20) in 1992. From this Table, the volume of water pumped to 3 areas, C and D in July and E in August, is 1/4 to 1/2 of the volume pumped to other irrigation area at the same month, while for May and June, the volume pumped to 5 irrigation areas is similar to each other. This is due to the difference in the water management between the first half and the latter half of the irrigation season. That is, for that year, a small quantity of rainfall fell at the beginning of the irrigation season, which was actually the lowest in 10 years as shown in Table 3. Therefore, all of the river waters were channeled into the lagoon to secure its volume stored, and irrigation water to the farm land was supplied only by pumps. However, after that, some farm lands used river water as irrigation water because the volume stored in the lagoon was judged adequate to lost until the end of irrigation season.

The amount of water supplied in this area (see Table 2) was calculated by adding Effective Rainfall (E.R), which is 80% of rainfall, to the volume of water pumped except for the period where water was supplied directly from the river. The total amount of Effective Rainfall during the irrigation season is 309 mm, and the water pumped during the same period is 908 mm. The total amount of both becomes 1,217 mm. The number of days irrigation water is required to be supplied is 78 days, and the schedule is for everyday for May and June, and after that because of changes to intermittent irrigation, every 3 days to August 20. Since the water requirement in depth for this farm land is 15 mm/day, then, the water demanded is 1,170 mm (78 days × 15 mm/day). The water supplied in the farm land meets the demand sufficiently. As shown in Table 3, 1992 had a drought which happens once every ten years. This concludes that this repetitive irrigation water system works well.

5. PROBLEM IN THE FUTURE

These days, many houses and factories are built around this farm land. The water drainage released from them flows into ditches or rivers, and hazardous substances are already found in the catch canals and the lagoon. In the future, it will be most important to maintain the quality standards for irrigation water.

6. REFERENCE

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Table 1 Outline of Tameike

Tameike's name	Irrigation Area(ha)	Capacity ($10,000m^3$)	Bank Hight (m)
Oike	22	6.0	7
Sugawaraike	--	20.0	10
Mikoharaike	--	27.0	24
Sakuraike	40	1.7	9

-- : not described in Tameike books

Table 2 The Volume of Water Pumped for Irrigation Area at 5 Pump Station

unit:mm

Station	Month					Irrigation Area(ha)	Weight
	May	June	July	August	Total		
A	298	275	230	119	916	91.6	0.23
B	264	252	234	107	857	98.7	0.25
C	300	275	111	147	833	150.7	0.37
D	312	308	58	141	819	43.7	0.11
E	287	212	181	67	747	18.1	0.04
Mean	291	270	217	130	908		1.00
E.R *(mm)	81	47	90	91	309		
Total	372	317	307	221	1217		

* : Effective Rainfall

Table 3 Ammount of Rainfall during Irrigation Season (May to August) for 10 years

unit:mm

Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
May+June	252	464	321	256	372	173	383	388	160	408
July+August	266	564	236	246	317	229	194	448	227	693
Total	518	1,028	557	502	689	402	577	836	387	1,101
Rank	7	2	6	8	4	9	5	3	10	1

Fig. 1

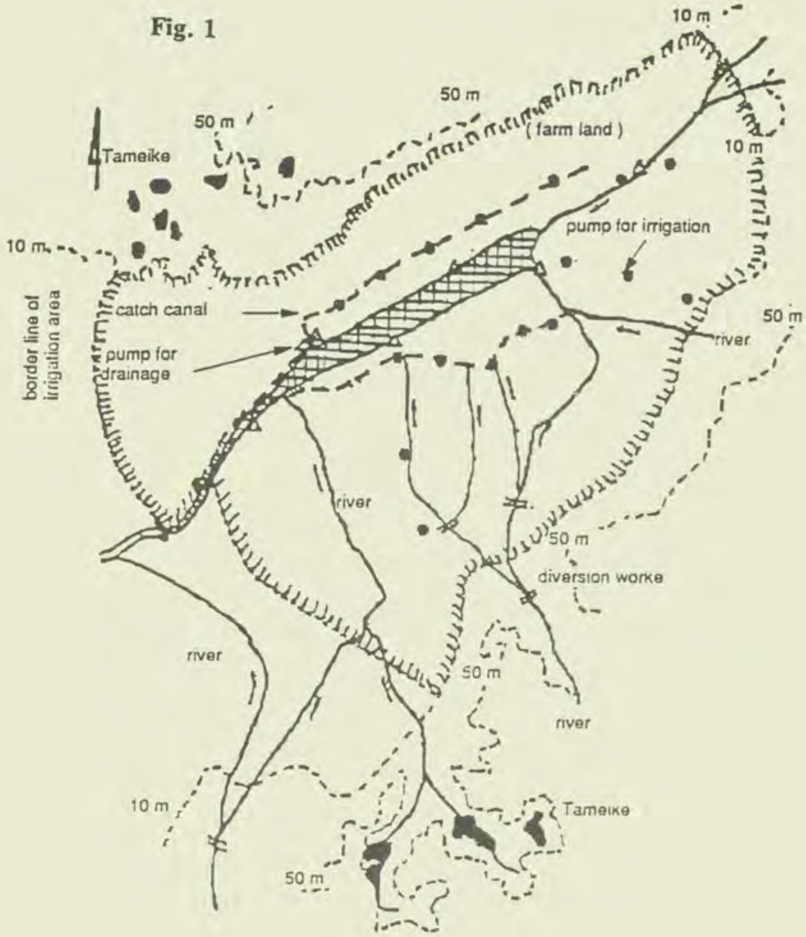
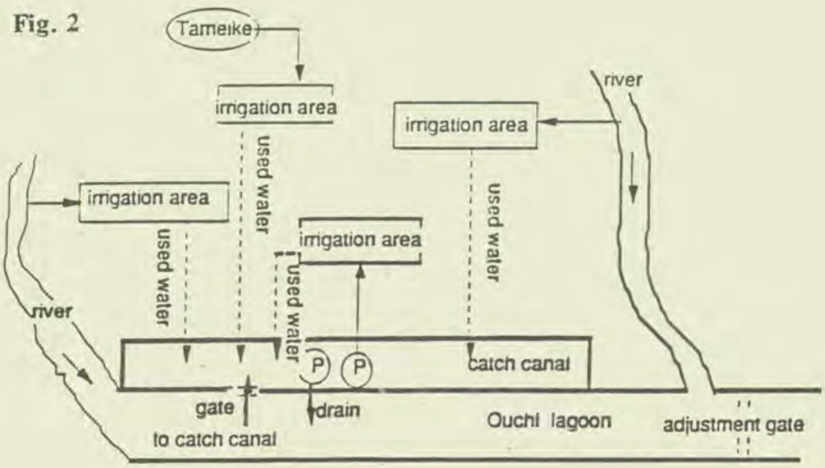

10 m
50 m
50 m
Tameike
(farm land)
10 m
10 m
pump for irrigation
border line of irrigation area
catch canal
50 m
river
pump for drainage
river
50 m
diversion worke
river
50 m
river
10 m
Tameike
50 m

Fig. 2


Tameike
irrigation area
river
irrigation area
used water
irrigation area
used water
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used water
used water
river
catch canal
P
P
gate
drain
Ouchi lagoon
adjustment gate
to catch canal

High-Density Fish-Farming Using Warm Water Discharged from Power Plant ——————Discussion on Rain Water Reuse

Shao Xiaozhi* **Shao Hua****

key words: water resources, water pollution, reuse of waste water, fish-farming

Dongning power plant located in Suifen river bank, East of Heilongjiang Province, with the capacity of 250,000 kw, it generates 150 million kw/hr of electricity annually, and the annual output value reaches 20 million RMB Yuan with annual tax of 2 million RMB Yuan. Through it comes first in the local list, it is an unknown one in the national list. However, the technique of high-density fish-farming using the warm water discharged from power plant has been awarded the third grade of National Xinghuo Plan Award and the second grade of Science & Technology Award of Mu-Dan-Jiang City, and spread in the same trade of the province.

High-density fish-farming means using the warm water discharged from power plants, nuclear power stations or industrial factories to raise fishes densely. At present, the efficiency of heat and water utility in the electricity generation systems at home and abroad are very low, a lot of heat and water are wasted as waste water discharge. Meanwhile, discharged warm water caused heat pollution in receiving water bodies, and destroyed natural ecological balance. Fish-farming using the warm water discharged from power plant has been paid great attention both at home and abroad, many other countries such as U.S.A., Former USSR, Germany, Japan, Switzerland, etc. make use of warm water discharged from power plant to do fish-farming. In China, Such works have been developed in many places, and all of the works have achieved good results.

The specific conditions and main points of this technique of Dongning power plant are given as follows. The average discharge of

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warm water from the power plant is 30 million t/a, i.e. 1 m^3/sec, with average temperature of 27°C . The area of running water fish pond is 1350 m^2, which produces 200,000 kg/a *Tilapia*, and gets 2 million RMB Yuan annual output, and 500,000 RMB Yuan annual tax, which means in case of keeping same capacity of equipments, the output value and tax of the plant increased 10 % and 25 % yearly respectively. On the other hand, it made the temperature of discharged water close to the normal temperature of the rivers, and protected natural balance in the environment, it also got economical and social benefits obviously.

The main points of high-density fish-farming technique using warm water are as follow:

(1). rational design running water fish pond. The fish ponds of the plant were built in concrete structure, rectangular forms side by side, with size 25 m long, 4 m wide and 1.5 m deep with 0.4 % bottom slope, average 1 m water depth running water conditions. Velocity of water exchange is 3-5 times per hour, water flows by gravity, and discharge is controlled by valves. The height of water input point is 30 cm higher than that of fish pond water surface, water falls down to the fish pond vertically to increase the concentration of dissolved oxygen in the water. Water is discharged from fish pond bottom, the widths of the water input and output should be not less than four/fifths of the pond width, so that the whole water in the fish pond is exchanged completely, and goes forward incessantly to complete exchange processes.

(2). strictly control water temperature. *Tilapia*, originated from Africa, is tropical fish, which likes to live in warm water rather than cold water. The appropriate water temperature for its living is about 30 °C, and the difference in temperature between day and night must be not larger than 5 °C. But actually, the temperature of water from the power plant is varying along with the changing of electricity generation. Sometimes, the difference in temperature during one day can excess 10 °C, so three times water temperature measurements are needed everyday and the temperature regulation should be done by opening hot or cold water valves whenever necessary.

(3). hold fish stocking rate. Fry of *Tilapia* should be selected in same size and good health, the stocking rate depends on fish species and water quality in the fish pond. The fry density in fish pond of this plant varies from 15 to 20 kg/m^3, the weight of *Tilapia* increases as 8-10 times as fry, the annual output of fish pond is 1.5 million kg/ha.

(4). forage and feeding. This plant combine local feed sources conditions with productive practice, develop an artificial compound feed No.2, which mainly made from soya cake, maize, wheat bran, fish meal, bone meal, multivitamin and mineral salts additive, etc. The feed forms granular with diameter of 2-6 mm (depends on the size of fish pond). The forage should be processed just before the time of fish feeding. An analysis and assessment of the forage made by Institute of Gain Fat Chemistry, Ministry of Commercial in Beijing, shaw that artificial compound feed No.2 has rational prescription, the contents of protein, fat, vitamin, mineral salts and trace elements in it n meet the needs of *Tilapia* growing very much. Some conditions and situations should be fixed and considered, feeding times, feeding timetable and feed quantity should be fixed, on the other hand, weather, water quality and fish situation should be considered. Fishes are fed for 20 minutes in every 3 hours, the quantity of feed is 3 % of fish weight. The feed should be processed according to the prescription strictly. In case of good weather, high water temperature and clear water quality, and during fishes growing very fast phase, more feeds are needed, otherwise less feeds are needed.

(5). careful management. The staff members must follow the operation regulars strictly to avoid feed molding, and not scamp work and stint material. The sanitation and anti-epidemic condition in the fish farm area should be improved to prevent fishes from diseases. In case of fish diseases occurring, died fishes should be removed from fish pond promptly, otherwise sporadic fishing should be as less as possible.

In general, high-density fish-farming using warm water has many benefits, such as short feeding period, fish weight increasing quickly, high stocking rate, large fish output, good economic benefit, saving lands, protecting environment and so on. Fish-farming enable the inhabitants in north-east China to consume fresh fishes in all the year round. It is reported that there are more than 300 power plants in China, if half of the whole power plants develop the high-density fish-farming using warm water, the estimated total fish output in China will be doubled.

Soil water conservation practices and their research advances in Northern China

Cao Jianru Zhang Guansheng [1]

Abstract

The dryland in China is mainly located in the Vast North China. For the dryland which basically relies on Rainfall for production, the core issue is to conserve as much as possible the natural rainfall, reduce water loss, increase crop's water use efficiency. In term of water conservative tillage, farmer has accumulated a wealth of experiences from practice. Recent research in soil water conservation also achieved great progress. The paper analyzed the position/roles of dryland farming in North-China, its distribution and characteristics of rainfall, summarized the traditional and the on-going water conservative practices in North-china, reviewed the research progress on water conservative tillage.

Key words. soil water, conservation, advances, North-China

Drought is one of the biggest threatens for agricultural production in the dryland of Northern China. Northern China has a vast territory, where the dryland in China is mainly located. Dryland in Northern China makes up 78% of China's total arid area. In addition, most of the dryland relies absolutely on rainfall for agriculture production. Therefore, taking effective field soil water conservative measures to catch natural rainfall as much as possibly to reduce water loss will have a profound significance to agricultural production in this region.

1. The position of dryland agriculture in Northern China, its distribution and rainfall feature.

Dryland agriculture is mainly concentrated in Northern China. The Chinese statistical yearbook showed that there are 54.501 million hectares of dryland in Northern China, taking up 78 % of China's total dryland area. It involves 15 provinces, cities, or autonomous region(National statistical Bureau, 1993). Of the 54.501 million hectares of dryland in Northern China, 34.4104 millions hectares are rainfed dryland without irrigation condition, which is 63% of total dryland acreage in northern China. Geographically, it is mainly located in loess plateau,

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North-China and west parts of Northeast China.

Northern China has a vast territory, with complicated climate condition. However, most parts belong to monsoon climate. In summary, rainfall in this region possess following distinguished features.

1.1. Geographic distribution of rainfall varies. Annual rainfall gradually decrease from east cost to northwest interior. In east cost region, annual rainfall usually is over 800 mm, and 1000 mm at the most, while in interior north-west, annual rainfall very often is below 250 mm. In the driest regions such as Talimu, Chaidamu, and Tulufan basins, annual rainfall is no more than 50 mm. In the seme-arid and seme-humid loess plateau, north-china, and west part of Northeast China, where the rainfed dryland is mainly located, the annual rainfall is usually between 300-500 mm and 600 mm in some places (Niu 1984).

1.2. Annual rainfall varies among different season. In Northern China, summer rainfall usually makes up half of the annual rainfall. Spring is a season with least rainfall. In loess plateau, North-China and North-east China, summer rainfall approximately takes up 50-70% of the annual total. Rainfall in Winter is usually less than 5% (Agro-meteorologic research division of Chinese Academy of Agriculture Sciences 1980). Because rainfall is concentrated largely in summer and the winter is long and dry, spring drought occurs very frequently in this region.

1.3. Rainfall varies greatly among different year. Annual rainfall variation in Northern China is usually over 25-30%. In some places, the variation can be as high as 40-50%(Niu 1984). The rainfall between a dry year and wet year varies greatly. For example, in Beijing, average annual rainfall is 636.4 mm. However, in the driest year in 1891, annual rainfall is only 168.5 mm , while in the wettest year in 1959, annual rainfall is 1406.4 mm, which is 2.2 times of the average (Agro-meteorologic research division of Chinese Academy of Agriculture Sciences 1980).

1.4. Use efficiency is poor. In Northern China, the rainfall is not only concentrated in summer, but also its intensity is high, mostly in storm and sounder storm form. Therefore, it is very easy to cause soil and water erosion, and very little is conserved into soil. Water use efficiency is low. Plus the fact that it is dry and evaporation is strong, the rainfall use efficiency is poor.

2. field water conservation practice and its research advances.

2.1. Practices of field water conservation.

To catch rainfall and retain soil water as much as possible are the basic points for dryland farming in Northern China. Various farming practices with their own characteristics in trapping rainfall and retaining soil moisture have been developed in Northern China.

2.1.1. Level the land and make terrace field.

In Northern China, landscapes varies greatly. There are a great many of sloping land. Rainfall is very easy to runoff. Therefore, making terrace field, levelling the land, Planting in furrow and ridge can prevent the surface water from run off. Field ridging is also effective in preventing the rainfall from flowing out of field, increase its penetrating time. Making terrace field could effectively conserve sloping surface runoff, increase field moisture. According to experiment, soil water moisture of 0-50 cm from March to June in terrace field is 35% higher than that in sloping land (Yu 1992.).

2.1.2. Deep plow, subsoiling.

Deep plow has been a water conservation practice for a long history in dryland region of Northern China. Plow depth and time are usually determined based on rainfall condition and local soil texture. This practice is to break the plow pan to deepen the soil active layer. Combining with applying organic fertilizer, deep plow is effective in increasing the water conservation capacity of the soil reservoir, accelerating water penetration into soil.

Sub-soiling is a kind of relevantly new tillage methods. The purpose is also to break plow pan to increase soil water conservation capacity. Compared with deep plow, it is only to loose the soil layer rather than turn it over. At present, strip sub-soiling is typically practiced, which is to sub-soil the land in a certain interval. By this methods, a kind of loose and compact mixed soil structure can be developed. In the deep- dug parts, water permeability is good. Rainfall can penetrate into deep soil layer in a fast speed. Therefore it can retains large amount of rainfall. The surplus of retained rainfall could be stored in subsoil layer to supplement the whole cultivated layer. In compact strip without sub-soiling, it retains less rainfall in rainy season and therefore could resist flood damages. It has been proved by practices that this method has a significant effectiveness in water catchment and yield increase. Experiments showed that by strip sub-soiling, available soil moisture increased by 4.o-5.6%, permeability increased by 13-14%,crop yield increased by 10% (Chen et al 1993).

2.1.3. Conservative tillage and field mulching.

Harrowing, compacting, intertill are all the traditional water conservative tillage practices.

There are spike-harrowing and straw-harrowing. In Northern China usually spike and straw harrowing are combined together. After plowing, the land is spike-harrowed followed by straw harrowing. The purpose is to break the soil lump, level the land and make a compact and flat top layer mulched with fine soil particles so as to reduce soil water evaporation.

Compacting is a kind of soil water conservation tillage practice when capillary water column is disconnected. Its main effect is breaking the lump, sealing the cleavage to prevent soil moisture from evaporation. According to the studies at Dingxi Agriculture Institute of Gansu Province, in a timely harrowed field after plow, soil water content of 20 cm in spring is 7.2% higher than that of un-harrowed field. Soil compacting can increase soil moisture by 8-12.5% compared with un-compacted soil (Li, Xiao and Chen 1989).

Intertill refers to various tillage activities during crop growing season such as hoeing etc. The effect of intertill is to loose the surface soil, break up capillary water column, reduce soil water evaporation. It also can break the soil surface crust, improve soil permeability. Especially after rain, intertill can significantly reduce soil water evaporation.

Field mulching is a methods of covering the soil surface with a layer of pebble or straw or plastic film to form a protected mulching layer to reduce soil water evaporation. All of the different mulching materials have a obvious effect in reducing evaporation. In Northern China, one of the unique methods is pebble mulching tillage which was developed in Qing Dynasty in Mid-Gansu province. This methods is still being widely used by farmer in Gansu and Qinghai province. The method is to lay a layer of pebbles in the field first and then seeding and harvesting on this pebble field. This methods can increase water permeability by 9 times (Luo 1991). Daily evaporation in pebble mulched field is 4 time lower than that in naked field (Yang 1992). In addition, straw mulching and plastic film mulching have been developing very fast in recent years. This is especially true with the plastic film mulching techniques. By the end of 1987, plastic film mulching area had reached 2.2 million hectare (Xin et al 1992).

2.1.4. Drought resistant water/fertilizer conservation tillage.

In northern china, there is vast area of dryland with various characteristics. In drought resistant water/fertilizer conservation tillage, farmer has gained great many experiences according to their local condition.

2.1.4.1. Furrow planting. It is originated from basin culture in Northern China. The method is to open a furrow in the field, and crop is seeded in the wet soil at the furrow's bottom. This methods has been prove by practice being able to conserve moisture, improve fertility and increase crop yield. It is proved that water content in the furrow is 10% higher than that in the ordinary field, and crop yield increased by 20-50% (Li, Xiao and Chen 1989).

2.1.4.2. Pit planting. This method is to make the field into great many strip like or square like pits. Crop is seeded in the pit. In the pit, the soil is loose, water retention capacity is large. Almost all of the rainfall can be retained. Thus crop yield is increased.

2.1.4.3. Drought resistant high yielding furrow. It is an improved form of furrow seeding method. The methods is to make a 40 cm raw soil ridge every 40 cm in the field, and to put the two times of surface soil and fertilizer in seeding furrow. Therefore the surface soil in the furrow is doubled and the fertility is increased. Using this methods, pre-seeding soil organic matter can be increased by 30.9% (Yang et al 1992). Under same rainfall condition, the amount of rainfall conserved in 0-7 cm soil layer is 9.7% higher than that in traditional tillage field. Water use efficiency increased by 7.8-10.8% (Tuo, Ren and Dai 1992). Crop yield increased by 40% (Shi and Yang 1984).

2.2. Research advances.

In recent year. national government has paid a great attention to dryland farming and the dryland research. A great progress in soil water conservation has been made. The main progress can be reflected as follows:

2.2.1. Soil water movement and water requirement pattern of crops.

Through regular and location fixed observation, systematic studies on soil water movement for semi-arid and semi-humid area of Northern China has been implemented. Soil water movement and its change pattern on major soils have been clarified. Water requirement patters of wheat and corn has been determined (Li 1992, Zhang 1989, Wang 1989, Zhao 1986,). These research progress provided a scientific base for soil water adjustment and soil water conservation practices.

2.2.2. Traditional techniques is improved

Traditional water conservation techniques are valuable treasure accumulated by farmer during the process of struggle against drought. In recent years, modern technology has added new vigour to dryland development. Scientists, by means of modern techniques, have deepened the research and improved the traditional practice. In addition, based on the traditional experiences and the achievement of the integral research of numerous year, great many of books in dryland development and water conservation tillage have been published, which systematically studied the water conservation techniques in China.

2.2.3. New water conservation techniques and their extension.

In recent years, aimed at new water conservative technology, scientists have developed many effective integral approaches according local condition. Typical techniques are as follows: integrated dryland cropping techniques which combine furrow seeding and deep plowing with field mulching and moisture seeking resin (Intensive dryland farming technique group of Shanxi Province 1991), integral approach of sub-soiling, field mulching and no-till furrow seeding techniques (Li 1993), straw mulching and no-till techniques (Zhu and Cao 1988), drilling water penetrating hole on sloping field (Ye et al 1992). All of the above mentioned techniques have been proved in production be very successful.

In addition, new progress has been made in the research on new materials such as chemical mulching agent, moisture seeking agent, anti-evaporation agent. New products have been developed and some of them have been widely extended, e.g. paraffin emulsion, water conservation agents, SA serials, LAP serials, Kh841 moisture seeking agents. These new materials have opened up a new way for water catchment on dryland of Northern China.

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The Way to Improve Water Use Efficiency on Rainfed Area

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ABSTRACT

The fixed research work on the rainfed farming ecological system of rainfall-crop-soil water was carried out at Hebei low plain in the years of 1984-1990. there are four basis in terms of theory about cultivation following rainfall:

(1) Abundance or lack of soil water is depended on annual precipitation ; (2) The balance of soil water have three types in different crops: (a) the type of water surplus; (b) the type of water losses; (c) the type of balance in the main; (3) The constant of saturating rain has been determined in different seasons, because the full seedlings and the yield of crops are depended on the precipitation. (4) The yield of crops is depended on abundance and lack of soil moisture. The way to raise water use efficiency is cultivation following rainfall in the rainfed field.

A comprehensive technology and intensive cultivation have been worked out for cultivation following rainfall: (1)According to rainfall and soil moisture measures of tillage should be taken to ensure full seedlings, In order to reduce loss of top soil moisture, we take plastic film mulching. (2) the conditions of rainfall and soil moisture determine the sow time and which variety of crops is used.(3) According to the rainfall and growth of crops, basal fertilizer combined with topdressing fertilizer should be adopted. (4) based on rainfall and soil moisture , the planting structure should be adjusted for proper rotation of crops. The production practices has shown: Since the technique of cultivation following rainfall were adopted, the rainfall use efficiency of dryland grain and cotton has raised more than 50%, and water use efficiency of grain crops come to 1.289×10^{-3}kg/kg.

Key Words: Dryland field, Cultivation following rainfall, Rainfed farming, Way of water application

INTRODUCTION

Hebei low plain belongs to a region of semi-moist and liable to drought. Arable land is about 2.85 million hectare in which nonirrigated and semi-dryland take up 80% of the total. It is still an area of low-middle yield. As it is short of water resources and drought becomes more and more serious, it is significant to develop rainfed farming in this area. The cultivation following rainfall refers to agricultural planting must be fit in with regularity of rainfall and condition of water resource; and flexible comprehensive measures were adopted for improve production capacity and water use efficiency and economic benefits in the rainfed fields.

1. The Present Situation and the Characteristics of Plants.

(1) Resources of sunshine and temperatures are adequate; and multiple crop index is high but soil is seriously short of water.

This area belongs to a warm-temperate zone and a monsoon climate. The mean annual temperature is 13°C.The frost-free period is over 200 days, the activity accumulated temperature above 20°C is 4420°C, which meets crops double-mature in a year . Meanwhile, majority farmers take advantage of the synchronization both rain time and heat, resulting in double-mature of grain crops in a year following by a high multiple crop index, which increases consumption of soil water. For example, the dryland wheat consumes about 280 mm water in growing period. but the precipitation is only 100-120 mm, so 100-150 mm of the soil water has to be consumed .Water is in relation to the fluctuation of yield as the drought is serious in the growing period.

(2) The random distribution of irrigated and rainfed lands; gradually short supply of irrigation water; and enlarged area of dryland .

While rainfed field in area of arable land take up more than a half, but the area that can ensure the full irrigation is only 20-30%, so it pose a random distribution of irrigated and rainfed lands. Grain crops are planted in the irrigation and cotton is planted in the nonirrigation posing a distribution of grain crops alternating with cotton. Despite of developed irrigation farming and improved low-yield conditions, shortage of supply water results in over-exploited deep layer ground water. Therefore, ground water level has dropped and density of "ground water funnel" has been increasing. Some pumping equipments are forced to update, so the area of dryland has gradually gone up again.

(3) Concentrated rainfall causes seasonal droughts.The annual precipitation is above 500 mm, which distribution is more concentrated than some other provinces of Northeast and Northwest.

Rainfall forms a peak of precipitation from June to August , but the coefficient of variation is very large in different years. The lowest water year is only 300 mm and the highest water year is more than 700 mm which brings about a unstable agricultural production. It is serious that seasonal drought in low plain in spring, early summer , dog-days and autumn appears in a high frequency of 40%. Generally, spring drought influences crops full seedlings and dog-days drought influences crops yields seriously. There is successive droughts in recent years, and the evaporation is 3 times more than the precipitation in the area, the dryland wheat can only maintain lower yields,and the summer crops even can not yield at all in some fields for the serious shortage of water.

In view of above characteristics,the only way of planting is to combine rainfed farming with water-saving farming in the aspects of planting system and tillage system and application fertilizer system the direction of development is cultivation following rainfall.

2. The theoretical basis of the cultivation following rainfall.

Water production efficiency is a index for measure a level of production in rainfed field ,which refers to the ratio of crop yield to the amount of water consumed per unit area. The water- using efficiency depends on soil water-storage capacity . precipitation in the growth period and crops output. The technique of cultivation following rainfall adopted is the regulation of soil moisture by mean of saving or conserving to improve capacity of crop absorbed water to realize full use of precipitation in growing period and full exploitation of production potentiality of soil water.

The theoretical basis of the cultivation following rainfall falls into four parts:

(1) Annual soil water-shortage or water-plenty was determined by rainfall. Result from fixed position test for 6 years has shown that there are four characteristics

about dryland soil water movement in annual.

(a) drought and loss of moisture in spring: from soil unfreezing to spring sowing period, there is a very little rainfall and atmosphere is very arid. At this period the evaporation capacity of soil water is 110 mm which is about 2 times of the rainfall .Mean moisture content of topsoil is about 9%(W). By statistics and analysis, the relation of the losing moisture (Y) and the moisture-storage (X) has a linear equation as follow:

$$Y = -166.2 + 1.066 X \qquad (r = 0.937)$$

This period is a peak of soil water loss, so the principal objective of cultivation to conserve moisture in early spring is to reduce the ratio of moisture loss. In sowing time ,if there is a chance of 10 mm rainfall ,the topsoil moisture content is enough to ensure full cotton seedlings (b) moisture and moist increasing in rainy season. As rainfall concentrates on the July, August and September, soil begins to store moisture, making a peak in annual. In rain-plentiful year, effective water-storage capacity is 248 mm in 0-100 cm soil layer and 304 mm in 100-200 cm soil layer. In majority years the precipitation can meet requirements of cotton or summer crops for water, but in minority years , a brief drought takes place before rainy season , which leads to topsoil moisture content below wilting coefficient and leads to dropping of cotton squares, bolls, flowers .

In this period , because soil moisture and air temperature are beneficial to evaporation, the second peak of soil water loss emerges, so the measures such as deep tillage or straw mulching must be adopted to increase rainfall permeating and reduce soil water evaporation.

(c) The moisture loses slowly in autumn: From October to November, as rainy season has passed, the soil moisture content is gradually reducing ,the ratio of moisture loss becomes small,and topsoil moisture content decreases from 18%(W) in rainy season to 14% at wheat pre-sowing.

(d) Stable moisture in winter. Since there is little rainfall in December, the soil water carries on a internal redistribution till next year March .Soil water content is relatively stable and the enrich deep moisture formes a good basis for wheat seeding next year.

(2) Three types of soil water balance in different crops.

According to water balance equation of farmland: $R = E + \pm I + r$ there is another simple equation: $I = (R - r) - E$

$(R - r)$ ---- the effective precipitation

E --- Water consumption in growing period

I --- Soil water surplus or deficits

It was proved through 6 years' study results that according to the different kind of crops, That balance of soil water falls into three types: (a) The type of water surplus: that precipitation of growing period of summer corn, summer soybean and sesame is more than water consumption, about 54-65 mm of water surplus providing a water condition for next years' rotation; (b) The type of water deficits: the precipitation in the growing period of winter wheat is 100 to 120 mm, but total consumption is 240 mm, so about 130mm soil water was consumed by winter wheat ; (c) The type of balance in the main: the water balance of sweet potato ,cotton, alfalfa are regularly changed following by precipitation annual.

(3). "Saturating rainfall " for season or process determined crops full seedlings and fields.

According to crops water-using conditions in different grow-develop periods, the main parameters of saturating rainfall were made up in a aspect of cultivation system.

(a) 10 mm rainfall for spring sowing to ensure seedlings: In year of rain-plentiful the plough layer moisture content (0-20 cm) is 12%(W)at pre-sowing, if it has a chance of 10 mm rainfall the soil moisture content will come to 16%(w) which can ensure cotton field full seedlings.

(b) 30 mm rainfall to ensure summer crops full seedlings: At date of wheat harvesting the plough layer moisture content is only 4% (below wilting coefficient),It is 30 mm of rainfall that can meet the requirements of the full seedlings.

(c) 50 mm rainfall at dog days drought : In July and August , dog days drought while the soil horizon of 0-50 cm moisture content is nearly wilting coefficient, 50 mm rainfall is necessary for dissolution of drought signs.

(4) The soil water-plentiful or water-short determining crops yield.

The bumper of wheat is based on the adequate subsoil moisture. Results of fixed position of soil water show: the precipitation provides a half of total water consumed by dryland wheat in growing period, about 130 mm soil water is consumed. The relation between the water-storage capacity (X) and the wheat yield (Y) may be described as following linear equation :

$$Y = -47.8 + 1.064 X \quad (r = 0.975)$$

In the area of shallower ground water that makes a great contribution to the increasing of the wheat yield . Therefore ,According to the soil total capacity of water-storage we can predicted yield of wheat before sowing.

3. The Techniques of Cultivation Following Rainfall in Rainfed Fields

(1) According to rainfall and soil moisture measures of tillage should be taken to ensure full seedlings at adverse circumstances .Generally, in different year type, the appropriate measures of cultivation are adopted. At rainfall-plentiful year of fall later, with the adequate subsoil moisture the routine methods of tillage----fall ploughing, fertilizer applying and spring harrowing are adopted which utilize soil water to ensure full seedlings. but at rainfall-short year of fall later, because topsoil moisture content is nearly wilting coefficient without any more moisture conserved , the simply measures of only harrowing and no ploughing were adopted. In order to reduce loss of topsoil moisture , the measures of preserving soil moisture are adopted by that rainy season deep tillage , straw or plastic film mulching to restrain soil water evaporation. In sowing time , if topsoil is short of water , a little water should be given to the seedbed by mean of hill seeding which is "water hole after covering earth".

(2) According to rainfall and soil moisture , we can plan sowing time and determine which variety of crops is selected for alleviate the dog days drought. The result of study has shown that the earlier the spring crops is sowed the more the crops suffer from drought during dog days. The optimum time of sowing is the key to alleviate harm of drought in dog days. Generally, The early maturing variety and deep-rooted plant have characteristic of drought alleviation and have a great degree of freedom of sowing time. In earlier sowing , the later maturing variety is used and later sowing for waiting rainfall , the early maturing variety should be used.

(3) According to the rainfall and soil moisture to supply fertilizers. In order to raise the efficiency of the fertilizer application , the method of basal chemical fertilizer combined with topdressing fertilizer should be adopted under rainfall and soil moisture and state of crops grow-developing. In the year with the lowest-rainfall or the highest-rainfall ,the nitrogen fertilizers of application should

be reduced because excessive N fertilizer will distinctly reduce crops yield. In summer corn field take advantage of raining time to topdress fertilizer was advocated resulting in the water use efficiency come to 2.34×10^{-3} kg/kg.

(4) The planting structure are regulated for proper rotation of crops under rainfall and soil moisture. To directed against the characteristics of random distribution of irrigated lands and rainfed lands and the types of soil water balance, the planting area dryland wheat should be cut down and the area of drought-resisting economic crops should be enlarged, for example, cotton ,sweet potato and peanut. According to the annual precipitation and soil water-storage capacity to plan multiple rotations, the variety of drought-resisting plant with deep-rooted plant and multiple bear fruits should be selected to suit the dryland ecological environments. In order to reduce the multiple crops index in the year lack of rainfall , the fallow rotation was adopted for soil so as to improve water condition by planting a crop in a year, in the year of rich rainfall , the pattern of double-mature in a year or three mature in tow years are carried out.

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USING THE RAIN WATER RESOURCE TO PROMOTE THE DEVELOPMENT OF AGRICULTURE AND ANIMAL HUSBANDARY

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Abstract: Shihezi farm is at the south edge of Zhunger basin. It's a purely irrigated farm. The agriculture production has been promoted by using and developing the rain water resource. There had been only few grazing action in Ziniquan sheep pasture in the farm in the recent year for the problem of the short of the livestock's drinking water. From 1950s, by the situation that the precipitation in spring is 117mm, taking 46.7% of that in a year, and using the nearby nature geographical environment, eight puddle or dam mainly collecting rain water have been built in low-lying areas among mountains to supply water for livestock's drinking. Their reserve capability is 45, 000 m3 and can adjust 70, 000 m3 water a year.This have resolved more than 10, 000 sheep's and other livestock's drinking water problem.The pasture has breeded Chinese Meilinu fine wool sheep, which have greatly promoted the development of sheep raising facility in Xinjiang Automous Region. There are about 10, 000 ha irrigated land in the south of Wulanwusu.In the early days of development, the short of water resource had affected the agricuture production. From 1970s, the irrigating way by water to land covered with snow, which mains change the irrigation complete with river water in spring sow time to irrigating by little quantity river water to the land covered with snow when the snow collected in winter began to thaw. This way makes the snow water resource betterly used and about 7, 500, 000 ton water has been saved in this 20 years. The grains' sowing time is put forward 10 days and their productions have been rised. Now the outputs of wheat, rice and sugar-beet are 525 tons/ha, 750 tons/ha and 4500 tons/ha differently, about 40%, 40% and 20% higher than before. There is a 50, 000 hectares large irrigated farm. The evaporation quantity here is 1946.5mm and is 16.5 times of precipitation. Using the snow fall in winter, combined the rain fall in spring, by the way of "stubble irrigation", the problems of rain water resource using and the water lacking in spring have been solved. From 1980, the "stubble irrigation" has been large populized and the total areas are about 200, 000 hactares. About 1.2 billion tons of water has been saved. This kind of irrigation way can also makes the early spring grains sowed in time and the autumn grains' sowing time 7 days earlier. At the same time the ground water replenishment is reduced and the producing of the secondary salinization and alkalization are avoided.
Kay words: using of rain water resource, development of agriculture and livestock's

productions

Shihezi caltivated farm is at the south edge of Junger'er Basin in Xinjiang, where is in the center of Asia-Europe Continent and is far from oceans. The average precipitation is 110-200mm a year and the average evaporation is 1500-1900mm a year. It is a typical continental monsoon climate area and is a pure irrigation agriculture area. The precipitation in this farm is small and its intensity is not enough. But the precipitation is concentrated and is convenient for use. So by the local agriculture and livestock's production situation, the Ziniquan Breed Sheep Grazing Land, Wulanwusu region and Muosuowan irrigation area in the farm have used some suitable engineering way to relatively rational use the rain water resource. The agriculture production has been greatly promoted.

Charp 1:

Ziniquan Breed Sheep Grazing Land is in the hilly land before the north foot of Tanshan Mountains. There is a 36, 000 hactare large grassland called Halahaiditu-mutu. The grass contented here is large and grass quality is high. The cool summer and the cold winter here is espically suit for developing sheep breed facility. Although there were few grazing actions in the resent years, it were in moving to find pasture situations for the unsolving problems of the seasonable water lack. For fully use the valuable Halahaiditumutu grassland, in 1953, nation decided building the breed sheep grazing land mainly to raise sheep and breeds new varieties sheep. After the grazing land was built, a 30 km long stone bank canal called Dazimiao canal had been built first. At the same time, two retation feed regions had also been built.These have mainly meet the needs of human, livestock and agriculture grains. The sheep have developed from 2638 in 1952 to 8867 in 1956.

With the development of the production, Dazimiao canal built before can not meet the production need. The canal is a seasonal canal and can not ensure the water using in spring and in autumn. Espacially in sheep's busy birth time in spring, many labours and machines must be used to take water 10 km far away in the low reaches of NingJia River. The time and the labourpower were wasted and sheep breed price was high. The little lamb's living proporation was low. The precipitation here is relatively higher in Xingjiang Region. It in spring (from April to June) is 117mm and takes 46.7% that in a year. Also in April, the collected snow in winter and spring begains to shaw, and large quantity runoff produces. By this condition and fully use the nature geographical environment around, in the diffrent area of the grassland, by sheep breed needs in different seasons and using the low-lying land between the mountains, 8 little dams (puddles) have been built to supply water for sheep drinking. Their total reserve capability is 45, 000 m3 and can adjust 70, 000 m3 water a year. At the same time, by the seasonal change, using different way to purify and handle the collected water resource. Because of the thoroughly resolve of the drinking water problem and the utilize of the grassland in the low mountain grass regions, the sheep breed have gain a great prograss in inproving and building. After 1970s, using the Australia Meilinu sheep hybridized to the fine wool army farm sheep, the Chinese Xinjiang army farm fine wool Meilinu sheep has been breeded. This has greatly promoted the sheep breed facilities in Xinjiang Autonomous Region. There were 79, 786 sheep exported from 1956 to 1974 and 5, 250 tons sheep wool were handed in or selled. At the same time, the wool and leather industries have also been created and developmed.

Chapter 2

The main grains in south Wulanwusu irrigation area are wheat, rice and sugar-beet. The water, espically the water seasonal unblance is the main factor restaining the development of agriculture. In this nearly 10 years, using water to irrigate the land covered with snow and collecting rain water in flood time to irrigate have made agriculture production continous improve.

The south Wulanwusu irrigation area is at the up part of Ningjia river's alluvial fan. The land here is unsmooth and the slope grade is larger (12-24%). There are 100, 000 hactare caltivate land here and some water conservancy projects had been built, but affected by the water resource unblance distribution in time and in spaces and because of the little quantity coming water from the large rivers, the irrigation before sowing was holded after and the sowing time had to be postponed. The agriculture grains production were affected.

The precipitation here is 198.8mm. But in winter it is 35mm, takes only 15% that of a year. The spring time here is short and the tempreature rises fast, combained with the large land slope, the surface runoff can easily been maked to form flood and washes the agriculture land away and makes the soil erosion. From 1970s, the work of irrigating by water to the land covered with snow has begun. It mains changing the irrigation only by river water in past as irrigating the farm land ridges caltivated in autumn by a little quantity of water when the snow in land collected in winter is begining change from thick to thin, the indensity is increasing, the structure is turning from loose to grain and is beginning thaw. This irrigation way increase the snow thawing rapid and the farm land water resource. That the river water flows slowly in land surface can make the soil temperature rise and increase the soil thawwing and make the river and snow water seeping in soil in time and keeping enough soil water in caltivated layer. This irrigation way have four benefits. First, the snow water resource has been fully used and turns the flood hazards as flood benifits. Second, the irrigation period is put forward and the grains sowing time can put forward 10 days. And the grains outputs have rised(Now the wheat, rice and sugar-beet outputs are 525 tons/ha, 750 tons/ha and 4500 tons/ha, about 40%, 40% and 20% differently higher than before). Third, the irrigation diffculty formed by the large land slope has been solved and soil erosion formed by runoff has been avoided. Fouth, water resource has been saved and water resource unblance problem has been resolved. From 1970s to 1994, about 5000 hactares lands were irrigated by water to the land covered with snow and total 10 hactares lands have been irrigated. The saved water quantity is 7, 500, 000 m3. At the same time, some little dams as Kaziwan dam, Niujuanzi dam and Dashibei dam have been built to collect the snow and rain water. The total collected capability is 4 million M3, and adjusts about 1 billion M3 rain water a year. This way not only solves the problems of water lacking in spring but also adds the water resources for grains' growing. Now the Shihezi farm have populized this irrigation way in the same condition areas and every year more than 7500 hactares land have been irrigated by water to the land covered with snow. The snow water resource has been used efficiently.

Chapter 3

Mosuowan is a 50, 000 hactares irrigation areas. From 1982, the "stubble irrigation" has been populized. This irrigation way not only fully use the precipitation water in spring and saved the irrigation water before sowing, but also greatly changes the production condition in the farm.

The stubble irrigation in mains the land is irrigated lightly (the water quantity is 60% that irrigated after ploughing) in the land with stubble and without caltivating and ploughing after the grains have been haversted in autumn. Before the winter come, the land is ploughed and leveled for sowing. In the spring next year, the snow water collected in winter and rain water are replenished to soil to suit the grains sowwing.

The evaporation in Mosuowan irrigation area is 1946.5mm which is 16.5 times that of precipitation. The grains' growing must depend on the coming water from the large rivers. But this area is in Guerbantonggute large desert, the river water can not meet the grains' growing need either in time and space distribution or in total quantity. Although the precipitation is little, it is concentrated (about 60% water falled in winter and in spring) and its itensity is higher. The efficiency times of precipitation are more. So the irrigation in the stubble land make it efficient to use the rain water resource.

From 1980, the way of irrigation in the stubble land have been populized and produced a great production beneficial results. First, the total irrigation areas in the region is 200, 000 hactare. Each hactare have saved 600 M3 water and the total saved water is 1.2 billion M3. The rain water resource have been better used through this irrigation way. Second, by the change of irrigation way, the wheat sowing time have changed from winter to spring. The freeze hazards caused by the unstable collected snow have reduced. The wheat outputs have been rised from 300 tons/ha sowed in winter past to 480 tons/ha sowed in spring now. Third, the irrigation period have been shorted. The early spring grains are sowed in time and the autumn grains have been sowed 7 days early. Their growing times are postponed and the agriculture produce output and quantity have been raised. Fourth, the contradiction of the irrigation, the machines and the labours concentrated in spring has been relaxed. Fifth, the little quantity irrigation haved reduced the shallow ground water replenishment and prevented the happen of the secondary salinization and alkalization caused by large irrigation water. Now, the irrigation way is one of the main irrigation ways in the farm. In 1994, the areas of irrigated stubble is 30. 000 hactares.

Except the stubble irrigation, by the forecast of the local climatic deparment, if the precipitation water in winter is enough and the temperature rises fast in spring, the snow thawing is concentrated. The efficient fall water in spring makes the soil contented water enough. The machines power, human power and others were concentrated to irrigate the land. In 1994, the land irrigeted by this way is 30. 000 hactares and 45, 000, 000 M3 water was saved.

There are other rain water using ways in Shihezi farm as: Collecting water in desert to make afforestation; Affecting the weather to turn the rain water into surface runoff; Reducing the grains irrigation water quantity by the precipitation intensity and their growing periods, etc. Now, the main water resource in the farm is used in agriculture and animal husbandry's production. The large development of the rain water resource is waiting for the experience summary and the deep studies.

IMPACT OF WHEAT STRAW MULCH ON UTILIZATION OF RAIN AND SNOW RESOURCES IN ARID LAND OF CHINA

Pei Liuyun*

Agricultural production plays an essential role in national economy in arid and desertified areas. Hexi corridor of Gansu Province is a typical representative in such areas. There are more than 10 million mu of cultivated land, accounting for 18.4% of the province total, however, its grain production makes up 31.9% of the total of the province. Thanks to the sufficient light and heat resources, per unit grain yield here is one to two times that of the other places in the province. Moreover, it favours to develop commercial-grain-dominated production along side diversified economy of farming and side-line occupations. But as farmlands here are enclosed by vast extent of gobi desert, they are characterized by the so-called "oasis agriculture". Influenced by the "effect of rope for airing clothes", the scattered oases have an annual average evaporation of 2020mm due to the impact of seasonal heat waves. Precipitation is relatively small, it decreases from 200mm to less than 50mm from east to west, and from south to north. The maximum precipitation for a single event is generally no more than 30mm with aridity ranging between 4.5 to 8. As agricultural production here entirely depends on irrigation with glacier-melt water, it has long been known as a irrigated agricultural area.

Rain/snow resources have been neglected in the past years due to their small proportion in water for agricultural purposes. In recent years, because of retreat of glacier groups in Qilian Mountains within the region, drop of surface runoff year by year, rapid development of industry and agriculture, drastic increase of water requirements of various sectors, and water shortage induced contradictions becoming more and more obvious, local people's concept have to be changed accordingly. They began to pay attention to the exploitation and utilization of rain/snow resources and to develop water-saving agriculture. To this end, studies on the improvement of rain/snow water utilization rate with wheat straw mulching have been carried out. Experimental results indicated that mulching can improve top-soil physical and chemical properties, promote the transformation of rain/snow water into soil moisture, and offer the prospect for comprehensive utilization of water resources in arid areas.

1. Experimental Treatment and Methodology of Study

The experimental site is located in the Water Administrative Office in Xiying of Wuwei city. Soil in experimental site belongs to neutral in nature, unit weight of soil is 1.37g per cubic

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cm, porosity is 46.06%, field maximum water holding capapcity is 23.4%, and permeability is 12cm/h. The area of the plot is 3 x 6 sq. meters. Treatment procedures are described below.

(1) Mulching by wheat straw spreading (PM) Wheat straw are evenly spread on the field and pressed slightly for getting in touch fully with top soil.
(2) Mulching by piling wheat straw (DM) Wheat straws are piled into strip ridges along rows of crops, in natural loose state.
(3) Barren ground without coverage for contrast (CK).

Wheat straws are cut into pieces of 8 to 10 cm in length, and converted into the amount of straw used in the light of 300kg/mu. The treatments were repeated three times. Soil moisture content was measured by using oven drying method, soil temperature variations were determined with U-shaped ground thermometer, and soil permeability was measured with constant water supply method.

Pot experiment was also carried out simultaneously with field experiment for contrast and testing. Earthen pots have a diameter of 15cm and height of 20cm. Some 4kg of soil were contained in the pots in layers. The treatment and designing procedures exactly followed that for field experiment, and each procedure was repeated four times. Water supply installations are home-made sprayers which can simulate natural precipitation. Both raindrop size and rain intensity can be controlled. Soil moisture content of the pots were measured mainly with oven drying method supplemented by tensiometer.

2. Results and Analyses

2.1 Impact of mulching on rain water utilization rate

Moisture contents of soil of 0 to 20cm thick obtained by timely pre- and post-rainfall measurements are listed in Table 1.

Table 1 Impact of mulching on rain water utilization

Single event precip.(mm)		19.3	17.8	11.4	9.5	3.5	2.7	Mean
Pre-rain soil	DM	13.5	14.8	12.7	14.7	15.0	11.9	13.77
moisture	PM	15.1	14.6	15.8	13.5	12.4	16.3	14.62
content (%)	CK	13.8	14.1	11.6	12.7	12.5	11.2	12.65
Post-rain soil	DM	18.8	19.7	15.8	17.1	15.9	12.6	16.65
moisture	PM	19.9	18.7	18.8	15.6	13.3	17.0	17.22
content (%)	CK	17.0	17.0	13.6	13.6	13.1	11.7	14.33
Increment of	DM	+5.3	+4.9	+3.1	+2.4	+0.9	+0.7	+2.9
soil moisture	PM	+4.8	+4.1	+3.0	+2.1	+0.9	+0.7	+2.6
content(+%)	CK	+3.2	+2.9	+2.0	+0.9	+0.6	+0.5	+1.7

From Table 1 one can see that mulching can raise rain water utilization rate. Soil moisture content via piling mulch (DM) can be increased by 0.3% than that of even spread (PM), and by 1.2% than the contrast (CK). Increment of moisture content tends to increase with the increase of precipitation. This is because the wheat straw functions like a soft cushion which absorbs rain splash monmentum and reduces raindrop loss caused by splash in addition to the adsorption of mulching, rain water infiltrated into the soil was increased naturally. The other reasons accountable for the highest utilization rate of rain water treated by means of DM are the strip-ridged piling of straw, the downward-inclined loose wheat straw suitable for catchment and permeance of rain/snow water into soil. If we convert soil moisture content increased in a 20-cm-thick soil layer into water layer depth, then the effective utilization rate of rain water in the case of DM would reach 73.5%. This is a quite promising soil water source to the arid areas.

2.2 Impact of mulching on smow water utilization

Snow water, a result of precipitation in the form of snowfall during slack season in winter in northern China, serves as an important source for replenishing soil moisture prior to sowing. But in arid areas, the fewer snowfall frequency with small amount of one-single-event snowfall makes it difficult to preserve the snow on the frozen ground because part of it are blown-off and part are lost due to direct evaporation. Therefore, they are almost valueless in replenishing soil water storage. However, mulching can not only preserve soil water of farmland but also increase snowfall interception, raise moisture content of soil layer of 20cm thick in winter (Table 2).

Table 2 Impact of mulching on snow water utilization

Single event snowfall(mm)		18	56	94	Mean
Variation of	DM	+0.13	+0.41	+0.62	+0.39
soil moisture	PM	+0.10	+0.40	+0.43	+0.31
content (+%)	CK	-0.21	-0.23	-0.19	-0.21

Experimental results showed that soil moisture content of bare ground reduced by around 0.21% due to evaporation loss whereas it increases by 0.31--0.39% in mulched fields. The amount of increase is equivallent to 12.6--20% of snowfall that have been effectively utilized. The reasons accountable for this are due to ground resistence improved by straw mulching, the snowfall interception by gaps of straw, and higher ground temperature under mulch which is favorable for the conversion of snowfall into soil water.

2.3 The function of mulch on maintaining soil structure

Upon receiving the first precipitation, soil under mulch keeps basically the original physical properties while more apparent changes occur on top-soil of bare ground. Differences of unit weight and permeability of the both case are shown in Tables 3 and 4.

Table 3 Impact of mulch on soil unit weight

Soil layer depth (cm)	Unit weight (g/cm)		
	DM	PM	CK
0--5	1.14	1.15	1.21
5--10	1.29	1.29	1.28
10--20	1.35	1.36	1.36

Table 4 Impact of mulch on soil permeability

Permeating time (min)		5	10	20	40	60
Permeability (mm/min)	DM	4.49	3.09	2.27	1.98	1.54
	PM	4.46	3.11	2.23	1.89	1.53
	CK	2.77	2.01	1.73	1.23	1.01

Experimental results indicated that initial rainfall exerted the greatest impact on soil structure of 0--5cm. Under the effect of raindrop splash and collapse, soil aggregates scattered and soil particles rearranged and bare ground collapsed by 2--5mm. Consequently, a compact crusting was formed, and the unit weight of soil of this particular layer increased by 5.8% than that of DM treated, but permeability was only 65.5% of the DM treated. Top-soil structure of bare ground brcomes worse which constitutes the main reason for hindering the entrance of continuous rain/ snow water into the root layers. With PM and DM treatment, a buffer protection was resulted in to top-soils, unit weight variation becomes smaller which maintained the original loose state. Hence, permeability is 31--62% higher than that of the bare ground and rain/snow water utilization rate has been great during the entire mulching period.

2.4 The rôle of mulch in temperature regulation and moisture preservation

According to observation results of experimental plots during the period of 1993-1994, diurnal variation law of temperature for soil layers of 5--10cm thick is that temperature of mulching at 8 hours in the morning is 0.3--0.5 C higher than that of bare ground, it is 0.5--0.8 C lower at 14 hours during noon time and ground temperature is 1--1.2 C lower than that of the contrast. With the increase of soil layers, temperature differences among the three treatment procedures become smaller gradually. Similar variation law was also observed from experiments carried out in the neighbouring areas, i.e., diurnal mean ground temperature is 0.5--2 C higher in the 0--10cm thick layers of mulched furrow land in winter, which led to the thickness reduction of frozen ground by 4-8cm. In summer, the mulched ground temperature is 0.3-1 C lower than that of the bare ground. It thus can be seen that mulch can narrow the ground surface temperature variations and generates the temperature reduction effect" during high-temperature seasons. These advantages are particularly striking in the case of DM.

The mulch can not only regulate temperature by means of separating direct solar radiation of light and heat with low conductivity but also limit soil moisture evaporation by cutting off direct connection soil moisture and near surface atmosphere. Table 5 indicates soil moisture loss during spring wheat reproduction period via continuous measurements.

Table 5 Impact of mulch on soil moisture consumption

Observation period (date/month)		Soil water supplied (mm)	Replenished volume of water (mm)	Total water water consumed (mm)	Comparison with CK (+ mm)
20/March--	DM	2.7	88.5	91.2	-57.9
21/July,	PM	6.8	110.6	117.4	-31.7
1992	CK	3.9	135.2	149.1	/
23/March--	DM	6.0	92.6	98.6	-46.8
25/July,	PM	6.0	107.5	113.5	-31.9
1993	CK	5.6	129.8	145.4	/

From Table 5 one can see that soil evaporation was reduced by 21.3-38.8% as a result of mulch treatment. Of which DM treatment with greater space has a high capability in limiting evaporation. In the case of growing period of spring wheat, per mu of cultivated land can save ineffective consumed water by 31.2-38.6 cubic meters. If the amount of water preserved by mulching during furrow season in winter is included, the irrigated water that can be saved throughout the year may exceed 45 cubic meters.

Excellent production conditions are provided for crops by mulching due to its function of temperature regulation, moisture preservation and soil fertilization. In constrast to CK, yield of spring wheat increased by 10.5-17.1%, the maximum per mu yield reached 493kg. As for maize, per mu yield in the experimental plot was 1016kg, an increase of 11.2% in contrast to CK.

3. Conclusion Remarks

(1) Mulch improved rain/snow water effective use, the maximum utilization rate of rain water reached 73.5%, and snow water, 12.6--20%, opening up a new channel for rain/snow resources utilization.

(2) Wheat straw mulch can prevent top-soil crusting, improve soil ventilation, and increase permeability rate. Compared with Ck, an average increase of 0.89mm/min. was gained for the case of PM and 0.92mm/min. for DM, which are favorable to intercept rain/snow water and improve effectivity of moisture.

(3) Mulch can constrain soil surface temperature fluctuation, reduce evaporation induced water loss, and increase soil anti-drought ability. During spring wheat growing period, water consumption of DM can be reduced by 14.9--26.2mm compared with PM, and 46.8--57.9mm in contrast to CK, equivallent to the reduction of the amount of water consumed for one-time irrigation.

(4) PM is the better option for mulching, which can gain the maximum rain/snow water utilization rate. To prevent wheat straw blown-off, the suitable mulching time is at later period of spring wheat tripartiting. Wheat seedlings then are wind-resisting and the adverse effect of early spring and microtherm on wheat seedling growth caused by mulching can be avoided as well.

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Researches on Rain Conservation Measure

for Unirrigated Date Trees

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Abstract: The rain water consertvation measure for unirrigated golden thread date trees can raise the phisiological indexes of the date trees, keep fruit and storage the natural rainfall, which is a good way to tap the potentialities in raising the yields of the unirrigated date trees and improve the economic development in the date producing area.
Key Words: rain conservation measure, storage pits, observation by selected trees and branches, increase of the date yield

0. Preface

The golden thread date, one of the major specialities in Cangzhou, is well-known for its thin coat, small stone, thick flesh, fregrant taste as well as its sweatness. Statistically, the date trees planted in Cangzhou area are more than 99,000 hm^2, among which only 53,000 hm^2 can be irrigated for once and twice a year and the rest 47,000 hm^2 is really dry land beyond irrigation, with an annual output about 3~10 kg per tree. In order to exploit the potentialities of the date yield, we began to make an experiment on rain conservation in the main date producing area—Cangxian County from the spring of 1989 to the winter of 1993 and achieved good results.

1. General Conditions of Experimental Field

The experimental field was located to the south of Donglu Villege, Cangxian County. Being high, far from deep well and salty in shallow water, the land could not be irrigated. The date trees aged 40~50 years grew there, arranged in a row interval of 7.8 m and a tree space of 4.5 m, with an average annual output of 8~10 kg each tree. Owing to the favourable rainfall of 1989, the output was the highest in the history, with 11.9 kg per tree in Zone No. I and 13.4 kg in No. II averagelly. The intercrops such as bean, mellet and sweat potatoes planted between the trees in 6~10 rows, whose yields were not very stable, especially in the draught. After careful negotiation with the local farmers, we selected 30 date trees in three rows to make rain water conservation experiments. The experimental field was divided into two—Zone No. I with 11 trees for experiment and No. II with 19 trees for comparison. In the zones, observations were made on secondary branches from the selected trees of the similar growth and the same tree-age and on soil moisture content. A rain gauge post was also set up 400 m away from the experimental field to measure the rainfall regularly.

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According to the data of the soil section, the soil and its layer texture in the field was suitable for the growth of date trees, with medium loam 0～40 cm deep beneath the ground, heavy loam 40～100 cm, parting clay 100～120 cm (the parting as thick as 10 cm) and 120 cm further beneath was silt sand.

2. Main Technical Measure of Experiment

2.1. Location and specification of storage pits

As the tree-crowns were small(in an average radius of 205 cm)and the trees grew weakly in the experimental field, the storage pits of 2 m in length, 0.8 m in width and 0.6m in depth were dug between the date trees in order not to effect the intercropped plants between the tree rows.The centre of each pit was on the vertical projected line of a maximum tree crown.

2.2. Digging, Filling and Operation of storage pits

When a pit was dug, the soil from it was put aside as the original arrangement of its layers. After the completion of it, the surface soil was refilled into the pit mixed thorouthly with raw fertilizer 0.25 m^3, fermented excrement and urine 10 kg, urea 1 kg, moderate water and crop stalks. The refilled surface was 10～15 cm from the ground and over it was covered with plastic film to prevent the evaporation of water. The film, 10～20 cm larger than the perphery of the pit, was covered with earth 20 cm thick to keep the film from aging and damage.

The time to dig the pit was generally before the sprouting of the date tree (usually in late March). While before the flooding season (in late June) the surface soil and the film were removed and the land under the tree crown had to be leveled to form a slight slope down to the pit and the intercrop ridges were made in perpendicular to the tree rows. Meanwhile, the pit had to be made the lowest part for converging water so as to collect the rainfall within the crown area and the excessive runoff of the intercropped area into the pit. But after the flooding season (in late September), the plastic film should be recovered over the pit above which was the earth 20 cm thick to keep the moisture.

2.3. Fertilization and Management of Date Trees

The fertilizing amount and period of the trees in comparison zone were in step with that in experimental treatment zone.The fertilizer was put in shallow ditches and small holes according to the habit of the local farmers. In addition, the spraying for fruit keeping and prunning in winter and summer were also carried out simultaneously in both zones.

3. Results of Experiment

After four years of observation from the spring of 1990,the moisture content, physiological indexes and the yields of date trees with rain conservation measure were improved evidently.

3.1. Moisture content in root soil layer

In the experimental and comparison zones, soil was collected specifically to measure its moisture content in order to study the change and result of the storage in the root layer with the rain conservation measure. The time to collect soil was before the sprouting (in mid and late March) and flooding seasons (in mid and late June), and before the freezing period of the ploughed layer(in early Jenuary). The average moisture content of the principal root layer is shown as table 1 below:

Table.1 Average Soil Moisture Content in 1990-1992 (dry soil weight%)

Period	Treatment	Soil collecting layer(cm)					
		0~20	20~40	40~60	60~80	80~100	100~120
Pre-sprout	Storage	14.74	21.07	22.78	27.62	25.40	26.30
	Non-storage	12.64	16.80	21.36	24.13	23.65	16.17
Pre-flood	Storage	12.96	16.48	25.17	22.05	22.46	29.14
	Non-storage	11.61	15.97	19.99	22.96	24.23	18.32
Pre-freeze	Storage	13.90	19.50	26.00	25.10	28.80	30.10
	Non-storage	10.00	14.50	20.40	24.60	21.30	17.80

From the table it can be seen that the moisture storage result of the major root layer is improved significantly with the water storage measure. The calculation shows that the moisture content of the deep soil 120cm beneath the tree crown area rose by 0.56 m^3, 1.25 m^3 and 0.82 m^3 per tree respectively before the flooding, freezing and sprouting periods by comparison of the storage condition with that of non-storage, that is to say the moisture content is increased by 424.5 m^3, 945.0 m^3 and 621.0 m^3 per hm^2, so that more water is provided for the growth of the date trees. As a result, the rainfall more than 42 mm, 95 mm and 62 mm is preserved, so this method is good for holding rainfall.

3.2. Physiological indexes and fruit keeping percentage of date trees

By selected tree and branch observation,we can see from table 2 that the physiological indexes are raised considerablly with rain storage measure than that without it except for the date shoot and bud ratio and the length of the date shoot. For example, during the late physiological fruit dropping period, the date and shoot ratio under water storaging condition went up a little more than 20% averagelly in four years; but before the date collecting period, it suddenly rose to 82.60%, more than three times. During the first year of the experiment, in the late date dropping period, the date and shoot ratio was only up 8.2% under water storage condition than that under the non-storage condition; but before the collection of the date, the ratio was twice more. The other indexes such as hundred fruit weight and hundred leaf weight were also improved considerably. The date drop investigation of the same period showed that the average fruit dropping rate was 3.5 dates/m^2 under the tree crown with water storage before collection, while those under the non-storage condition were 54 dates/m^2. The sprouting investigation in spring presented that the trees with water-storage sprouted 3~7 days earlier than that without water storage and the colour of the leaves also looked strong.

Table 2. Major Observation Data of Physiological Indexes

Year	Treatment	Shoot bud ratio	Fruit shoot ratio		Average shoot length(cm)	Hundred fruit weight(g)	Hundred leaf weight(g)
			Late physio-drop period	Before collection			
1990	Non-storage	1.73	1.46	0.44	12.70	349.20	12.50
	Storage	1.79	1.58	1.32	13.45	420.60	15.63
1991	Non-storage	2.36	0.84	0.49	12.77	330.80	13.50
	Storage	2.51	1.17	1.03	12.43	415.15	16.30
1992	Non-storage	3.02	0.54	0.43	10.58	376.20	12.80
	Storage	3.11	0.78	0.62	11.44	410.40	14.50
1993	Non-storage	2.88	1.20	0.93	11.39	410.00	10.60
	Storage	3.06	1.35	1.20	12.33	517.00	15.00
Four years	Nonstorage	2.50	1.01	0.57	11.86	379.05	12.40
	Storage	2.62	1.22	1.04	12.41	441.01	15.58
Increased yield(%)		4.80	20.80	82.46	4.6	16.35	25.65

Date Shoot length—A date shoot is a fruit spur of date trees. The shoot length is the total length of a shoot, an index indicating the growth capacity of date trees.

Date shoot and bud ratio — A date bud is a short fruit mother stem to bring out the shoot. The date shoot and bud ratio is the proportion of the total number of the shoots to the number of the buds in the same secondary branch, an index showing the fruit bearing capacity of a date tree.

Date and shoot ratio —The ratio of the total fruit number in a selected branch to the number of shoots, an index presenting the yield of a date tree.

3.3. Yields of date trees

After the beginning of the rain conservation experiment, the date yields in both small zones were examined, besides that the yields of the specifically observed date trees with rain conservation measure were collected independently every year. We can see from table 3. that the tree with rain conservation measure can have a good harvest in the first year. After the study of the observed data, it can be seen that the yields rose more than 70% in 1990 and 1992, even if in the date harvest year of 1991 and 1993 with adequate rainfall and suitable climate for the growth of date trees, the increasing range was 45.5% and 21% with water storage measure. Four years of experiment shows that the average output of the selected date trees increased more than 9.9 kg per tree averagely, up 48.1%. As to the average output per tree in the entire experimental field, the achievement with rain conservation measure is considerable. For example, in the first year of the experiment, the trees with water storage produced 22.7 kg per tree, 10.9 kg more than that of 1989, the biggest harvest year in the history; while in the contract zone, the average output a tree was only 16.2 kg with attentive management (insectiside spraying, fertilizing and prunning), 2.8 kg more than that of 1989. Thus those with water storage increased their output 6.5 kg more per tree than that without water storage, up 40. 1%. The average yields in the whole experimental field went up by 6.0 kg per tree, up more than 34.3% in four years.

Table 3. Date Yields in Experimental Field kg/per tree

Treatment		Year 1990	1991	1992	1993	Four year average
Entire field	Storage	22.7	22.3	23.4	25.4	23.5
	Non-storage	16.2	18.9	15.1	19.7	17.5
	Increase(%)	40.1	18.0	55.0	28.9	34.3
Selected tree	storage	28.0	27.5	31.3	35.1	30.5
	Non-storage	16.2	18.9	18.1	29.0	20.6
	Increase(%)	72.8	45.5	72.9	21.0	48.1
Annual rain-fall(mm)		411.0	605.2	313.6	468.5	449.6

4. Conclusion

After four years of experiment, it is proved that significant achievements have been made in utilizing the rain conservation method to preserve natural rain-fall so as to keep the fruit and improve the yields of the date tree. This measure is simple to be taken, low in cost, acceptable and easy to be spread, which is a new way to tap and make use of natural the rain-fall resources and to exploit the potentialities of raising the yields of date trees as well.

COUNTERMEASURES FOR DEVELOPMENT OF RAINFED AGRICULTURE IN HILLY AREAS OF QINGHAI PROVINCE

Yang Xueliang*

1. General Introduction

Hilly areas in arid land of Qinghai Province are mainly distributed in the section of Longyangxia to Shigouxia of the trunk streams of the Yellow River valley east of the Riyue Mountains as well as low-middle hills on both banks of the Huangshuihe valley, the main tributary of the Yellow River. They cover a total area of 12,446.8 sq. km with elevations ranging 2000-2800m. Of the 3,531,500 mu (15 mu equals to 1 ha), of cultivated land, irrigated fields occupy 359,000mu, and dry hilly land (mostly sloping land) approximates 3,180,600mu. The study area is dry with scarce precipitation and deficient water resources. Soil erosion is serious and natural disasters (hailstones, drought, debris flows, etc.) frequently occur. However, thanks to the thick soil layers and favorable temperature, light and heat conditions, spring wheat, qingke barley, pea, oil rapes and potatoes are suitable to grow here where natural precipitation is dependable for crops. It is a typical rainfed agricultural area which possesses the following characteristics.

1.1 High density of gullies on the broken terrain. Because of ages of rain splash, dissection, and over-reclamation as well as vertical development of joints of the loess, landforms with steep slopes and deep gullies, sparce vegetation and barren mountains are formed. Gradient of slopes mostly lies between 5 and 35 degrees, gully density is 2 to 4 km per sq. km and gullying area accounts for around 15% of the total land area. Most of gully eroded area extended up to the mountain ridge which has severely damaged the land resources.

1.2 Sparse vegetation with serious soil erosion. According to statistics, eroded area is 12,322.3 sq. km which makes up 98.9% of the total land area. Intensive eroded area with erosion modulus equivalent to or greater than 5000 tons per sq. km is 5390 sq. km, accounting for 43.7% of the total eroded area. Annual sediment discharge is averaged 46 million tons, representing 67.8% of the total silt discharged into the Yellow River of the region. As a consequence, top-soil loss on sloping land per mu per year is 2 to 4 tons. If it is estimated based on 1.06 kg of nitrogen (N), 0.72 kg of phosphorus (P), and 24.4 kg of potasium (K) contained per ton in soil, then the total loss of N, P, and K per year on the 318 million mu of sloping land would be 166,000 to 332,000 tons in the area. This is accountable for

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land impoverishment and abandondment. For instance, the cultivated land abondanded in Fohai Township of Huangyuan County totalled 1012 mu, accounting for 16% of the total cultivated land of the township.

1.3 Scarce precipitation and inadequate water resources. Annual precipitation averaged over years is only 300-400mm, which is unevenly distributed in time and space. About 70-80% of precipitation is concentrated in June-September, the later period of growing season of the crops while monthly precipitation is only 10-20mm in March-May, the sowing season of the crops. The soil moisture is less than 8% which can not satisfy water requirements for sprouting. Hence, spring drought is quite serious. With the exception of rainy seasons, river courses and ditches are dried up almost all the year round, and the runoff volume that can be stored is negligible. Since the study area is far from the trunk streams of the Yellow River and Huangshui River, the high mountains, steep slopes, deep valleys and scattered cultivated land make the water diversion project being quite expensive. It is difficult to exploit and utilize the inadequate underground freshwater resources which are deeply buried.

1.4 The unbalanced agro-ecology accompanied by backward economy and culture make the local people's life extremely poor. Statistics reveals that annual income for people in two-thirds of the area is below 250 yuan. It is also difficult to get drinking water for both people and animals. About 690,000 people take water stored in pits and brackish spring water throughout the year, and the incident rate of intestine infectious disease is very high. In some mountain areas, local people have to fetch water several km away where height difference of ditches or minor springs would be around a hundred meters. About 45 million person/day is devoted to this particular exercise every year.

2. Countermeasures

Factors such as drought and severe water shortage, soil erosion and harsh eco-environment have seriously constrained agricultural development in dry hilly areas of Qinghai Province. In order to change the poor and backward situation of mountain areas, it is suggested that multi-channels in aspects of law, policy and techniques such as overall planning and integrated management, combination of engineering measures with biological measures, slope harnessing along with gullying control, combination of field capital construction with water storage and soil conservation as well as management and protection taking lead while exploitation and utilization next should be followed simultaneously centered around small catchment management. Specific procedures are highlighted as below.

2.1 Implementation of overall management under contract system in waste mountain and waste slope harnessing. The principle of who undertake(s) the management and protection by a contract, who would benefit is introduced. By so doing, the issue of harnessing being out of line with management has not only been solved but the combination of responsibility with right and benefit has been realized. Meanwhile, technical guidence should be strengthened, and unitary management should be directed towards multi-channel integrated development for the sake of improvement of economic benefit and sustsinable steady and healthy development of waste mountains and slopes management.

2.2 Comprehensive planning and arrangement of exploitation and utilization of minor river and spring sources. Firstly efforts should be made to clarify characteristics of temporal-spatial variation of water resources of tributaries with differing sizes on both sides of the Yellow River and Huangshui River valleys as well as chemical patterns of water quality. And then the exploitation and utilization programmes of three waters (rainwater, surface water and ground water) in different localities suitable to local conditions should be drawn. Finally a package of key water diversion and storage projects must be identified aiming at providing fundamental solutions to drinking water for man and animals and development of irrigated farming.

2.3 Energetically conducting researches on rainwater collection and utilization and desalinization of brackish water as well as its application. It has been an aged-old practice in mountain areas of Qinghai Province to collect and store rainwater in pits and ponds for man and animal use. However, most of the exercises are still approached with premitive method in collection water with natural earthen ground. Experiments carried out by Gansu Institute of Hydraulic Engineering revealed that rate of water collection can be increased to 0.6-0.8 after the ground surface was paved with concretes. In places with annual precipitation of 250-450mm, both drinking water for man and animals and irrigation for courtyard cultivation can be solved.

Investigations indicated that there are rich brackish water resources in some gullies and valleys in Huzhu, Ledu and Pingan counties. Therefore, the advanced technique of desalinizing brackish water can be introduced and adopted to improve the existing drinking-water conditions and promote economic development.

2.4 The fundamental way-out in harnessing drought in mountainous and hilly areas is to conduct integrated management of mountains, waters, forests, fields and roads. Principal measures are identified as following.

2.4.1 To develop agro-ecology by planting trees and grass and closing hillsides to facilitate afforestation. Soil and water loss is the source of vicious circulation and poverty. Without land how can man survive? The essential issue is thus to plant trees and grass. With tree and grass covers, evaporation can be reduced, water source can be preserved, soil and water can be conserved and land productivity can be increasted. Take Shaodaijia catchment in Xishan Township of Huzhu County as an example. The eroded area was 5.05 sq. km, accounting for 29.7% of the total catchment area. Before treatment, vegetation coverage was 7.56% and per mu output was 88 kg. After treatment, vegetation coverage and per mu yield increased separately by 17.12% and 140.5 kg, both social and economic benefits are quite obvious.

2.4.2 To raise land productivity by means of soil fertilization. Both crop growth and yield is affected by five production factors of light, heat, water, air and soil. In this region, light, heat and air are fairly favorable whereas the crux is water and soil. According to experiments, per mm of precipitation can produce 0.75-1.0kg of grain on per mu of land where soil fertilization has been practised. But in this region, per mm of precipitation can only produce 0.3-0.5 kg of grain. The very cause accountable for this is topsoil-loss induced land impoverishment which affects potentiality of natural precipitation to yield improvement being brought into play. We thus suggest to take the following measures to increase productivity of per-mm precipitation for the purpose of soil fertility improvement.

----To develop forage and fodder production. Grazing-dominated practice should be replaced by rearing livestock in pens. Thus, not only fine quality barnyard manure can be provided but commercial economy can also be developed.

----To plant green manure by a big margin and adjust cropping patterns. Experiments indicated that 2.9 kg of N, 1.4 kg of P and 8.1 kg of K can be added if 1250 kg of green manure can be turned up the soil over pe mu of land. Consequently, water-holding capacity of tillage layer can be increased by 17.3-21.6% and crop yield can be increased by 30%. Cropping pattern adjustment refers mainly to reduce fallow land but incrase green manure production. For instance, in Shalianbao Township, the plantation ratio of cereals, economic crops and forage used to be 92:7:1, after it is adjusted into 70:10:20, total grain output increased from 1,509,000 kg to 2,040,000, an increase of 35.2%.

----Deep ploughing and soil amelioration. This can enable the increase of impermeability of natural precipitation and soil moisture preservation to a layer below 20 cm, the thickness suitable for crop root adsorbtion.

2.4.3 To practice "deep ploughing and soil fertilization in autumn and non-tillage and drilling in spring". This particular technique is regarded as advanced farming methods of using autumn water in spring, preventing spring drought in autumn, and keeping a full stand of seedlings by means of anti-drought. Precipitation mainly occurs in autumn in the region. Deep ploughing and soil fertilization makes it possible to receive more rainwater and thorough decomposition of crop stubbles. Non-tillage in spring makes it possible to reduce soil moisture evaporation, prevent wind erosion, and soil conservation and water preservation. Experiments carried out at hydrological station of Hualong County showed that comparisons of the plot applying the above-mentioned method with contrasted plot indicated the water holding capacity of the soil increases 0.83% on an average level, seedling emerged 7 days early, rate of germination increases 18.4%, and per mu yield rises 32.2 kg.

2.4.4 To build levelling terraces and field to ensure stable yield. Terracing is an essential means to improve production conditions, develop dry-land farming, and increase of per unit yield. Experiments indicated that levelling terraces can lead to surface runoff deduction of 72.9-89.2, silt inteception of 81.9-96.0%, an increase of soil water holding capacity by 30%, and yield increase by 30-70% in contrast to sloping land. Take the case of Yangjiawan village in Minhe County. Here some 3660 mu of terraces were built, which made up 36% of the cultivated land, per capita averaged 2.26 mu of terraces, and annual grain yield increased from 100,000 kg to 350,000 kg in the whole village. The experiment of "turning sloping land into terraces" carried out in hydrological station in Datong County showed that per mu of terrace can receive a precipitation of 130-330 cubic meters. To build 1000 mu of levelling terraces whould be equivallent to build a reservoir with a capacity of 130,000-330,000 cubic metress.

Production practice proves that soil and water conservation centered around small catchment management is the life line for developing agricultural production in hilly areas and foundation for eliminating mountain torrents and flood disasters as well as exploitation of water conservancy projects. We think that watershed management taking small catchment as a unit will still be an important task in water conservancy construction in arid and semiarid areas in the next century. Efforts should be energetically made to do a better in this field for its sustainable, orderly and healthy development.

THE DEVELOPMENT OF RAINWATER CATCHMENT SYSTEM FOR PADDY IRRIGATION IN THE MUDA IRRIGATION SCHEME, MALAYSIA: A CASE STUDY OF IN-SITU RAINWATER HARVASTING[1]

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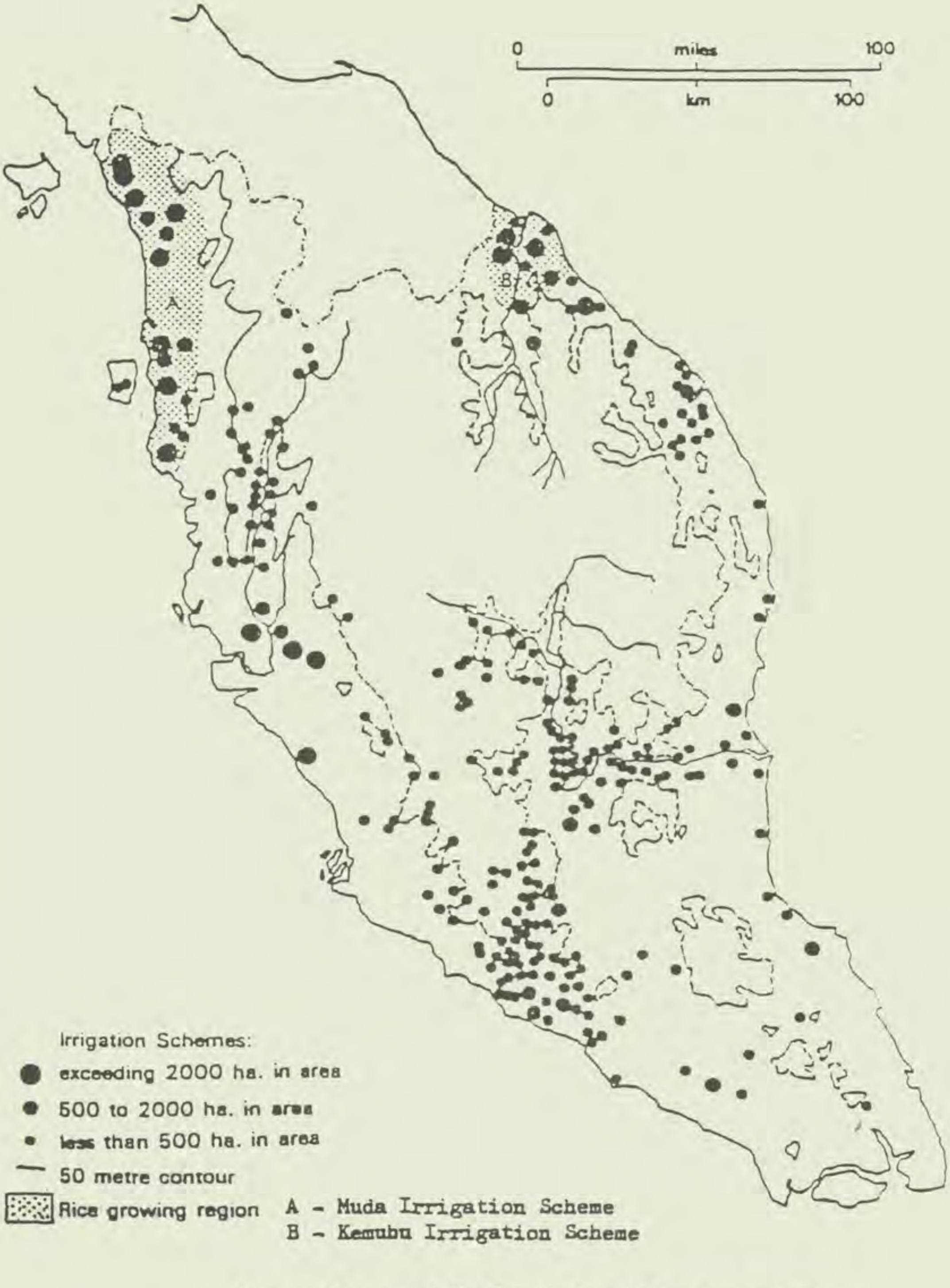
INTRODUCTION

Generally, Malaysia with tropical monsoon climate is water rich with an average annual rainfall of about 2.5 meter per year. In terms of total amount of water resources, this is about 990 billion m^3. However, a large proportion of these water resources goes back to the atmosphere as evapotranspiration (360 billion m^3 or 40 percent) in the form of surface flow or runoff (566 billion m^3 or 57 percent). The remainder 64 billion m^3 or 3 percent percolates through the ground as groundwater recharge (JICA, 1982). The high rainfall and water resource availability especially from river runoff makes many parts of Malaysia favourable for paddy cultivation.

In spite of its favourable weather and physical conditions Malaysia is a net importer of rice and has more or less abandoned its full self-sufficiency policy (National Agriculture Policy, 1992). It has, however, intensified production in the major rice growing areas or granaries and one of them as shown in Map 1 is the Muda Irrigation Scheme.

1
Paper presented at the 7th International Rainwater Catchment Systems Conference, 18-25 June 1995 Beijing, China.

Map 1



Irrigation Schemes and Rice Growing Areas in Peninsular Malaysia

In many respects irrigation is the most important water use in Malaysia. It involves the largest withdrawals of water from rivers and streams. One estimate gave a figure of 82 percent of the total quantity of water withdrawn (DID, Kuala Lumpur, 1976). Much of these were utlised for the irrigation of paddy. Recent figures have shown that in the Muda irrigation area this percentage figure has decreased and so also it is in absolute sense (Sardar, Uzir 1994).

Irrigated agriculture has been confined mainly to the cultivation of paddy. The total area currently under paddy cultivation is about 664,000 hectares of which approximately 52 percent or 343,650 hectares have irrigation facilities. And for those with irrigation facilities about 80 percent or 274.920 hectares have adequate facilities for double cropping.

Though Malaysia is water rich, deficiencies are being felt in some months due to increase in demands from population growth, urbanisation and industrial development and this requires that agriculture be less wasteful in its use. In many instances the increasing demands from the other sectors are at the expense of supply for agriculture and this is especially true in the Muda irrigation area.

The Muda Irrigation Scheme is the largest granary in the country with an area of about 95,000 hectares and this forms about 44.8% of the total granery areas in the country. The scheme obtains its irrigation water from the Sg. Kedah/Padang Terap river systems mainly through a gravity feed system. However, due to a number of problems and the increasing diversion of the water for non-agricultural uses the supply of water for the Muda irrigation scheme has fallen short of demand giving rise to the need for increasing water-use efficiency and augmenting existing supply sources.

This paper will first outline irrigation development in Malaysia with specific reference to water management in the Muda irrigation scheme. It will then examine the circumstances that allow rainwater to be initially used as a supplementary source in the form of river run-off and pre-saturation supply source and how it can now be harvested in the paddy fields themselves as in-situ harvesting to be used especially in the dry season. Its implications in terms of increased productivity and savings in foreign exchange will also be given consideration.

DEVELOPMENT OF IRRIGATION IN MALAYSIA

The irrigation of paddy fields has a long history in Malaysia, probably, even predating the long history of colonial administration. However, its formal development started with the establishment of the Drainage and Irrigation Department (DID) early this century under British Colonial Adminstration. Greater development in irrigation works started after the Second World War when the government initiated the Guaranteed Minimum Price (GMP) promote self-sufficiency in rice. Despite the great improvements in terms of paddy areas under irrigation, there have been little improvements in irrigation techniques during this period. In most paddy areas the method of irrigation is that of sheet flow, allowing the water to flow freely by gravity in the irrigated areas. The water distribution within the paddy areas was from lot to lot, and within the farm lot from plot to plot, as no on-farm distribution existed. There is a great deal of water loss considering the amount of water that flows back into the drains before going back into the river system. However, this system was adopted mainly due to low capital cost and also much cheaper to operate and maintain. Canals and drains density were low and so also are the number of structures.

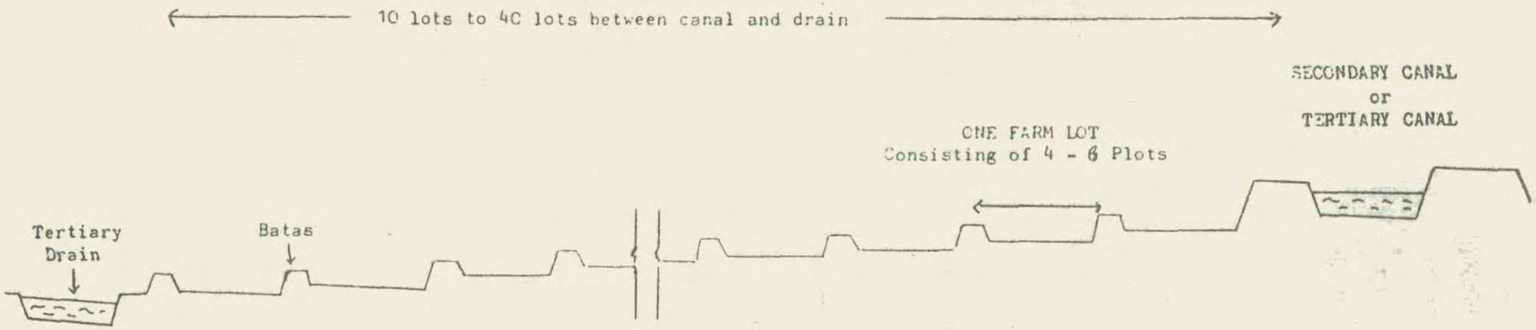
Daring the last decade two to three decades, canal and drainage density of many paddy schemes have been improved from 2 meter/hactare to 10 meter/hactare and now finally to 30-35 meters/hactare, partly to increase the areas under double cropping and also to improve paddy yields. With this development there was also improvements in the land structure becoming more levelled and making water management much easier at the farm level. These features as well as the fact that rainfalls in the area are high and quite evenly distributed as shown later augur well for the introduction of rainwater catchment system.

Generally, irrigation for paddy in Malaysia can be seen traditionally as a continuous process of supplying water to paddy field at one end from an irrigation canal, while at the same time excess or unwanted water is being continuously drained out from the paddy fields at the opposite end. The short dry season of 1-2 months is the fallow period. Where 2 crops of rice are grown, this dry period of 1-2 month is usually the longer fallow period between rice crops, followed by a relatively shorter fallow period between the off-season crop and the main season crop.

This continuous flood irrigation method occasionally evolved into rotational flood irrigation to cope with occasional water shortages. However, even in the rotational flood irrigation system, irrigation water is continously applied albeit for shorter periods to paddy fields under a particular schedule.

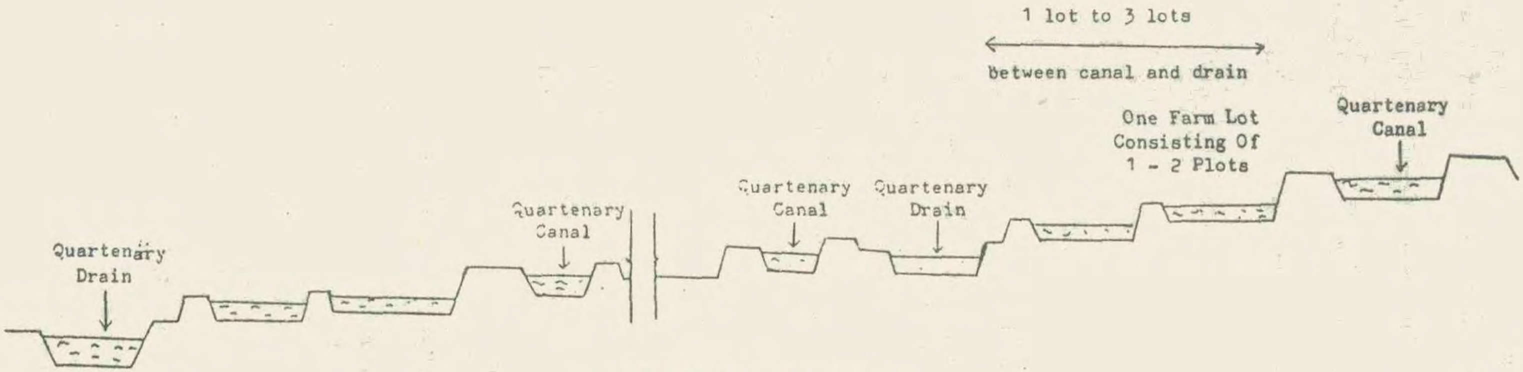
However between the canal and the drain, there could be 10 to 40 farm lots owned by different farmers. Each farm lot is usually composed of 4-6 plots which are bounded by "batas" (small earthern dikes). The number of plots are dictated by the prevailing micro topography within the farmer's lot (see Figure 1).

FIGURE 1



TRADITIONAL IRRIGATION SYSTEM

(LOW IRRIGATION DENSITY)



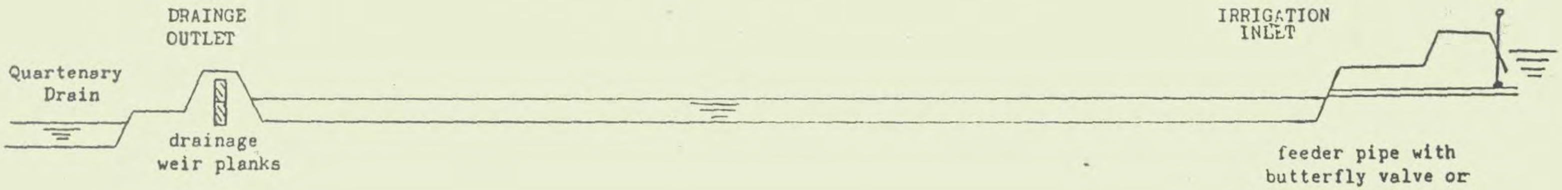
IMPROVED IRRIGATION SYSTEM

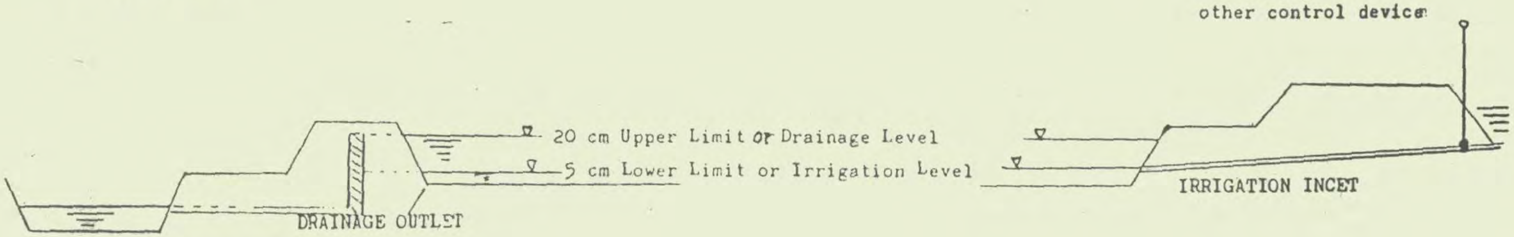
(HIGH IRRIGATION DENSITY)

FIGURE 2

TYPICAL ONE FARM LOT
(TRADITIONAL)
(4 - 8 PLOTS WITHIN 1 FARM PLOT)

TYPICAL ONE FARM LOT
(After Land Levelling)
(NORMALLY 1 - 2 PLOTS WITHIN 1 FARM LOT)





Irrigation water which is released from the canal to the adjoining farm lots, passes from lot to lot until it reaches the remotest farm lots which adjoin the drain. The passage of this irrigation water requires the collective cooperation of all the farmers located between canal and the drain. Thus water distribution within the paddy areas as indicated earlier was between lots and within the lot from plot to plot.

Similarly the passage of excess water or storm rainfall water also followed the same method viz from lot to lot towards the drain. Such mode of irrigation and drainage did not favour the development of water-tight and properly constructed 'batas' nor the need for appropriate irrigation inlets or drainage outlets. As long as water availability was generally not of prime concern, there were no pressures to be efficient in the use of irrigation water or rainwater.

This continuous plot to plot flood irrigation sometimes referred to as 'wild irrigation' was the norm in paddy irrigation until recently. This irrigation method requires less irrigation infrastructure (lower density of canals and drains, and lesser number of irrigation turnouts and drainage outlets) and hense was cheaper to construct and management. Whilst this method was acceptable in the past when there was ample water supply, this is no longer so with new and competing uses.

However the irrigation system for paddy cultivation as described above was not static. Irrigation development in Malaysia can be categorised into 4 phases from the pre-60s to the 90's and beyond (Sardar, 1993).

The first phase refers to the pre-60s, when irrigation infrastructure was to support only one crop of paddy in a year grown during the rainy season. The main features during this first phase of development were the low density (at around 2 m/ha) of canals, drain and farm access to support subsistence farming using labour intensive production system.

All these changed when paddy production increase became a major strategy from the 60's onwards to improve self sufficiency and the socio-economic status of the rural community. This second phase of development (60's to mid 70's) required big investments in irrigation infrastructure and technology to support double cropping of rice. Time then became an essence in irrigation management to ensure that a season is completed within a specified duration, to allow the next to begin on time. The irrigation infrastructure density had to be increased to 10 m/ha to speed up water delivery to farm plots as well as its removal. During this phase, tractors began replacing buffaloes and this marked the beginning of the Age of Mechanisation.

In the third phase, sometimes referred to as The Age of Water Management (mid 70's to the end of 80's), greater productivity was achieved through yield increase and extensive mechanisation. Tertiary level infrastructure was added on to the existing primary and secondary levels, for better water management and to support extensive mechanisation which by now included combine harvesters. The density of canals, drains and roads was raised to 30-35 m/ha, allowing for 80% of the farm lots to have direct access to water management facilities (Thavaraj, Sardar, 1977). The balance 20% of farm were only 1 lot or 2 lots removed from the canals or drains. The infrastructure development process in the third phase of improvements, besides development of water resources, was confined largely to increasing densities of canals and drains from 2 m/ha to 10 m/ha and subsequently to 30-35 m/ha. These were main system related improvements and there was little emphasis on non-farm improvements.

The early 90's mark the beginning of yet another phase of irrigation development. The country's policies for industrialisation began to show rapid progress. This provided more job opportunities and choices. The most significant impact on irrigation was the shift of labour from agriculture to industry. As the country becomes more industrialised, labour shortages become more acute in the agricultural sector as the opportunity cost of labour tends to favour the manufacturing sector. Whilst land preparation and harvesting has been mechanised earlier, the highly labour demanding activity of transplanting was being replaced with low labour demanding activity of direct seeding. Land levelling became imperative in this case due to the need for precise water control required for direct seeding. As such farmers increasingly undertook to level their farms and in many cases the plots within the farmer's lot dissapeared.

The competition for water between the agriculture and the non-agriculture sectors is bound to increase as industries expand and population increases. The agriculture sector, which has a lower priority, will be compelled to seek new water saving strategies. It is within this context that in-situ rainfall harvesting concept becomes more relevant. The pre-requisites for in-situ rainfall harvesting viz. levelled fields, and close proximity to the canals and drains are now being realised.

WATER RESOURCE MANAGEMENT IN THE MUDA IRRIGATION SCHEME

The Muda Irrigation Scheme as indicated earlier is the biggest paddy irrigation scheme in the country covering an area of about 95,000 hectares or 44.8% of the 8 total granaries hectarage in

Malaysia. As shown in Map 2 the scheme is irrigated by supplies from the Kedah and Muda river systems through the Pedu and Muda dams. The total irrigation withdrawal from these systems in a year of around $1,500 \times 10^6$ m^3 is the largest withdrawal amount from a river system in the country. However, in recent years, due to lower yields from the Pedu and Muda dams, the off-season crops have to be shelved and these are getting more frequent in recent years as shown in Figure 3. In order to overcome this problem, the relevant authority has adopted the "partial supply strategy" for the off-season crops. This requires that irrigation of the paddy fields only takes place after the fields have been soaked (presaturated) by rains and this usually happens during the months of March/April. Figure 4 shows the daily rainfall of one station in the Muda area. This partial supply strategy is related to the "dry-bed" direct seeding method. The farm practices related to this method and associated water management is shown in the Appendix. However yields using this method which are around 3 tons/hactare, fall short of the main season yields of about 5 tons per hactare normally achieved within the scheme. This could largely be attributed to insufficient amount of water available during this season.

RAINWATER CATCHMENT SYSTEMS

Rainwater catchment systems in Malaysia as illustrated in provious studies have been mainly confined for rural water supply and this is also as a matter of lost resort (Uzir, 1982, 1988, 1992). The rainwater cistan system (RWCS) is only to be provided in those areas where potable supplies are not available or will not be made available in the near future and that other systems such as handpumps and gravity feed system are not feasible. The scheme was part of the Rural Environmental Sanitation Programme (RESP) under the Ministry of Health. The RWCS scheme was also closely tied to the rural sanitation or excreta disposal programme. Rural water supply has been given a great deal of emphasis in recent years. In 1990 about 66 percent of the rural

Map 2

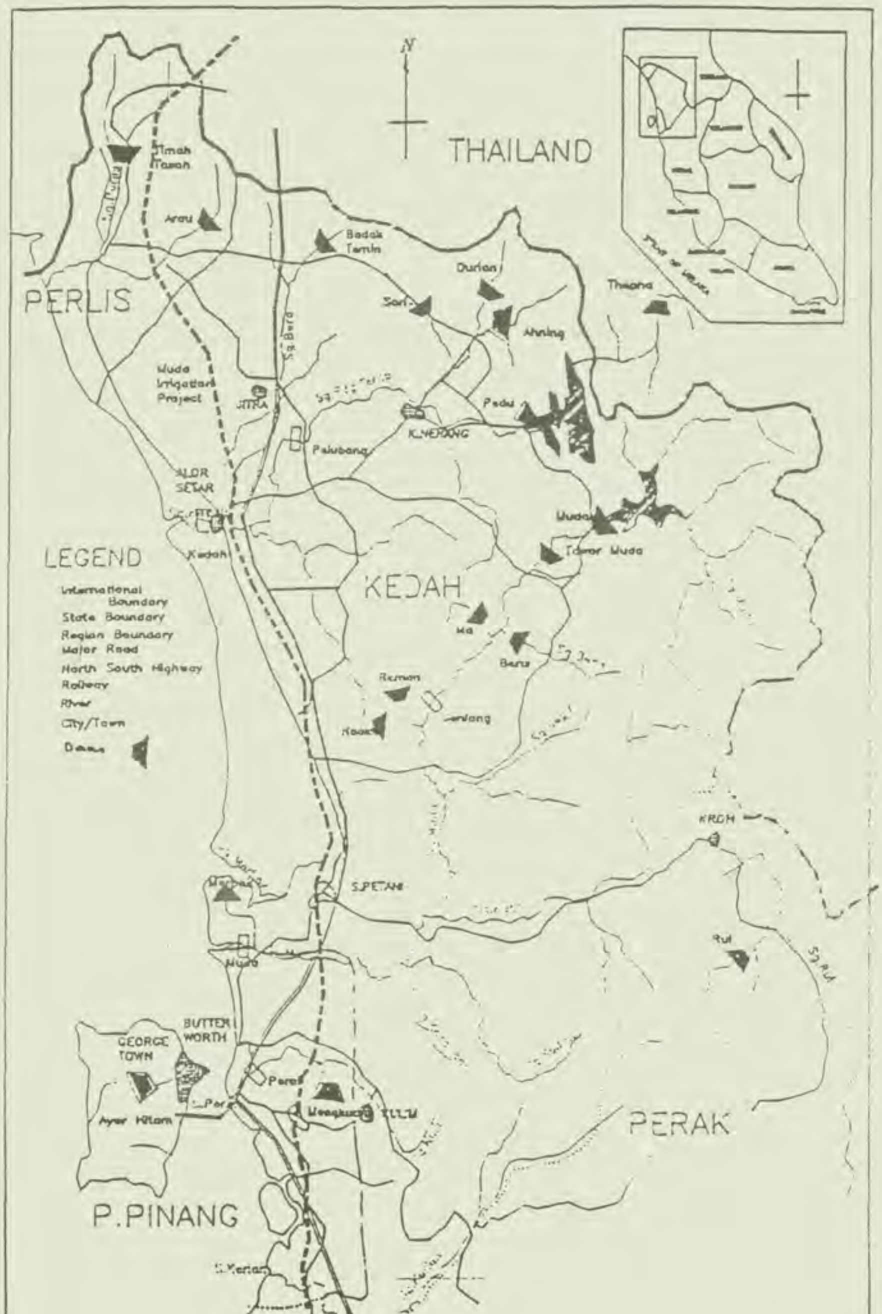
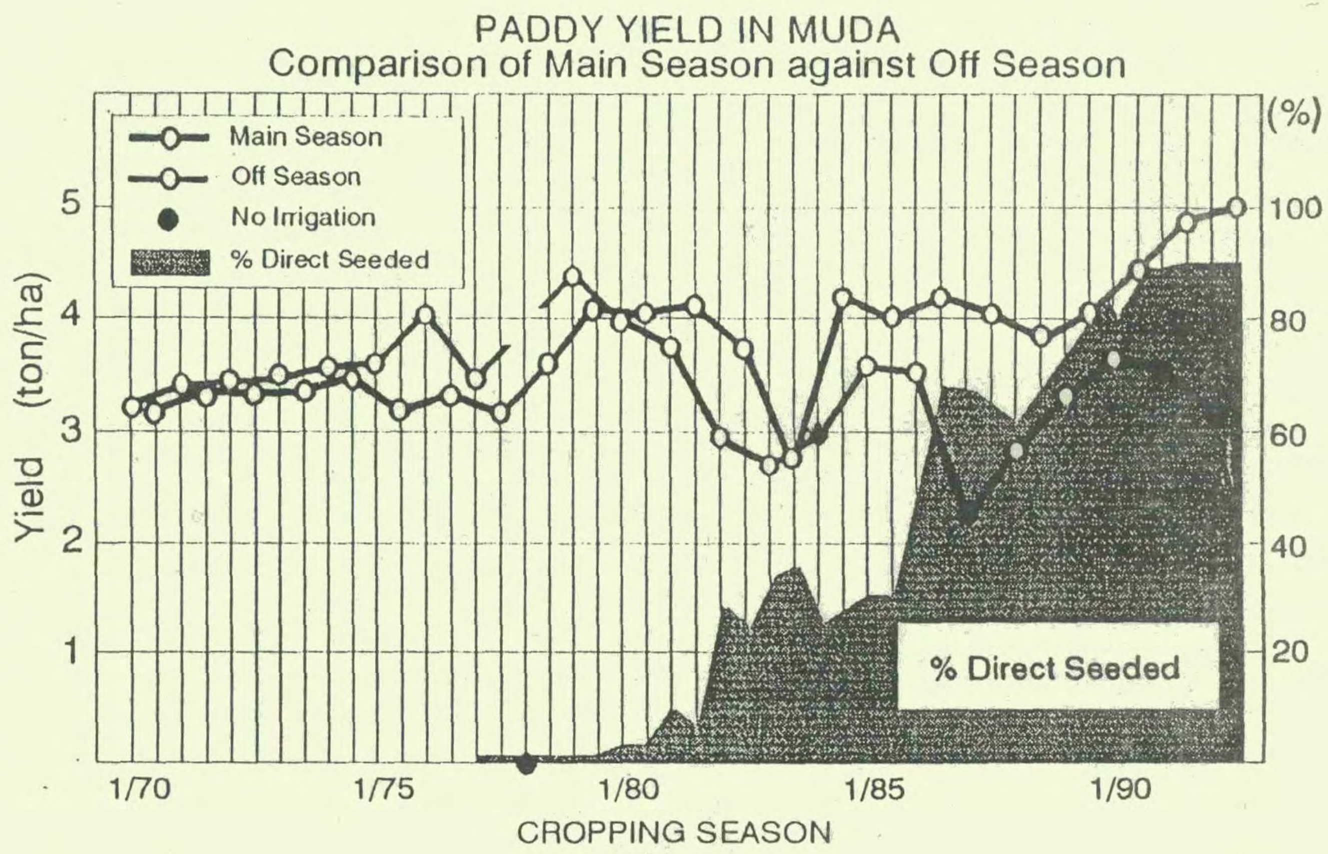

THAILAND
PERLIS
KEDAH
PERAK
P.PINANG
LEGEND
International Boundary
State Boundary
Region Boundary
Major Road
North South Highway
Railway
River
City/Town
Dams
Muda Irrigation Project
ALOR SETAR
JITRA
Pedu
Muda
S.PETANI
GEORGE TOWN
BUTTERWORTH
Ayer Hitam
KROH
Durian
Ahning
Timah Tasoh
Badak Temin

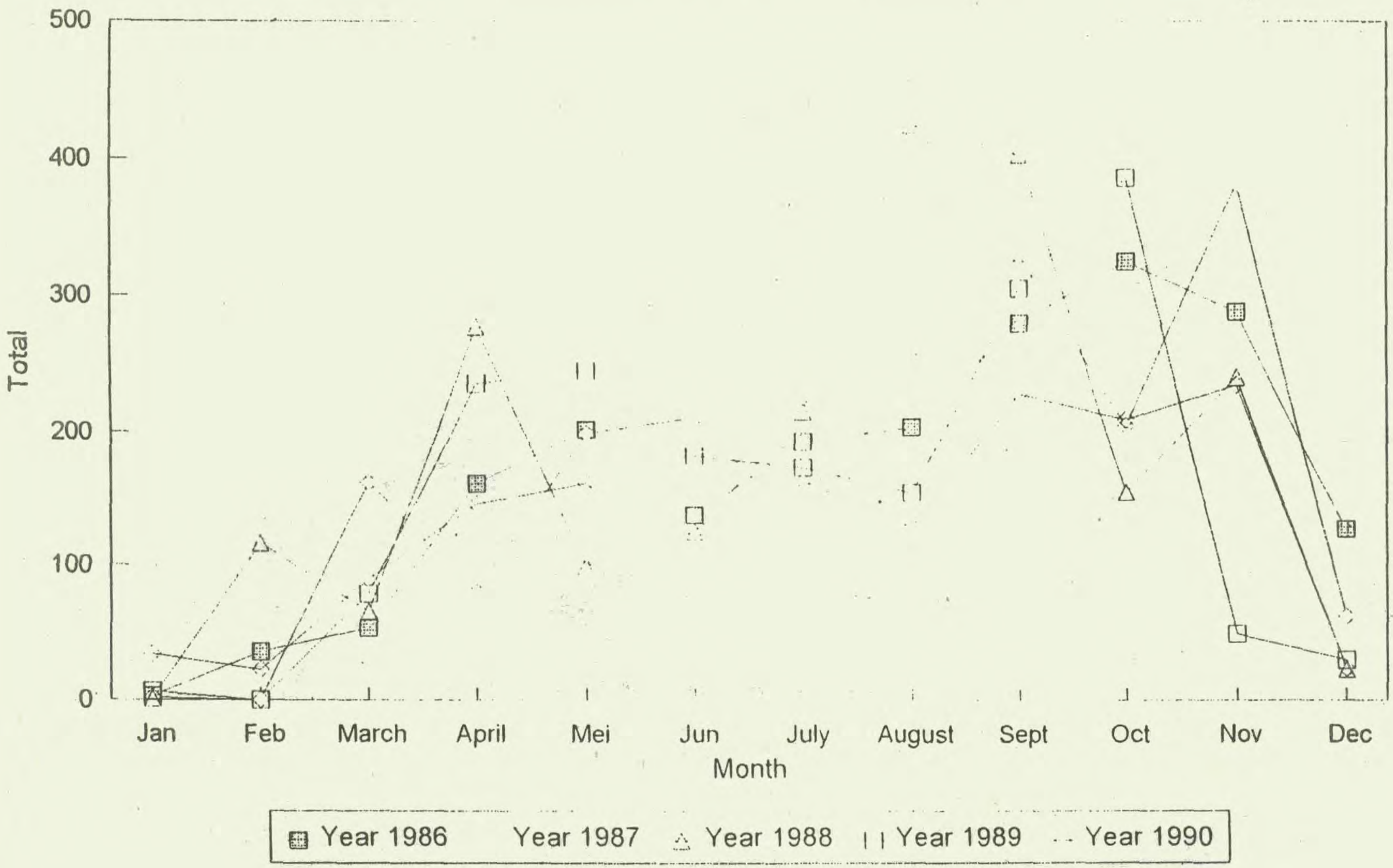
Figure 3



PADDY YIELD IN MUDA
Comparison of Main Season against Off Season
Main Season
Off Season
No Irrigation
% Direct Seeded
Yield (ton/ha)
5
4
3
2
1
(%)
100
80
60
40
20
% Direct Seeded
1/70
1/75
1/80
1/85
1/90
CROPPING SEASON

Figure 5

TOTAL MONTHLY RAINFALL IN ALOR SETAR
BETWEEN 1986 - 1990



population was provided with potable water supply. The coverage for 1995 is expected to be 79 percent. As such, the RWCS scheme will eventually be phased out as potable rural water supply expands its coverage.

Rainwater catchment systems have never been applied for purposes other than for drinking and domestic purposes in Malaysia. Partly, this is due to the fact that the supply need for other purposes such as agriculture and industries are relatively big and could not be tied to a cistern system. However, a rainwater catchment system using existing farm plots as catchment areas and the water to be used in-situ may prove feasible.

IN-SITU RAINFALL HARVESTING

Rainfall harvasting is not a new concept having been practiced in many arid areas of the world. The operation normally involves traping rainwater by using an unpermeable medium from a certain area and then transfering it to the area of usage either for agriculture, domestic or other purposes. In this paper we are refering to trapping of rainwater and using it in the same area (in-situ) albeit at different times. Since the Muda scheme has soil of low pemeability it does not require any form of lining. What are required are mainly impervious 'batas' and control gates to contain the excess rainwater when required and to release it when it reaches a maximum level or when its presence is no longer required. This is practicable in paddy culture where the plants can tolerate flooding, which would allow the paddy fields to act as reservoirs. However, to adopt this practice will require some field modifications and changes in farm practices. The sheet flow irrigation system as currently practised does not encourage the development of impervious bunds or 'batas' which is a pre-requisite for the rainfall harvasting system. Farmers under this system also need to play an active role in regulating water in their farm lots.

This potential for greater utilisation of effective rainfall is possible with the practice of operating the paddy fields as 'reservoirs' (with rising and falling levels), with the upper level set at 20 cm (drainage level) and the lower level at 5 cm (irrigation level). This practice, meaningfull after the panicle initation stage of the plant growth (due to the plant being tall enought to preclude submergence) can nearly eliminate further irrigation after this stage. However, success of this concept as indicated above hinges on the construction of robust bunds or 'batas' and the provision and operation of plank weirs set in the 'batas' (See Figure 2). The weir level should be set at 20 cm, after panicle initiation stage, to trap the rain water. Automatic drainage of the paddy field would occur should the water level rise beyond 20 cm due to heavy rains. However, if the water level in the field should fall below 5 cm (during dry spells), then irrigation water should be allowed in. As shown in Figure 4 on the average there are occasional rains even during the dry months.

Under this concept, unless a drought sets in, rains can sustain the plant growth without any further need of irrigation. Under a really ideal situation, a 20cm of water can sustain the plant for about 29 days based on farm requirements of 7mm/day (5mm of evapotranspiration and 2mm of per colation losses). This concept, together with the dry rotovation concept, can reduce irrigation requirements to a bare minimum. It hinges, however, as mentioned earlier, on the fields being level and having direct frontage to canals and drains (see Figure 2). The concept though known before, is now practicable as farms in the Muda scheme today are quite level and closer to the irrigation system.

The full adoption of the in-situ rainfall harvesting technique in the Muda irrigation scheme has important economic and financial implications. As indicated, the scheme is the main granery in the country and as such if adoption of the technique results in an increase in productivity, the level of self sufficiency in rice for the country as a whole will also increase. Currently it is only around 65 percent. This will also bring about some savings in foreign exchange. A recent estimate shows that if production of the off-season crop could be increased from an average of 3.0 tons per hactare to 5.0 tons per hactare under complete irrigation possibly using rainfall harvasting technique it could generate a total income of RM112.4 million per season*. If this technique is also adopted in the other 7 granery areas, the increase in self-sufficiency as well saving, in foreign exchange could be really substantial. Modifications in field structures are rather small requiring capital expenditures well within the budget of paddy farmers. This method therefore brings water management responsibility to the farm and the farmers both physically as well as financially.

CONCLUSION

Rainwater has always been an important source of water for paddy cultivation in Malaysia. However, the introduction of new high yielding paddy varieties which allow double cropping requires an irrigation system with water storage capacities for making water available during the relatively dry seasons. In recent years as the country progresses towards more industrialisation, more water is demanded for non-agricultural uses especially industrial processing. In a number of areas including the Muda irrigation scheme, this water is supplied at the expense of the paddy

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**This is based on an acreage of 95,000 hectare, 65% mill recovery and ex-Bangkok price of Thai white rice 100% B of US350.00 per ton. The Malaysian exchange rate is RM2.6 to US1.00.*

sector. Although there have been improvements in water use efficiency at the paddy farm level through using the direct seeding method and recycling of irrigation water, water for irrigation is getting scarce especially for the off-season crops which are cultivated during the relatively dry months of the year.

In view of the above, development of rainwater catchment system in the form of in-situ rainwater harvasting in paddy fields and plots could improve the water stress situation in the Muda Irrigation Scheme as well as the other graneries. This system is praticable in the Muda Irrigation Scheme and probably in other granaries of Malaysia due to high rainfall and its evenly distribution throughout the year. In addition, the intensification of irrigation works in these areas as well as levelling of paddy fields have allowed water management to take place at the farm or plot level. Adoption of this practice would bring about benefits in upgrading the self-sufficiency level for rice in the country as well as savings in foreign exchange.

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Increasing the Rainfall Effective Utilization by Making Full Use of the Forecast on Meteorology and Soil Moisture Content

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Abstract

There is a very great potential in rainfall utilization while water resources are heavy limited in the north China. On the view of this situation, on the basis of rainfall transformation and water balance method, the paper puts forward some measures, such as adjusting the soil moisture condition in crop root spread and improving rainfall collection capacity, to increase rainfall effective utilization ratio, at the same time, an irrigation forecast model is founded by making full use of rainfall and soil moisture content. Tested by the living examples, irrigation guided by irrigation forecast may avoid wasting the rainfall and the irrigation water caused blind irrigation, and greatly increase rainfall effective utilization ratio. The irrigation forecast model has remarkable economic and social benefits.

Keywords: Rainfall Utilization, Soil Reservoir, Forecast

Having fertile lands, the north China is an important grain crop and commercial crop production base in China. But water resources are heavy limited in the area, for example, the amount of water resource per man is only 1/8 to that of the whole country's average and 1/22 to that of the word average. In medium year, water deficit is about 1/3. To keep a higher speed in agricultures and industries development, large amount of ground water has been drawn. This leads to many kinds of severe results, such as the marked drop of ground water level, thick dry soil horizon, low capability of fighting for natural calamities, the sink of earth's surface. Faced the condition, while water saving industries and agricultures is greatly advocated and using water resources from out of basin, improving rainfall effective utilization ratio has a major realistic significance.

1. Problems

The rainfall utilization has a long history both in China and all over the world, on which many rich experiences have been accumulated. With the modern irrigation method spreading, the rainfall utilization has been neglected for a time. In 1980's, owing to water crisis, masses of water for agricultures squeezed, again the rainfall agricultures is attaching more and more importance, especially improving the crop direct utilization ratio is paid more attention in crop growing season. Having the advantages as economy and saving energy, rainfall agricultures is affected by meteorology factor and the production is unstable, now bumper harvest, now poor harvest. If the rainfall effective utilization is increased to the maximal degree in the crop growing period, the part of water deficit is partially supplied by artificial irrigation, it is no problem keeping the crop yield stable, decreasing the artificial irrigation, alleviating the water contradiction between agricultures and industries and lowering the production cost the to agricultures . This is also the main topics in the paper.

In fact, the rainfall direct utilization of crop(it is referred to the soil water utilization in the crop root spread transformed from rainfall)really has a great potential. For example, while planting winter wheat and summer corn, two crop per annual, if the output is 1500 kg/ha, the total amount of water consumption is about 800 mm, the annual rainfall volume is about 550 mm in general year. In tradition, irrigation frequency is 6-7 times and irrigation quota is 75 mm for two crop per annual. Let irrigation frequency as 6 times, net irrigation volume is 450 mm, the amount of rainfall direct utilization is 350 mm, which is 63.6% of the total rainfall volume. In author's water saving irrigating experiment base in Jing county of Hebei province, guided meteorology and soil moisture content, the irrigation frequency is only 4, the total irrigation volume is 300 mm, 1500 kg/ha, the same product can be obtained, rainfall utilization ratio reaches 90%. It is tested by the living examples that improving remarkable rainfall effective utilization ratio, decreasing the amount of artificial irrigation so long as making full use of the forecast on meteorology and soil moisture content, guiding irrigation scientifically.

2. Adjust Rational Soil Moisture Condition to Improve Soil Moisture Accumulation Capacity.

What's called soil moisture accumulation capacity, is the soil moisture content in root spread (in general, soil horizon is 1-2m) within the limits permitted by crops, that is between maximal percent moisture content (θmax, in general, θmax is field capacity) and minimal percent moisture content. The effective soil water accumulation capacity can be determined by following formula:

$$Ui=H*r*(\theta max-\theta i)$$

where:

Ui--------soil water accumulation capacity at arbitrary(mm);
H--------the calculating soil horizon(in general, H=1-2m);
r----------unit weigh of dry soil(t/m^3);
θmax-----the upper limit of soil percent moisture content within the limited permitted crops(in general,θmax is field capacity, express the percent of soil weight);
θi--------the mean of percent moisture content in calculating soil horizon(express the percent of soil weight).

We know about the inverse ratio relationship between the effective soil accumulation and soil percent moisture content. From above formula, the smaller θi is, the bigger U is, while θ=θ min, it shows that the soil percent moisture content has dropped to the lower limit within the limited permitted by crops, crops need irrigation. At this time, the soil water accumulation capacity reached maximum. If it happens to rain, and the rain infiltration P0<Umax, the utilization of P0 reached 100%, while θ=θmax, U=0, it shows that irrigation just now happened, soil water content is field capacity, the soil water accumulation capacity is 0. If it rains in some days, the most of rainfall transforms into deep percolation, not into effective soil water in calculating soil horizon.

2.2 Water Balance Formula in Calculating Soil Horizon.

The soil moisture content relates to the transporation from vegetation and evaporation from soil, rainfall volume in the interval, ground water, artificial irrigation. In the end of interval, the soil water content may be determined by following formula in the calculating soil horizon.

$$W_t=W_0+P_0+M-(e-k)*h$$

where:

W_t-----water accumulation in the calculating soil horizon in the end of time interval(mm);

W_0-----water accumulation in the calculating soil horizon in the beginning of time interval(mm);

P_0------the effective rainfall amount in the time interval(mm);

M------irrigation volume(mm);

e------the crop water consumption intensity per day in the interval(mm/d);

k------ground water supply intensity per day in the interval(mm/d);

t------the total days in the interval.

If we know the water consumption per day, ground water supply intensity per day (obtained from irrigation experiment), and rainfall forecast data, we can calculate the effective soil water accumulation in arbitrary time. and forecast the next irrigation date and rational volume (figure 1).

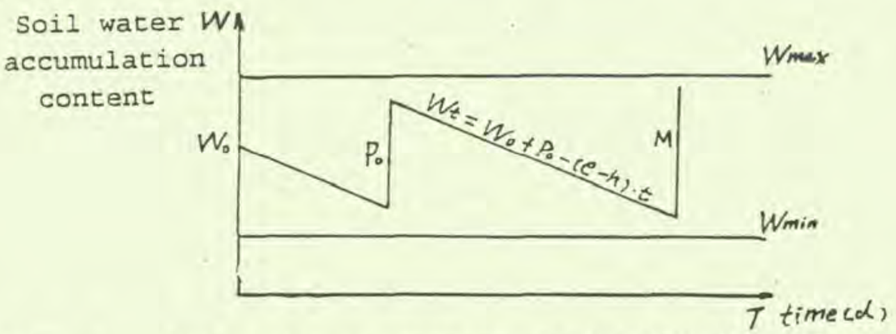

Fig. 1 Soil moisture content regularity in soil horizon

The soil moisture content can be forecast judging by formula. and rational irrigation date and volume can be determined on the basis of crops growing condition and rainfall forecast. Then we can avoid the waste of artificial irrigation and rainfall caused by blind irrigation. For example. it rains after irrigation just now happened, the rainfall utilization ratio decrease greatly, at the same time before rainfall season comes. we can vacate consciously soil water accumulation reservoir so as to accumulate the more rainfall to improve rainfall utilization ratio.

3. The Model for Irrigation Forecast.

The forecasting model need fundamental data, such as the original soil percent moisture content, the crop water consumption intensity per day, the ground water supply intensity per day, rainfall forecast in the interval. the crop water consumption intensity per day and the ground water supply intensity per day can be obtained from local experimental station, rainfall forecast can be got from meteorology agency, calculating interval may be either the seeding time or one irrigation time. At the time the original soil percent moisture content may be field capacity or nearly(depends on irrigation volume). The above data is too difficult for farmer to get. thinking about this condition, we analysis regularly masses of original experimental data, found a irrigation forecast model, so long as farmers input crops kind, forecasting yield, fertilizer quantity, soil quality, previous irrigation date and volume, weather forecast, the model will automatically output soil moisture content forecast and next irrigation date and volume.

3.2 Found the Irrigation Forecast Model

Irrigation forecast model includes three parts: data handling, calculation on water accumulation in soil horizon, decision and optimum. data handling includes data transfer and data distinguish, which can automatically examine the data rationality, reject or revise unreasonable data. calculation includes parameter determination, distinguish on deep percolation, calculation on effective rainfall accumulation. decision and optimum includes determination irrigation date and volume, and choose a optimum plan according to user's requirement to get highest rainfall utilization ratio and best economic benefit. The logical figure of the forecast model is as following:

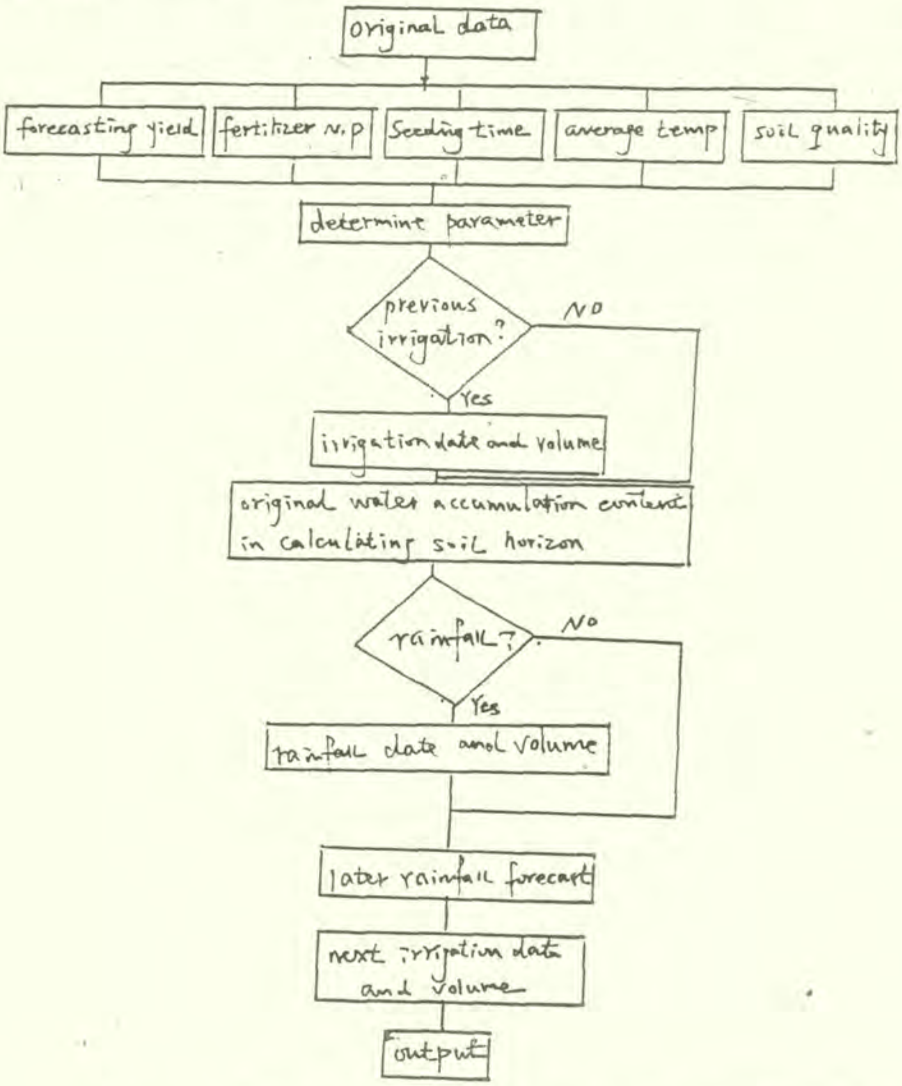

Fig. 2 The logical figure of the forecast model

4. Example

The winter wheat is experimented in 1994 in one irrigation experiment station in Hebei province, the soil quality is median soil, the mean unit weigh in 1 m is 1.43g/cm, the upper limit of soil percent moisture content within the limit permitted by crops is filed capacity, the lower limit is 60% field capacity, the depth of ground water is 12.0m, before seeding, fertilizer N is 750 kg/ha, fertilizer P is 750 kg/ha, previous irrigation date is April,11, irrigation volume is 67.5 mm. The above material should be inputted into the computer. If the farmer don't require any other problems, three plans will be outputted: irrigation volume is 60 mm in May,16; irrigation volume is 75 mm in May,19; irrigation volume is 110 mm in May,19. After irrigation ,the effective soil water accumulation separately is 36.5 mm, 35.0 mm, 0 mm. If the forecast data about middle rainfall in May,25 and requirement about one irrigation quota is 60-70 mm are inputted, the output is irrigation volume is 60 mm in May,19. After irrigation, there still is 50 mm in effective soil reservoir to prevent the middle rain in May,25 from depth infiltration. According to tradition without forecast, a large irrigation volume is 90 mm in May ,19. it must leads to depth infiltration of middle rain in May,25, and to waste rainfall. According to the material in 1994, the effective rainfall utilization ratio which irrigation is guided by rainfall forecast model is 15-30%, higher than others near farmer without forecasting.

5. Conclusion

It is tested by the living example that improving remarkably effective rainfall utilization ratio by making full use of forecast on meteorology and soil moisture content so as to decrease artificial irrigation volume. The water amount saved may large irrigation area or supply industries. or decrease amount from drawing ground water, the economic benefit. social benefit and ecological benefit is remarkable.

THE EXPLOITATION OF RAINFED AGRICULTURAL REGION

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ABSTRACT

In this paper, the system engineering method is used to determine the rational land use structure model for farming, forestry and animal husbandry. Collecting water for irrigation in the semi-arid regions, to store the rain water and preserve soil moisture for stable development of agriculture. This single measure can't obtain a good result therefore, the comprehensive technique of combining with biological method, engineering method and tillage method as a whole must be adopted, developing animal husbandry to promote farming so that both can help each other. From what has been said above in the semi-arid rainfed agricultural region of the Loess Plateau in north west China requires simultaneous methods for agriculture, Foresty, and animal husbandry.

Key Words: Rainfed Agriculture, Exploitation

Drought is a key problem in the World. For a long time, the exploitation of Water resources of arid regions and agricultural development has had increasingly great importance attached to it, especially in the large semi-arid rainfed agricultural regions of the loess plateau in northwest China.

The Loess Plateau, which is located in the mid region of the Yellow River in North China, has a total area of 560,000 square kilometers and is almost covered by loess of 100-200 meter depth. The annual rainfall ranges from 300 to 600 mm. Harsh natural conditions and improper utilization of the land have resulted in a worse ecological environment, serious erosion, infertile soil, drought and extremely low productivity. In this area, population density is 82 persons per square kilometer, which is 4 times more than the average density of semiarid areas in the world. Overloaded population increases the difficulty to solve agricultural problems in this region. So that, this area has been known as a low yield and poor area in China. Take Lanzhou Beiyen and Dingxi Districts for example. The long term average annual rainfall is about 400 mm, which is near absolute duty of water of rainfed agriculture. Water stress is the main limiting factor which restricts the development of agriculture, in this region Over-reclamation (over-reclamation index is 50-70%) has damaged the ecological environment which is the foundation of developing stable agriculture, the erosion modulus is as high as 4,000-10,000 tons/square kilo-meter, followed by bare mountain, muddy water, impoverished soil and poor life. Cultivated layer of the soil is only 15-20 cm, organic matter contents are less than 0.8%. The level of total nitrogen is 0.01-0.04%. Available phosphatic is about 5 ppm, agro-production depends on the low nutritional level.

On the contrary to the unfavourable environmental conditions, the advantage of the area is that it has rich light energy with yearly solar radiation of 120-160 kcal/square centimeter, and sunshine hours of 2,600-3,000 hr/year, in addition, the photosynthetic potentiality runs to 6,600-7,800 kg/acre, the annual average temperature is 6-9 centigrade with the accumulated temperature of >=10 centigrade at 2,270-3,460 centigrade. In addition, there are abundant land resources for rational utilization of farming, forestry and animal husbandry. The average cultivated land is about 0.5 acres per person, which is twice the average level of China.

In one word, the agro-production in the region is at the traditional, extensive stage with the single and low crop yield. Crop yield is only 420 kg/acre. Average income per person is less than 50 dollars. It did not take advantage of the light and heat resources, especially, the productive efficiency with the limited rainfall is very low only about 1 kg/mm, acre, which just is 1/3 of the production potentiality of precipitation. That is, in the middle area of Gansu province where the precipitation is about 1,000 mm. Based on present knowledge, there are 2/3 of precipitation potentiality which can be ultilized.

It goes without saying that water stress is the main limiting factor in the semiarid rainfed agricultural region. Therefore, full use of light and heat resources, in the region, is needed to enhance productive potentiality of precipitation and to make a comprehensive, study and exploitation of rainfed agriculture in the region, that is, regarded the limited factor-drought as breach and chosen improvement of using water efficiency as direction the comprehensive development of agriculture, forest and animal husbandry, in order to provide a model of agricultural sustainable development for loess plateau.

A. Develop agriculture technique of collecting water

Precipitation is the most valuable water resource in this region. Only take the part of the loess Plateau in Gansu Province as an example, the total of rainfall is more than 60 billion cubic metres in which, water loss is about 10--15%, only 20% formed primary productivity, ineffective evaporation is 65--70%, that is 40 billion cubic metres, and most of which is evaporated on the surface of barren slope land, gully and bad slope field. So collecting rainfall and developing irrigation has potentiality. Lanzhou University Drought Research Institute has done a simulated experiment of supplying 360 cubic meters of water per acre by collecting technique, the yield of interplanted wheat and corn has reached 3174.6 kg/acre, which is 8 times as the yield of the sole crop in this region. The cost of collecting water is 516 Yuan/acre. Based on this result and deep investigation, synthetical experiment of developing different kinds of collecting water technique for compensation irrigation will be made, in this item, evaluating output benefit, economic effect, soil and water conservation effect. Determining the favourable condition of different collecting water engineering and establishing the spreading model in the region.

B. Land use and coordinated research technique

System engineering method is used to determine the rational land use structure model for farming, forestry and animal husbandry, studying the coordinated field structure for food crops, commercial crops and feed crops, and developing the species of tree coordinated techniques for different conditions and the species of forage coordinated techniques for terrace and slope field in order to advance the system management model for rational land utilization in the Loess Plateau region.

C. Develop techniques of dryland moisture conservation tillage

To store the rain water and preserve soil moisture for stable development of agriculture may be the key point in semi-arid regions. Based on the foundation of reevaluation of local traditional tillage, reappraising the new tillage techniques which include deep ripping tillage, different mulch tillage, minimum or zero tillage, contour tillage and furrow-ridge should by tested inspectively in this region. Thus, the drought-resistance tillage technique system to suit the semi-arid region of loess plateau should be provided also.

D. Develop techniques of coordination of water and fertilizer

According to the theory of field ecosystem, the dynamic character of the field water system, the management method of water and nutrient should be probed. Based on the test of adjusting moisture by organic fertilizer and deciding chemical fertilizer by moisture, the adaptor of water and fertilizer should be determined, providing the evidence to the technique of adjusting moisture and fertilizer. Thus the technique that fertilizing soil as a means and raising the precipitation using efficiency as a core should be established.

E. Develop techniques of controlling soil and water erosion

In the semi-arid region of the Loess Plateau, serious soil and water erosion resulted in infertile soil, low and unstable productivity and poor. ecoenvironment accelerate soil and water erosion in return. A single measure can't obtain a good result, therefore, comprehensive techniquse of combining with biological method, engineering method and tillage method as a whole must be adopted. The biological and engineering method should be surmounted as a/focus, the soil and water conservation tillage should be studied with water preservation tillage system which includes planting multifunction forestry, especially water reserve forest, rotating crop and forage, building level terrace, slope terrace and reserve slope terrace, putting up small reservoirs, gully dams, warp dams and so on in order to control soil and water erosion, and improve ecological environment.

F. Develop techniques for improving efficiency of stock production

According to the principle of food in China, raising proteinfeed and developing forage should be chosen as a breach.The efficiency of stock production can be improved by developing forage to decide the numbers of livestock, adjusting the composition of livestock, scientific raising livestock on a large scale, developing animal husbandry to promote forming so that both help each other. In this way agricultural production will be propelled forward.

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Practices on the Rain Fed Land Agricultural Development in Heilonggang Area of Hebei Province

Qu Shengli[1]

Abstract

Hebei Heilonggang area is located in the northern part of Yellow river-Huai River Plain including 50 counties or cities in 2.4 million ha crops land. Water shortage is a main problem of agriculture production. Rain fed land is accounted for a half of total farmland. and agriculture development in rain land is very important.
This paper covers the rain fed land farming development ways or measures in Heilonggang area based on the dry land farming research and practices and local climatic and agriculture conditions. the major measures of rain land agriculture development and as the followings: 1: Adjust planting pattern to cereal. economic and forage three type -structure. for the regional rainfall effectivity and whole agriculture development: 2. Use soil water storage function fully and develop irrigation. scheduling and soil water conservation for increasing water use efficiency; 3. produce wheat area in rain fed land and increase the crops that the rainfall can meet its vigorous growth stage to improve crop drought resistance ability; 4. improve fertilizer application to increase limited water use efficiency; 5. utilize the chemical control technique to increase crop drought resistance ability and reduce water loss from ET.
The above measures must be employed integratedly to improve the water resource use efficiency and prompt sustainable agriculture development in Heilonggang Area.

Key words: Heilonggang Area. Rainfed land Agriculture practice.

The Heilonggang area is located in the north of northern China plain. It covers an area of 39.41 billion hectare. The farm land is 2.4 million ha. about 36.1% of the farm land in Hebei province. The land area per capital is 4.1 mu. Among them. 2.4 mu is farm land. with comparatively a larger capital farm land. Historically, drought. flood. waterlogging and alkaline frequently occured in this area. After the management and development for 30 years. the productive conditions and the level of agriculture productions have improved remarkably. It has gotten to be the main producing area of food and cotton of the province. but its agricultural environment is still very weak. Drought /lack of water is the main factors in prohibit the development of local production. the irrigation land is only about half of the farm land. The acreage with effective irrigation is less then 30% of farm land. Rainfed agriculture plays a very important role in agricultural production. The research in development rainfed agriculture is very important in promoting the local social-economic development.
Now. a simple summarize and recall of the rainfed agriculture research is developed in Heilonggang area for ten years will be made in the following.

1. The characteristics of water resources in Heilonggang area

1.1 Poor precipitation. big variation. and poor distribution in time and space. With bad reliability of rainfall. poor utility. drought happens frequently. Yearly precipitation is 500-600mm. 68% of them in summer. Yearly variation of rainfall greater then 20. monthly variation greater then 50%. Yearly vaporization is 2 times of precipitation. It is an area of frequent drought in Heilonggang Plain (table)

Table 1. Drought frequency in Heilonggang Area (%)

Item	Heilonggang	Yellow-Huai-Hai River Plain
bad spring drought	63--74	21--40
spring drought	70--83	46--48
early summer drought	60--65	43--44
summer drought	52--55	57
fall drought	77--83	48--56

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1.2 Water supplies is decreasing and water quality is becoming poor. The ground water procession of per capita is only 52.4 m^3, 2% of the nationwide, 0.44% of the worldwide. The water flow from outside becomes less and less. Its problem becomes very much seriously. the main river in the region, Fuyang River has become an polluted river. Due to the shortcome of outside water, the river has lost it self-pure power, this intensified the need-supply contradiction of water.

1.3 Over-collection of ground water makes the water table deeper. Statistically, the shallow water table has drop 9.8m on average from 1987-1992, about 2m per year. Because of over -collection of deep water, back-supply is difficult. Thus it drops much quickly, and forms Hengshui, Cangzhou ground water funnel is about 18% of the whole region. A potent of shortage of water has become daily clear.

2. The potential and practice of rainfed agriculture in Heilonggang Region

The situation of water resources in this area determines the agricultural development of this area must combine water-saving agriculture with dry farming. In comparison with many dry farming areas in inside or outside China, the Heilonggang area has the matures of its own, and has great developing potential. Firstly, the light ad heat resources is in a good company with the rainfall, with a small frequency of summer drought. This is good for the growth of medium heat or heat-like crops, and for better yield. Thus the meteorological productive potential is large. For example, Hengshui is in the center of drought, according to the climate productive potential. The yield of one crop in a year on nature precipitation may come to 8.25 tone/ha, and 11.25 tone for two crops in a year, but the actual yield is nearly to the half. According to our investigation in the Canada-China experimental region, the crop water use efficiency is only 34%, if the water use efficiency get to 50-80%, the agriculture yield will come up to 46-133.6%. The potential is very big. Secondly, the distribution of water land and dry land is separately, most of the irrigated land water with well. Because of this land is local basic land, this kind of irrigation can not only provide drought seeding irrigation, but also emergency water supply. Improve water use efficiency and productive ability. Third, because of the deep, smooth soil layer, and its multi-type, suitable multi planting, increase the benefit of resource usage. For example, all the famous Shenzhou honey peach, Tianjin sweet pear, Dezhou water melon, Canzhou date are produced in this area.

3. The developing route and measurement of rain fed agriculture of Heilonggang area.

Rain fed agriculture is a unstable ecological system. To make this area's agriculture developing stably, we must make decision according to the actual condition, increase soil productivity and improve ecological environment, make full usage of natural rain fall, as well as the character of multi distribution of planting, combing the rain fed agriculture and irrigation agriculture in to one system, combing the full usage of natural water and water saving by crop, to increase water use efficiency, make the rain fed agriculture have their own character.

3.1 In order to treat the agriculture as a major industry and adjust the agriculture structure, we must change the idea that agriculture is grain productivity in mind, decrease grain area in dry land, establish the three factor system: grain-forage-cash crop, increase the overall drought resistance ability and economic benefit.

For example, Wuyi county, is a drought-flooding-salinity and low yield county, have planted 2,900 hectare forage in no-grain crop suitable land recent several years, combine with residuals of crops , increase breed industry, gained a huge benefit socially and ecologically. In 1993, the animal total income are 927,400 yuan, 30.9% of total income, the merchandise of breed is 92,22,000 yuan, 80.68% of total plant industry, 41% of total agriculture industry. They also developed 6700 hectare Red Fuji apple trees. Because the agriculture-forestry-breed industries have a good structure, overcomed the salinity and the drought, benefit from the big area of land, and convert it into economic benefit and merchandise benefit, promoted the development of agriculture, in 1994, 24,924 hectare's grain land produced 6858 kg/ha, cotton and oil yield was also good, become the top county of these region.

Cangzhou city, according their regional character-clay soil and salinity, developed a alternative date and crop intercropping pattern, have founded a 130,000 hectare's golden date, average yield is 1500-2250kg/ha, several times higher then grain field economically. Liuzhong, Beishuzha(China-Canada Dry Farming Test Area in Hengshui)have 1,000ha cultivable land, 200 ha dry land are used to planting fruit, the other dry land are used to planting drought resistance crops-cotton, and oil crops, irrigated land rotated twice a year. Compare with previous 31 years, in 1990, grain, cotton and oil products increased more then 25% per unit area, total income increased 35%, 6%, and 29% respectively, capital income increased 12%, reaches 600 yuan.

It have been proved by the fact that reasonable adjust agriculture structure is effective means to increase resource use efficiency and transfer benefit.

3.2 Change traditional cultivation hibit, apply measurements for soil water saving, increase rain-water use efficiency

In some extents, soil water conservation is a main effect to determining rain-fed crop yield. So, we must use all the possible measurements to save soil water and make full use of water saving ability of soil:

• Shift the spring applied fertilizer to fall, sampling plough operation drow a harrow over the field to save water. After fall harvest, use the harrow or disk harrow immediately, applied fertilizer, then plough, harrow. In this case, if there are plenty of water in autumn, or 20mm spring rainfall, can make sure fully seedling. In 1991, we use this technique successfully, before sowing, the precipitation is only 27,2mm, the autumn seedling completely, the fiber yield was 825kg/ha.

• Use stock cover soil surface, restrain evaporate, increase rainfall efficient.

According to our research results in China-Canada cooperation Station and Dafeng Station, use stock cover techniques at the seedling stage of cotton and soybean, can restrain evaporate and weeds effectively, and mild soil temperature, cultivate soil fertility, increase water use efficiency. According to the research of stock cover test of soybean fields, if cover 1kg/m^2 of stock, can decrease weeds 55,97%, dry weight of weeds decrease 86.64%, increase yield 12.06%, soil water content(80-100cm) increase 3-5%, there are similar result to cotton field, the amount of stock is 2250-6750kg/ha, in this case, more stock, more effective, whenever the stock should applied evenly.

• Carry out scattered irrigation . Most of the irrigation systems in Heilonggang Area are conventional ditch. The water sources are the deep well and canal water and the ground water distribution is not uniform in this area. Low pressure pipeline irrigation system should used to meet the crop water requirement in spring season. Experimental results indicates that soil moisture conservation in rainfed land is a effective measure to ensure the crop full seedlings.

3.3 Adjust the cropping structure based on the timely and spatial distribution of water resources.

3.3.1 Reduce the wheat acreage in rain fed land, and develop the drought resistance crops such as cotton and soybeans. The study result from long term experiment indicates that soil water from dryland wheat was short 28.8-173.3mm in soil water annual budget at one meter deep, but water for the other crops in dry land is over the requirement. So the strategy for adjusting cropping structure is to reduce wheat area and develop drought resistance and better rainfall satisfied crops such as cotton and autumn harvested crops. This is a effective and high output measure.

In 1985, Zaoqiang demonstration area, the cereal crops mainly wheat acreage in Zaoqiang reduced one third and cropping index reached 175.5%, and the cotton, beans and other cash crops area increased 67.6%, and the yields of cereal crop, cotton and beans increased 162.1%,46.9% and 29.6%, respectively. Cotton land extension of Hebei province from east to west makes Heilonggang region a commercial cotton productive base, grain yield reaches a higher level.

3.3.2 Study results and productive practice shows that different crops and varieties have different drought resistance. Water requirement and water productivity. Adupting drought resistance and high yielding varieties in early, middle and later maturity, and cooperating the suitable sawing date to make the crop vigorous growth and development period in rain and hot season is the key idea for raising rainfall use efficiency. According to the cotton experimental result at China-Canada experimental station in 1992, the average ginned cotton yield middle and late maturity variety sowing in April 21, is 411.4 kg/ha, while the yield of middle and early maturity cotton seeded at May 20 is 528.3 kg/ha. So it is vary important to select suitable varieties and rational seeding date.

For improving rainfall use efficiency in dryland, eight crops and 19 varieties including beans were introduced from Canada to improve dry land crop planting pattern and rain fall use.

3.4 Improve rainfall use efficiency by increasing fertilizer application. Drought, salinity and low fertility limits water productive potential in Heilonggang region. Fertilizer is a flexible factor compared with rainfall satisfaction. Increasing fertilizer and improve application method are effective measures for raising rainfall use efficiency.

3.4.1 Increased fertilizer application can increase soil water use efficiency. Table2 and Table 3 show that the water benefit from cotton and winter wheat in rain fed land are increased under larger amount of fertilizer. Improving fertilizer application is one of the most effective measures to increase crop productivity.

Table 2. Rainfall productivity in different fertilizer application amount in rain fed land cotton

Year	Rainfall in growth period (mm)	Fertilizer N240P120	(Kg/ha) N120P60	N(nitrogen) N60P30	P(P2O5) N0P0
1983	356.5	2.510	2.064	1.839	1.544
1984	493.3	2.946	2.475	2.188	1.557
1985	360.5	2.310	2.453	1.993	1.716

Table 3. Water benefit from N fertilizer applications in rain fed land wheat

	N fertilizer	application	amount	(Kg/ha)
	75	150	225	300
0 -100 cm soil water consumption(mm)	106.5	119.8	121.9	126
water benefit (Kg/mm.ha)	14.06	17.82	18.48	18.06

3.4.2 Improve fertilizer application methods to increase water and fertilizer use efficiencies. Fertilizer application in dry land must base on crop requirement and rainfall pattern so that the rainfall supply can meet the crop vigorous growth stage.

Winter wheat in rain fed land primarily depend on the soil water storage becausse there is less rainfall during the growth and development stages. According to the experimental data. the soil water deficit at one meter mass is 140.7mm per year . so the applied fertilizer can not fully take effect. All the fertilizer short applied before sowing at the range of 83.7 to 106.5 Kg/ha N and 54 to 62.5 Kg/ha P_2O_5 based on the soil water content. For the cotton and autumn harvest crops. because there is more rainfall in crop growth period and the rain and hot season meets the crop water most require stages. The fertilizer application method is different from wheat. It applied before sowing and in the growth stage at rational amount of 120 -240 Kg/ha N. 60-120 Kg/ha P_2O_5 for cotton and half of it applied during crop flouring stage. The fertilizer dressed during growth stage can adjust the total amount for obtaining the maximum fertilizer benefit.

3.5 Adopt the chemical control technique to increasing the crop drought resistance and reduce water loss from ET.

In 1989. we conducted the experiment by using Fa to treat winter wheat seeds. the result shows the yield in Fa treatment was similar to the yield in irrigated land.

The experiments conducted in China-Canada Experimental Station indicates that the chemical can control the soil surface evaporation and adjust the crop population. the yield in chemical treatment increase 50.3 percent compared with conventional management. Chemical adjustment for crops has a good future in dry land farming.

Conclusion

Dry land farming in Heilonggang Area has great potential. For tapping the potential. following measures must be taken: (1) combine the dry land farming and water-saving agriculture together in crop production: (2) adjust the cropping structure and pay attention to attain the annual crop yields: (3) focus on the water use efficiency improvement and fulfill of the objective of high yield. good quality and high effectiveness: (4) Actions must be taken for rational resource utilization and sustained agricultural development.

A NEW TECHNOLOGY FOR THE EFFECTIVE UTILIZATION OF RAIN IN AGRICULTURE

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Abstract

The "covered and storing water ditch for high yield" is a new technology to make full use of rain in agriculture. It make it become an organic combination to block, divert, store and remain the rain water. In this paper, firstly, the composition, the standard, the structure form and the constructing procedure of the "high yield ditch" are introduced. Secondly, the diverting and storing rain mechanism and the ecological effects in the cultivated fields of the "high yield ditch" are expounded. Finally, the direction for further studying these problems is proposed.

1 Introduction

The "covered and storing water ditch for high yield" is a new technology to make effective use of rain in agriculture. It is called as a new technology because it would make the district field planting, the deep ploughing, the ground membrane covering, the spreading manure and other measures become an optimistic and organic combination and a intensive farming system. From the view of making effective use of rain, this technology would make it become an organic combination to block, divert, store and remain rain. It will change the passive preserving the soil moisture to the positive storing water and moisture. It will make the soil rich in manure and increase the soil ability to block, store and remain rain and decrease the water consumption of the soil. This new technoogy will greatly enchance the utitization ratio of rain in agriculture. According to the stastics, the utilization ratio has been in creased from 38.5% up to 82.5%. The four year's typical experiments has shown that the average grain yield has reached 612.25kg each mu, 200kg more than the contrast field. These experiments had been made under a bad conditions in which there were a dry year, a flood year, a dry year and a hailstone year. In the first year of the experiments (1987), it happened to be a very arid year, the total amount of rain in one year

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was 274. 4mm and much worse it had no rain and only a high temperature weather that continued for 40 days from July 7 to August 10. Under such bad natural condition, the grain yield was greatly reduced in most of the fields. However, the grain yield in the experimental fields reached 485kg and 7 times more than the contrast fields. This technology can be widely spread in the dry and water shortage areas for effective using of the rain to get a high yield.

2 The constructing and membrane covering of the "covered and storing water dithch for high yield"

The basic cultivation unit of the "high yield ditch" is the "cultivation belt". A "cultivation belt" consists of a "raw soil ridge" and a "plant ditch". Each belt is 1. 2m in width, the ditch and the ridge is separately 0. 6m in width. The redge is 0. 3m in height and the cultivated soil in the ditch is 0. 5m deep. The constructing procedure of the ditch is that the cultivation belts are set up one by one from the outside to the inside edges of the slope land along the isocatabases. (A). to dig the soil of 15cm deep in the first cultivation belt in 1. 2m wide and put them on the second cultivation belt (see figure 1, a); (B). to dig a ditch 0. 6m wide and 0. 3m deep, and build up a ridge whose bottom is 0. 6m wide and is 0. 3m high and make the top shape of the ridge like a bow (see figure 1, b); (C). to plow the bottom raw soil of the ditch deeply for 0. 2m and then spread manure 5000kg dung, 50kg phosphate fertilizer and 50kg carbonic acid ammonium per mu. (see figure 1, c); (D). to put the cultivated soil dug in step A back into the ditch. Now the first cultivation belt has been constructed. To repeat the work stated above we can construct the cultivation fields of "covered and storing water ditch for high yield" (see figure 1, e).

The membrane covering steps of the "high yield ditch" are the following: (1) to smash the clods, to clean the roots and weeds out and to build up the bed surface with a bow like top shape whose vector height is 5cm. (2) to cover the ditch using the membrane with the thickness changing from 0. 005m to 0. 014mm according to the plant changes, when covering to remain separately a permeating path along the two sides of the ditch. The covering time is decided according to the time of constructing the ditch. If the ditch is constructed in spring, it should be covered at the same time; if it is constructed in Fall or in Winter, it should be suppressed no time delaying and covered in the following spring after the soil melting. The membrane should be unfolded along the cultivation belt and contacted tightly with the soil. The protection soil belt, which is 10cm wide and 5cm thick, should be put on the membrane every other 3～5m to avoid the membrane being taken away by the wind.

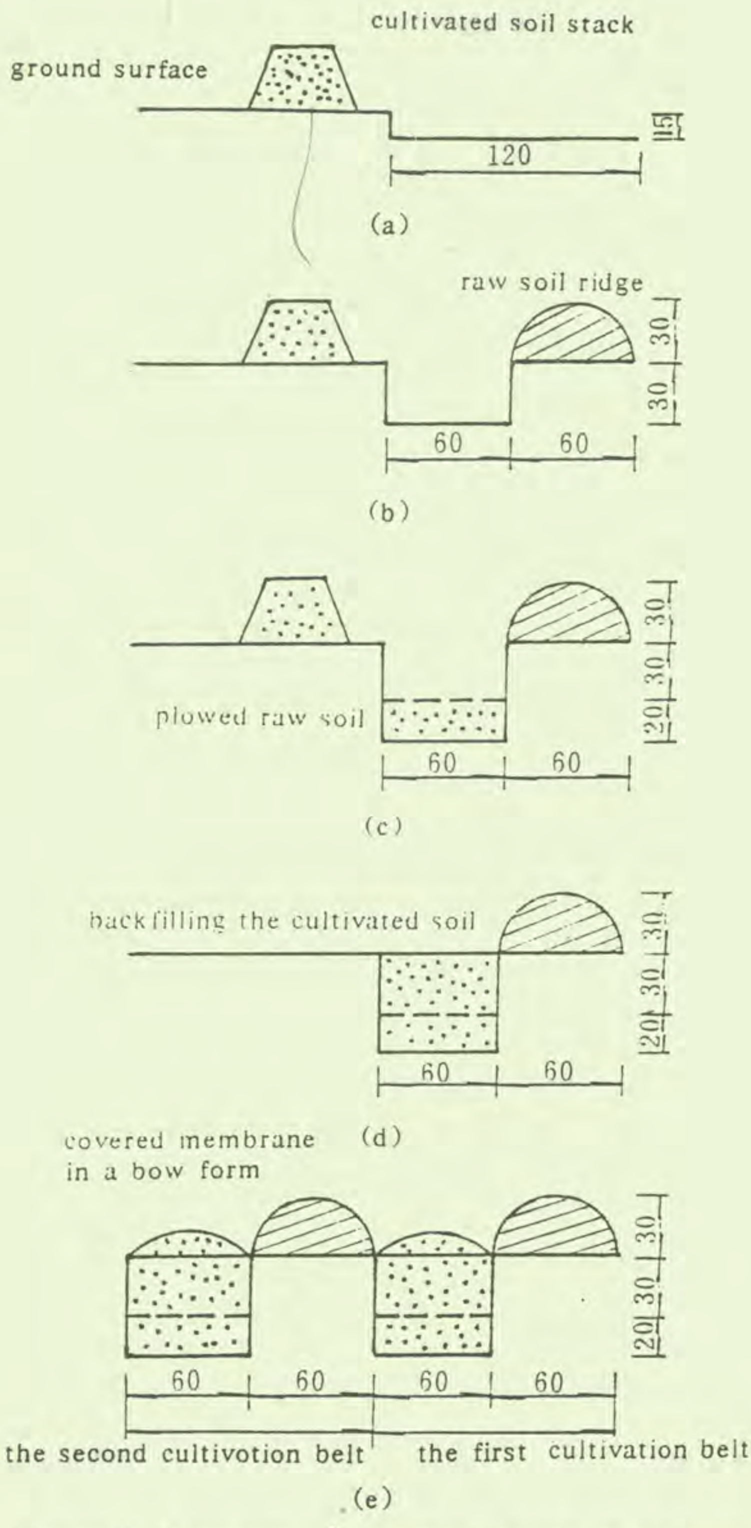

Figure 1 Constructing Procedure sketch of the ditch

3 The mechanism of blocking and storing rain of the "high yield ditch"

The plant consuming water amount in the arid area is generally about 400～450mm. Therefore, analysing it from the view of the plant consuming water, the true reason that cause the land in the mountain and hilly area dry is not it rains little, but is that it rains unevenly and the effective utilization of water is too low (about 30%). Taking the Jinzhong region in Shanxi as example the average rainfall in stastics is 503.7mm. It is 549.1～601.1mm in the mountain area and 511.3～538.1mm in the hilly area. If most of the rainfall or all most of the rainfall may be obsorbed by the plants, it would meet the plants' requirment for water. By blocking, diverting, storing and remain the rainfall, the "covered and storing water ditch for high yield" has achieved the comprehensive utiliaztion of the rain fall and enhanced the utilization ratio of the rainfall.

3.1 Shortening the length of the slope, changing the micro ground shape and blocking the runoff

Each ditch and ridge is construted separately along the isocatabases in the slope field. The original cultivated fields are divided into several acltivating units which consists of some cultivating belts. The length of the slope is only the width of the cultivating belt and is much shorter than the original. During constructing of the "high yield ditch", the micro ground shape has been changed, the difference of the soil between the high and the low has been reduced and the slope of the ground has become evener. Therefore, the speed of the runoff is reduced and this is advantageous to the permeating of the rain. Secondly, the raw soil ridges, constructed along the isocatabases, are like some dams which would block the runoff of the rain within a certain area. According to the stastics when the raining amount is 100mm a day there is no water and soil being washed away and this would prolong the permeating time of the rain. Thirdly, since the raining amount blocked in each cultivation belt is ralatively well distributed, the rain fall state which is not well distrbuted in the original cultivated fields has been improved.

3.2 Diverting the "gust water" and expanding the water source

The blocked runoff of the rain that has been discussed before refers to the rain received by each cultivation belt. In addition, the ridges function can be brought into full play to block and divert the "gust water" which refers to the rain runoff in the uncultivated land. In the arid slope land area, the slope is steep and the covering area is wide and runoff amount is large. If these runoffs are blocked and diverted into the "high yield ditch", it is tantamount to the increasing of the rain and the expansion of the water source.

There are two ways of channeling the "gust water". One is directly to receive the runoff, that is to say that the mouth of the "high yield ditch' is faced to the direction of the runoff and the slope runoff can be directily led into the ditch. The antother is cross blocking and longitudinal channeling. That is to say that the direction of the ditch is perpendicular to the slope direction and it is possible to build up the horizontal canal to channel water into the ditch.

3. 3 Improving the physical nature of the soil and enhancing the soil ability to store rain

The soil ability of storing water is affected by the soil grain, texture, the organic matter and other factors. They affect the soil ability by changing the physical nature of the soil.

3. 3. 1 Action on the soil grain

The soil grain refers to the mechanical composition of the soil and consists of different grains and directly affect the soil poriness. If the soil grain is fine, it refers that it have some samll and much more pores, and the total poriness is big and the unit weight is small. If the soil grain is coarse, it refers that it have some big and less pores, and the total poriness is small and the unit weight is big. Compared with the contrast fields, the physical sand grain in the "high yield ditch" are reduced, the physical clay grain are increased by 4. 34% and the clay grain less than 0. 001mm in diameter are increased by 5. 49%. Since the mechanical composition of the soil has become more rational, the soil poriness has increased by 23. 2% and the unit weight has reduced by 17. 3%. These have established the soil foundation for receiving and storing water.

3. 3. 2 Improving the soil structure

The natural soil consists of various united bodies of the soil, which are called the soil stracture. Different structure has different nature and the granule structure is a good soil texture. The micro united bodies of the soil lay the foundations for the granule structure. Compared with the slope land, the micro united bodies larger than 0. 01mm in the cultivation fields of the "high yield ditch" have in creased by 2. 52~7. 78%, the general united bodies account for more than 70%, and water stability of the united bodies have the tendency to increase. The " covered and storing water ditch for high yield" technalogy has made the temporary structure 2~0. 25mm and 5~0. 25mm of the soil increased respectively by 1% and by 6% and the temporary structure larger than 5mm reduced by 9%. The soil structure has been greatly improved. If the soil have more granule, the soil structure is porous, the unit granule, the soil structure is porous, the unit weight is reduced and the proportion between the capillary pore and the uncapillary pore is proper. The capillary pores in the granule are the places where the water and the manure are stored, and the places among granules are the uncapillary pores which are the passageways for water and air. When it rains, the water quickly permeate the soil by the uncapillary pore way and during the permeating the water go into the capillary pore and is stored. This work avoid the soil and water being washed away, which would happen if the water permeating is slow and the water become runoff on the ground. When the soil water evaporates, the granule would cut off the capillary pore which is passageway between the soil bottom and the air. There fore, the water amount that the soil water go up to the surface by the capillary pores has greatly reduced. Also, when the water in the soil surface is evaporated, the granule volume would contract and the capillary pores, which connect the surface soil and the lower layer soil, are cut off. The surface soil become isolation layer and the water evaporation of the soil would be greatly reduced. The soil ability for storing and remaining water has increased.

The collecting manure and the improving the soil effects in the cultivation fields of the "high yield ditch" creat a favourable conditions for the forming of the granule texture. Since the manure is spread according to the prescription, deeply and concentrately and the organic manure amount is larger, the manure effects have enhanced and the organic and inorganic colloids have combined tightly and these would promote the forming of the water stability granule structure. According to the experiment data conducted by Shanxi Agriculture Institute, comparing the deep plowing and high manure with the deep plowing and low manure, the water stability granule larger than 0. 25mm have increased by 10. 1%, the granule texture large 1~3mm have increased by 13% and the remaining texture have increased by 12. 8%. These show that the spreading manure according to the prescription and applying more organic manure are the effective measures ofr creating the water stability granule texture and would raise the soil ability to remain water.

As stated above, the collecting manure and the improving the soil effects and the increasing temperature effects by membrane covering have accelerate the soil mellowing and kept the soil being porous. According to the experement, the unit weight of the soil deep 0~50cm is 1. 24g/cm^3, the poriness is 53. 47%. Compared with the contrast fields, the unit weight has reduced by 0. 26g/cm^3, the total poriness has increased by 10. 07%. Within them, the capillary pores have increased by 1. 9% and the holding water pores in the field have increased by 1. 2~1. 5%. Therefore, each ditch is look like some "soil reserviores" which can greatly receive and store water. The experiment show that the "high yield ditch" can receive and store 40~60mm rain fall in 12 hours, 80~120mm rain fall in 24 hours and 150mm rainfall in 72 hours, and there are no water and soil being washed away. The increasing of the capillary pores is advantageous to the capillary pore moving around with the help of capilliary action and the increasment of remaining water pores in the fields show that the soil ability to remain water has increased. The experiment show that, compared with the contrast fields, the remaining water pores in the fields have increased by 3~4%, the natural containing water in the surface soil has inereased by 16%, the rising speed of the capillary water has increased by 25% and the water permeating speed is 2. 2 times more than the original one.

Table 1 Containing water of the plants in different growth stages and in different soil depth

growth stage	before sowing			seedling stage			jointing stage			heading stage			mature period		
soil depth(cm)	0~10	10~20	20~25	0~10	10~20	20~25	0~10	10~20	20~25	0~10	10~20	20~25	0~10	10~20	20~25
containing water in the "high gield ditch" (%)	13.1	15.2	17.3	18.6	20.7	22.1	11.2	10.5	10.2	29.6	31.3	32.1	17.2	18.6	17.9
containing water in the contrast fields(%)	9.1	10.6	11.8	14.4	16.3	15.1	8.7	9.1	9.0	21.2	27.6	29.4	12.5	14.1	14.4

3.4 Changing the moving way of the soil water by membrane covering

When the sun irradiate directly the ground, the water will go up from the lower layer soil to the surface and evaporate gradually because of the existence of the soil heat difference, while the water evaporating would consume a great deal of air potential heat. In the "high yield ditch" covered by the membrane, the soil water would not be evaporated because of the membranes isolation. Therefore, the heat comsumption is reduced and the soil temperature would inerease. The experiment show that the soil temperature in the "high yield ditch" is 3° higher than that in the comtrast fields. This will make the soil heat difference become larger and will make the soil water go up. Since the membrane cut off the changing passageway between the soil water and teh water of teh air near the ground, the scattering of the soil water air has reduced. The evaporated water coagulate under the membrane, return into the ground with the help of the gravity and permeate into the soil. As stated above the circulations happen again and again, the water evaporation of the soil is effectively restrained and the containing water of surface soil has increased. The big circulation moving way of the sol water has been changed into the small circulation which is conducted between the membrane and the cultivated soil. The table one shows the contain water of the soil in the "high yield ditch" and in the contrast fields, which are tested in different growth stages and in different soil depth. The experiment results show that, compared with the contrast fields, the containing water of the soil 0~10cm, 10~20cm and 20~25cm deep in the "high yield ditch" has separately increased by 4.16%, 3.72% and 3.98%. Since the ground membrane covers the soil all the year, it would regulate the rainfall distribution unevenness round the year and it has a very good effects for the fighting a drought and storing water in the arid areas. Moreover, since the ground membrane cover the soil in a bow form, the gradient is larger and the membrane is smooth, there is no water on the membrane after rain and these not only reduce the water evaporation during the raining and after the rain, but also form a runoff on the membrane when it rains little (less than 5mm), which would permeat the soil along two sides of the ditch. This would raise the utilization efficience of rain. The actual test results show that the utilization of the natural rain in the "high yield ditch" is as high as 82.5%.

4 The organisms' habits conservancy effect of the cultivated fields in the "high yield ditch".

Since the cultivated fields of the "high yield ditch" consists of the ditches and ridges, which are constructed one after another, the slope length of the original slope land has been greatly reduced, the micro ground shape has been changed, the ground gradient is ralatiuely slower and the runoff speed has been reduced. The ridges would block the runoff and the ditches would receive and store water. All these comprehesive actions will prevent the water and the soil from being washed away. For example, although there was a 20 minutes rain and the rainfall amount was 29.1mm on June 6, 1990, no ridges in the experiment fields broke off. Because there is one ridge after another ridge and the ditches are covered by the membranes, the ground roughness has greatlyincreased. The actual test results show that the ground roughness in the "high yield ditch" is 6 time as much as that in the contrast fields and this would make the wind near the ground reduced. The actual test results show that the wind speed 20cm above the ground has reduced by 52.3%, compared with the contrast fields and these would greatly enhance the soil ability to resist the wind. All these works may not only protect the local agriculture organisms' habits environment, but also reduce the dust in the air and also protect the down—stream areas against being affected by the water and soil washed away.

Since the manure are applied concentrately and deeply and the ditches are couered by the ground membranes, the atmodphere and water environment pollution caused by the manure salution, volatilization and washing is prevented.

The cultivation modle of the "covered and storing water ditch for high yield" is a new technology that can make full use of the rain in the arid areas and make the areas to get a high and stable yield and it is based on the foundation of water soil protection. If this technology is popularized in the arid and warer shortage areas, it is possible to cultivate less land and get a higher yield, and develope the agriculture in the direction of intensive farming and ecological agriculture.

5 Problems remained to be solved

Analysing the "covered and storing water ditch for high yield" from the point of effective utilization of rain, the main problems are the followings: one is to enhance the soil ability to receive and store water and the another is to reduce the void comsuming of the soil water. Around these problems there are some other ralative problems that remain to be solved.

5.1 To study the best ditch depth and the most suitable time to construct the ditches

That the "covered and storing water ditch for high yield" can receive and store the rainfall is realized by collecting manure, changing the soil and building the "soil reserviores". Saying about a area, there is a rainfall distribution nunevenness in time and there is water evaporating during constructing the ditches. Therefore, there is a most suitable time for the ditch constructing. Saying according to the theory, the best time to construct the ditches is when it rains much and the evaporation is less. This is because in this time the cultivated soil of the "high yield ditch" may most receive and store the rain and the soil water comsumption may be reduced to the lowest. However, this would contradict the other farm works. Therefore, we should have a good master of the local rainfall and soil water consumption law changing with the reasons, coordinate the ditch constructing and the farm works and search for the best time to construct the ditch.

Considering the physiological nature of the plants, the root system action layer concentrate on the soil layer 30～50 deep. Considering the soil water utilization of the plants, within the growing period the plants not only absorb the water stored in the root system action layer but also absorb the water stored in the deeper soil with the help of the capillary action. In addition when the ditch is constructed deeper, it cost much money. Therefore, we must comprehensively consider ditch depth, the utilization ratio of rain, the cost and so on, and to do some contrast experiment to search for the rational depth.

5.2 To study the applying manure measures for the better soil structure

That the soil has a better structure refers to it has much more granular stracture. The forming of the granular structure is the results of the coacervating and gluing actions. The substance that would glue the soil grain is the internal cause for the forming of the soil are the humus, hypha, mucus, gluing grains, iron aluminum oxide, silicic acid gel and the lime. As the humus are said about, only the newly formed humus have a more powerful coavervating ability. To remain the granular texture of the soil requires continuous changing of the humus. Therefore, it is required to apply the organic manure frequently. This requires that we further study the much better prescription of the manure and the new applying manure measures.

5.3 To study the relations between the soil structure and the no plowing plantion

The granular structure may gradually form under favourable circumstances and it may be destroyed after the humus are resolved when the cultivated soil layer has become hardened and impervious because of the natured and human reasons. That is to say that the soil granular structure developes as it forms and is destroyed. By studying the relations between the soil structure and teh no plowing plantion and taking suitable measures, the soil granular structure forming could be made to be in an advantageous position over the destroying. This would make the granular structure inerease gradually and keep a good structure in the cultivated layer.

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Studies on the Optimal Development of Paddy Field in Songhuajiang Prefecture, Heilongjiang

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Rice is a high-producing, stable, and profitable crop. The development of rice production is of great significance for increase of farmers' income, improvement of people's life and the development of national economy. The development of paddy field is affected and limited by farming policy, state finance, rural economy, natural conditions, water and land resources, water works, and farming techniques, etc. It is a complicated systematic engineering. To obtain the best selection with theoretical, analytical, economical and statistical methods is an important topic for water conservancy researchers.

The optimal development scale were studied based on the surface water and underground water resources and their distribution in Songhuajiang with conservation theory, and calculation methods. Thus, the mathematical model for paddy development scale was established. The optimal development in local region could be obtained according to the changes of various factors, providing basis for policy making for paddy development.

1. STUDY PROCEDURE

The study was in four steps, The first step was collection and study of historical information. Such as, the water utilization facilities, the development of paddy field, rice production, water and soil resources, the effects of social economy and scientific and technological progress on agricultural production. Hydrographic and meterological information. The second step-Survey and investigation, the investigation on factors affecting on water crop development. The third step-the theoretical study. Analyze the relationships among the factors affecting paddy development. Establish the preliminary mathematical model. Through calculating and modification, the historical, current and future water crop developments tend to be in accordance. Establish the final mathematical model for optimal paddy development scale. The forth step-the results.

2. STUDIES

2.1. The Limiting Factors

the development scale for paddy field are affected by 40 factors in 7 categories.

(1). Resources: water, soil, light, air and heat;

(2). Water works: water source, farming facilities, investment, managenment of water facilities, irrigation method, irrigation regulation and water conservancy technology;

(3). Farming technique, seedling culture, transplantation, cultivation, improved varieties, pest and disease prevention;

(4). Policy: tax, price, rice production information, free labor;

(5). Materials for farming: fertilizer, pesticides, plastic film for farming, diesel and electric power;

(6). Farming machines: small-type farming machine, rice transplanter, harvester, diesel engine, and water pump;

(7). Others: crop composition, rice by-product processing, farmers' technical level and rice planting habit etc.

2.2. Analysis of the limiting factors affecting paddy field

Like other crops, rice needs suitable soil, light and heat; unlike other crops, it needs more water. So the water, soil, light and heat are the essential factors for paddy field development.

(1).Light and heat resources: sunshine in the prefecture is 2450 to 2700 hours with energy of 110-120 kilocalorie/cm2, average temperature 1-4c, accumulated temperature 2300-2900c, frost free period 110-145 days, rice grow period May-September, energy requirement for rice 60-64 kilocalorie/cm2. Therefore the whole area in the prefecture is suitable for rice growth.

(2). Land resources: in the prefecture, there are 4000,000 mu less productive plain and 4000,000 mu high-producing land fitted for paddy field, accounting for 56.7% of the cultivated land.

(3). Water resources: the prefecture is rich in waterways. Annual discharge flow of rivers is 9.09 billion m3, underground water supplement 2.97 billion m3, 1 billion m3 recoverable, and 1.34 billion m3 in reservoirs. But there are still 3 disadvantages for paddy field: a) uneven distribution of water; b) large variation in water flow during the year; c) uneven distribution of rainfall in the year. Thus, water is a limiting factor for paddy field development.

2.3. Determination of important factors and set up of mathematical model

(1). Water resource x1: a limiting factor expressed in annual discharge and recoverable underground water. that is: x1=9.09+1.0=10.09 billion m3.

(2). Water efficiency x2: in 1989 in the prefecture, industry took water of 485 million m3, agriculture 2,438 billion m3, residents 486 million m3. The water efficiency is 0.25.
So, we assume x2 to be 0.25, 0.30, 0.35, 0.40 and 0.45. x2>0.5 is excluded. According to conservationist, when the water efficiency is over 0.5, the ecological balance on earth will be destroyed, natural rivers polluted.

(3). The proportion of water used by agriculture x3: in 1989, water for agriculture was 2,438 billion m3 accounting for 96.7%, water for industry and residents 971 million m3, account for 3.83%.with the development of industry and improvement of people's life, water consumption will increase. Songhuajiang prefecture is a farming based prefecture, its water use for industry will not be more than 20%(the world average 21%). The current water use for industry is 12.04%, for farmers 87.96% in china. Thus, we assume x3 to be 0.9, 0.85, 0.80, 0.75, 0.7.

(4).The proportion of water use for paddy field in the farming total(x_4). The annual average irrigation water is 2.253 billion m3,92.41% of the total for farming. with the development in farming,afforestation, animal industry, fishery etc., water consumption will increase. We assume x_4 to be 0.85, 0.8, 0.75, 0.7.

(5). The amount of water needed for paddy irrigation x_5: in Heilongjiang, the amount of water needed for paddy irrigation is 800-1250 m3/mu. with the use of new techniques, the amount needed will decrease. Thus, we assume x_5 to be 13,000 m3/shang (1 shang=15mu), 12,000m3/shang, 11,000m3/shang, 10,000m3/shang, 9,000m3/shang, 8,000m3/shang.

(6). Mathematical model for optimal paddy field development scale. Five viables has been adopted in determining the development scale. for each viable, there are 4-6 levels. Various developing scales can be obtained with the viables assuming different values. The mathematical model for optimal development scale:

$$A(\text{optimal}) = x_1 * x_2 * x_3 * x_4 / x_5$$

Input the 20 values of the 5 viables. 600 results are obtained. The viables assume different values; the results differ. The optimal development scale can be determined by selecting values suitable for the region.

2.4. Conclusion

(1). Model test: In 1989, for the whole prefecture, x_2=25.13%, x_3=96.17%, x_4=92.41%, x_5=11051m3/shang (average), Actual irrigation area for the year is 3,057,000 mu, in accordance with value of 3058,700 mu calculated using the model.

(2).Example of the model: in 1995, after the set up of Shangli and Xiangmoshan Reservoirs, there is 498 million m3 more water available. The water efficiency is raised to 30.06%. Water for industry increased 10%. Water for paddy irrigation accounted for 90% of the total for farming. The amount of water needed for paddy field was 10,000m3/shang. Take these value into the model, the paddy scale of 3,680,000mu is obtained.

(3)The approximate maximum paddy development value. Based on the economy development, water efficiency will be 50% in the future, water for industry will be 20%, water for paddy field will account for 80% of the total for farming. The amount of water for paddy irrigation will be 8,000 m3/shang. Take these values into the model. The approximate maximum value for paddy field development is 6,054,000 mu.

(4) Conclusion. Optimal development scale of paddy field is not only a topic for farming. But it is a topic of how to reasonably allocate natural resources for every sector of the national economy and to have them developed balancely.

The viables for the model are base on the water resource of our prefecture but the model is adaptable the whole country or the whole world. While using the model, the situation of the local area should be investigated. Input the reasonable data for optimal results.

Spacial Characteristic and Related Techniques of Rainwater Utilization for Dry-Land Wheat

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According to experimental data and farming practice, the relations between rainwater use before seed time of dry land wheat and rain time, rainfall, climatic feature in rainy season have been analyzed. It is proved that the Soil Effective Storage of Rainwater (SESR) before seed time and the rainfall after seed time have seen effect. The calculated method of SESR before wheat seed time has been set up, and its calculated results are in good agreement with actual observation. Moreover, the effect of its practical application is very good based on its calculated optimum seed time, seed quantity and the Optimum Quantity of Nitrogenous Fertilizer Application (OQNFA) before seed time, the Optimum Amount of Supplemental Fertilizer (OASF) in the period of stem pushing in different years under different climatic conditions.

Key words: dry-land wheat, rainwater use, optimum seed time,
the representative intercept of economic output,
Optimum Quantity of Nitrogenous Fertilizer Application.

Deficient rainfall is the main constrict factor for agriculture production in the north of China. And it is very important whether the limit water can be put into a good use. In order to make a full use of water, it is necessary to make a good investigation and get a good understanding on the relationship between water utilization and environment. So, it is the key step for dry-land farming and technique implementation to the analyze the relationship between rainwater use and spacial distribution, characteristic of rainfall from the point of productive practice. According to experiments and farming practice, some basic problems on rainwater utilization for practice, some basic problems on rainwater utilization for dry-land wheat has been analyzed and discussed in this paper.

Experiment and Analysis Means

1. Data Source

Experiment and survey data come from She County , which locates in 36°18'54"-36°53'16"N, 113°59'46"E and belongs to sub-humid climate of Hebei with two crops a year , or three crops in two years. Its annual rainfall is 569 mm, annual evaporation is 1720 mm and average air temperature is 12.4°C.

Because the tendency of meteorological observation data from experimental sites is in a good agreement with whose from meteorological bureau of She County, in addition, they are applied to analyzing the production of large area of land, the data form meteorological bureau are used in this paper and those from experimental site are used in making correction in exceptional year about exceptional data.

2. Field Experiment

Field experiment began from 1979 and ended in 1994. Ten representative sites without any irrigation conditions were set up in She County. They were under the same management of uniform cultivation pattern, and each experiment was repeated for two times, double-cropped and calculated the yield after harvesting in unit kg/667 m^2, From 1986, observation of precipitation and soil moisture was added to each experimental site. The observation depth was two meters and soil moisture was determined by the means of storing. Experiments on fertilizer between 1986-1991 were divided into three different kinds according to fertility. Each kind of experiment under different fertility was established at two sites repeated for three times and conducted under following rule: fertilizing pure N 3, 6, 9, 12, and P_2O_5 8 kilogram per 667 m^2.

3. Analysis method of data

Regression analysis and regulation calculation were applied to analyzing the data. The experiment was conducted under natural condition, thus the seed time of dry-land wheat, which is under the influence of precipitation during September and October, is different in different year. The earliest seed time is on September 26th while the latest is on October 22th. The average seed time is October 8th . The average seed time is used in calculation the average response quantity, in the same way, when calculate the response quantity of each year, the actual seed time is adopted.

Analysis of the Results

1. Spacial Characteristics of Rainwater Utilization

(1) Rainwater utilization before seed time and the time

The annual output from 1980-1994 were worked out by calculating the yield statistic average of ten experimental sites. In proper order, they were 49, 43.8, 51.7, 193.6, 135.1, 146.3, 145.5, 42.3, 76.2, 138.6, 195.6, 108.3, 82.0, 141.1 kilogram. The relationship between crop yield and rainfall before or after seed time can be expressed as such formula:

$$Y = -11.4444 + 0.211\ P_a + 0.4443\ P_B \qquad (1)$$
$$R = 0.821^{***}$$

Where Y----crop output

P_A —the rainfall before seed time (mm)

P_B ---the rainfall after seed time (mm)

R----the correlation coefficient.

In this paper, symbols *, **,*** respectively represent the degree of confidence 0.05, 0.01, 0.001 of the regression analysis.

It is shown clearly by above formula that the output of dry-land wheat is strongly affected by rain fall.

In double-cropping land, the rainwater before wheat seed time is affected by Autumn crops. Climate in different year affects both summer crops and Autumn crops. It is the season in which the impact factors are at most and their change are most complex. Ascertain the actual situation of the features of rainwater utilization before wheat seed time, is very essential also the premise for analyzing the rainwater use of wheat. So, further analysis of data was conducted with following model.

$$y = y_0 + \sum_{i=1}^{T} F_{Ai} \cdot P_{Ai} + F_B P_B \qquad (2)$$

$$i = 1, 2, ... T$$

Where: F----the efficiency of rainwater use

T----the number of Xun(a period of ten days) between wheat harvesting time in the past year and seed time in this year.

i----the note of Xun.

Rainfall data begin from the second Xun after the harvesting time in the past year in which rainfall has an strong relationship with wheat yield. (In local area, it begins from the first Xun in July. Although the first Xun does not involved in analysis, it still occupies the order before seed time). Taking twenty days as time step length and taking the middle of each step length as the order of Xun, analysis starts form 1987, The data from '1979 to 1987 are analyzed in 1987. In the same way, the data from 1979 to 1988 are analyzed in 1988. Annual data are analyzed in the same order, The obtained F_{Ai} of each year form 1987-1994 are shown in Table 1.

Table 1. F_{Ai} of each period before seed time.

Year	F_{A2}	F_{A4}	F_{A6}	F_{A8}	F_{A10}
1994	0.1788	0.134	0.4483	0.437	0.7502
1993	0.1789	0.1363	0.4593	0.4549	0.7857
1992	0.1791	0.1317	0.4681	0.4557	0.7676
1991	0.2023	0.1711	0.3222	0.5887	0.8022
1990	0.2019	0.1687	0.3245	0.6054	0.7284
1989	0.1641	0.1998	0.2791	0.7659	0.5502
1988	-0.0159	0.1994	0.2337	0.7795	0.6861
1987	-0.1414	0.1285	0.3412	0.6806	0.6195
average value (F_A)	0.1185	0.1587	0.3596	0.5965	0.7113

Note: the degree of confidence of each year analysis is beyond 0.01.

It is shown in Table 1 that due to each year is involved in analysis, fluctuation of F_{Ai} is brought about. If we regard the average value F_A as the value which gets rid of the impact of the fluctuation, its change shows the tendency of rainwater use and its process in time. The tendency is increasing along with the time's extension and it can be well stimulated by the function of time of each Xun before seed time:

$$F_{Ai}=0.6787\left(\frac{T_i}{T}\right)^{1.2013}, R=0.9632^{**} \qquad (3)$$

Ti is from the harvest time in the past year, and its numerical value is equal to i, which is the order of Xun in different period. Rainwater consumption before wheat seed time is the residual left by the Autumn crops in the past year. Only the rainwater during seeding period is entirely used by wheat. In formula(3), $(Ti/T)^{1.2013}$, regarding rainwater use efficiency as 1 in seed period, its value can be defined as the rainwater use efficiency in each period before seed time. Coefficient 0.6787 can be taken as Water Use Efficiency (WUE) before seed time, Because WUE is obtained from data by analysis, another coefficient r is required, and together with WUE, they can be expressed by C, So the general expression of F_{Ai} is:

In above formula, K is the parameter showing the intensity of impact and K is the average response intensity.

$$\overline{F_{Ai}}=C\left(\frac{T_i}{T}\right)^{\bar{k}},i=1,2,\ldots,T \tag{4}$$

(2) Rainwater use before seed time and the climate features in rainy season.

Water consumption of crops is under the control of climatic conditions. There is a rainy season between the last Xun in June and the middle Xun in September in local areas, which is the main water source for wheat before seed time, and also the growth season for Autumn crops.

After the coming of rainy season, moisture of the soil is stored and preserved before wheat seed time which it is consumed by Autumn crops in the same time. The climate in rainy season is certain to impact the rain water use efficiency before wheat seed time. In order to unravel the relation ship between rainwater use before seed time and climatic feature in rainy season, in the same way given in the above, work out the annual rainwater use efficiency F_b after seed time in proper order from 1987, and subtract the yield before seed time which is equal to the product of rainfall and its use efficiency after seed time from annual wheat output since 1987 (to see Table 2) meanwhile, select the ratio between the rainfall before and after the end of July, which is the interval between nutriment growth and propagation growth for Autumn crops, as the Climatic Feature Quantum of Precipitation Distribution (CFQPD) in rainy season. It is indicated through correlation analysis between the yield before seed time and the main factors of climate in rainy season that the output has an obvious relationship with precipitation distribution. rainfall. evaporation in rainy season , and the correlation coefficient respectively is -0.6674*, 0.7036*, -0.8021**. It was supposed in this paper that all these factors be baking effect through the parameter k, which was involved in formula(4), therefore. the yield before seed time calculated through k must be in a good agreement with that showed in Table 2. By fitting, following expression with the biggest correlation coefficient is obtained:

$$F_{Ai}=0.395\left(\frac{T_i}{T}\right)^{0.9326\cdot\sqrt{\left(\sum_{i=1}^{6}P_{ij}/\sum_{i=1}^{9}P_{Aj}\right)\cdot\left(\sum_{i=1}^{9}E_{ij}/\sum_{i=1}^{9}P_{Aj}\right)}} \tag{5}$$

In above equation, E is evaporation. It is clear that rainwater use before seed time is under the control of annual deviation degree of regional climatic spacial features.

Table 2. Yield before seed time and main climate factors in rainy season

Year	1987	1988	1989	1990	1991	1992	1993	1994
Yield (kg/667 m^2)	6.6	38.8	92.3	61.6	36.1	89.7	39.8	61.9
Ratio of rainfall (CFQPD)	5.4984	1.1455	1.2573	1.4454	1.3039	0.8123	1.1004	1.7269
Rainfall (mm)	240.7	286	533.7	338.2	221.4	323.5	288.8	422.4
Evaporation (mm)	548.8	541	444.6	475.5	493.0	499.8	562.4	450.4

(3) Regular pattern of rainfall storage before seed time

In theory, rainfall, its time and its accumulation in soil vary with the change of time. After the last Xun in June, as the rainfall increases moisture starts to be stored and preserved in soil and reach its peak W_A at seed time. W_A has relationship with rain time rainfall and the climate in rainy season. They are all functions of time. The value of W_A can be obtained by following expression:

$$W_A = \int_{T1}^{T} V \cdot f(TPE) \cdot P \cdot dT \qquad (6)$$

Where:

W_A--- *the effective storage of rainwater in soil before seed time.*

f(TPE)--the function of the accumulation intensity of effective storage of rainwater.

P---the intensity of precipitation

V---undetermined parameter.

The function of rainwater use efficiency before wheat seed time has already been defined in the above. As far as dry-land wheat be concerned, it is the function of accumulation efficiency of effective storage of rain water. Substitute it into equation (6) and express in difference:

$$W_A = \sum_{T=i}^{T} V \left(\frac{T_i}{T}\right)^{Kv \cdot \sqrt{(\sum_{i=1}^{4} P_{Ai} / \sum_{i=5}^{9} P_{Ai}) \cdot (\sum_{i=1}^{9} E_{Ai} / \sum_{i=1}^{9} P_{Ai})}} \cdot P_{Ai} \qquad (7)$$

i=1, 2,....T

Where: V, Kv—undetermined parameters

In this experiment, runoff and leakage only in 1988 are about 70 mm. In other years, they can not flow out of lands generally. Therefore, runoff and leakage should be subtracted from the corresponding P_{Ai} when they are about. The soil effective storage of rainwater before seed time worked out by expression (7) has a very good agreement with that determined by the formula of field water balance(Table 3, $R=0.9704^{***}$, $V=1.0353$).

Table 3. Calculated value and observance of soil effective storage of rainwater

Year	1987	1988	1989	1990	1991	1992	1993	1994
Calculated value (mm)	45.6	140.3	236.0	146.3	97.8	179.2	115.0	157.6
Observance (mm)	43.2	136.5	213.4	159.6	108.3	196.7	102.8	158.4

It is clear that above calculation methods tally well with the actual facts.

(4) Rainwater use in the whole period of wheat growth

The sum of soil effective storage of rainwater before seed time and the rainfall after seed time is the whole rainwater for wheat in its growth period. It has a good linear relation with wheat yield:

$$Y = -24.9903 + 0.5065\ P_{AB}, \qquad R = 0.973^{***} \qquad (8)$$

It is clearly shown that the soil effective storage before seed time has same effect on wheat with the rainfall after seed time. Regarding yield as self-variable, the expression of rainfall requirement can be obtained as following:

$$P_{AB} = 59.008 + 1.8885\ y \qquad (9)$$

Much investigation and statistic analysis show that all expressions of rainfall requirement deduced by regression method have a intercept just as that in (9). It varies little when the cultivation technique and crop rotation do not change, and it increase as the coefficient of rainfall requirement decreases when soil fertilities are different. In local area, it is characterized by relative stability, Soil observation indicated that, apart from that in 1988, annual soil water content in two-meter-depth after wheat harvest is about 265 mm, and varies a little in different years. It reaches or approximates wilting water content with depth from 0 to 120 cm in soil section. The depth gradually increases to 180 cm as soil fertility rises, and soil reaches or approaches the summit of water supply. So the intercept of rainfall requirement under such condition is regarded as the representative intercept of economic output in this paper. It shows the rainfall consumption supporting the essential nutritive skeleton to reach the certain about level. Therefore it also indicate the productive level just like rainwater use efficiency does.

2. Related Techniques

(1) Effective storage of rainwater before seed time, seed time and seed quantity.

Appropriate seed time and seed quantity are of great importance for sound seeding and colony adjustment. Rainfall is deficit in the period from seed time to coming Spring in arid areas of Northern China. For this reason, effective storage of rainwater before seed time becomes the prominent factor influencing crops. Meanwhile, it also determines the moisture quantity for crops to consume. According to experiment from 1987 to 1990, the linear relation between optimum seed time, seed quantity and soil effective storage rainwater is:

$$Y_T = 18.1 + 0.04\ W_A,\ R = 0.967^* \qquad (10)$$

$$D_T = 2.5 + 0.03\ W_A,\ R = 0.993^* \qquad (11)$$

$$Y_D = 3.3 + 0.02\ W_A,\ R = 0.958^* \qquad (12)$$

Where:

Y_T---optimum seed time which begins from September

d_T---optimum range of seed time, its unit is day

y_D---the optimum seed quantity, its unit is kg/667 m^2.

It is proved by practice for many years that the increase of yield is remarkable when the optimum seed time and seed quantity are determined in the light of effective storage of rainwater before seed time.

(2) Features of rainwater use and utilization of nitrogenous fertilizer

Increasing or reducing the quantity of fertilizer based on the abundance or deficiency of soil moisture, is not only favorable to crop growth, conducive to arising its water use efficiency, but also decreasing the loss and waste of fertilizer, enhancing economic profit. Much research shows that the quantity of Necrogenous fertilizer depends on water supply. The more is rainfall in dry land, the more is rational quantity of N. In this paper, the optimum quantity of N is calculated and shown in Table 4.

Table 4. Annual optimum quantity of N

	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991
High fertilized land (kg/667 m²)	3.6	4.0	7.2	7.8	6.6
Middle fertilized land (kg/667 m²)_	5.8	6.0	8.1	9.1	7.2
Low fertilized land (kg/667 m²)	6.2	6.7	10.9	9.2	7.5

Table 4 shows that lands with same rainfall and different fertility, low fertility land needs more N than that of the higher. The outcome of Table 4 has linear relation with rainfall in the whole period of wheat growth. It is:

$$N = 3.26 + 0.0137\ P_{AB},\ R = 0.7512^{**} \quad (13)$$

$$N = 4.0705 + 0.0175\ _{WA},\ R = 0.5979^{*} \quad (14)$$

Dry-land wheat has curvilinear relation with rainfall. However, it is smoother than that of irrigated land. Although there are some inflection points in the curve, they are not remarkable.

Base manure to the subsoil has a good effect for dry land wheat. N is often applied as base manure in one time. It is satisfying that the optimum quantity can be calculated out before seed time by expression (14). However, there are two defects in its application:

(1) The expression is deduced from statistics, but the estimate of rainwater is a average value after seed time. In a year with a small rainfall after seed time, the estimate is slight higher than the actual value. For this reason, based on farming practice and statistic, when rainfall after seed time is reach 150 mm, after fertilizer can be applied in the spring regardless of the rainfall pattern. Through analyzing those years with plenty rainfall, the lowered corresponding intercept of fertilizer application is worked out. The intercept in expression (14) has been already modified.

(2)In a year with plenty rainfall after seed time ,fertilizer applying quantity is slight lower. Further analysis shows that the sum of effective strong of rainwater before seed time and the rainfall before stem pushing has a good linear relation with the optimum quantity of N application. It is:

$$N = 3.2583 + 0.0186\ P_m,\ R = 0.7446^{**} \quad (15)$$

P_m is the rainfall before stem pushing. It reveals the importance of rainfall before stem pushing in the growth course of dry land wheat. It has already been explained that the representative intercept of economic output, which reflects productive level, is directly represented by rainfall. The sum of ESR before seed time and rainfall before stem pushing (Pm) cutting off the difference between that of different fertility pattern and its minimum has a better linear relation with the optimum quantity of N application:

$$N = 3.2138 + 0.02\ P_m,\ \ R = 0.7889^{***} \qquad (16)$$

The difference between the quantity of N application obtained from expression (16) and the optimum quantity before seed time is the amount of supplemental fertilizer in a pluvial year. Regardless of the rainfall before seed time, the rainfall between after seed time and stem pushing cutting of certain rainfall can directly indicate the amount of supplemental fertilizer. By calculation, this rainfall is just the representative intercept of economic output, and that part cut off belongs to different fertility level. Therefore, the amount of supplemental fertilizer is corresponding to different fertility.

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'Bao Lu' Irrigation of Paddy Field to Promote Rainwater Use Efficiency

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Based on the practice of popularizing the techniques of 'Bao Lu' irrigation of paddy field, the profits of 'Bao Lu' irrigation, such as water-saving, increase in grain production, energy-saving and pollution control etc, are introduced in this paper. Furthermore, the reason of water-saving is also analyzed and a concision is put forward that 'Bao Lu' irrigation can raise rainwater use efficiency in a large scale of area.

Key words: 'Bao Lu' irrigation, rainwater use
effective rainfall, chemical pollution
increase in grain production

Agriculture is the department of the largest water consumption as well as the department of the largest water waste in the whole society. Improving the rice conventional irrigation methods. Popularizing the techniques of 'Bao Lu' irrigation is an important approach for promotion of rainwater use efficiency. It is also the potential of water saving in the whole society.

1. Disadvantages of Rice Conventional Irrigation

Since 1960's, the irrigation method of "light and frequent irrigation" has been widely adopted in china. Compared with traditional irrigation methods, such as deep irrigation and flood irrigation etc., this irrigation method has made a great progress. However, is this method, apart form the late tillering stage and yellow ripeness stage in which the methods of drying and alternated drying and wetting are applied separately, flood irrigation is still applied in other stages of rice growth. Because paddy field is covered with water almost all the time. Soil oxygen is deficit and the oxidation potential is low, and toxic substances, such as ferrous iron (F--), hydrogen sulfide (H_2S) etc. are produced. So, the environment for growth of rice is degenerated which strongly affects the normal growth of root system, impedes the absorption of moisture and nutrient elements, and further , prevents the paddy field from high rice field. Additionally, water resources which is very valuable is wasted.

2. Techniques of 'Bao Lu' Irrigation

For Zhejiang province, the experiment of water saving irrigation techniques on paddy field was started from 1980. After four-year's trial and screen it succeeded in 1983. From then on, it has been improved and perfected day by day during the course of popularization and finally, it has been named as 'Bao Lu' Irrigation techniques for paddy field, Here, Bao—refers that irrigation water layer should be as thin as possible. Each time, the depth of irrigation water should be no more than 20 mm, and it is enough as long as the saturation of soil is met. Lu--refers that after each time of irrigation (including precipitation). Paddy field must be dry and open in air for some time when irrigation water is dried up naturally. The length of time of continuous submergence of paddy field should be on more than five days, and if it is beyond five days, paddy field should be drained off and open in air. In the reviving stage of rice deep water is still used for heat preservation or lowering the temperature when there occurs low or high air temperature. In the periods of preventing and controlling plant disease and pests, and applying fertilizer, water requirements are also met. Using this irrigation method, the number of field openness times is greatly increased. Generally, it is increased by 9-12 for early rice and 12-16 times for late rice. The length of time of field openness accounts for 45-60% of the whole period of rice growth . It not only saves water resources, but also suppress the unbearing tillering of rice, raises soil temperature, enhance soil aeration, improves soil environment, activates rice root system strengthens the resistance to lodging, reduces in sect pest, and further, promotes the rice field of paddy field.

3. Profits of Water Saving and Yield Increase

Demonstration land has been experimented for eight years in Sheng County, Zhejiang Province. The compared statistical results show, that the average quantity of water-sowing is 2190 m^3/ha. water-sawing rate reaches 32.3%, Meanwhile, grain field is increased by 1871 kg/ha, which is raised by 13.7% (see Table 1.)

In 1993, 'Bao Lu' irrigation techniques was applied to 3356 ha of paddy land in Yuyao City. Up to 1994, The area of paddy field irrigated with 'Bao Lu' irrigation techniques was added up to 10000 ha. The average water saving is 2292 m^3/ha, and Water - saving rate is 30.30%. The saving of electric power for irrigation is 121.5 kwh/ha, in the same time, the increase of grain field is 1289 kg/ha, the increase rate is 9%(see table 2.), The increase of farmers' net income is 70-200 U.S. $/ha.

Table 1. comparison of water consumption, grain yielded of the demonstration plot with 'Bao Lu' irrigation in Sheng county.

Year	Water consumption(m^3/ra)			Yield (kg/ha)		
	Bao Lu	conventional Irrigation	Water saving	Bao Lu	conventional Irrigation	Increase in yield
1885	4980	6825	1845	16323	14477	1846
1986	5100	7095	1995	15656	13393	2263
1987	5295	7215	1920	16626	14338	1929
1988	5550	8085	2535	15062	13823	1239
1989	5355	7635	2280	15275	13580	1695
1990	8775	6600	2325	15449	13248	2201
1991	2625	4395	2820	14409	12893	1575
1992	3495	6540	3075	15532	13314	2218
average	4590	6700	2190	15503	13632	1871

Table 2. comparison of water consumption grain yield of the large area with 'Bao Lu' irrigation in Yuyao City.
(early rice and late rice are calculated together)

Year	Water consumption(m^3/ha)			Yield (kg/ha)		
	Bao Lu	conventional Irrigation	Water-saving	Bao Lu	Conventional Irrigation	Increase in yield
1993	4080	6255	2175	14303	13178	1125
1994	6150	8559	2409	13668	12416	1252
average	5115	7407	2292	13986	121797	1289

4. Raising Rainwater Use Efficiency

Water requirement of 'Bao Lu' irrigation is about one-third less than that of conventional irrigation methods. The reasons for water-saving of 'Bao Lu' irrigation include two aspects: promotion of effective rain-water use efficiency and its reused rate.

(1) increasing the quantity of effective rainwater

Due to the thin irrigation water layer of 'Bao Lu' irrigation and frequent drying of paddy field. More rainwater is retained in paddy field during a precipitation. Of course, rainwater use is related to the intensity of precipitation and its spatial distribution. When the distribution of rainfall is even in space, and the intensity of precipitation is low, rainwater use efficiency is high. According to the four-year's experimental records which was made under the conduction of this paper's author in this region, the annual average quantity of extra utilized rainwater is 37.8 mm equal to 380 m^3/ha and accounting for 29.6% of the total water-saving amount. The effective rain water use efficiency is increased by 130% (see Table 3.)

Table 3. water quota of different irrigation methods

Irrigation Methods	water consumption		rainwater use		water quota	
	mm	m^3/ha	mm	m^3/ha	mm	m^3/ha
Bao Lu	757.4	7574	326.6	3266	430.8	4308
conventional methods	845.5	8455	288.8	2888	556.5	5565
Comparison (%)	-88.1	881	+37.8	+378	-125.7	-1257
	-10.4		+13			-22.6%

(2) raising the rate of reused rainwater

Transpiration of plant and evaporation between plants are lessened. Foliage transpiration is essential for rice. However, it can be curtailed by rational irrigation and drainage and its effectiveness is also raised. Additionally, unbearing tiller is effectively controlled by 'Bao Lu' irrigation. So, colony transpiration is also lessened relatively. The evaporation between plants is moisture evaporation of paddy land, and most of which is ineffective evaporation using 'Bao Lu' irrigation, there is no water layer covering the paddy land for about one half time. So, the evaporation of water surface is changed into soil surface. the evaporation of water surface is changed into soil surface evaporation, and it is greatly decreased. Based on the analysis of the experimental data, both the transpiration and evaporation are reduced by 20-30%, which accounts for 50% of the total amount of water-saving.

Vertical percolating water is reduced. The vertical seepage of paddy Land has a relation with soil texture, depth of groundwater and the thickness of irrigation water layer.

According to Darcy's law, infiltration Velocity equals to the product of permeability coefficient and the gradient of water head, that is $V= k.h+z/z$. For soil of same plot, k and Z are constant, So, percolation rate is the function of the thickness of water layer. Due to the thin water layer of 'Bao Lu' irrigation and short length of time of water covering, the vertical seepage of soil is small and it is 31.3% less than that of conventional irrigation methods in the light of test analysis.

5. Improving Water Environment

Because the photic and aeration conditions of paddy land is improved by 'Bao Lu' irrigation, the relative humidity of the land local climate is lowered by 8-10% and the pathogenic bacteria is restrained from propagation and dissemination. Especially, the effect of alleviating fusarium wilts very remarkable. Disease investigation shows that the occurrence rate and disease index of fusarium wilt is reduced by 10-30% (see Table 4) in general . So, pesticide requirement is lowered and the number of its application can be reduced by 2-3 times.

Table 4. Investigation of fusarium wilt of early rice in 1993.

Farmer's name	irrigation method	disease rating						Occurrence rate (%)	disease index
		grade 0	grade 1	grade 2	grade 3	grade 4	grade 5		
Pan Zhang-hai	Bao Lu	241	9	2				4.4	0.026
	Conventional method	156	82	20				39.5	0.24
Xi Chunlin	TOE	19	79	86	34	9	5	92.4	0.36
	Conventional method	0	13	85	86	47	80	100	0.66

As a result of the reduction of rainwater loss owing to 'Bao Lu' irrigation, the loss of chemical fertilizer and pesticide from paddy field is also curtailed. Moreover, river pollution is also mitigated. Additionally, the capacity of flood control and waterlogging prevention is raised because the field water storage is enlarged and surface flow is lessened. All of them have a positive effect for amelioration of agricultural water environment.

6. Prospect for the Popularization of 'Bao Lu' Irrigation Techniques

According to the practice of Zhejiang Province, it is very feasible to widely popularize 'Bao Lu' irrigation techniques in large scale of area, save water 1500 m^3 and harvest rice 750 kg more from each ha of paddy land. There are 1.5 million hectares of paddy field. Among which, if 700,000, hectares are irrigated by 'Bao Lu' irrigation technique, each year 1000 million m^3 of rain-water resources can be saved the increase of crop yield is 500 million kg, the increase of farmer's net income is 500 million Yuan and 80 million Kwh of electric power is saved . If the saved rainwater resources is used in agricultural irrigation the irrigated area can be enlarged by 100,000 hectares . If it is used in industry, the economic loss caused by water shortage can be reduced by 1200 million U.S$. Meanwhile, great benefit of both ecology and society will be brought about.

7. Conclusion

'Bao Lu' irrigation techniques can promote rainwater use efficiency, increase crop yield, mitigate chemical pollution and ameliorate drought and waterlogging. The fee of technological training and dissemination as popular science for government to popularize the irrigation technique is 2-3 U.S.$/ha, while no extra productive cost is added when farmers apply it to practice and all charges of electric power, pesticide and man power are decreased. There fore it is a very favorable technique for farmers and can be applied in all appropriate regions.

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The Transformation of Inferior Soil by Rain Water

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There is 19780,000 Mu (667 m^2) purple soil land in Hunan province, which mainly distributes in the middle and the west of Hunan Province and areas of Huai Hua and Ling Lin.

It is very difficult to discriminate the soil horizon in purple soil section which is quite similar to its parent soil material, and at its juvenile development stage with thin soil layer, low soil organic material and high content of elements calcium (Ca), Phosphorus(p) and potassium (k) Purple soil has the same property of purple layer rock sediment, which is of close texture, brittle, soft, low water permeability, low water-holding capacity, high mechanical weathering and with square granular weathering product called by local farmers as "Jian Feng Xiao" (easy to decay).

According to the difference of its contributing factors, purple soil can be classified into three categories: acid purple soil, neutral purple soil and alkali purple soil.

Due to the characteristics of low water permeability low water-holding capacity of purple soil, the natural vegetative cover is not good and fruit trees are difficult to grow sound.

In the middle of Hunan Province, there are well-developed economy of both industry and agriculture, relatively dense population and a relatively better economic basis. We chose Gunlian village in Tanzishan town, Hengnan county, which is near Hengyang city in the middle of Hunan Province, as our experimental area. This village, where the second transport company of Hengnan county locates, is not far from 319 National Road. It has more than thirty buses and good economic conditions. All of the land of the village is purple soil which consists of acid, neutral and alkali purple soil. The geographical environment of the village is very particular, it is a north-south word narrow basin with three hills covered with purple soil surrounding all the rice paddy land of the village which is more than one thousand Mu(667 m^2). Not far from the village, there is a stream flowing into Xiang River.

We built a water canal, which is 1.5 meter wide and 2 meters deep, and accessible to all the village and reaches a small dam in the end which is built at the lowest site of the village. So, rainwater can be harvested in rainy season. Meanwhile, the gleization and subgleization processes of rice paddy soil are changed which lead to a high crop yield.

Three Large water detention ponds, which are of ten meters diameter, eight meters height and water storage up to 410 Tons , are built at the tops of the three highest hills (altitudes are 110 m) of the village. A small water motor has been built on the stream. In rainy season rainwater is harvested from vice paddy field and flows along with the canal, then into the small dam, finally flows into the stream to drive the water meter and generate electricity by which rainwater is pumped up to the three large ponds on the three hills and replenishes them. In dry season, rainwater stored in the three ponds is discharged to water the trees on the hills and irrigate the rice paddy land.

In six years, all the hills, total area about ten thousand Mu and divided into three groups. were developed into orchards and wood land. The method is: First step is to make hills into level terrace land; Second step is to make holes for explosion by steel spade on the terrace land, which is one meter deep and with a space of two meters between each two rows of holes, after explosion, Man-made furrows are digged out which are one meter deep and one meter wide, five meters long; Third step is, after weathered for one year, to fill these furrows with urban treated rubbish, poultry dung from large chicken farms of Heng Yang City and some strange soil; Forth step is, to plant apple, orange, plum and peach trees of good quality after gratting, as well as yellow locust and foreign pine trees which are drought-enduring, in the next early Spring. Naturally, all these activities depend on the rainwater stored in the ponds built on hill tops for irrigation

In the past ten years. a remarkable achievement were obtained: rice yield increased by 50 kg/Mu. purple soil on hills is preliminarily improved. the content of N. P, K is enhanced. fruit trees are filled of apples. plums oranges or peaches. and yellow locust foreign pine trees grow sound forming a heavy forest.

Based on the practice mentioned above, a variable simulating analysis on the elements of N.P,K in the wood has been carried out.

Samples are sampled following the method of average ruling stem from different topographies and locations: dry bark is sampled from different parts in different regions. branch and leaf are sampled from different levels of tree crown (high, middle low) and different aspects (east, south, west, north), net work of roots is sampled from different levels and grades. Water sample is sampled 3-5 times a month (in rainy and dry seasons, five times a month, in others, three times a month) separately from different topographic locations (upper, middle, bottom) and respectively at the early, middle and end of a month in the light of infiltration water, groundwater and surface water, and the chemical analysis of water samples are conducted separately. At certain time in each month, withered and fallen matter is collected three times a month and the dry weight of different groups of leaves branches, flowers, fruits and organic pieces is determined separately according to the locations of valley, piedment and hill side.

Biomass is divide into five groups respectively of branch, leaf, trunk, bark and root following the classification method of Klarft, and its green weight and dry weight are also separately determined. Additionally, using the relative growth method, the regression equation between the dry biomass of each group and D^2H is established:

$$W_i = a(D^2H)^b$$

then the total biomass of whole tree corresponding to each group can be worked out.

N is determined by the semi minor method of Kaishi. P is determined by molybdenum blues calorimetric method and K by atomic absorption spectrophotometer method.

The biogeochemical cycle of nutrient elements in the ecosystem of man-made wood land has a close relation with hydrological process. When researches on the cycle of nutrient elements and hydrological process in a basin is carried on, with the help of basin's nutrient cycle and water cycle of its runoff, nutrient content of the input and output runoff fields is determined. And the input-output biogeochemical cycles of the three elements N. P,K are shown in following Table 1.

Table 1. Annual Input-Output of Elements N,P,K

Term	N	P	K
Annual Input (precipitation)	4.85	0.43	9.56
Annual output (runoff)	0.64	0.07	2.31
Annual net gain	4.21	0.36	7.25

Note: In Table 1 annual input mainly refers to precipitation (minor dust and N_2, O_2 etc. gases are not included), runoff largely refers to surface water and groundwater.

It is clearly shown in Table 1 that, in the eco-system of man-made wood land, the annual net gain of elements N, P, K is between 0.36-7.25 kg/10^4m^2, and their order is (from high to low): $K>N>P$.

In the ecosystem of man-made wood land, biological cycles generally complies with following equation.

$$\text{Loading} = \text{Stocking} + \text{Returning}$$

Stocking refers to the element's total annual increase in plant's perennial organs. Returning refers to the total loss from plant community back to soil by withering and the leaching of rainwater. Through determination, biological cycle of elements N, P,K in the ecosystem of man-made wood land is shown in following Table 2

Table 2. Biological Cycle Model of Elements N, P,K ($kg/10^4m^2a$)

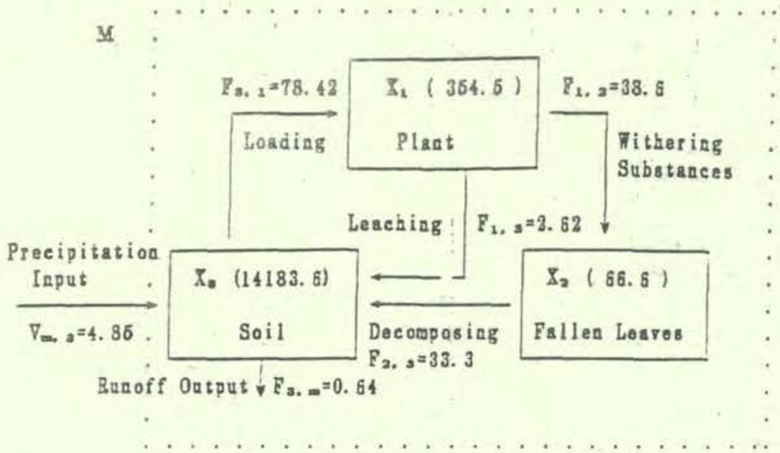
Nutrient Elements	Balance Parameters					Circulation Rate (Returning/Loading)
	Loading	Stocking	Returning			
			Withering	Leaching	Total	
N	78.42	37.22	38.6	2.62	41.22	0.53
P	4.41	2.41	1.48	0.52	2.00	0.45
K	41.03	19.63	3.81	17.59	21.40	0.52

It is indicated in Table 2 that the order of circulation rate of each nutrient element is N>K>P. The rate of P is the lowest and its annual loading assimilated from soil by plant is merely 4.41 $kg/10^4m^2$, which only accounts for 5.6-10.7 percent of that of N and K. Additionally, the ratios of Returning and Stocking of N, P,K approach 1. Based on data analysis, it should not take place under normal natural condition. However, as the age of tree increases, tree gradually degenerates, in the sometime, natural thinning becomes strong. So, it is possible for such situation to occur. The reason for its occurrence of our experimental stand, apart from these factors such as snow pressure etc. in experimental period which results in a rapid increase of withering material from the stand, can be mainly attributed to too large density of the stand which can be conformed by the recent determination of stand's canopy density which is more than 0.9. Therefore, in order to promote the stands net productivity, the density of stand must be controlled and a appropriate thinning becomes very necessary. After the above data are obtained, it is possible for us to establish a variable mathematic model on the cycles of elements N, P, K. However, it is very complicated because stand is a continuous time-changing system. For the sake of simplifying the calculation, We treat it as a continuous constant system. Therefore, an approximate result is easy to be obtained.

Taking N as an example, according to the results of its actual observation, analysis and calculation, the variable process of element N can be shown in following Diagram 1.

In blow diagram, the dotted lines represent the bound of the ecosystem and beyond which is its environment M. Each frame stands for the divided parts of the system. The bracketed numeral value in each frame stands for stocking of N ($kg/10^4m^2$), and the numeral value beside each frame represents the flux of N ($kg/10^4m^2a$).

Diagram 1. Variable Process of Element N in Ecosystem of Man-made Wood Land



It is known from Diagram 1 that the whole system is divided into three parts. M is the environment. Vmi is the input of i part of system from the environment. Xi is the total quantity of certain element in each part. $F_{i,j}$ is the flux of elements (it is the quantity of certain element coming from i part to j part). $a_{ig}=F_{ig}/x_i$ stands for circulation rate (it is supposed as a constant.). So the general form of local variable equation of certain element's cycle in system is :

$$dx_i/dt = \sum_j a_{ji}X_j - \sum a_{ij}X_i + V_{moi}$$

The continuous constant system also can be expressed by matrix as:

$$dx(t)/dt = FX(t) + GV(t)$$

in which F and G are both matrixes.

Therefore, the variable mathematic mode of N is obtained:

$$N \begin{cases} dx_1/dt = 0.1163\ X_1 + 0.0055\ X_3 \\ dx_2/dt = 0.1089\ X_1 - 0.5000\ X_2 \\ dx_3/dt = 0.0074\ X_1 - 0.5000\ X_2 - 0.0056\ X_3 + V_{mo3} \end{cases}$$

Expressed by matrix, then

$$\frac{dx(t)}{dt} = Fx(t) + GV(t)$$

In which;

$$F = \begin{bmatrix} -0.1163 & 0 & 0.0055 \\ 0.1089 & -0.5000 & 0 \\ 0.0074 & 0.5000 & -0.0056 \end{bmatrix}$$

$$G = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Similarly, the variable mathematic models of elements P, K are:

$$P = \begin{cases} dx_1/dt = -0.0713\ X_1 + 0.0010\ X_3 \\ dx_2/dt = 0.0528\ X_1 - 0.5000\ X_2 \\ dx_3/dt = 0.0185\ X_1 + 0.5000\ X_2 - 0.00102\ X_3 + V_{m.3} \end{cases}$$

$$K = \begin{cases} dx_1/dt = -0.1024\ X_1 + 0.0004\ X_3 \\ dx_2/dt = 0.0182\ X_1 - 0.5000\ X_2 \\ dx_3/dt = 0.0842\ X_1 + 0.5000\ X_2 - 0.00043\ X_3 + V_{m.3} \end{cases}$$

According to the above mathematic models of elements N, P, K, taking the nutrient stocking of each frame in the system as models' initial condition and regarding the input ($V_{m.3}$) and output ($F_{3.m}$) of the system changeless (just as that shown in Table 3), simulating analysis has been carried out through using computer SHARP Pc-150 in accordance with the procedures shown in appendix 1. The result of simulating analysis is shown in Table 4.

Table 3. Parameter Values of N.P.K for Variable simulation

($Kg/10^4m^2 \cdot a$)

Initial Value	$X_1(to)$	$X_2(to)$	$X_3(to)$	$X_{m.3}$	$F_{3.0}$
N	354.50	66.60	14183.60	4.85	0.64
P	28.04	1.86	4356.68	0.43	0.07
K	209.03	41.74	91819.93	9.56	2.31

It is shown in Table 4 that when $t_i=1, 3, 5, \ldots\ldots, 10$, the stocking of N, P, K shows a trend of gradual increase year by year, while the absolute value of net accumulation has a yearly gradual decrease tendency. Especially, it is more remarkable in early five years. Up to ten years old, due to the interaction, mutual restriction and coordination between each two parts of the system, the absorption, transformation and loss of N, P, K of each part approach equilibrium state. With the lapse of time, the accumulation of each element tends to a constant, which indicates that the ecosystem of man-made wood land has an inner function of self-adjustment to keep its stability.

Table 4. stocking and net accumulation of N. P. K of each frame in the system and their change in time ($kg/10^4m^2 \cdot a$)

Nutrient element	age	plant (X_1)	net accumu lation	fallen Leaves (X_2)	net accommu lation	Soil (X_3)	net ambul ation
N	1	386.51	32.01	87.31	20.71	14107.02	-76.58
	3	387.13	0.62	104.43	17.12	14118.84	11.82
	5	387.25	0.12	105.48	1.05	14143.27	24.43
	8	387.35	0.10	105.51	0.03	14167.38	24.11
	10	387.45	0.10	105.53	0.02	14141.50	24.13
P	1	30.23	1.19	2.05	0.19	4353.02	-3.66
	3	30.24	0.01	2.30	0.25	4354.24	-1.22
	5	30.24	0	2.32	0.02	4356.40	2.16
	8	30.24	0	2.32	0	4358.54	2.14
	10	30.24	0	2.32	0	4360.68	2.14
K	1	222.77	13.74	31.42	-10.32	91845.09	25.16
	3	222.93	0.16	27.57	-3.85	91853.99	8.90
	5	222.95	0.02	28.00	-0.43	91862.19	8.20
	8	222.96	0.01	28.00	0	91920.86	8.01
	10	222.97	0.01	28.00	0	91968.63	8.00

It is known in the light of above simulation analysis that changes of elements N, P, K, in each part of the system are more remarkable in the early five years, then they become smooth and stable and tend to a constant after ten years. If fertilizer is applied at the age of five years old and intermediate cutting is carried out when plant is eight years old, the change can be analyzed and simulated by following model.

(1) under the condition of applying fertilizer and the input (Vm.3) is assumed doubled, the changes in time of stocking, net accumulation and flux of elements N, P, K of each part in the system are shown in Table 5.

It is indicated in Table 5 when input is doubled by application of fertilizer, the stocking of N, P, K in the divided parts of plant and soil is remarkably raised. Compared with that of before fertilizer is applied, the stocking of N in the plant divided part is increased by 32,95 $kg/10^4m^2$, of P is increased by 2.20 $kg/10^4m^2$ and of K is increased by

13.95 $kg/10^4m^2$. In soil divided part, the stocking's increase of N is 7.93 $kg/10^4m^2$, of P is 4.01 $kg/10^4m^2$ and of K is 48.73 $kg/10^4m^2$. In the part of fallen leaves, N and P is increased while K is decreased. The reason can be possibly attributed to the easier washing out of element K in this part of the system.

Table 5. changes in time of elements N. P. K. of each part in system when Vm.3 is doubled (applying fertilizer)

Nutrient element	age	plant	net accumulation	fallen leaves	net accumulation	Soil	net accumulation
N	0	354.50		66.60		14183.60	
	1	386.54	32.04	88.42	21.82	14116.70	-76.90
	5	387.21	0.67	104.57	16.34	14142.99	17.20
	10	387.45	0.24	105.82	0.04	14191.53	9.68
P	0	28.04		1.86		4356.68	
	1	30.23	1.18	2.05	0.19	4353.88	-2.80
	5	30.24	0.01	2.30	0.25	4356.39	-0.87
	10	30.24	0.00	2.32	0.02	4360.69	0.86
K	0	209.03		41.74		91819.93	
	1	266.77	13.74	31.42	-10.32	91834.10	14.08
	5	222.94	0.17	27.57	-1.26	91872.88	10.47
	10	222.98	0.04	27.40	0.17	91868.66	9.13

(2) under the condition of intermediate cutting and its intensity is assumed to be 50% which is equivalent to a reduction of 50% of the plant part(X_1), the changes in time of stocking, net accumulation and flux of elements N, p, K in each part of the system are shown in Table 6.

It is shown in Table 6 after the intermediate cutting of high intensity (50%), Stockings of N, P, K in the plant part(X1) show a trend of gradual increase, and their variation ranges in ten years are 177.25-228.45 $kg/10^4m^2$, 14.02-17.15 $kg/10^4m^2$ and 104.51-128.14 $kg/10^4m^2$ respectively. In soil part , the stockings of N and P is reduced year by year (in ten years, the annual average reduction of N and P are 3.95 $kg/10^4m^2$ and 0.25 $kg/10^4m^2$ separately) while K is raised year by year. Changes in fallen leaves part are just similar to those which is under the condition of fertilizer application. These changes can mainly attributed to intermediate cutting which improves the state of stand, provides the left plants with more nutrient elements, promotes their net productivity. However, after intermediate cutting, plants are reduced and so are the fallen leaves and the nutrient elements back to soil.

In order to unravel the influences of fertilizer application and intermediate cutting on the changes of elements N, P, K in the ecosystem of man-made wood land, the circulation rates obtained by simulation can be compared under the two states explained above, and the results are shown in Table 7.

Table 6. Changes in time of elements N. P. K in each part of the system when Xi is reduced to one-half.

Nutrient element	age	plant	net accumu lation	fallen leaves	net accumu lation	soil	net accumu lation
N	0	177.25		66.60		14183.60	
	1	227.48	50.23	89.01	22.41	14107.58	-76.02
	5	228.34	0.04	105.23	17.56	14119.67	4.03
	10	228.45	0.03	105.94	0.13	14144.07	4.85
P	0	14.02		1.86		4356.68	
	1	17.13	3.11	2.11	0.25	4353.05	-3.63
	5	17.15	0.02	2.34	0.05	4354.27	-1.24
	10	17.15	0.00	2.35	0.01	4354.12	-0.64
K	0	104.51		41.74		91819.93	
	1	127.86	23.35	31.49	-10.25	31799.18	-20.75
	5	128.12	0.26	28.32	-0.63	91825.96	8.92
	10	128.14	0.02	28.13	-0.05	91873.96	8.58

It is shown in Table 7: (1) circulation rates at the age of 1, 5, 10 under the condition of applying fertilizer are all higher than those of before applying fertilizer (initial condition), which indicates that fertilizer application can promote the circulation rote of nutrient elements. It is also shown in Table 7 that at the age of 10, the rates of N, P, K all approach 1, namely, Returning is almost equal to Loading, which stems from the ever-increasing of fallen leaves along with the growth of age and the gradual reduction of loading. (2) under the condition of intermediate cutting of high intensity(50%), the rates of N, P, K at the age of 1, 5, 10, are all remarkable lower than those of before intermediate cutting, which shows that intermediate cutting of high intensity can suppress the cycle of nutrient and lower the circulation rate remarkably, obstruct the nutrient cycle and disturb the balance of nutrient, and further, affect the growth of the stand.

Table 7. Circulation Rate of nutrient elements at different age stages under different conditions (Returning/Loading)

Condition	Initial condition			applying fertilizer (doubling			Intermediate cutting		
age	1	5	10	1	5	10	1	5	10
N	0.78	0.93	0.94	0.79	0.98	0.99	0.40	0.49	0.50
P	0.56	0.73	0.74	0.84	0.98	0.99	0.53	0.50	0.50
K	0.65	0.77	0.88	0.85	0.98	0.99	0.53	0.50	0.50

According to above experiment, conclusions can be summed up as following.

1. In the decade-ennial ecosystem of man-made wood land the net accumulations of N, P, K are between 0.36-7.25 kg/10^4m^2, and their order is (from high to low): K>N>P.

2. Circulation rate of each nutrient element is ecosystem has a direct influence on the growth of the stand. In the ecosystem mentioned above, the rates of N, P, K, are 0.53, 0.45, and 0.52 respectively, and their order is N>k>P.

3. Based on the variable mathematic model established in this experiment, the results of the simulation analysis on elements N. P, K in the ecosystem of man-made wood land show that the distribution of the input quantity of each nutrient element corresponding to each part of the ecosystem are varying along with the growth of age. The changes are relatively y remarkable in the early years old, which tend to be stable gradually after eight years old, which indicates that the ecosystem of man-made wood land has an inner function of self-adjustment to maintain its stability.

4. Applying fertilizer on ecosystem not only increased the stocking of nutrient in soil , but also raises the circulation rate of nutrient in the ecosystem. The results of simulation analysis show that under the condition of fertilizer application, the rates of N, P, K at the age of 1, 5, 10 are higher than those of before applying fertilizer.

5. Appropriate intermediate cutting can improve the state of stand, and relatively raise its net productivity. However, intermediate cutting of high intensity will disturb the inner function of self-adjustment of ecosystem and make the cycle of nutrient elements out of balance. Therefore, intermediate cutting of high intensity can destroy the stability of the entire ecosystem. The results of simulation analysis also indicate that when intermediate cutting intensity reaches 50%, circulation rates of N, P, K, are all lowered.

Section 7

RAINWATER UTILIZATION IN URBAN AREAS

INTEGRATED WATER MANAGEMENT FOR URBAN AREAS

Dr.-Ing. Wolfgang F. Geiger[1]

ABSTRACT

In the past water management supported mainly economic growth. In consequence water supply, storm drainage, sewerage collection and treatment were dealt with more or less separately. Water resources were exploited and the environment was damaged as a whole. Only now in urban areas with economic stagnation, the importance of clean environment and its socio-economic feedback is realised.

Along with the old industrialised area of the Emscher River Basin, an integrated approach for water management in urban areas is developed, which considers the interactions of technical measures, their ecological effects, and socio-economic consequences. Especially sustainable methods for urban storm drainage are discussed.

1. INTRODUCTION

The renewal of old urbanised and industrial areas is a growing concern in industrialised countries. The short-sighted use of resources in the past, especially water resources, has changed the natural environment and now threatens further use of old developed areas. When renewing old developed sites, it must be recognised and accepted that each project will be "special" reflecting specific climatological, geographic, ethnological and cultural background, and socio-economic conditions in an area. Although no standard methods for a renewal exist and objectives may be poorly defined, there is a recognition that general requirements must be met :

- Human well-being must be secured. This includes that every person should have a dwelling that provides protection from changing weather and climatic variability, particularly from natural disasters such as flooding.
- Environment, including air, soil, vegetation, surface water, and groundwater, should be in a condition that supports human well-being, ensuring especially health.
- Resources as a whole, especially water resources, should only be used to an extent that protects them for future generations. A critical issue is that future generations should not be forced to pay for the environmental degradation of earlier generations.

Water availability and water quality are obviously strongly linked with human well-being and the socio-economic condition of man. Consequently, renewal programmes can benefit from an integrated approach to water management.

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The Emscher River Basin is an example of an old urbanised and industrialised area which is undergoing renewal at present. The Emscher area is the core of the Northrhine-Westfalian industrial region usually called the Ruhr region. With approximately 5.3 million inhabitants the Ruhr region is one of the oldest and largest industrial areas in the world. The reason for its industrial development lies in its geographic location within the north-west European bituminous coal belt. The carbon layers penetrate the surface of the earth on both sides of the Ruhr valley. While 130 years ago the area was still largely agricultural, with less than 300,000 inhabitants, within a few decades it has changed completely into an industrial area dominated by coal and steel and with a population of more than 5 million. On the basis of coal and steel, the area became the most industrialised and energy producing part of Germany. The Emscher River Basin, with approximately 865 km² and seventeen cities, forms the centre of the Ruhr region, with 2.5 million people.

From its nature, the structure of the Emscher river is not suited for larger settlements. In the middle ages it was a flat and partially swampy area with only small water courses. In addition, due to coal mining, the land surface subsided up to 20 m at some points, opposing natural drainage. The extremely difficult drainage conditions could only be solved by straightening of the natural surface waters to carry the waste flows produced by population and industries. Because of land subsidence, it was not possible to place a wastewater collection system underground. Further, the Emscher River and its tributaries, in some parts, had to be dyked and bridges had to be adapted to the continuous land subsidence. Most tributaries of the Emscher River obtained concrete inlays to increase their hydraulic capacity and to allow for the constant maintenance. Pumping stations and flood retention basins were installed to prevent flooding (Figure 1).

Originally, waste flows only were treated mechanically, which with increasing pollution due to the industrial inputs, was no longer feasible at some stage. Today, biological treatment takes place at the Emscher mouth treatment plant located at Duisburg-Dinslaken and at the treatment plant Duisburg-Kleine Emscher.

2. EFFECT OF CONVEYANCE-ORIENTED DRAINAGE

Old industrial sites are typically plagued with ineffective or inadequate wastewater treatment and stormwater drainage. Past industrial activity has also often left environmentally damaging residuals on surfaces and in the ground.

2.1 Sanitation and Industrial Wastewater Treatment

In many fast-growing cities, sanitary provisions often do not keep pace with the rapid development. Domestic and industrial wastewaters sometimes are untreated into open water courses, or are infiltrated into the soil, contaminating the various sources of water. This practice not only leads to low human perception values of open waterways, but also exposes people to the risk of epidemic diseases, such as cholera and typhus. The increasing contamination of wastewater streams with industrial by-products, which are often toxic, eventually reach the point where the natural recuperative capacity of the receiving waters is exceeded. Degraded water courses may produce human health problems and limit further economic growth. Many now developed countries were already confronted with this problem, and have implemented Master Plans for the majority of their cities to neutralise such risks. Where man fails to consider water resources degradation, permanent damage may result. If the eco-system deteriorates and water resources are destroyed, the basis for urbanisation and industrialisation is withdrawn.

The need for safe drainage and wastewater disposal has been recognised early in the Emscher area. In consequence the Emschergenossenschaft has pioneered many developments of new techniques in wastewater treatment. Today 98% of the sewered areas in the Emscher River catchment have combined systems. All together at more than 3,300 points, wastewater and storm runoff are drained into the Emscher River and its tributaries

As mentioned in Chapter 1, the Emscher and its tributaries are all open drainage channels transporting wastewater and natural flows to the treatment plants. As water for public and industrial water supply are, to a large extent, imported from neighbouring river catchments, due to the extremely high waste flows, the flows in the surface waters in the Emscher system are much higher than they would be under natural conditions. The total mean flow in the Emscher river under dry weather conditions of 10 m^3/s today consists of 8 m^3/s from communal and industrial wastewater, 1 m^3/s of mining water, and approximately 1 m^3/s of natural flows. Furthermore the high impregnation of surfaces increases storm runoff and increases the danger of flood flows.

2.2 Stormwater Drainage and Flood Flows

While on pervious and vegetated surfaces 0% to approximately 20% of the rainfall runs off, for roofs, asphalt or concrete surfaces the percentage of runoff amounts to 90% to 100%. From mineral surfaces still more than 80% of the rainfall may runoff, dependent on the degree of condensation of the surfaces. Figure 2 compares the water balance of natural vegetated and more impervious surfaces. The dynamic of rainfall runoff depends on the slope and condition of the surfaces. The form of runoff hydrographs is also influenced by the structure of gutters and culverts. If those collection systems are narrow and straight, runoff is accelerated in addition.

An excellent example for the effects of increasing urbanisation and industrialisation on flood flows is the Emscher area, where, since 1950, the runoff coefficient increased from .07 to .20. It is astonishing that within the last 40 years, twice as many urban surfaces have been impregnated that up to the year 1950 (Londong, 1984). Figure 3 accordingly presents the increase of flood flows and flood frequencies within the same time span. While between 1950 and 1959 only one flood was registered and from 1960 to 1969 eleven floods with lower flood peaks were registered, already during the 80's, six floods with high flood peaks have been observed. In 1954 a peak flood flow of 143 m^3/s was registered, while the flood peak in 1981 was 243 m^3/s.

Over the last decades in the Emscher area, millions of DM have been invested into flood protection, especially for raising the dykes and building large retention basins. In spite of this investment, still local flooding occurs. As flooding to a large extent influences the socio-economic condition in the area, flood protection measures are considered as a major part of integrated water management in the Emscher area.

2.3 Drainage, Treatment and Receiving Water Interactions

For a long time the importance of the small scale interactions of storage and evaporation of stormwaters on urban surfaces, the delayed runoff by vegetation and detention, was overlooked. The same is true for larger scale interactions which link :

- runoff dynamic within urban areas with downstream flooding;
- sewer network capacities with wastewater treatment efficiency;
- storm drainage and treatment provisions with recharge and contamination of groundwater; and
- storm drainage with the ecological value of urban water.

Figure 4 shows that with increasing imperviousness of surfaces, groundwater recharge deteriorates. While flood conditions increase in urban and industrialised areas, base flows of urban waters decrease. Especially in urban areas there is a danger that small urban waters will dry out if groundwater levels are lowered. Another consequence of low groundwater tables is the low soil moisture and lack of vegetation, which may change regional climates.

On the other hand, the high runoff dynamics in the case of combined systems endanger the efficiency of wastewater treatment. Especially at activated sludge plants, sludge may be moved to receiving waters under heavy rain conditions. The high storm runoff dynamics also cause intermittent shock loads to receiving waters, flushing aquatic life if it exists. Dependent on the frequency of loading, re-establishment of the habitat may be limited.

Runoff quality affects river ecology. On urban and especially on industrial surfaces, dust and dirt accumulates and are washed off when it rains. Accordingly, the pollution of runoff changes in wide ranges, depending on land use and flow times. Runoff from urban and industrialised surfaces often contains oxygen demanding matters, toxic substances, which limit the use of urban water significantly. The looks and odours of urban waters in industrialised areas are often unaesthetic.

In the Emscher area, most of the mentioned interactions were observed. Figure 3 showed the increase of flood flows with ongoing impregnation of surfaces. In consequence the biological treatment plant at the mouth of the Emscher River had to be protected against high wet weather inflows by by-passing all flows above 30 m^3/s untreated to the Rhine River.

In the Emscher River itself, there is no dissolved oxygen. Only in the effluent of the river mouth treatment plant the oxygen concentrations range between 2 and 4 mg/l, averaging, for instances, in the year 1988 at 2.8 mg/l O_2. According to the industries of the areas, the heavy metal contents in the Emscher river are significantly high. Due to mining inflows, chloride often exceeds values of 2,000 mg/l Cl^-. Also many of the tributaries through the Emscher River function as wastewater collection channels. Only in the upstream regions of the tributaries and of the Emscher River itself, where no wastewater is discharged into the river system, the water reaches good water quality.

Bottom sludges of the Emscher River and its tributaries pose a tremendous problem for the re-naturalisation of the rivers. It is still under discussion if the bottom sludges must be removed completely and be treated as hazardous waste, or if they can be concealed and incorporated into landscaping.

2.4 Socio-Economic Consequences

Environmental problems and specifically water shortage and water pollution yield negative socio-economic conditions. An external indication for this are the declining population figures that are caused by emigration of people from the area and by the death rates exceeding birth rates. Usually, the average age of people cannot be taken as an indicator because medical developments still increases the average age of man to a larger extent that health effects generally would decrease it in industrial areas.

Another socio-economic consequence is the rate of unemployment and the increase of crime rates in old industrial and devastated areas. New and clean industries, which are necessary for economic renewal, will only settle in old industrial areas if the environmental conditions are appropriate. There is obviously an internal cycle of ecological and economic conditions. On the other hand, old industrial areas need new economic investment in order to take revival measures.

The beginning of industrialisation in the Emscher area was also the start of a conflict of interest between economic growth and environmental conditions. Only today it has become obvious that at the same time the living conditions were destroyed.

A typical indicator for the socio-economic consequences of industrialisation and especially of the decline of coal mining and steel industries in the Emscher area is the development of the age structure. While in 1960 22% of the population in the Ruhr region was under the age of 15, today it is only 14%. On the other hand, the percentage of people over 65 has risen from 9.5% to 15.6% (KVR, 1990). The unemployment rate especially in the Emscher area is rather high. While in 1957 there were still 607,000 coal miners, today there are only about 90,000, and in 1967 in the steel industry 300,000 workman were employed; today this figure is only about 80,000. In spite of all attempts, it has not been possible to compensate for this loss of jobs. The Ruhr area has the highest unemployment rate in the old German states.

The open transport of wastewater in the straightened creeks have become a burden and increasingly are found disturbing by the people. Their bad image and ecological conditions hinders a new economic development of the area. More and more a nature-like conditions of rivers and creeks is demanded. Since 1989 the Emscher area has been undergoing a substantial structural change by initiation of a variety of revival measures. Along with this change the demands of the population for living quality constantly grow. This indicates that there is a direct and fast interaction between economy and social conditions.

3. PRINCIPLES OF INTEGRATED WATER MANAGEMENT

The general goal of integrated water management is a sustainable utilisation of water resources respecting the social, economic and environmental interests. The linkages between society, economy and environment are shown in Figure 5. Considering the close inter-relationship between society and economy, the first two groups are usually aggregated into socio-economic issues. The goals and objectives of integrates water management involving all three components must be formulate on local, regional and river basin wide levels.

3.1 The Holistic Approach

Integrated water management recognises the system complexity and interconnectivity of its elements. Holistic in its approach, it equally involves local and regional authorities, engineers and natural scientists, environmentalists and decision-makers, politicians of all parties, governing and in opposition, as well as the people affected. The holistic approach sometimes is called ecosystem approach. Sustainable water management ensures that no matters are accumulated or energy lost by recovery and re-use techniques. This approach requires novel, environmentally-sound technologies.

Water management is cross-sectorial by its nature, and the division of the society and its institutions into various sectors becomes an obstacle in achieving the goals of integrated water management. The creation of inter-sectorial links, supporting cross-sectorial co-operation and integrated multi-disciplinary actions, represents the greatest challenge in implementation of integrated water management. This task is also made difficult by the current sectorial educational systems which are not designed to impart the broad integrated knowledge necessary to promote a multi-disciplinary, holistic approach to resource management problems. In consequence, integrated water management needs novel administrative approaches and a holistic education.

In 1988 representatives of local governments, mining and industrial companies decided on a joint solution to the problems of the open and combined systems of natural and wastewater drainage in the Emscher system. All activities were incorporated into a plan of the government that aimed at an ecological renewal of the Emscher area. This includes :

- *abolishment and compensation of economic disadvantages, which were left over from the old industrial structure;*
- *improvement of the environment in the densely populated area and the activation of ecological potential in surrounding areas;*
- *improvement of the built environment to gain better living, housing and working conditions.*

To achieve these goals, in 1988 the government installed the International Building Exhibition (IBA) Emscher-Park. Building exhibitions are institutions with a long history in German architecture. They always aimed to bring together urban planners and politicians to address new challenges. With this objective in mind, the government of Northrhine-Westfalia staged the International Building Exhibition Emscher-Park, for a period of ten years. At present local authorities, private investors, individual citizens and the state of Northrhine-Westfalia are involved in more than 80 projects, which are divided into five main groups :

- *ecological revival of the 350 km of the Emscher River system;*
- *modernisation of workers' settlements and construction of new housing;*
- *development of fallow land to areas following the principle of "working in the park";*
- *preservation of old industrial-heritage sites and conversion to new uses;*
- *protection and reclamation of open spaces on the regional project "Emscher Landscape Park".*

Due to their scope, the projects are sometimes planned for a duration of 10 to 20 years. Once of these long-term projects is the revival of the Emscher system.

3.2 Assessment of Water-Related Integration Issues

General values may be ascribed especially in densely urbanised and industrialised areas to water. The economic value of water, i.e. potable water supply, water for industries, irrigation, fishing or navigation, is evident and widely recognised throughout the world. In contrast, the availability of public facilities, like a well-functioning potable water distribution system within the urbanised area, available to all citizens, can be considered a matter of socio-economic status.

Less evident and consequently often less recognised are ecological, aesthetic and human perception values of the various urban water systems. Due to low standard of living and lack of money, the preservation of natural assets has often no high priority and (local) political preferences select options that often do not include the ecological soundness of water systems that would be precious to the general appearance of the city and the welfare of its inhabitants. It may be said that the degree of development of a given area commonly reflects in the degree of preservation of the latter three values.

These values were assessed for the Emscher area by a small number of inter-disciplinary expert reports :

- *for the decentralisation of wastewater treatment and the development of new urban drainage concepts;*
- *for urban planning, ecological revival and integration of rivers and creeks into the urban landscape;*
- *on the possibilities of reduction of peak flows in the Emscher River;*
- *on the possibility of a new water quality concept for the Emscher River system.*

3.3 Environmental and Ecological Issues

The most important environmental/ecological goal is the protection and enhancement of ecological integrity. For this, space and time are important. The species present at any time in an area depend on what has happened in earlier times. Thus the management strategy cannot focus on present conditions, but must consider past history and the current characteristics of organisms present. The ecosystem characteristics that are critical for system maintenance have been defined by Herricks and Schaeffer (1987). The following characteristics can be used as a basis for identification of critical ecosystem integrity attributes, which include elemental dynamics, energy dynamics (physical), food web (trophic dynamics), bio-diversity, critical species, genetic diversity, dispersal and migration, natural disturbance, and ecosystem development :

- habitat for desired diversity and reproduction of organisms;
- phenotypic and genotypic diversity among organisms;
- a robust food chain supporting the desired biota;
- an adequate nutrient pool for desired organisms;
- adequate nutrient cycling to perpetuate the ecosystem;
- adequate energy flux for maintaining the trophic structure;
- feedback mechanisms for damping undesirable oscillations;
- the capacity to temper toxic effects, including the capacity to decompose, transfer, chelate or bind anthropogenic inputs to a degree that they are no longer toxic within the system.

Environmental and ecological issues demand sustainable water resources management. In general goals could be listed as follows :

- apply source controls wherever possible
- reduce impregnation of surfaces
- infiltrate stormwater on-site into the ground
- stop pollution at the source
- prevent accumulation of non-degradable toxic substances
- practice re-use of water and other materials
- prevent transport of contaminants
- sustain or enhance existing surface and groundwater uses
- manage energy use
- develop and use non-polluting energy sources
- minimise land desertification
- prevent water-related diseases.

The separation of clean and polluted water also is a fundamental pre-requisite for achieving the ecological basis of the new Emscher system. Putting the sewage flows underground and re-shaping the formally straightened river beds, the natural impression of the rivers can be reclaimed and integrated into the surrounding countryside. Efficient decentralised sewage treatment will release pressure from the biological central treatment plant at the confluence of the Emscher and Rhine Rivers. With decentralisation of treatment, water quality in the Emscher River itself can be improved significantly. Further, it will also provide clean water to increase base flows of rivers in the area. Together with this effort, as much stormwater as possible will be infiltrated into the ground to increase base flows of the tributaries.

3.4 Socio-Economic Issues

In defining socio-economic objectives, one must consider cultural, geographical, economic and political conditions. Socio-economic objectives are connected with supply needs, flood protection, and preserving natural environmental conditions. Without question, sustaining and protecting human life is the most important socio-economic objective of water management. But also maintaining diversity of the ecosystem in at least a part of urban areas is an important socio-economic goal. Provision of open space, particularly space that includes vegetation and water, is another crucial socio-economic goal as well. Conscientious, compatible use of the usually-limited water resources also is a socio-economic goal. Many developed areas have obliterated the natural systems and now must incur great costs to take remedial action. To quote an old saying, "an ounce of prevention is better than a pound of cure".

The inability to quantify, in monetary terms, a socio-economic dimension of an urban water management project does not determine its importance. Analysts should differentiate between price and value in situations where price is a current, transient factor, and not an accurate measure of ultimate value. The conventionally used monetary costs should be supplemented by environmental costs, which consider positive environmental effects as well as environmental damage caused by implementation of environmental measures. This is needed for attaining sustainability of water resource management.

Although for some old industrial areas it would be desirable to have a co-ordinated drainage concept as it already exists in the Emscher area, there it status is unsatisfactory. An open wastewater system does not represent the conditions necessary to attract new and clean industries, nor does it fulfil today's living standards. In the Emscher area it was understood that the desired socio-economic change can only be realised by complying with ecological and environmental demands. Incidentally, in adjacent areas to river stretches where wastewater has been separated from rivers and the old straight channels were removed and water like river paths were landscaped, property prices and rents went up, with the consequence that for low income families new problems were inadvertently created.

3.5 Water Management Objectives

The above objectives do not receive the same priorities. At different stages of societal development, different objectives receive more importance. In the pre-industrial society, emphasis was placed on drinking water supply, transportation and water supply for irrigation. In the industrial society, generation of hydropower and waste disposal and transport are prioritised. Finally, in the post-industrial society, high emphasis is placed on aesthetics and ecology. Figure 6 sketches the interaction of industrialisation, reflecting priorities set for water management and the environmental condition. While the existence of changing priorities must be recognised, at the same time lower priority uses cannot be neglected over a long term, because of interdependency of various uses.

Safe, reliable and equitable water supply is one of the most important objectives of urban water management. Conventional solutions, involving water imported from distant areas, are not acceptable because of great environmental costs incurred in the area of water withdrawals and along the transport route. In urban areas, concentrations of population, properties and economic business activities are particularly high. Consequently, the objectives of protection against harmful water effects, and particularly against the loss of human life, receive the highest priority. Sanitation and protection of surface water quality are very important objectives, not only from the point of view of environmental protection, but also from public health point of view. In selection of control measures, emphasis must be placed on appropriate technologies matching the local conditions in terms of local climate, resources (funds and human skills), and cultural traditions. Water-based recreation is widely practised in industrial and post-industrial societies. To protect public health, various guidelines for quality of recreational waters have been promulgated.

Water management in industrial areas strives to meet the demands of economic growth by optimal development and utilisation of water resources and to create an optimum living environment, which would protect society against harmful effect of water. These objectives emphasise two groups of interests - society and economics. Only after introducing the third group of interests, environment, a truly integrated approach can be achieved. For a holistic approach, all objectives must be developed on a river basin scale by a stakeholder group broadly representing social, economic and environmental interests.

In the Emscher area, the water management objectives ideally can be followed-up, as the responsibility for objectives except water supply lies with the Emschergenossenschaft. The Emschergenossenschaft is a board comprising cities, industries and other stakeholders representing the public. This is an ideal condition to follow an ecosystems approach by integrated water management. However, economic constraints sometimes restrict the implementation of the desired measures or even worse influence setting priorities.

4. INTEGRATIVE PLANNING PROCEDURES AND TECHNOLOGIES

Although various forms of single or multi-purpose water management have been practised in many areas, a comprehensive approach to water management in industrial and urban areas is still uncommon.

4.1 Sustainable Technologies

Technologies for sustainable water management combine natural solutions with technical skills. As it is impossible within this paper to discuss all possible techniques for water supply, urban drainage and wastewater treatment in equal depth, possibilities of sustainable drainage in densely populated and industrialised areas are exemplified.

In the past, abatement of storm runoff and combined flows was usually implemented at the "end of the pipe". New principles for stormwater management reducing runoff peaks and volume are :

- avoid impervious surfaces and infiltrate stormwater at the point of origin;
- if necessary, detain and treat stormwater prior to infiltration;
- use stormwater as much as possible for household, commercial and industrial purposes;
- if de-central infiltration is impossible, collect stormwater, treat it if necessary, and infiltrate it in central infiltration facilities;
- If the underground does not permit stormwater infiltration, detain stormwater and lead it into the nearest water course;
- collect only polluted stormwater and treat it in central facilities;
- make use of the sludges produced in treatment for construction material.

For the Emscher River catchment with a ratio of imperviousness of 20%, it was estimated that the overall ratio of imperviousness only may be reduced by about 1%, if 5% of the impervious areas are disconnected from the sewer system. Furthermore it was assumed that in addition per hectare approximately 50 m^3 of rainfall may be distracted for secondary water uses, such as sprinkling of lawns. Such measures are important to support base flows in the small tributaries of the Emscher River. However, their contribution to reduce flood peaks is quite limited. The effectiveness of both measures on the flood-peak in the Emscher River may be seen in Figure 7, 2nd row. Under loading conditions with a return interval of 2 years, the peak flow may be reduced by 10%, while for a return period of 200 years, the flood peak only is reduced by 2% at the most.

According to present design practice in the state of Northrhine-Westfalia, a combination of combined flow detention basins with overflows and additional detention after the overflow are planned. These measures amount of a total storage volume of 1.8 million m^3 for the Emscher River basin, which corresponds to 120 m^3/ha impervious area. The effectiveness of these measures for reducing flood peaks under different storm frequencies can be seen in row 3 on Figure 7. Here the reduction of peak flows with increasing return periods unfortunately still diminishes significantly. While for a return interval of 2 years the flood peak is reduced by 50%, at a return interval of 200 years it only diminishes by 6%. Again the advantage of these measures are dampening of overflow peaks under lower flood conditions, which is important for the ecology of the small tributaries of the Emscher River. However, the main purpose of combined sewer overflow treatment facilities is the reduction of pollution loads.

From Figure 7 it can be concluded that, to control floods, source controls and small detention basins will not solve the problem. The only possibility to abate flooding in an area like the Emscher River catchment is to provide for large-scale flood retention basins. These basins show a significant effect on flood peak reduction. 25 existing and 31 additional retention facilities were investigated, as well as four additional storage volumes along the Emscher River itself. The retention volume of all basins is 6.5 million m^3 in total, which corresponds to 400 m^3/ha impervious area. Flood flow retention reduced flood peaks by 30% under flood conditions, with a 200 year return interval (Figure 7, 4th row).

The concept for the re-naturalisation of the rivers (Emschergenossenschaft, 1992) demands that the present triangular profile of the rivers is replaced by wider cross-sections stepped for low and average flow conditions. Again, on the basis of the real potential for widening the river sections, the effectiveness of this measure on the flood peak was estimated (row 1, Figure 7). Herewith only minor reductions of 3% to 5% of the flood peak under different return intervals can be achieved. The relatively large retention volume, which is provided by widening the river beds only has little effects on flood peaks. However, the advantage of this measure mainly is seen in the possibility to create river side vegetation and to lower the bottom shear stresses.

Also a variety of combinations of above measures were investigated, which are summarised in Figure 8. One can see that combining cases I to III (1st row), the reduction of flood peak diminishes with increasing return intervals. Only the combination I to IV (3rd row) shows the desired effect. At a return interval of 200 years, the reduction in flood peak is 50%. If in addition runoff control is applied, the reduction of peak flows is even larger.

4.2 Consecutive Steps to Integrated Planning

Problem identification is a first step for integrative water management and includes :

- investigation of all water resources and specification of their capacities
- detailed identification of water pollution levels in groundwater and surface waters
- specification of the effects of deteriorated water quality on man and fish
- specification of aquatic life in all parts of the surface water system
- evaluation of the water budget specifying dry, wet and mean conditions
- mapping of all discharge points of stormwater, industrial, commercial and household wastewaters
- specification of existing treatment measures (mechanical, biological, chemical) and treatment efficiencies
- survey of the potential of commercial wastewater discharges into communal sewer systems (cleaners, dentists, laundries, galvanic outfits)
- mapping of the ecological potential in still existing green areas
- specification of land uses throughout the area
- specification of dust fall-out and rainfall contamination
- mapping of flooding areas according to their occurrence
- specification of soil contamination and mapping of contaminated areas
- definition of groundwater movement.

Planning should be staged as follows :

- river basin wide management plans
- operational plans for water-sheds or parts thereof
- city-wide master plans
- planning and design of individual drainage structures
- plans for operation of drainage systems or individual drainage structures.

Criteria must exist for different sub-systems within the total system in order to co-ordinate and plan individual measures. It is also necessary that the interfaces between the different sub-systems are clearly defined. In today's planning, due to different responsibilities, sub-systems are often planned parallel. The key of integrative planning is to interact between individual planning levels. A possibility for such interaction is shown in Figure 9, where integrative planning is sub-divided into three levels :

- **Level A** : determines development of quality concepts that consider the ecological function of the system, possible water uses, defines water quality criteria and specifies user-dependent quality types as well as characterises the specific water system

- **Level B** : represents the actual planning of individual measures which in the first place must fulfil minimum requirements, and secondly must be adaptable to fulfil advanced requirements. These measures refer to the conception of treatment plant facilities, the design of drainage networks including facilities for treatment of storm runoff and combined overflows, the definition of measures in receiving waters. This level also addresses in detail the necessary costs and financing.

- **Level C** : presents the control of the effects of implemented measures, locates monitoring stations, defines, analyses programmes and necessary maintenance, as well as derives from the findings new developing tendencies.

The key to operating such a system is that Level C must be given a chance to improve measures planned under Level B. The findings of Levels B and C may well lead to an adaptation of the water quality goals originally anticipated under Level A. This fact must be provided in the planning process. It is nearly impossible to try to achieve with today's planning, a definite final condition. In many cases it is useful to plan step-wise and to allow further improvements of later planning steps in the future.

Water quality criteria must relate to the objectives and to water uses at a very early stage of the planning process, whereby the type of pollution and its effect, the type of pollution source, as well as the type of receiving water system, should be taken into consideration.

According to the development stage and need, the methods necessary for integrative planning should be built up over time. The benefit of a growing system is that the responsible authorities will finally identify themselves with the methods applied. It is not advisable to import complete systems developed on other cases.

4.3 Implementation Strategy

The implementation of an integrated management approach requires a number of steps, which are summarised below and then explained in some detail :

1. Establish a common cause of all interest groups.
2. Establish a stakeholders group.
3. Develop a plan of action - by selecting the best alternative.
4. Develop a funding mechanism.
5. Engage in political lobbying to gain political support.
6. Involve politicians in promoting the plan of action.
7. Revise institutional arrangements to support the plan implementation.
8. Implement the plan.
9. Verify the plan success by post-audit.

In every river basin, there is a number of agencies, organisations, associations and programmes involved in various aspects of river basin management. Such institutions are often depicted in a two-dimensional (i.e. vertical and lateral) schematic diagram reflecting responsibilities and jurisdictions of these groups. The challenge of the integrated plan is to rearrange these parties into a circular arrangement, in which all parties carry the same weight and communicate with each other (Hartig and Vallentyne, 1989). To be successful in water management, all interest groups must feel that they are part of the ecosystem in the studied area, and that their interests are served by the proposed course of action.

The next step is to develop a plan of action. This is often done in several stages, where the first stage may represent just problem definition of objectives, and the second stage would be the actual plan of action. The plan must be specific in terms of objectives, correction of existing problems, listing of remedial options, identification of preferred options, and definition of the final state of the basin, with all desirable water uses and functions restored. The plan should also include the means of verification that the objectives have been achieved and can be sustained.

Plan implementation is an important stage which involves extensive activities often dispersed throughout the basin studied. Important elements include co-ordination of remedial activities so that they proceed in a timely manner and cost over-runs are avoided.

Following the plan implementation, a post-audit is conducted. The essential steps in post-audit comprise the comparison of the predicted and actual results, and evaluation of the planning methodology. Remedial measures have to be designed using data containing large uncertainties and that may affect performance in relation to plan goals. Consequently, the design should be flexible to allow for corrections where design objectives are not met.

In the Emscher area, renewed drainage concepts and revival of receiving waters are closely linked. Therefore, measures for renewal of the systems must be carried out parallel and require careful co-ordination. At first the treatment facilities must be built before wastewater can finally be separated from natural flows. Planning must involve at the same time, the construction of new transport sewers, storm and combined flow treatment, as well as the re-naturalisation of urban waters.

The first projects for the revival of the Dellwiger Bach in Dortmund and Lepkes Mühlenbach in Essen and Oberhausen, as well as for the Vorthbach in Bottrop and the Emscher itself within the Westfalen Park in Dortmund, yielded good and encouraging experiences. The projects have been accepted by all agencies involved as well as by people living in the areas.

Even under very favourable conditions it is expected that the ecological and urban renewal of the Emscher area will take 30 years. This assumes that the necessary administrative procedures will be carried out extremely quickly. This might be difficult for some parts of the step-wise planning anticipated. However, step-wise planning for the reasons mentioned, is of utmost importance for carrying out the large number and time-consuming revitalisation measures.

5. ORGANISATIONAL REQUIREMENTS AND CONSTRAINTS

It is clear from the problems identified in the previous section, that water resource problems of old urban and industrial areas can only be tackled by efficient water resources management bodies having sufficient political support. In most nations such organisations are found, either at provincial or municipal level.

5.1 Managerial Conditions

There exists a significant difference in the follow-up of projects brought to life. Although knowledge is available and money for investments can be obtained, there is often a lack of maintenance. This problem, which is usually considered solely technical or financial, is more often organisational and institutional. Another constraint is deficient management during disasters, which may result in great damage, both to the welfare of citizens and to socio-economic life. An important question, related to such events, is the degree of acceptance (from the public) of such occurrences. In most developed countries this degree of acceptance is low, because the existing management organisation is simply expected to foresee such events, have the money and other resources, and able to cope with the problem.

The existence of the Emschergenossenschaft provides an excellent background to cope with renewal of the Emscher system. The reason is that the responsibility for planning, construction and operation of the whole water system lies in the hands of that one authority. If the responsibilities would be split, as is usually the case in many countries, renewal of the Emscher system due to co-ordination needs obviously would have had much less progress. The momentum of the renewal only can be maintained if responsibility is kept on a local or regional level. As soon as the responsibilities would be shifted to higher levels, the identification in connection to the area would be lost and again progress would suffer.

5.2 Planning Constraints

A major planning constraint is the lack and inappropriate use of data. Water-related projects in urban areas require reliable and accurate data for both design and management purposes. The time and space resolution needed may not always be available from standard sources. As an example, correct storm drainage design requires rainfall data of a resolution between 1 to 5 minutes, whereas the meteorological services rarely produce these data at a resolution lower than 5 minutes. And even if the required data would be obtainable, existing historical data have not been processed accordingly, or even not at all.

In the composite process of planning of water resources management, there is often a discrepancy between financial and technical responsibilities. The final decision often lies with political decision-makers, who may have little technical background. When selecting a technical solution to an environmental or ecological problem, a purely technical approach unconnected with financial realities can create solutions that are unrealistic.

There is a general tendency to deal ineffectively with risks. Unknown features of the planning process tend to paralyse decision-makers, limit the innovative potential and result in stagnant technology and inappropriate solutions. New methods of risk assessment and public discussion of the risks involved in a particular approach are needed.

The political context under which planning processes must progress, often blocks an efficient planning procedure. In general the planning process tends to be reactive rather than pro-active.

One of the major planning constraints in the Emscher region is the lack of a conclusive documentation of water uses, quality conditions and the formulation of emission goals for improvement of the system. Most of the projects done so far follow the idea "leaning by doing". However, for reaching the overall goal of the renewal of the Emscher system, a quality management plan is needed.

5.3 Obstacles to the Implementation of Integrated Water Management Plans

In spite of generally acknowledged attractiveness of integrated water management there are many obstacles and constraints encountered in integrated management planning :

- A personal perspective of obstacles - threats to livelihood, fear of job loss, hopelessness resulting from perceived loss of control; mistrust of governments and industry; confusion caused by issue-by-issue reporting; and, differing perspectives resulting from diverse background and specialisations (Christie et al, 1986).
- An industry perspective of obstacles - the desire for demophoric growth (the growth of energy consumption); competition, mistrust of competitors and government, and suspicion of emotional influence that environmental organisations are thought to exert on government (Christie et al., 1986).
- A voluntary association perspective - inadequate representation in the decision-making process, organisations and finances that are weak, and ineffectiveness of adversarial organisations in responding to common causes (Christie et al., 1986).
- A government-perceived perspective - lack of legislation incorporating the integrated management concept; lack of public support for integrated policies; and lack of trans-institutional networking reflected in poor inter-agency planning (Christie et al., 1986).
- Common obstacles - lack of holistic perspective - our knowledge of inter-relationships is limited, instead piece-meal action is more typical; predominance of self-interests in utilisation of water resources; and, lack of preventative approach - much of our response is retro-active - reacting to crises caused by past mistakes, rather than pro-active - trying to anticipate and avoid future crises (Christie et al., 1986).
- Other constraints frequently encountered include differences between the technical perspective emphasising engineered systems as opposed to natural systems, lack of generally accepted valuation systems for environmental benefits, professional conservatism, relying on proven practice and blocking technological innovation, lack of understanding of the nature of and control opportunities for diffuse sources of pollution, and pre-occupation with transport processes detracting from the assessment of impacts on receiving waters.

In the Emscher area there are some deficiencies if it comes to the approval of individual projects. One example is putting infiltration facilities to reality. The inherited drainage *design requests for the connection of all impervious areas to drainage networks. In some cases it proved to be rather difficult to introduce the new methods of infiltration of stormwater and to obtain approval for this. However, at present the responsible water authorities are alerted and hopefully attitudes will change quickly.*

5.4 Administrative Background for Integrative Planning

New methods of integrated water resources management require appropriate legislative and administrative support. In general there are no single typical policies which would fit all specific conditions. Normally parliament has to pass laws, which also include water laws determining rules for the use of water and the constitution of corresponding administrative bodies. The duty of these bodies is to execute rules and to supervise compliance with such rules.

Experience shows that it is desirable to separate water authorities on national, regional and communal levels. In any case, responsibilities should be chosen in such a way that administrative boundaries are not artificial or political, but rather related to river basin catchments or water-related defined parts of it. The responsible authority for all water-related planning with a catchment must be linked to national or even international planning levels.

Examining specific legislations in various countries, it seems that integrated water management can be successfully implemented without legislative creation of special bodies for it. Usually structures to cope with integrated planning do exist. It is only necessary to convey appropriate rights and order to existing authorities.

In order to aid co-ordination and presentation of projects in the Emscher, the government of Northrhine-Westfalia established a planning company operating as a private enterprise - the IBA Emscher-Park Pty. Ltd. The IBA Emscher-Park was equipped with a budget of 35 million DM and has its headquarters in Gelsenkirchen. At present they operate with a staff of approximately 30. Its task is to prepare to stage architectural and planning competitions, to implement results together with the project organisers, and to act as an intermediary throughout the planning process.

Decisions as to which projects are to be included into the IBA Emscher-Park activities are made by a steering committee chaired by the Minister of Transportation and Urban Development, Mr. Franz-Joseph Kniula. Members of this committee are representatives of state government departments, towns, industry, trade unions, nature conservation organisations, as well as planners and architect associations. The board of trustees is chaired by the Minister President of Northrhine-Westfalia, Mr. Johannes Rau.

5.5 Financing

Funding mechanisms, based on polluter/user pays principle, are most appropriate. Those include taxes on consumptive resource uses (e.g. water withdrawals for cooling, irrigation), developing full cost pricing by incorporating pollution costs and full-cost pricing for new developments, and developing options for charges and tax incentives that shift more of environmental protection costs from the taxpayer to the consumer. Again, while many of these options seem attractive, political realities may render them unfeasible in various political systems and situations.

At present the IBA Emscher-Park co-ordinates approximately 80 projects. The responsibility for the individual projects lies with local authorities, private companies and different organisations in the region. The projects are frequently financed jointly by the state, the cities and private companies. In some cases, for example the Landscape Emscher Park, all costs are met in principle by public funds. Many projects also receive support from the central government of the Federal Republic of Germany and the European Community. In summer 1993, the total current expenditure on projects amounted to 2.5 billion DM, 1.7 billion DM of which came from public funds, and approximately 800 million DM from private sources.

For the entire duration of the revitalisation of the Emscher system, it is expected that approximately one-third of all costs are subsidised by the state. The remaining finances including also the funds necessary for operation and maintenance of the new system, must come from the wastewater fee collected from inhabitants and industries. It was calculated that the wastewater fee of presently 0.7 DM per m^3 will have to be raised to 2.10 DM per m^3, in order to provide the necessary finances. These cost calculations show that the area decided not to rely on international funds. In addition to the wastewater fees mentioned, wastewater costs for the individual cities of the amount of 2 DM per m^3 must be added. As a result, at present the wastewater fee of 2.7 DM is collected, and in future this amount is estimated to be 4.70 DM per m^3. This amount seems to be reasonable and compares to wastewater fees collected from inhabitants in other parts of the Federal Republic of Germany.

6. PUBLIC INVOLVEMENT AND AWARENESS

Bringing the public into the decision-making process can include either public involvement or public participation. Public involvement is the older method of bringing the public into the decision-making process. Public involvement takes the form of public review and comment on well-developed planning. In the typical public involvement programme, notice will be published of an anticipated action, plans will be available for review, and the public is encouraged to comment. Comment may be written, or given verbally in public hearings.

Public participation is a much newer procedure. In public participation the public is informed of a planned action at the earliest stages of the planning process. Members of the public, usually called stakeholders, technicians, engineers, and managers, meet together to plan, develop and implement a project. The major difference between involvement and participation is that in participation the public is intimately involved at all stages of the project, rather than being limited to providing comment when certain stages of planning or development are reached. Full public participation effectively changes the entire planning and design process producing, what many feel, is a better design that can move through the construction or implementation phases very quickly.

Figures 10 and 11 illustrate the differences between the more traditional public involvement and the public participation process. The public involvement approach is fundamentally "top-down" only involving the public late in the planning process. The consequence of this approach is that key policies and environmental priorities are not dealt with until near the end of the project when change is more difficult. The public participation model is a "bottom-up" planning process that addresses public concerns and reviews policies and environmental priorities from the earliest stages of the planning process. A characteristic of the participation model is that the public, often with no technical or professional training, are asked to consider and act on technical as well as non-technical issues. Stakeholders are educated during the participation process, building their expertise, understanding, and a recognition of the need for compromise and trade-off to achieve a common goal. The primary advantage of the participation process is the early identification of critical issues and the development and evaluation of engineering alternatives early in the planning process.

Originally the concept for the revival of the Emscher system was developed by staff of the Emschergenossenschaft and other state authorities. Action was spurred by people living and working in the Emscher basin who had complained for many years about industrial pollution and the smell of sewage transported in open channels. However, the public long-accustomed to the condition of the Emscher, did not demand an effort with the scope of the Emscher renewal. It is only now, with completion, and success, of the initial renewal projects, that the public is becoming aware of the full scope of the renewal efforts. The public is now making new demands for revival.

At the beginning of the renewal project, authorities in the Emscher basin provided information sheets on the technical measures used in the revival that were designed for water management professionals. When the IBA Emscher-Park started to co-ordinate projects for the revival of the area, they put special emphasis on public awareness and made special efforts to integrate the public in projects. This public awareness and participation campaign included :

- *initiating public competition for the solution of problems*
- *initiating projects that involved women and children*
- *inviting local residents to opening ceremonies of restored buildings and industrial sites*
- *using restored sites to provide theatres and playgrounds, and holding festivals on restored sites throughout the Ruhr region*
- *involving residents in housing renewal to keep costs low*
- *involving local universities, such as University of Essen,, into all phases of the renewal projects to provide scientific and technical support while depending on the universities for the generation of new ideas*
- *sponsoring design competitions at universities to encourage student participation in the renewal efforts*
- *providing information boards throughout the area reminding people on the individual project goals*
- *co-ordinating and providing public relation leaflets on all ongoing projects*
- *actively using the press to report on projects and inform the public of events*
- *publishing a newspaper devoted to the revival of the Emscher system.*

By combining public awareness the public participation activities, the developing renewal programme gained tremendous momentum and public support. The end result is an increased interest in the revival of the Emscher system. The public also starts to realise that their financial support is needed to continue the revival effort. The public has also come to recognise the role they can play in the revival effort.

7. CONCLUSIONS

The following is concluded from the evaluation of different case studies presented at the two UNESCO workshops mentioned at the beginning, and from experience gained with projects in the context of the revival of the old industrial Emscher area.

- Environmental revival of devastated areas can only be achieved by economic development through clean industries.
- It must be the people living in the area who must request the change, carry it and live it.
- The right balance between no or low cost initiatives in the area, state funding, private investment and international help must be found. The basis for the success is always local initiatives.
- Small low-cost pilot projects carried by local authorities are often more effective than large-scale national or international funding programmes. Therefore, it is advisable not to start with large-scale programmes, but to start with local activities in order to create the necessary momentum.
- Established long-term programmes are of little use. However, there must be a long range frame-work that is filled step-wise with projects. Each project must be evaluated for its success. Experiences and findings must immediately be translated to approve or to adapt long-term goals.
- To revive a devastated system taken as much time as it took to establish the bad condition. It took 60 to 90 years for the Emscher system to develop into today's status. Therefore estimates that the system can be revived within 30 years seem to be too short.

The many projects aiming for revival of the old industrial zone of the Emscher area today present a holistic approach involving integrated water management in most activities. The spirit existing today after five years of intensive planning and implementation proves that revival of old industrial areas can be achieved also in times of financial constraints. The vision of the Emscher area developing into the greenest industrial zone of Europe can be achieved.

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Studies on Rainfall Run-off Utilization in Urban Area in Beijing

Chong Yuqi, Zhang Weihua and Duan Wei

ABSTRACT

Situation of water resources in Beijing is introduced. Water quality of natural rain water, rainfall run-off from building roofs, roads and grass lands are analyzed and assessed. Methods of rainfall run-off flood water utilization was studied. Experiments of rainfall runoff collection, diversion and soil filtration were made. Methods and results of experiments are also introduced. Water quality before and after filtrating process using different soil filtrators were analyzed and controlled within acceptable grade of water quality standard. Feasibility study shows that utilization of rainfall run-off as a water source of ground water recharge have the functions of flood reduction and water resources increase and with the advantages of low cost and easy to operate. Geological structures in Beijing urban areas are suitable for this kind of activity. Through suitable soil filtrating process, Rainfall run-off used in ground water recharge will not cause ground water pollution.

INTRODUCTION

In recent decades in Beijing, due to continuous drought weather, rapid increase of population and fast development of industry, ground water has being excessively exploited and reduced rapidly. Although some measures have been adopted to save water, the gap between water supply and water demand becomes wider and wider. Water shortage becomes one of the most serious problems in Beijing. Water shortage and the degradation of water environment has already considerably hindered the development of the city and its industry and agriculture. In addition to pursue the realization of the South-to-North Water Transfer Project, we make every efforts to increase the degree of utilization of the limited water resources. To block rainfall run-off in rainy seasons and reduce the amount of water that flow out of the city as a method of water saving and water resources increasing is a effective way of releasing the tension of water shortage.

On the other hand, because the very fast on going urbanization inBeijing, large areas of farm or natural lands has being taken by impermeable structures like buildings and roads which changes conditions of land surface and break down the natural water cycling system. Results of such activities are in two fords: one is that less water is going to infiltrate into ground, the other is more rainfall run-off produced in even shorter time. Which in turn cause two kinds of problems: drop of ground water table due to lack of water, damage of flood due to too much run-off produced in too short time.

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Water Quality Standard

Because soil in Beijing areas are alkaline soil. The base line of soil component are of very complex. Our experiments, therefore, cannot cover all of impact studies of rainfall run-off ground water recharge on quality of ground water, which need a special study. On the view of present serious shortage of ground water resource, and the surface water quality deterioration situation, it is obvious that utilization of rainfall run-off as a source of water for ground water recharge will sure benefit the city and improve its water environment. So it is feasible to use every methods to recharge ground water by means of utilization of rainfall run-off. And rainfall run-off in urban areas in Beijing city should and can be re-utilized rather than left it run away.

1. Pilot System

There are many ways to use rainfall run-off in ground water recharge. In addition to let rainfall run-off in low grass lands directly infiltrate into ground, rainfall run-off from building roofs, courtyards and roads are all possibly be used. In this project, a pilot ground water recharge system was set up on use of rainfall run-off from building roofs.

A recharge well was used in the pilot recharge system which controls 1830 m^2 of building roof area. Rainfall run-off produced on roof of buildings was collected and piped into the recharge well. The depth of the recharge well is 8 meter, diameter of top 6 meter of the well is 3 meter, and that of the lower 2 meter of the well is 1.5 meter. the total volume of the well is 45.88 m^3. The bed of the well is medium sand and gravel with a hydraulic conductivity of $6*10^{-3}$ to $6*10^{-2}$ cm/s.

Well flood routing was made, according to different designed rainfall return periods and based on experimental facilities currently available. This is to analyze the effectiveness of soil filtrating process in terms of water quality and quantity. The routing were based also on different rainfall run-off conditions and water come from different areas of building roof. Rainfall conditions and infiltration conditions are also taken into consideration. According to flood routing, the system can process run-off of 2500 m^2 roof area with ten year return period, or 96 % run-off of 8000 m^2 with 2 year return period.

2. Feasibility

The topography of Beijing urban area has a feature with its altitude declines by degrees from northwest to southeast. The geological structure is that, in the west part of Beijing urban area there large area of thick high permeable gravel and sand layer siting on bed rock, while in the east part of Beijing urban area there are layers of sand and clay with low permeability.

In view of the above mentioned geological structure features in Beijing urban area and according to the experiments and analysis result. It is not a difficult nor very complex technique in implementation of soil filtration programme by ways of utilizing rainfall run-off water from building roofs, courtyards and roads and piping the water collected into recharge wells. This kind of system is easy to set up and easy to operate. The diversion system that connect recharge well to the rainfall run-off collection outlet can be made of earthen pipes or no-liner sewer. In order to prevent the sewer be silted up or blocked, some simple methods of waste or dust blocking or screening treatment can be used before water entering recharge wells. In view that the buried depth of high permeable gravel and sand

To utilize rainfall run-off flood water in urban areas, activities of ground water recharge has been considered a direct and effective way. In doing this, water quality in rainfall run-off water is a major concern in order to make sure that recharged water will not contaminate water quality of ground water. So studies in this paper and in this field are of real important meaning, especially to the increment of water sources in large cities with serious water shortage problem.

WATER QUALITY ASSESSMENT OF RAINFALL RUN-OFF

In order to monitor water qualities of natural rainfall and rainfall run-off, 12 sampling points were set up in the east, south, north, west and at the center of Beijing urban area. Samples were taken from natural rain water and from rainfall run-off from roofs of buildings, roads and grass lands. In case of rainfall exceeding 10 mm, samples were taken simultaneously. 14 water quality parameters were analyzed in this programme.

According to the overall analysis of the monitored data during 1991 to 1993, water quality assessment of natural rain water, rainfall run-off from roof of buildings, roads and grass lands in urban area was made using Degree Index Multi-Assessment Method. The result is given in table 1.

table 1. Assessment of Rainfall Run-off Water Quality

	Natural Rainfall Water				Runoff fr. BuildingRoof				Run-off from Road		Run-off from grass Lands	
	Urban area		Indus. area		Urban area		Indus. area					
item		gr		gr		gr		gr		gr		gr
PH	7.3	1	7.6	1	7.5	1	7.8	1	7.7	1	7.3	1
Hardness	16.2	1	—	1	52.8	1	—	1	56.4	1	32.2	1
Chloride	1.42	1	1.85	1	2.04	1	8.48	1	7.95	1	0.51	1
Sulfide	9.38	1	14.49	1	49.3	1	24.9	1	35.1	1	3.19	1
Ammonia	2.49	>5	3.06	>5	1.92	>5	2.60	>5	2.55	>5	0.80	4
Nitrate N	0.77	1	0.83	1	1.57	1	1.21	1	1.45	1	0.24	1
Nitrite N	0.042	1	0.055	1	0.267	4	0.149	3	0.10	3	0.0053	1
COD_{mn}	4.7	3	4.4	3	6.2	4	7.9	4	21.3	>5	4.9	3
BOD_5	2.1	1	—	—	2.3	1	—	—	19.35	>5	2.2	1
VP	0.013	>5	0.006	4	0.008	4	0.005	3	0.028	>5	0.004	3
Cyanide	0	1	—	—	0.004	1	—	—	0.004	1	0	1
Arsenic	0	1	—	—	0.003	1	—	—	0.003	1	0	1
Mercury	6• 10-4	3	—	—	9• 10-4	3	—	—	0.0002	4	0	1
Lead	0.025	2	0	1	0.012	3	0.005	1	0.019	2	0	1
Summery	> 5		> 5		> 5		> 5		> 5		4	

Note: units —— mg/L (except PH),

gr —— grade
VP —— Volatile phenol

From table 1 we know that, water quality of natural rain water, run-off from roof of buildings and roads were worse than the 5th grade of National Surface Water Quality Standard. Only water quality of rainfall run-off from grass lands are accordance with the 4th grade of National Surface Water Quality Standard. Although water quality of rain water, run-off from roof of buildings and roads exceeding the 5th grade of National Surface Water Quality Standard, but in most cases it due to only a few of parameters exceeding the water quality standard.

SOIL FILTRATING EXPERIMENT

According to the monitored data, water quality of natural rain water is already exceeded the 5th grade of National Surface Water Quality Standard due to air pollution. So when such kind of water be used as a ground water recharge source, it is unrealistic to require it meet high water quality standard. According to the required water quality in ground water recharge that when it is re-pumped out, through some treatment, can be used for drinking purpose, water quality of rainfall run-off used for ground water recharge can be allowed to be controlled within the third grade of Surface Water Quality Standard. And according to this regard, water quality parameters of rainfall run-off that commonly exceeds water quality standard are only ammonia nitrogen, and volatile phenol. At a few of points, parameters like potassium permanganate index (COD_{mn}), lead, nitrite nitrogen and BOD some times exceeds the standard. When rainfall runoff is used as a water source in ground water recharge, it infiltrate through a layer of soil and sink into ground water, in this soil filtrating process, concentrations of some matters may decrease while some others may increase. In order to have a better understanding of this process, a programme of preliminary experiments was developed.

a. Experiment Method

Plexiglass tubes was used to hold the soils used as filtrator in the filtrating experiments. The inner diameter of the tube is 19.2 cm, its height is 2.5 meter. the thickness of soil column inside the plexiglass is one meter. water used in the experiment was taken from rainfall run-off at the early stage when surface run-off begin to produce at the sampling points of road surface and roof of buildings. the water taken then poured into the plexiglass tube on top of the soil column, to let it sink quickly, the initial head of water column is 1.5 meter. When doing this, water samples were taken at the middle and bottom of soil column. Soil materials used in the tests are loamy soil, fine sand, medium sand and coarse sand. Water used in the experiments infiltrate through different kinds and different thickness of layers of soil. Samples of source water used and water samples taken from at middle and bottom of soil column was analyzed and compared against different experiment conditions.

b. Analysis of Experiment Result.

Concentrations of suspended solid, poisonous and pernicious matters, non-organic pollutants before and after filtrating process were analyzed and compared. Results are listed in table 2.

Table 2 indicate that, soil filtrating process can effectively reduce concentrations of suspended solid and most of pernicious heavy metals in source water. It also have good effects on pernicious matters, volatile phenol and chloride reduction. And there as well some effect on potassium permanganate index concentration reduction.

A few of heavy metals not detected in source water has been fund after filtrating process, this is directly related to the content of the soil used in filtration. But concentrations of such matters are commonly very low and accordance with the third grade of water quality standard. According to some of relevant studies, heavy metals normally concentrated at surface layers of soils and can hardly transfer into deep ground. So this will not pollute ground water.

According to the tests, concentrations of sulfide and chloride varies within a small range. Total hardness has been fund has a tendency of positive relation with the thickness of soil that water go through. However in the tests, its concentration still within the line of the third grade of water quality standard.

tab. 2 Comparison of Poisonous and Pernicious Matters, Non-organic Pollutants Before and After Filtrating Process

experiment conditions / parameters	source water	0.5 m		1.0 m		third grade standard	water quality assessment after filtrating
		medium sand	coarse sand	medium sand	coarse sand		
Suspended solid	1040	128	--	55	--	--	accordance with the third grade of National Surface Water Quality Standard
cyanide	0.004	ND	ND	ND	ND	0.2	
Arsenic	0.015	0.014	ND	0.015	ND	0.05	
mercury	ND	0.0001	--	0.0001	0.0001	0.0001	
Lead	ND	0.034	ND	0.025	0.039	0.05	
Volatile phenol	0.034	0.007	0.004	0.004	0.005	0.005	
chloride	21.5	13.9	15.1	19.8	23.8	250	
sulfide	100.0	61.0	87.6	81.6	118.0	250	
COD_{mn}	50.1	11.5	8.4	13.0	5.7	6	
total hardness	77.1	257	166	203	237	450	

note: ND ---not detected,
unit --- mg/L

Table 3 shows the variations of concentrations of organic matters before and after infiltration. And reasons of total hardness increase also studied based on this table.

From table 3 we know that, there are significant reduction of ammonia nitrogen, BOD and nitrite nitrogen after filtrating process. While concentrations of nitrate nitrogen, calcium and magnesium etc. have a small increase. We consider that the reasons of these changes are the followings:

1. The nitrogen components in rainfall run-off water may mainly consist the four forms of organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. Reduction of nitrogen concentration in soil filtrating process is due to

alternative actions of nitrification and counter-nitrification. The counter-nitrification process acts when soil soaked with water and nitrification process acts when soil exposed to air and with a good oxygen environment. Our experiments mainly in conditions of nitrification process so cause the slight increase of nitate nitrogen. When implicated in real conditions of well ground water recharge, it should be no problem, through counter-nitrification, to remove a proportional of nitrate from water used in ground water recharge.

2. Soil (include fine sand, medium sand and coarse sand) in Beijing areas are alkaline soil. The PH value in rainfall run-off water is obviously less than that of in soil. When rainfall run-off water infiltrate through soil, Due to the alternative positive ion absorption actions happen on surface of filter particles, the low-solubility calcium sulfate, calcium carbonate, magnesium sulfate will separated out, so that the total hardness increase and specific conductance increase accordingly.

table 3. Comparison of Concentrations of Organic Matters, Calcium & Magnesium in Rainfall Flood Water Before and After Soil Filtration

test condition	1			2			3			
	SW	1 m	2 m*	SW	1 m		SW	1 m		
items		fine sand	fine sand		medium sand	coarse sand		loamy soil	medium sand	coarse sand
PH	7.1	7.9	7.8	7.4	7.3	7.2	6.8	7.5	7.5	7.3
conductivity	145	120	320	41	44	96	84	377	251	659
ammonia nitr	9.96	1.30	1.35	7.61	1.34	0.47	5.28	0.51	0.38	0.27
nitrate nitr	1.58	1.37	25.8	2.50	3.16	4.52	1.26	11.70	37.30	0.56
nitrite nitr	--	--	--	1.00	0.014	0.026	0.06	0.065	0.035	0.046
BOD	42.2	4.3	4.4	25.8	20.0	6.8	19.7	6.2	2.0	3.6
calcium	--	23.4	63.2	28.2	28.2	--	12.2	91.9	63.7	59.9
magnesium	--	8.5	34.3	4.7	8.3	--	3.2	19.8	28.8	25.2

note: * --- two times filtration of one meter soil column.
SW -- source water
unit -- all unit are mg/l except PH and conductivity (specific conductance, μs/cm).

FEASIBILITY STUDY OF RAINFALL RUN-OFF UTILIZATION

According to analysis and studies, it is clear that water quality of rainfall run-off in Beijing areas are worse than the 5th grade of surface water quality standard, but we also noted that only a few of parameters exceeds that standard. Through soil filtration experiments we have got some preliminary knowledge on changes of water quality before and after soil filtrating process. The process, according to the experiments, has significant effect on the reduction of concentrations of poisonous and pernicious matters, organic and inorganic pollutants. but there is a tendency of increase of total hardness after soil filtrating process. Water quality of filtrated water meet the third grade of the National Surface layer in the west part of Beijing are very shallow, normally the required well depth used for ground water recharge is only in the range from 2 to 8 meters.

So all in all, the rainfall run-off re-utilization and its corresponding soil filtrating system are of low cost, easy to operate and economically reasonable.

CONCLUSIONS AND RECOMMENDATIONS

As water resource is a major natural resource and essential element of environment, and also the support system of ecosystem. Water resource shortage is a serious problem in Beijing. The excessive exploitation of ground water has yet cause some problems. Water saving, finding new water sources and water re-use are important strategies in serving these problems and must take long view. Utilization of rainfall run-off as a water resource in ground water recharge is a effective and important way of water saving. According to rainfall run-off water quality assessment, rain water has yet affected by air pollution. Water quality of rainfall run-off exceeds the 5th grade of National Surface Water Quality Standard. But the fact that only a few of parameters exceed quality standard has also noted. By soil filtrating process water quality can meet the third grade of national standard, and can be used as a ground water recharge source. According to experiments of soil filtration and recharge well system and technique-ecology feasibility study, utilization of rainfall run-off to recharge ground water have the functions of flood reduction and water resources increasing in city urban areas. In urban areas in Beijing city the geological conditions is ideal for this kind of ground water recharge. Through careful planning, suitable well sites selection, suitable well diameter, well depth and suitable water collection and diversion system designing, rainfall runoff water can be maximally utilized which will sure make considerable benefit both to economy and environment.

STUDY ON MAKE USE OF RAIN WATER IN CITY AFFOREST

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ABSTRACT

Global fresh water resources which are over exploited are becoming less lack day by day. Many countries have taken emergency measures to save water. There are about 300 cities which are short of water among 528 cities in China. The discrepancy of water between supply and demand is increasely serious. Therefore, We take the campus of Gansu Agricultural University as a study field to probe the problem of using rain water to plant trees in and around the city for solving the lack of water resources in semi-arid regions. This paper puts forward a proposal of suiting measures to local conditions and multiple-purpose using small storage pond, spillway, penstock, inverted syphon for irrigation.

Making use of rain water irrigates the fields of planting trees and flowers in Lanzhou city. We can not only save the problem of using water conflict between industry and agriculture, and the problem of lacking water resources, but also save a large amount of energy resources.

Key words: Make us of, Rain water, Afforest, study

Global fresh water resources which are over exploited are becoming less day by day. Many countries take emergency measures to save water. There are about 300 cities which are short of water among 528 cities in China. The number of cities which are seriously short of water is more than 100. Lack of volume of water is 1,000,000 cubic meters. We can't obtain 100 billions R.M.B of the industrial value of output because of shortage of water. Lack of water leads to blind exploitation of underground water, it makes underground water resources unbalanced, the surface of some cities can be damaged.

Lanzhou, named Jincheng (Golden City) in ancient times, has a history of more than two thousand years. It is now the capital of Gansu province. Greater Lanzhou has a total area of about 14,000 square kilometers and includes three countries and five districts under its jurisdiction with a population of 2.43 million. Lanzhou proper has about 220 square kilometers and a population of about 0.6 million.

There are more than 30 ethnic groups in Lanzhou. The city stretches along the Yellow River as it snakes its way through the valley.

Lanzhou is located on the loess plateau of northwest China with an average elevation of 1520 meters. The weather is dry in this area, with little precipitation. The annual rainfall is about 400 mm. Lanzhou Belongs to a semi-arid region.

Lanzhou city has made use of water in the Yellow River and underground water resources from 1955, setting up 4 water plants, and has the ability to supply water of 180,000 tons every day. The volume of supplying water increases by 3.5% every year, but the volume of demand for water increases by 6% every year. The discrepancy of water between supply and demand is increasingly serious. Therefore, we take the campus of Gansu Agricultural University as a study field to probe the problem of using rain water to plant trees in and around the city to solve the lack of water resources in semi-arid regions.

I. It is important to make the city green by planting frees and flowers

The cities should have a neat, clean beautiful, pure and fresh, environment. To get this garden-type city, the main measure is to turn the land green with parks and woods. On the one hand, planting trees in and around the city is to conserve water and soil, to improve weather condition, on the other hand, it can regulate the climate and make fuller use of natural resources, especially for the University and college, making green by planting trees, flowers is an outside green classroom, it plays an important part in protecting dust, noise, wind, sunshine, cold, wet fire and so on.

II. Present situation of making use of rain water in City

In Lanzhou city in most of the factories, enterprise and public fields, the elevation is higher than the zone of trees and flowers which surround them. About 70% are using tap water to irrigate field of trees and flowers. Because of small flow quantity of tap water, using large duty of water to irrigate the fields green results in a loss of water pressure for domestic use. Supplies of water for people can't be ensured, industrial us of water is becoming serious. On the contrary all of rain fall from public places, roads, surfaces, and roofs runs into drainage ditches or pipes, which can't be used to irrigate the fields of trees and flowers, in summer and autumn therefore, water resources of rainfall are wasted.

III. The feasibility of making use of rain water in City

The key problem of making use of rain water is the area of collecting rain water and seepage prevention. In cities most of the roof drainage, terrace drainage, some of surface drainage, road, sports ground of factories, schools and enterprises have been paved by using concrete or bitumen. There is a good condition for collecting rainwater. Therefore, some small diversion structures according to the different topography can be used to irrigate the fields of trees and flowers. In city afforestation plans, roads and public places of units which are going to be built should be higher than the fields of trees and flowers, old units should suit measures to local conditions with multi-purpose use of small storage ponds, spillways, penstocks, and inverted syphon for irrigation. According to the annual distribution of rainfall in Lanzhou see table 1. mean annual precipitation.

Table 1. Mean annual precipitation (mm)

Months	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
rain	2.4	2.9	10.6	25.5	48.2	46.0	83.7	92.0	62.8	30.3	6.6	1.5	412.5

Now we take the campus of Gansu Agricultural University as a example to study the feasibility of making use of rain water in the city.

The total area of campus of Gansu Agricultural University is 40 ha, the area of planting trees and flowers is 13.3 ha. The duty of water for the area of planting trees and flowers is 4500 cubic meter/ha.

Total amount of irrigation water requirement on campus:

4,500 X 13.3=60,000 cubic meters

According to table 1 total annual precipitation is about 1,000 mm, excluding snow and invalid water of rainfall 100 mm.

Effective precipitation is:

400 - 100 = 300 mm

The total amount of collecting rain water is:

0.3 X 26.67 X 10,005 = 80,040 cubic meter

From what has been said above the total amount of collecting rain water is more than total amount of irrigation water requirement on campus. In conclusion there is the problem of lacking water. For solving this we can use rainwater to irrigate the fields of trees and flowers in Lanzhou city.

IV. Social efficiency and economic revenue

Making use of rain water irrigates the fields of trees and flowers in Lanzhou city. We can not only solve the problem of using the water conflict between industry and agriculture and the problem of lacking water resources, but also save a large amount of energy resources.According to the statistical figures of the water tower of Gansu Agricultural University, the cost of water for each cubic meter is 0.45 R.M.B with the cost of resources for each cubic meter is 0. 1 R.M.B.. The total cost of water which is used for planting trees and flowers is:

0.55 X 60,000 = 33,000 R.M.B

If making use of rainwater irrigate the fields of trees and flowers in Lanzhou city,we can save 10 million cubic meter of water, to save the total cost of water is:

0.55 X 10,000,000= 5,500,000 R.M.B

ONSITE STORAGE OF STORMWATER RUNOFF FOR FLOOD CONTROL

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ABSTRACT

Storage of stormwater runoff in small onsite detention storages can be used to reduce flooding in urban catchments. The reduction in flood peak depends on the size of the outlet and on the volume of water stored. Permissible site discharges are generally based on pre-development or natural catchment conditions, and are set depending on the selected storm frequency and duration. To control flood peaks for a range of storm durations, the permissible site discharge should be set using the longer duration design storm. Because these storages are usually small, simplified design procedures can be used, and an example is given.

1. INTRODUCTION

Collection and storage of stormwater runoff has two potential benefits. It can provide a source of water to supplement normal household supplies, and it can be stored onsite to reduce flooding in the catchment. In Australia the first of these has received most attention in rural areas which are remote from water supplies, while the second has been used in cities to reduce flooding. Australia is currently suffering from a severe drought(1991-1994), as a result of the El Nino phenomenon, and storage of rainwater is being considered in suburban areas for washing and garden watering. Never the less, the predominant use of onsite storages in Australia is for flood control, and this is the subject of this paper.

Flood control can be achieved using a large dam, or by using several medium sized detention basins, or using many small onsite storages scattered throughout the catchment (Fig.1). Noting that flood protection is only obtained downstream of the storage, the advantages of onsite detention storage are clear. Flooding is reduced at many points in the catchment; and flood storage is distributed throughout the catchment, better representing catchment conditions before urbanisation. An additional advantage is that costs are spread over many individual landowners rather than falling on the controlling authority. Opposing this however is the loss of control by the authority for maintenance and performance monitoring of the many small storages.

Onsite Detention storage (OSD) is usually required because development of the catchment has caused the capacity of the existing stormwater drainage system to be exceeded. The storage is therefore designed to reduce flooding from the post- development urban condition to pre-development or natural values.

2. PRINCIPLES OF FLOOD DETENTION STORAGE

The basic principle of detention storage is that the runoff from a catchment or from a developed site is temporarily stored, thereby reducing the downstream flood peak. The same principles apply, whether it is a large dam with spillway located on a major river (Fig.2a); a medium sized detention basin consisting of an embankment with culvert outlet located on a stream (Fig.2b); or a small onsite detention storage located to store runoff from a small site (Fig.2c).

The reduction in runoff peak depends on the size of the outlet works (spillway, culvert, or in the case of OSD an orifice or pipe), and on the volume of water stored. Figure 3 shows a typical tank storage OSD. Runoff from the site (I) increases to a maximum then decreases as the storm ends. The depth of water stored (H) also rises to a maximum then decreases to zero. Similarly, the volume of water stored in the tank (S) and the discharge from the tank (Q) increase to a maximum then decrease to zero as the runoff passes through the OSD storage.

The storage volume S and discharge Q are functions of the water depth H, depending on the basin shape and outlet size respectively (Fig.3a). When H is a maximum, S and Q are also at their maximum values.

Figure 3b shows the effect of detention storage in reducing the peak runoff from the site to a smaller value. Note that the maximum volume stored is equal to the area between the inflow and outflow hydrographs. If the outlet size is reduced (i.e. a smaller orifice is used) Hmax and Smax increase (more water is stored in the tank), but Qmax decreases (point A on Fig.3c). Figure 3b shows the new discharge from the tank, and the corresponding increase in storage volume required.

3. DESIGN OF ONSITE DETENTION STORAGES

3.1 General Design Procedure

Design of an OSD storage requires firstly that the maximum allowable discharge from the storage be specified. This is commonly referred to as the Permissible Site Discharge (PSD). Secondly, the runoff hydrograph from the site into the OSD storage must be calculated. Next, the storage volume required to reduce the peak of the inflow hydrograph to the PSD value is determined. This volume is equal to the area between the inflow and outflow hydrographs as shown in Figures 3 and 4, and is commonly referred to as the Site Storage Requirement (SSR). Finally, the size of the outlet is determined so that the maximum outflow Qmax (which is equal to the PSD) occurs when the storage is full under head Hmax. The hydraulic relation between discharge Q, head H and orifice diameter D is used to determine D (Boyd,1985).

3.2 Pre-development and Post-development Hydrographs

Since OSD storage is usually designed to reduce the flooding caused by urban development to lower values, the design is based on reducing post- development flood peaks to pre-development values. This requires that hydrographs be calculated for the site in pre-development or natural condition as well as for the post-development urbanised condition.

It is well known that urban development increases flooding. Two factors are involved. Firstly, the increased amount of paved or impervious surfaces increases the runoff volume. Typically, 75% of the total impervious surfaces are connected directly into the drainage system (Boyd et al. 1993). Secondly, changes to the flow path, such as replacement of grassed surfaces with gutters or pipes, increase flow velocities and decrease travel times. This increases peak discharges because the runoff must occur over a shorter time, at higher peak flowrates. Travel times are usually related to the urban fraction of the catchment (Rao et al.1972; Aitken,1975; NERC,1975).

A range of methods is available to calculate flood hydrographs. The urban catchment models MOUSE (Danish Hydraulics Institute,1994) and ILLUDAS or ILSAX (O'Loughlin,1994) can be used if full details of the gutter and pipe drainage system are to be modelled. If broader modelling of the catchment in natural and urban condition is required, runoff routing models such as RAFTS(WP Software,1994) or WBNM94 (Boyd et al. 1994) can be used.

Because OSD storages are generally small and the site area is also small, it is also possible to use simplified methods of design. These can include the Rational method to estimate flood peaks, and the use of simplified hydrograph shapes to estimate storage volumes. A simplified method is described in section 4.

3.3 Selection of the Design Storm

The frequency and duration of the design storm must be specified. The frequency or Annual Exceedance Probability (AEP) is selected by balancing the cost of the design against the risk and consequences of a storm exceeding the design value. If the objective is to prevent flooding from the minor drainage system, and the cost of flood damage is not high, an AEP near to 1 in 10 years may be appropriate. This would apply to minor flooding of streets and residential areas, with little property damage. If the objective is to prevent flooding from the major system of trunk drains which would cause significant property damage in heavily built up areas, an AEP near to 1 in 100 years would be appropriate.

The duration of the design storm is equally important. For the pre- development condition, the critical duration would normally be the one which produces the largest runoff peak from the site. This sets the PSD for the design of the storage. There are however two cases to consider. Consider for example a 1 km^2 urban catchment which is made up of many one hectare properties, each with OSD. We can select a critical duration for the total catchment (approximately 60 minutes), or for each individual site (approximately 10 minutes).

If we select a 10 minute storm, the design rainfall intensity will be high and consequently pre - development discharges from the site and the adopted PSD will be large. However the total runoff volume for this short duration storm will be small, and the required storage SSR will be small. Because discharges from the site are allowed to be large, the outlet orifice from the OSD will be large. This design will control peak discharges for storm durations near to 10 minutes. Now consider the performance of this design for storms of longer duration, say 60 minutes. In this case the design rainfall intensity and peak discharge from the site are small. The large outlet orifice allows the peak discharge to leave the site with little reduction. Therefore selection of the PSD based on the site's critical duration storm may be ineffective in controlling peak discharges from longer storms.

If we select the PSD using a 60 minute storm, rainfall intensities and runoff peaks are small. The PSD is small and a small outlet orifice is required. Because total runoff volumes are large for this longer duration storm, the required OSD volume is large. This design will control storm durations of 60 minutes, and it will also control shorter duration storms. For example, the high discharge for the 10 minute storm will be reduced significantly by the small outlet orifice size.

To effectively control storms which are critical for the site (10 minutes) as well as storms which are critical for the total catchment (60 minutes), the PSD should be selected based on the longer duration storm. Note that this results in a low PSD, small outlet orifice size, and large SSR.

With the PSD selected based on pre-development discharges, the next step is to design the OSD storage to reduce post-development discharges back to this value. A range of storm durations is tried, and the critical duration is the one requiring the largest storage volume SSR.

3.4 Routing the Inflow Flood through the OSD Storage

Given the height-storage relation for the OSD, which depends on its geometry; and given the height-discharge relation, which depends on the outlet orifice size, the outflow hydrograph from the OSD storage can be calculated using standard level pool routing procedures, of which Puls' method is the best known.

In a standard OSD arrangement as shown in Fig. 4a, where the water level rises and falls gradually, the outflow hydrograph will also rise and fall gradually. As mentioned previously, the required storage volume SSR is equal to the area between the inflow and outflow hydrographs. In Australia an alternative arrangement, the High Early Discharge storage of Lees and Lynch(1992), has become popular. . In this case the storage has two compartments. The first compartment is of small volume and receives runoff from the site. It fills quickly to develop the design head Hmax and the outflow hydrograph rises quickly up to the design PSD. At this point, water flows over the weir into the larger compartment which contains a volume equal to the SSR. The result is that the outflow hydrograph rises quickly to the PSD and then remains constant before it decreases slowly back to zero. The major advantage of the High Early Discharge design is that it a considerably smaller volume of water must be stored, thus decreasing costs (Fig. 4b). As will be seen in section 4, it also allows a much simpler design procedure to be used.

4. A SIMPLIFIED PROCEDURE FOR DESIGN OF ONSITE DETENTION STORAGE

Because site areas are usually small, it is possible to use simplified methods to calculate the runoff hydrograph. In this example the Rational method, as specified in the Australian design guide "Australian Rainfall and Runoff" (Institution of Engineers Australia, 1987), will be used.

Consider a site area of 10,000 m^2 with the following properties :

Flow path length = 200 m
Flow path slope = 1.0 %
Flow path roughness = 0.30 (natural condition)
Flow path roughness = 0.025 (developed condition)
Travel time = 10.0 minutes (developed condition)
Runoff coefficient = 0.58 (natural condition)
Runoff coefficient = 0.85 (developed condition)

Site travel time is calculated using the kinematic wave equation.

1 in 10 year Annual Exceedance Probability of design rainfall :
Duration (minutes) 10 30 45 60 75 90 120
Intensity (mm/hour) 135 85 70 61 54 47 39

For the pre-development or natural condition, the Rational method gives a peak discharge of 99 litres/s, for a storm duration of 60 minutes, which is taken as the critical duration for the total catchment. The PSD is therefore 99 litres/s. Next, the storage is designed to reduce post - development runoff peaks back to this value.

The Rational method can be applied to the developed site to calculate the peak discharge and the runoff hydrograph for any storm duration. Figure 4 shows the resulting hydrographs, and Table 1 summarises values. Note that the developed site travel time of 10 minutes means that hydrographs take 10 minutes to rise to a maximum, and 10 minutes to decrease to zero.

Table 1. Summary of Developed Site Runoff Hydrographs

Storm duration (minutes)	10	30	45	60	75	90	100
Intensity (mm/hour)	135	85	70	61	54	47	39
Runoff peak (litres/s)	319	202	166	145	128	111	93
Runoff volume (m^3)	192	363	449	520	574	599	668
SSR (m^3)	91	155	157	147	117	58	0

Normally we would use flood routing of the runoff hydrographs through the storage using Puls' method, however by adopting a High Early Discharge arrangement we are able to use a simplified approach. Noting that the outflow hydrograph from the storage rises quickly to a constant value, we can make a good approximation of it by drawing a horizontal line at the PSD value of 99 litres/s (Fig. 4). The required storage SSR is simply calculated as the volume above this line (Table 1).

The design requires an SSR of 157 m^3 to reduce post-development runoff peaks back to 99 litres/s, for a storm duration of 45 minutes. For shorter duration storms, for example 10 minutes, the rainfall intensity and runoff peak are larger but the runoff volume is smaller. The outlet orifice designed to release 99 litres/s reduces the peak of 319 litres/s down to this value and only 91 m^3 of storage is required. The design therefore controls runoff peaks for the 45 minute storm and all shorter duration storms.

For longer durations, the first chamber of the high early discharge storage fills until it discharges at 99 litres/s. Runoff volumes are larger for these storms, but note that the runoff peaks become smaller as the duration increases. Required storage volumes are less than the SSR of 157 m^3, that is, only part of the storage is required. Eventually, for durations greater than 120 minutes, the runoff peak is less than the pre-development value of 99 litres/s and no storage is required.

The preceding example has been kept simple to illustrate the principles of OSD. More complex analysis is possible. A storm temporal pattern can be used, hydrographs can be calculated, and different discharge hydrograph shapes can be used.

5. SUMMARY AND CONCLUSIONS

5.1 General

Increases in flooding due to urban development of a catchment can be controlled using detention storage. This can be in the form of large dams or detention basins, or as small onsite detention storages. The use of many small onsite detention storages distributes the flood storage over the catchment in a pattern similar to the natural condition.

A variety of design techniques is available, ranging from the Rational method to computer models. The design storm should have a critical duration based on the total catchment rather than for the smaller site. As well as controlling runoff peaks at the outlet of the site, this will also control runoff further down the catchment where the longer duration storm applies.

Paradoxically, because OSD is used to control small runoff volumes from small sites, design procedures need to be simple. At the same time, the total number of OSD storages used in the urban catchment is large, and predicting the combined effects of these OSD on total catchment flooding is difficult. The designer needs to consider not just site based effects, but also the effects of OSD on flooding in the total catchment.

5.2 Site Based versus Catchment Based Design.

Site based design considers only the reduction of runoff peaks at the outlet of the site, and is therefore relatively simple (Section 4 covers this type of design). Although runoff peaks are reduced at the outlet of the site, we cannot be sure that runoff peaks further down the drainage system are also reduced. The designer can allow for this by basing the PSD on the longer duration storm for the total catchment, so that both short and long duration storms are controlled. However the possible interaction of runoff peaks from the many OSD storages is not considered. Catchment based design attempts to address this problem, and consequently is quite complex because the interaction of the storages must be modelled.

Catchment based design requires that peak discharges be examined at many points in the catchment, and runoff hydrographs be calculated for all sites and all OSD storages. Computer models such as MOUSE or ILSAX can be used for detailed analysis of the urban drainage system, and runoff routing models such as RAFTS or WBNM94 can be used for a broader analysis (McPhail et al., 1994). The following sections consider OSD from a catchment based perspective.

5.3 Must OSD Reduce Runoff Peaks in all Cases ?

In urban stormwater management, it is sometimes required to reduce runoff peaks for all storms at all points in the catchment. This will generally require very large storage volumes. Consider for example the requirement that all AEP frequencies be controlled. To control small AEPs such as 1 in 5 years, a small PSD and small outlet orifice diameter are required, whereas large AEP events will have a larger PSD and larger orifice. The small events therefore will set the design PSD and outlet orifice diameter. The storage volume or SSR however will be set by the large 1 in 100 year AEP events. The combination of 1 in 100 year event with outflows released at this small PSD requires very large SSR volumes.

Considering the reduction of runoff peaks at all points in the drainage system, it is certain that any drainage system will be under-designed (causing surcharge) at some points and over-designed (i.e. have excess capacity at other points). If runoff peaks are not reduced back to pre-development values at some point, whether this causes flood damage depends on whether the drainage system is surcharged. It is also possible that surcharging at some points will not cause flood damage because of the absence of infrastructure at that location.

Rather than controlling runoff for all storms at all points on the catchment, a better design would be to require OSD so that the capacity of the existing drainage system is not exceeded. This obviously requires a detailed analysis of the stormwater drainage system by the responsible authority. Key points could be identified where surcharging is likely, and flood damage will result. The OSD design criterion could then be set on this basis.

5.4 Is OSD Necessary in the Lower catchment ?

Because detention storage delays the time of occurrence of the peak, it is sometimes argued that it should not be provided in the lower catchment because it could delay these peaks to co-incide with peaks from further up the catchment, thus making the flood problem worse than if no OSD was provided (Curtis and McCuen,1977; Lakatos and Kropp,1982; Lumb et al.,1974; McCuen, 1979). This could be the case if hydrograph shapes were "peaky", when co-incidence of flood peaks would increase the combined peak considerably. However, the storms that effect both the upper and lower catchment will be of long duration and the runoff hydrographs from sites will be "flat". Co-incidence of peaks in this case will not have very dramatic effects. A survey of the effects of multiple detention storages on downstream flooding by Boyd (1993) found that increases of this kind were very unlikely.

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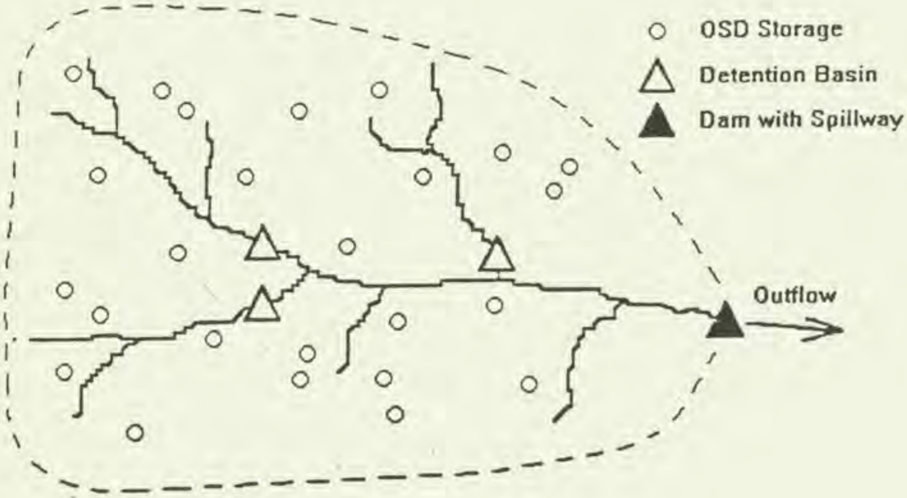

Figure 1. Schematic Catchment showing Flood Detention Storage.

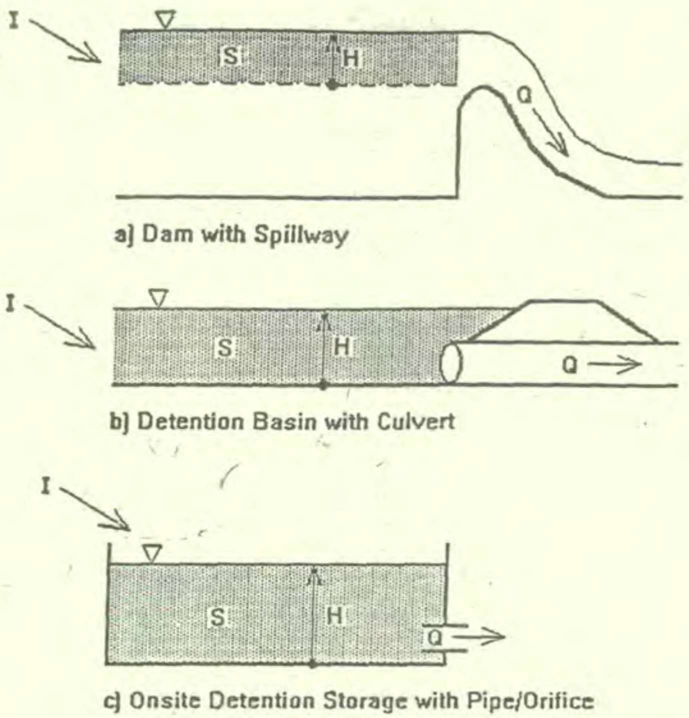

Figure 2. Types of Flood Detention Storage.

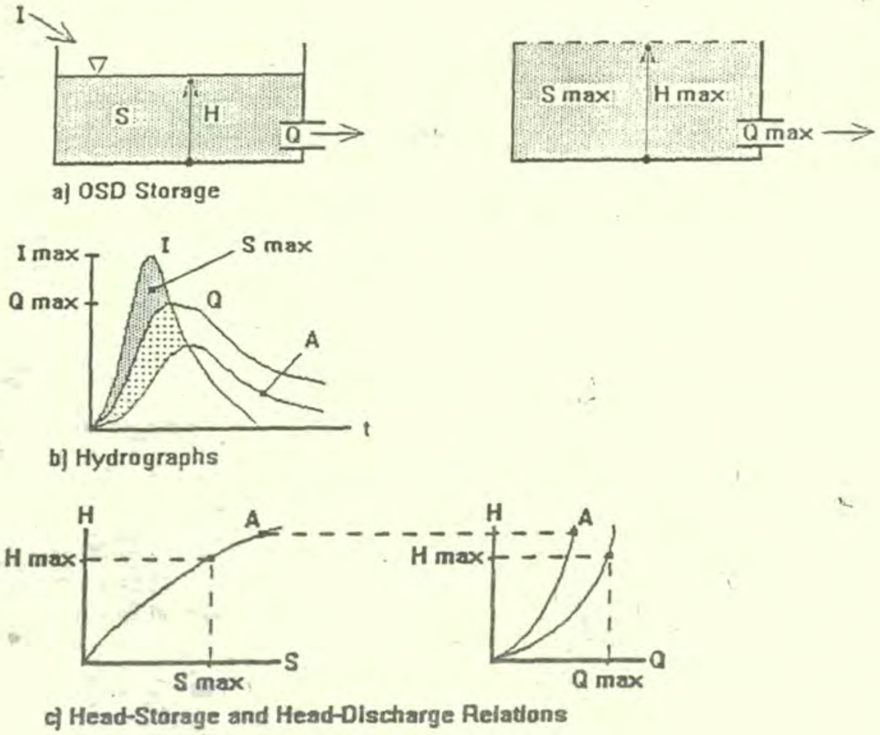

Figure 3. Flood Peak Reduction using Flood Detention Storage.

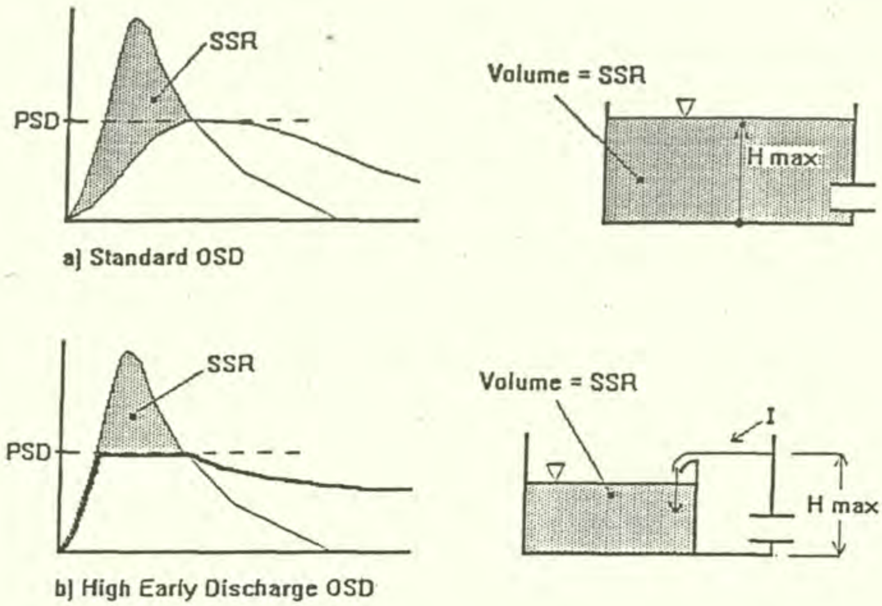

Figure4. Standard and High Early Discharge Storages.

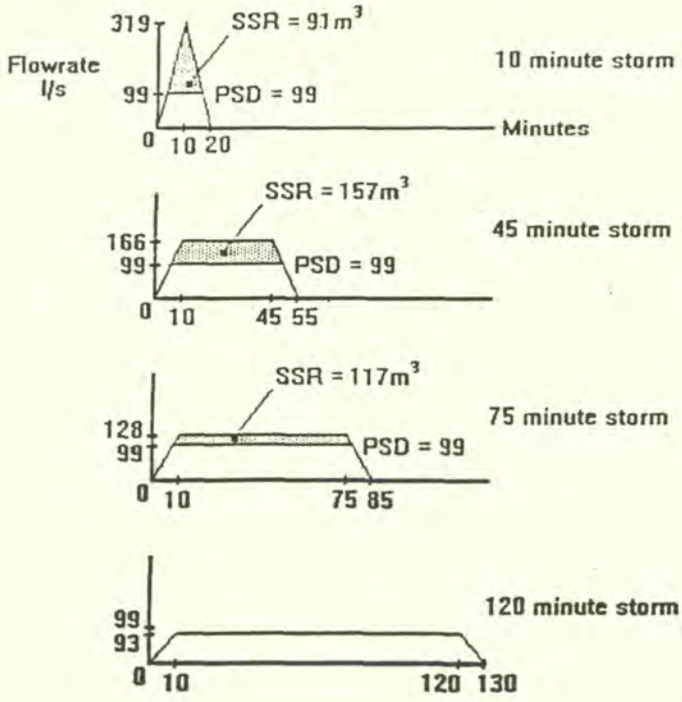

Figure 5. Runoff Hydrographs and Site Storage Requirements.

A REPORT OF A RAINWATER CATCHMENT SYSTEM IN A GOLF DRIVING RANGE

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ABSTRACT

This paper deals with a rainwater catchment system in a golf driving range in Singapore. This golf driving range, completed at the end of 1993, was designed to have an automatic ball-retrieval system where balls landing anywhere on the fairway would roll into 3 collection drains and be washed away to a central ball collection cistern and then conveyed back to the tee-off bays. The key components in this automatic system are stored rainwater which is recycled and a synthetic turf finish to the fairway.

This system shall be described and illustrated with emphasis on the inseparable relationship between the drainage plan for this golfing facility and the design of the rainwater catchment system.

INTRODUCTION

Singapore is located in the humid tropics and has an annual mean rainfall of 2400 mm. All her major surface water sources have been developed and yet she is not self-sufficient to meet water demand. Escalating water consumption rates are regularly highlighted in the press and conservation is continually encouraged by the authorities. Yet, there is no systematic implementation of rainwater catchment systems on this island republic nor has its adoption been made mandatory through building by-laws.

THE AUTOMATIC BALL-RETRIEVAL SYSTEM

The subject golf driving range is located at Toa Payoh Town in Singapore. It comprises a 2.4 hectares fairway and a 2-storey clubhouse with 96 tee-off bays, a pro-shop, and changing rooms. From the start of this private development, the owners decided against conventional labour intensive methods of collecting golf balls and maintaining the greens. They wanted an automatic ball-retrieval system and a synthetic turfed fairway which will require little attendance.

The automatic ball-retrieval system was designed such that all golf balls landing on the fairway would roll via gravity into collection drains where it will be washed away by recycled rainwater to a central cistern and returned to the ball dispensers at the clubhouse. When the dispensers are running low of balls, the automatic retrieval system would be activated. Stored rainwater in the cistern would be pumped to the summit of the collection drains. This flushes the balls in the drains into the cistern where the balls are caught on a suspended steel net and conveyed, mechanically, back to the clubhouse. This cycle takes about 30 minutes and is repeated according to ball turnovers. Maintenance to the collection drains and cistern have been negligible due largely to the synthetic turf and the absence of trees.

THE RAINWATER CATCHMENT SYSTEM

For this ball retrieval system to work, site contours are crucial. The given topography of the site had to be altered so that the final profile which can be said to be made up of 3 hills and valleys, will permit golf balls to roll off naturally into the collection drains at the valleys. The synthetic turf used as surface finish allowed the designers to determined the gradient required for the slopes so that the balls will not roll off too quickly. The slopes could not had been too steep for consideration had to be given to golfers who wanted to study their shots.

This automatic ball-retrieval system also determined the surface drainage system for this facility. By having this retrieval system surface drainage was simultaneously installed. The synthetic turf rendered the original ground impervious and enhanced surface run-off. The 3 ball collection drains also serves as surface drainage routes. The cistern for balls serves as rainwater storage and forms the source of recyclable water for the retrieval system; a source that is depleted through evaporation and absorption in the field and replenished by rain. This cistern is a covered one and is placed below ground level for inflows and spillage through gravity. Spillage is led directly to a municipal storm drain.

DISCUSSION AND CONCLUSION

1. This project's automatic ball-retrieval system's primary objective is, of course, to retrieve balls on the fairway and it is supported by sloping site contours, a synthetic turf finish, collection drains, a cistern and stored rainwater. The method used mirrors a rainwater catchment system. both in concept and form.

2. As a case study for rainwater catchment systems, it demonstrates the mutually inclusive relationship between surface drainage and rainwater catchment. More significant perhaps, it demonstrated a novel benefit in a rainwater catchment system by substituting a function, i.e ball collection, that is carried out normally through labour intensive means.

3. The capital costs incurred for this automatic ball-retrieval system was justified on account of projected operating costs on staff and maintenance for a conventional fairway.

ACKNOWLEDGMENT

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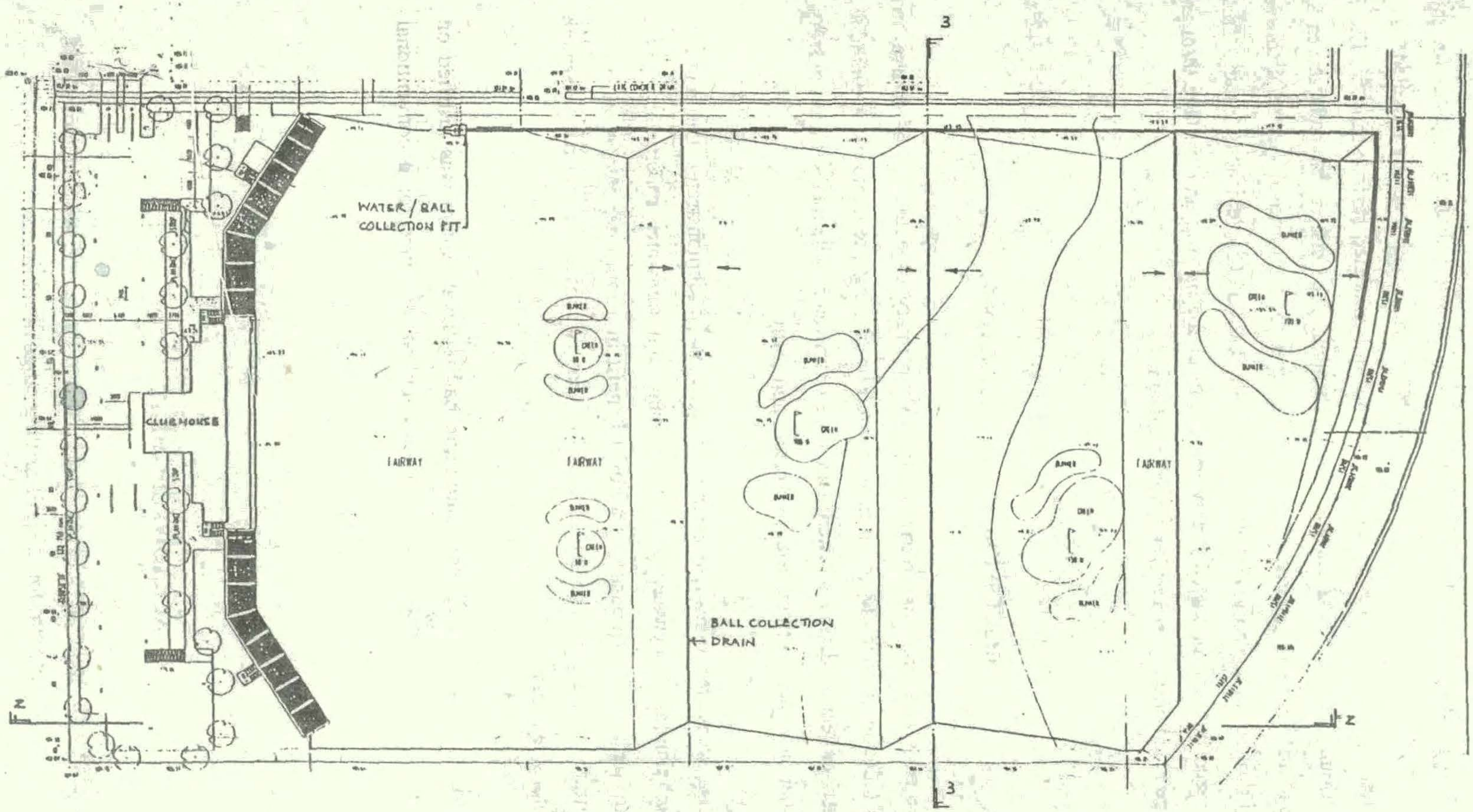
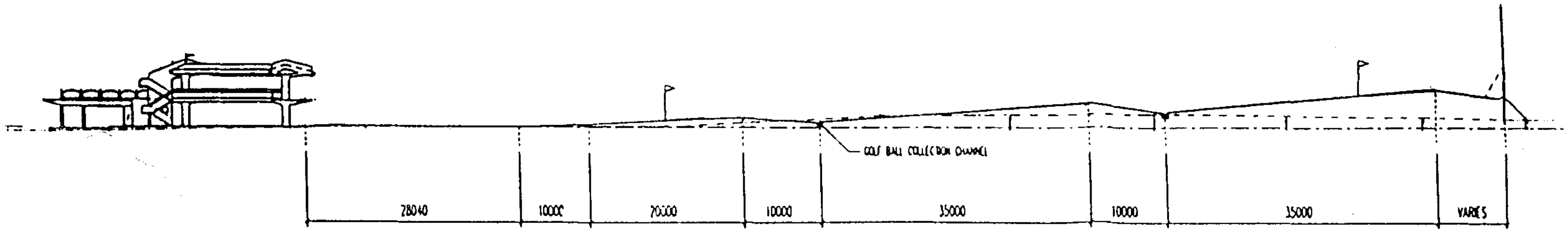


PLAN OF GOLF DRIVING RANGE



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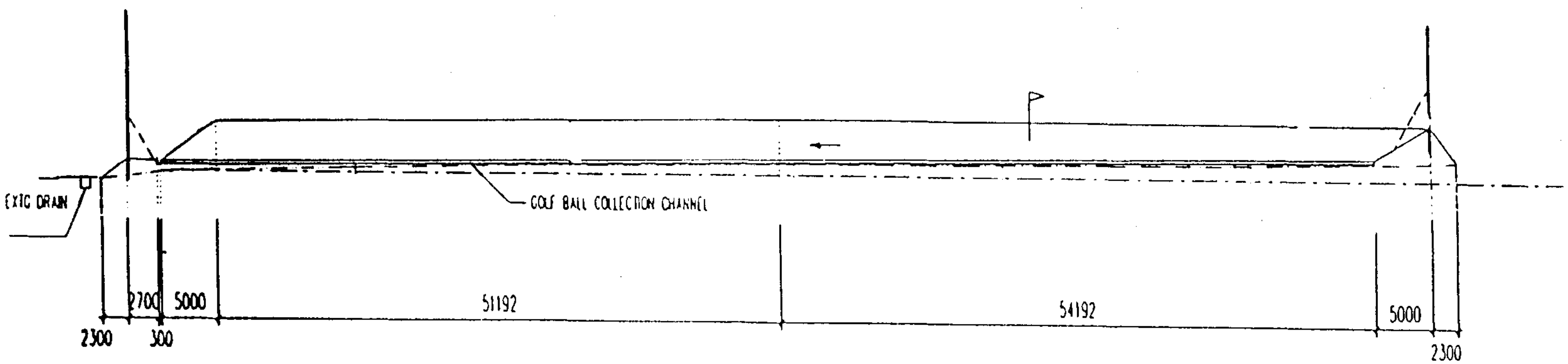

CROSS SECTION 3 - 3

Rainwater Utilization and Spring Conservation in Jinan

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Abstract

Jinan is famous for springs. In recent years, the frequent cutoff of the springs has been experienced due to the improper utilization and development of the water resources. This paper discusses the necessarily of the utilization of the rainwater resources for spring conservation, and gives the possible approaches to utilize the rainwater resources of Jinan in urban and mountain area.

I. Introduction

Jinan is well known as "spring city". The discharge of four large spring groups, Baotuquan, Heihuquan, Zhenzhuquan and Wulongtan, is more than 0.3 mcm/day. In recent years, ground water pumping has been increased dramatically due to the rapid growth of local economy. This caused continuous drawdown of the spring water table so as to frequent cutoff of the springs. It has ever been occurred that the spring dried up all over the year in 1981, 1986, 1988, 1989. This also affected the normal order of the local life and the development of local tourist trade.

In order to restore and keep the spring sprouting and lysis the water shortage, amount of research work have been done. While the rainwater resources utilization is not attached due important role. So it is necessary to probe into the necessarily and possible approaches of the rainwater resources utilization.

II. Necessarily of Rainwater Utilization

2.1 Introduction to natural geographic conditions in Jinan

Jinan is located in Shandong Province, China. It is continental climate with dry spring, hot summer, sunny autumn and cold winter. The mean tempreture is 13.4 0. The mean precipitation is 642 mm. More than 70 percent of the precipitation is concentrated in flood season which ranges from June to September.

The main rivers in the area are Xiaoqinghe, Yufuhe and Dashahe. Xiaoqinghe is the sole river to drain flood and pollutant in urban area. There are four small reservoirs with total storage of 2.50 mcm above Jinan in Xiaoqinghe catchment.

The urban area of Jinan is located in the joining area of mountain and plain. The southern part is karst mountain area. The groundwater flows to the north along the attitude of rock layer and topography, and rises to the ground surface to form the famous 'four large spring groups' because of the retardation of igneous rock. The southern part is plain. The groudwater in porous media is a separated system without connection with the fracture groundwater in karst area because of the partition of igneous rock.

2.2 Problems of water resources development and utilization

2.2.1 Low degree of surface water resources utilization

There are just 2 medium type reservoirs with total storage of 65 mcm in Yufuhe catchment, no large water storage project in other catchments in this area. In Xiaoqing catchment, there are only 4 small type reservoirs with total storage capacity of 2.5 mcm, just 1 percent of the total runoff from 1981 to 1991. This leads to great loss of local water resources.

2.2.2 Striking damage caused by water logging

This is caused by following reasons:
1.) Large slope in southern mountain area.
2.) Large impervious area due to high degree of urbanization.
3.) Low drainage capacity in lower stream. The return period of drainage is less than 10 years.
4.) Large runoff due to high concentration precipitation in rainy season.

During extraordinary storm '8.26' in 1987, the water logging leaded to damage of 150 million Yuan RMB.

2.2.3 Severe water pollution

Xiaoqinghe, the sole drainage river in urban area has been polluted by the severage and the nonpoint pollution of storm water from urban area. Most of the severage is drained directly to Xiaoqinghe with almost no any treatment. The nonpoint pollution of storm water is also very serious. Based on the water quality monitoring of the flood in lower stream in Xiaoqinghe in July, 1992, the pollution load was obviously higher than nonflood period.

2.2.4 Improper development and utilization of groundwater in karst area

1.) Overpumping of the groundwater
In 1950's, the discharge of four large spring groups is larger than 0.3 mcm/day while the pumping rate is about 0.08-0.1 mcm/day. In recent years, the pumping rate has been increased to 0.7-0.8 mcm/day and greatly exceeded the capacity of the groundwater recharge. This is the main reason that the spring dries up.

2.) Reduction of the groundwater recharge
The recharge of the precipitation and the percolation of the surface water are the main sources of the karst groundwater. It is showed that the water table of the spring has close connection with the precipitation. For example, the ground water table raised to 27.2m in August from 20.82 m, the lowest value in the history in June, 1990 because of the large precipitation in last 2 months (760mm).

The groundwater also receives amount of recharge from surface water percolation because Yufuhe and Dashahe river are covered the karst area with good percolation condition. For example, in August, 1990, discharge of 28 m^3/s from Wohushan reservoir to Yufuhe river was reduced to 5 m^3/s because of the seepage at Muli which is just 20 KM far away from the reservoir.

In recent years, both the recharge from precipitation and surface water have been reduced. For precipitation, since the annual precipitation just 576.6 mm from 1979-1989, is lower than the mean value of 642mm. It is clear that the groundwater recharge from the precipitation should be less. For the percolation of the surface water, the reduction is resulted from the follows:

1.) The reduced runoff because of the decreased precipitation and the reservoir construction upstream.

2.) The vegetation cover destroy and higher degree of urbanization. Especially the southern part of the urban area intrudes the recharge region of the karst groundwater and reduces the pervious area.

Based on the mentioned above, the rainwater resources unutilized is abundant. The utilization of the rainwater resources not only helps to restore and keep the spring spouting, but also to increase the water supply, and lysis the water shortage situation. It also helps to lessen the stress of flood control pressure, and decrease the water pollution down stream.

3. Approaches of rainwater resources utilization

3.1 Approaches of rainwater resources utilization in southern mountain area

The southern mountain area is the recharge area of the spring. The approaches to utilize the rainwater resources should be mainly helpful with the groundwater recharge as additional to some utilization approaches to satisfy the basic water demand of local people.

3.1.1 Area rainwater resources utilization

This measure pays attention to comprehensive treatment of the catchment and improve the vegetation cover condition. By doing so, the groundwater recharge can be increased since the good vegetation condition is helpful with water conservation and reduction of the flow rate of the surface runoff.

3.1.2 Use percolation wells and pits to increase the precipitation recharge

Some karst aquifers appear either above ground surface or covered by sand and gravel aquifer with good pervious capacity in southern mountain area. If some recharge projects such as percolation wells and pits are constructed in this area, it will increase the transformation from rainwater to groundwater.

3.1.3 Increase degree of rainwater utilization by improving the operating policies of the reservoirs to reduce the water loss

There are 2 medium type reservoirs upstream of Yufuhe catchment. Although the reservoir is helpful with the reduction of flood damage downstream and improvement of water supply condition upstream, it should be noticed that it will increase the evaporating loss from water surface. This may be solved by transformation of the excessive water in reservoir to groundwater. so it is necessary to do the research of optimal operation of the conjunctive use of the reservoir and the aquifer system downstream. If some retaining works such as barrages, low dams can be built at the same time, the effect will be much more remarkable.

3.1.4 Direct use

Construction of the facility such as water cellar to utilize the rainwater directly to satisfy the basic water demand of local people.

3.2 Approaches of rainwater resources utilization in urban area

3.2.1 Use water retarding works to store rainwater

1.) Water retarding works in branches

There are more than 10 branches in Xiaoqinghe without any storage works at present. If some retarding works such as barrages, rubber dams can be built, the stormwater can be stored in rainy season and increase the water supply. The water logging damage can also be reduced.

2.) Use lakes, discarding projects of civil air defense and low-lying land to store rainwater

It is observed that the lakes and the low-lying land have good storage capacity. For example, during the extraordinary storm in 1987, Daming lake stored 0.8 mcm, and the low-lying land stored almost 10 mcm.

The discarding projects of civil air defense also have good storage capacity. At present, the water supply of these projects is about 5 mcm per year. All of the water comes from the drainage of quaternary groundwater. If some facilities to collect rainwater to these projects can be constructed, the water supply of these projects can be increased.

3.2.2 Improve the urban planning and design to increase the groundwater recharge

Based on the latest statistics, the total urban area is 95.7 KM^2 with impervious area of 64.5 KM^2. The pervious area is just 30 percent of total urban area. So it is necessary to improve the urban planning to increase the vegetative area. That will be helpful with the increasing of groundwater recharge. It will also beautify the city and reduce the flood damage in lower stream.

The elevation of the green belt along the streets and the gardens in crisscross streets is higher than that of roads. These green lands can not receive the rainwater from the streets. So it is necessary to improve the form of the green land and plant the grass which is useful to increase the groundwater recharge.

One shortcoming of the present architecture design is that the rainwater over the buildings is drained directly to the ground from the collecting pipe and flows away. If some percolation wells, pits are constructed under the outlet of the collecting pipe, or diverting the drainage to the places such as garden,green belt, which is easy to leak by construction pipe or channel, it will increase the groundwater recharge and reduce the afflux speed and amount of the runoff from the urban area.

4. Conclusion

The rainwater resources is very rich in Jinan. The utilization of the rainwater resources will help to restore and keep the spring spouting by providing new water supply sources and increase the ground recharge. The utilization of the rainwater resources will also lessen the stress of the flood control downstream, reduce the water pollution and improve urban water environment to promote the development of the tourist trade.

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A TOTAL APPROACH TOWARDS THE DESIGN OF RWCS IN AIRPORTS SUBJECTED TO TIDAL EFFECTS

Appan A[1], T Jeyaprakasham[2] and S Punithan[3]

ABSTRACT

Most airports have excellent surface runoff drainage systems ensuring that the runways are always dry and will not hinder air traffic. The proximity of an airport to the sea, as in the case of Singapore, will largely influence the storage requirements of the reservoirs that will have to provide relief in the case of coincident rainfall and high tide. In this paper, a flowchart is shown for a total approach model (NTURWCS.MK4. Main 01) in which all the factors in such conditions are catered for. Appropriate checks will be done to ensure that the volumes of the storage and buffer reservoirs and also the pumping rates will be sufficient to abstract water for non-potable uses like fire-fighting toilet flushing etc., Available data on the Singapore Changi Airport was used extensively in the three computer programs developed. It was confirmed that the required storage reservoir should be not more than 100,000 m^3 (against the existing volume of 320,000 m^3) and the buffer reservoir should be 68,000 m^3 (against the existing volume of 100,000 m^3). Besides, if raw water is pumped at a rate of 164 m^3/h for 17 hours (against the current 128 m^3/h for 14 hours), there will be no need to supplement the rainwater with 13% of potable water that is currently being utilised. The total approach model has universal application in that it can be used for any airport, whether or not the surface runoff is subjected to tidal influences. The use of this program, clubbed with real life operational experience in Singapore, can help largely in the complete design of such RWCS in any airport.

INTRODUCTION

The demand for water, be it for domestic or other purposes, has a tendency to increase for multifarious reasons. These reasons can vary from an increase in population to industrial demands, both in developed and developing countries. As conventional sources of water supplies like surface impoundments and groundwater are stretched to their limits, it is prudent that other sources, like rain water cistern systems (RWCS), be investigated and extended to as large a scale as is feasible. One such typical RWCS, which is almost a small-scale abstraction system in the conventional style, is the collection and utilization of runoff from airports which, very often, are in close proximity to the sea. Airports are largely paved and have high runoff coefficients and their closeness to the sea means the drainage system will have to account for the effect of incoming tides. The main objectives of this paper are:

(a) to review existing models that have been developed to collect and utilise rainwater from small catchments,

(b) to develop appropriate computer programs incorporating the storage and yield for collectable rainwater and appropriate storage volume to accommodate sea water intrusions,

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(c) to integrate the above programs and arrive at a system catering for the separate collection of rain and sea water,

(d) to demonstrate the above concepts as applied to the Singapore Changi Airport (SCA) and

(e) to draw conclusions and make recommendations in the design of such systems

EXISTING RWCS MODELS WITH RESPECT TO STORAGE AND YIELD

(a) Computer Simulation Models For RWCS Design

Different types of computer simulations have been developed and these have varied from simple deterministic models (Hoey and West, 1982) to probabilistic (Fok et al. 1982), simulation (Perrens, 1982) and stochastic models (Lueng and Fok, 1982).

A program has also been developed in the United Kingdom to simulate rain that was to be used for toilet flushing (Fewkes and Ferris, 1982). This program used a one day discrete time interval and the rainwater data was simulated for each month of the year using cumulative probability distribution of rainfall. Using the Monte Carlo method for simulation, the percentage of water saved per annum for a range of tank capacities, roof areas and family size were generated. This study showed that the implementation of RWCS is feasible.

Schiller and Latham (1982) carried out a review of the computerised methods in optimising RWCS sizes based on Canadian data. The volumes of the cisterns sizes could be obtained by different methods like the conventional mass curve using historical data (Rippl, 1883), Yield after Storage Model (Jenkins et al., 1978), Rationing and Stocking Model (Perrens, 1975) or the Statistical Method (Ree et al., 1971)

In another computer simulation model (Morris et al, 1984), the storage required to deliver a constant flow rate at each rainfall station was determined for various catchment areas. A special feature of this model is the dual mode of withdrawing water which allows calculations to be made with and without rationing of water.

Another software package SNOP developed by Hydroscience, Inc. for the United States Environmental Protection Agency generates the statistics for analysis of the continuous hourly rainfall records. The primary event supplied by the SNOP includes average volume, duration, intensity and hours separated by a "minimum inter-event time" which is specified by the SNOP user (Dwornik et al., 1984).

(b) RWCS Models Developed in Nanyang Technological University (NTU)

From 1985, a number of computer simulation models have been developed for RWCS design. Initially a study was conducted on the feasibility of the use of rooftops of high rise buildings within an isolated housing estate in Singapore (Appan et al, 1987). Rainfall data was analysed and a computer program was developed to relate rainfall, storage and demand. A system was proposed to collect the rain water for flushing of toilets and a dual mode system of supply was incorporated wherein the regular potable water could be substituted when the supply of collected rain water had run out. The program was formulated in order to determine the optimum cistern volume, the spillage and potable water required for the non-potable demand.

In another similar study on the collection of rainwater from a Bus Park cum Interchange (Appan et al, 1988), a simple computer program (NTURWCS.MK1) was written to calculate the optimum tank size required to meet the daily needs of the Bus Park. In this program, there were facilities to incorporate runoff coefficients as runoff was from both the roof and paved areas.

In another investigation carried out in NTU to test the practicability of using a RWCS for non-potable uses (Chan & Heng 1992), a suitable computer program (NTURWCS.MK2) was developed, which is sufficiently versatile to accommodate varying discretised time intervals of rainfall data. Using the same rainfall data but for different discreet intervals of time, the impact on storage capacity, reliable yield and catchment area was studied. Using this model it was established that the utilization of data for ten minute time intervals gave the most acceptable levels of accuracy in terms of RWCS design parameters (Appan, 1993[a]).

In a study of the existing dual mode water supply system of the Singapore Changi Airport (Appan, 1993[b]), the model NTURWCS.MK 2 was used but it was upgraded. In this model (NTURWCS. MK3) the optimum rainwater reservoir size required to meet the hourly demand for fire-fighting and toilet flushing was computed using hourly rainfall data and varying the runoff coefficients for paved and turfed areas.

COMPUTER SIMULATION FOR THE COLLECTION AND STORAGE OF RAIN AND SEA WATER IN AIRPORTS

(a) **The problem**

When airports are located close to the sea, the drainage system is subjected to both runoff from the airport and tidal intrusions. A schematic diagram of the necessary arrangements in an airport where both runoff and tidal inflows are involved is shown in Figure 1.

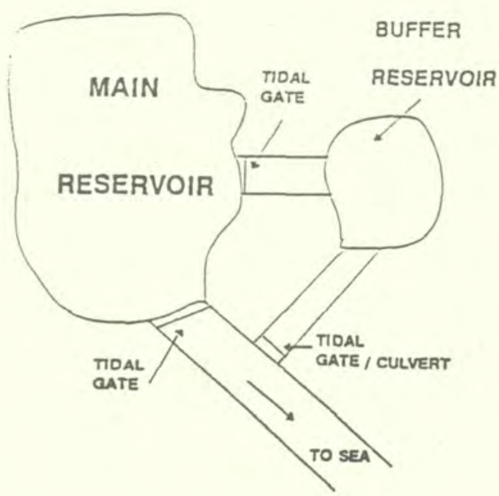

Figure 1: *Idealised arrangement of reservoirs and tidal gates*

By having such an arrangement of tidal gates, the rainwater stored can be released to either the drainage canal (during low tides) directly or to the buffer reservoir (during high tides). Such control of flows is to be done by proper operation of appropriate hydraulic gates.

(b) **Concept of Design and Operation**

(i) *Optimum size of rainwater storage tank:* Rainfall data in the airport are logged on an hourly basis with appropriate runoff coefficients chosen for the paved and turfed catchment areas. Based on the hourly demand for the use of water, the optimum volume of a rainwater storage tank is computed to ensure that all the water demands are met with.

(ii) *Optimum raw water pumping rate and treated water service tank size:* Demand pattern for treated water is continuously fluctuating during the whole day and hence maintaining a raw water pumping rate to vary according to the fluctuating demand is difficult. Therefore, an optimum pumping rate for the fluctuating demand has to be computed. If a 24 hour constant pumping rate equal to the maximum hourly demand is used with adequate equalizing storage, then the operation is relatively easy. However, if pumping is carried out for less than 24 hours then there is a need to fit the pumping hours during the maximum demand periods of the day to minimise the storage capacity of the service tank size. In this study, the pumping rate is computed averaging the maximum daily demand over the chosen pumping hours.

The main purpose of the service tank is to store the excess treated water, so that demand for water can be met outside pumping hours. To determine the minimum service tank size, it is important that the pumping hours, (if less than 24 hours), be during the maximum demand period of the maximum demand day.

(iii) *Buffer reservoir:* When the raw water storage reservoir is designed primarily with the objective of using the rainwater, there arises the need to discharge excessive runoffs. When airports are located very close to the sea, the excessive runoffs can be drained to the sea either directly or indirectly through a channel. As a result of this link between the reservoir and sea, there will be sea water intrusion into the reservoir during high tide conditions.

(c) **The current model**

The model (NTURWCS.MK4 - see flowchart in Figure 2) has been developed by merging an existing model for the determination of optimal rainwater storage volume with two other new subroutines for determining the rate of pumping of raw water to a water treatment plant clubbed with the appropriate volume of treated water service tank and the required volume of the buffer reservoir. The three inter-related programs carry out the following specific functions:

(i) The optimum storage volume of the rainwater storage tank by using the established model NTURWCS.MK3.(Appan, 1993[b])

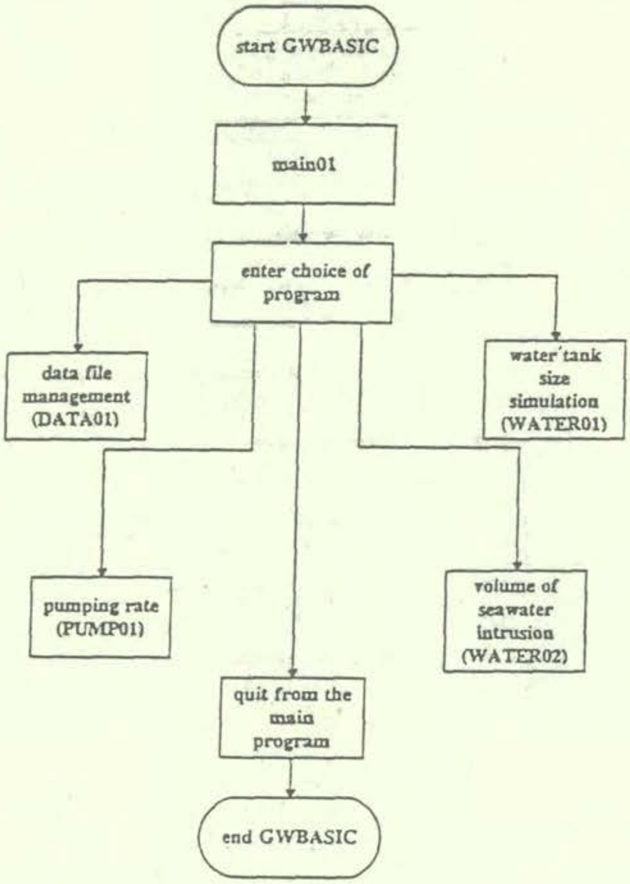

Figure 2: Total RWCS Model for Airports Subjected to Tidal Effects (NTURWCS.MK4.Main 01)

(ii) The optimum pumping rate of raw water (from the rainwater storage reservoir) and storage capacity of the treated water service tank (NTURWCS.MK4.PUMP 01) (for flowchart see Figure 3)

(iii) Volume of buffer reservoir to contain spill volume of excess rainwater as well as incoming sea water during high tide.(NTURWCS.MK4. WATER 02) (for flowchart see Figure 4)

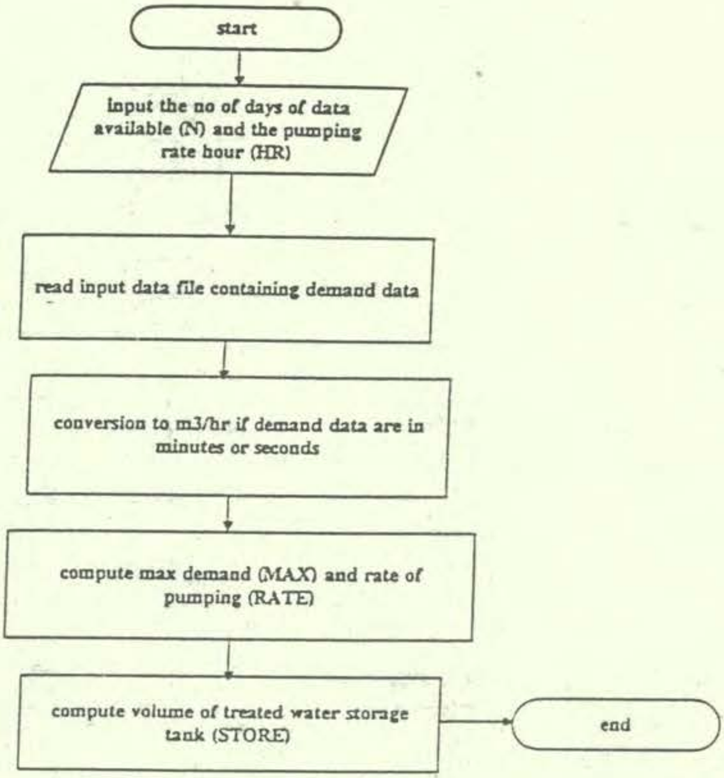

Figure 3: Model for Raw Water Pumping Rate & Service Tank Volume (NTURWCS.MK4.Pump.01)

CASE STUDY IN SINGAPORE

(a) The RWCS in Singapore Changi Airport

This system (Appan, 1993[b]) which is successfully being operated from 1986 involves a total catchment area of 1316 ha comprising 40% paved and the rest turfed areas. The runoff. which has an average quality, is directed through an excellent system of drainage channels and is collected in a storage reservoir. Some of the water is treated and then used for non-potable purposes. The system includes the South End storage reservoir (320,000 m^3) from which raw water is pumped at the rate of 128 m^3/h for 14 hours to a treatment plant and the treated water stored in a service tank having a capacity of 3332 m^3. This treated water is utilised for non-potable uses like fire-fighting, toilet flushing, replenishing of cooling water for air-conditioners and some irrigation. The volume used is about 30% of the total water demand of 3000 m^3/d. At times, when the storage of treated water is insufficient, there is an arrangement by which potable water is supplied to this tank. This volume has been worked out to be 13% of the total non-potable water utilised. To cater for the incoming tidal flows and the overflows from the rainwater storage reservoir, there is the buffer reservoir which has a capacity of 100,000 m^3.

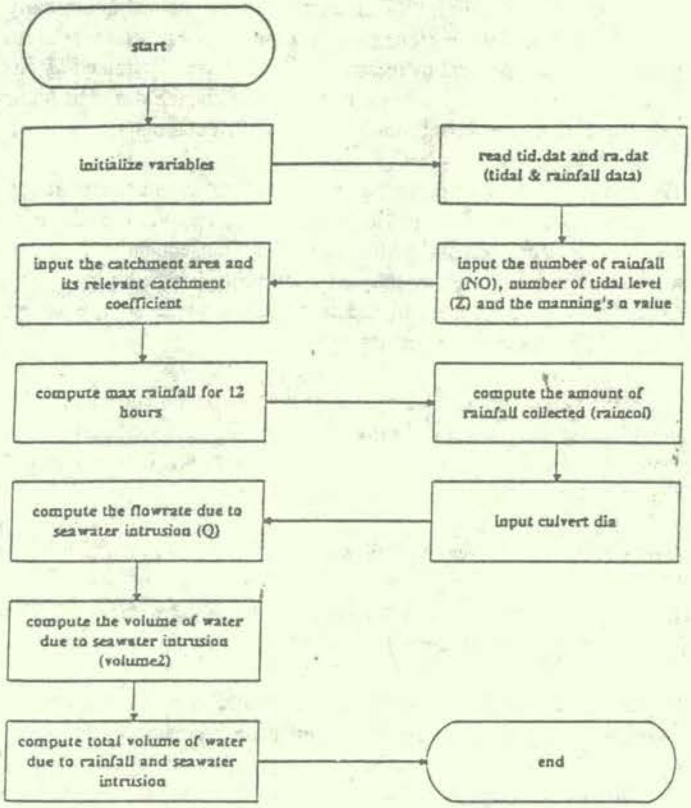

Figure 4: Model For Buffer Reservoir Size (NTURWCS.MK4.Water 02)

(b) **Computer simulation runs and discussion:**

Using the model NTURWCS.MK4, a series of runs resulted in optimal sizes for the rainwater storage tank, the rate of pumping of raw water to the water treatment plant, capacity of the treated water service tank and the size of the buffer reservoir.

(i) *Rainwater storage reservoir:* The results of the runs using one year's data have been explained for areas having runoff coefficients of 0.8-0.9 in paved areas and 0.5-0.6 in turfed areas (Appan, 1993b). However, using two continuous years of hourly rainfall data in the same model, the optimum size of the reservoir was computed to be 100,000 to 110,000 m^3 against the existing capacity of the South End reservoir which is 320,000 m^3. This overdesign could be attributed to the fact that, at the time of the original design, the main criteria was not the collection of the rainwater but the collection of runoff to ensure that the runways, under all conditions, should never be flooded.

(ii) ***Raw water pumping rates from rainwater storage reservoir and volume of treated water service tank:*** From the simulation runs, the maximum daily demand obtained is used to arrive at the various pumping rates for the different pumping durations. The variations in the demand of the maximum day are determined by field monitoring over a period of time. The various pumping rates for the different pumping hours and the respective computed service tank sizes are then computed..

The current raw water pumping rate is 128 m^3/hr, intermittent for about 14 hours a day, and the treated water service tank storage capacity is 3332 m^3. In the process, the non-potable demands cannot always be met. Consequently, the more expensive potable water, which is supplied by the water authority, is being tapped whenever necessary. Actually, there is no need to use this potable water source as there is an abundant amount of raw water that is running to waste.

If potable water is not to be used to make up for the current non-potable water needs, and if the current pumping rate of 128 m^3/hr is to be maintained, then the storage capacity required will only be 230 m^3 provided 23 hours of continuous pumping is maintained.

The existing water treatment plant capacity is 164 m^3/hr for 22 hours operation. If the present raw water pumping rate is increased to 164 m^3/hr, then the storage capacity of the treated water service tank would be 820 m^3 for 17 hours continuous pumping in which case there will be no need to tap the potable water source.

(iii) *Buffer reservoir:* Using only two years' rainfall data, the maximum spill volume from the main reservoir and the sea water intrusion, the storage capacity required has been found to be 68,000 m^3. This is about two-thirds of the existing capacity of 100,000 m^3.

CONCLUSIONS & RECOMMENDATIONS

(a) The model NTURWCS.MK4. incorporates three programs that satisfy the design requirements for the collection and use of rainwater in airports whose drainage systems are influenced by tidal effects. When these three programs operate in unison, the salient design volumes and pumping rates necessary for such an RWCS are obtained.

(b) In the SCA, the existing storage volume of 320,000 m^3 of the rainwater storage reservoir is excessive compared to the required volume of 100,000 to 110,000 m^3. This excess volume could be attributed to the fact that in this study only two years data were used besides which the priority at the time of design was to ensure that the runways would always remain dry. It is recommended that, rainfall data should be extended to a far longer period of time.

(c) Currently in the SCA, raw water is being pumped at 128 m^3/h for 14 hours and the treated water storage tank has a volume of 3332 m^3. Consequently, there arises the need to utilise about 13% of potable water. The use of the potable water can be overcome by increasing the pumping rate to 164 m^3/h for 17 hours but the volume of the storage tank need be only 820 m^3.

(d) The hourly pumping rates of raw water and the hourly demands of non-potable water are the only influencing factors to determine the volume of the service tank which, at present, is over-designed. Hence, during the design stage, there is a need to accurately determine the most representative hourly demands for different conditions of airport operations.

(e) The computed buffer volume in SCA is 68,000 m^3 against the actual storage volume which is 100,000 m^3. This design volume is based on the highest tidal levels recorded during the preceding five years. It is proposed that the worst tidal volumes or most frequently occurring levels be considered over a longer period of time.

(f) The existing system in SCA is such that the rainwater storage reservoir and the buffer reservoir are linked by a series of pipes resulting in some salt water intrusion. Hence, the proposed system of tidal gates will be more effective but only if close surveillance is kept on the incoming tides and tidal overflows and the gates operated appropriately.

(g) In any such project, the required quality of non-potable water has to be pre-determined. Based on field sampling of the raw water, appropriate unit processes must be incorporated in a water treatment plant before using the treated water.

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URBAN RAINWATER HARVESTING PROBLEMS AND CONSTRAINTS

G.K. Bambrah

ABSTRACT

An overview of the application of rainwater catchment technologies (with an emphasis on urban Kenya) formed the basis of a research project on Problems and Constraints for the application of Rainwater Catchment Systems in Urban Areas. This research which was sponsored by UNCHS (Habitat) also forms the basis for the development of an information data-base on urban rainwater harvesting currently held in the IRCSA Africa Region Office.

This paper reports the findings of the appraisal of the technologies, and techniques as well as the nature of constraints to wider application of rainwater catchment systems in urban areas. The paper concludes with recommendations on strategies for the promotion of urban rainwater catchment systems on a wider scale.

INTRODUCTION

Rainwater catchment systems are becoming increasingly important in many countries and a wide range of technologies and techniques that centre on rainwater utilisation are being applied in rural and urban contexts all over the world. Although a significant increase in the application of this technology has occurred over the last decade or so, much of this has been in rural areas. In urban areas, rainwater utilisation is still limited and yet this technology offers solutions to major water problems being faced by many cities in the world including:

- lowering of groundwater levels due to over-abstraction from this water source;
- land subsidence due to reduced infiltration and lowering of groundwater levels;
- stormwater and floodwater control;
- pollution control;
- conservation, reuse and recycling of water.

Continuous degradation of surface and groundwater, increased water demands, rising costs of large-scale water resources exploitation and decreasing capital reserves, all call for the development and application of innovative approaches to tap alternative sources of freshwater such as rainwater and to effectively manage the use, disposal and conservation of existing freshwater sources.

OBJECTIVES

The objectives the research which forms basis for this paper were:

(i) To review existing knowledge and experience on the application of rainwater catchment systems in urban areas with emphasis on Kenya; and to identify the main constraints facing the wider application of this technology in urban areas.

(ii) To outline a set of recommendations and a strategy for the application of rainwater catchment systems in urban areas in general.

CONCEPTS AND PRINCIPLES

The principle of collecting and using precipitation in the form of rain, stream flow, snow, dew or mist, from a catchment surface is referred to as rainwater harvesting. Catching rain before it touches the ground provides one solution to drinking water problems. Runoff control provides for flood prevention and agricultural improvement. In developing countries governments with their limited capacity cannot do everything. National policy formulations and legislation, law enforcement, facilitation of decentralised water supplies and information management necessarily need to be managed by the government. However, implementation of decentralised water supplies should be left to communities and water users themselves. Experience also has shown that when water supplies are controlled by individual families or community groups, the care and keep-up of these facilities improves. (Losteluis, 1994).

Water withdrawals have been increasing about 4 - 8% per year in recent decades to meet the needs of growing human activities. Furthermore, continued increases in productive activities and population will result in increased demand for freshwater resources. It is estimated that by the middle of the next century, the global population (now almost 6 billion) will reach 10 billion. The greatest part of this population growth will be concentrated in urban areas which in many countries are the focus of over 50% of the national economic and productive activities. Projections show that by 2015, approximately half of the population in the developing countries will be located in urban areas, and in some regions such as Latin America, over 75% of the people will live in cities. Regions such as Asia and Africa, which are experiencing rapid population growth at present, will be faced with sharp increases in industrial and domestic water demands and uses by the end of this century. These regions which are grappling with many difficulties in attending to present water demands will thus be faced with daunting challenges by the end of 1990's. (Dowdeswell, 1994).

Colombani 1993 looked at the availability of water per capita per year from 1750 to 2050, and according to him, the estimation of water availability made from estimated runoff and stable runoff showed a tremendous downward trend. These trends showed that 50% of the total potential water resources of Africa are held by five countries only, while others face a critical water situation even though only 5% of the potential resources of Africa are being used at present. Some countries however e.g. Libya already use 100% of their run-off, others such as Kenya face climatic and physical conditions that limit access to water resources.

Against this background characterised by the finite nature of water-resources, the need for environmental protection, rising cost of large scale water resources exploitation, the need to recycle and re-use water and the search for participatory approaches, training and information services, rainwater harvesting is increasingly being recognised as a complement to conventional water supplies, particularly in towns, and for soil and water conservation.

URBAN WATER NEEDS — A BACKGROUND

Provision of an adequate supply of water to agglomerations of population has been a matter of concern since the beginning of civilization. However, basic water requirements of an urban existence are a relatively new phenomenon being a product of the industrialisation process. Pre-industrial settlements had little need for large scale water supplies, partly because these settlements were not very large, partly because there was not always a separation of home from the work place for the majority of the people, and partly because the technological solutions for dealing with the environmental needs of the not-so-large populations had not been perfected. (Mcghee & Mobogwye (urban age)).

Industrialisation gave rise to the modern city, a creature of technology in which infrastructure provision on an extensive, continuous and self-sustaining basis became a critical need for efficient operation of urban enterprises and liveability in dwellings. Since much of this infrastructure could not be provided in small and regular increments on an annual or biannual basis, the provision of infrastructure was characterised by technical indivisibilities and investment lumpiness giving rise to a quantum leap which started with the change in the history of urbanisation.

In 1993, for the first time in human history, people living in urban areas exceeded those living in rural areas - the world is becoming more urbanised and more people live in cities. The rate of movement of people into urban areas is greatest in Africa, Asia and Latin America while the greater part of the rest of the world already live in cities. As we enter the next century, several cities will have populations in excess of 20 million people, and many more will have population exceeding 10 million. Many of these megacities will be in the poorer countries such as China, India, Thailand and Brazil. The rapid growth of cities and continuing urbanisation is likely to put great pressures on already stretched water resources. It is also likely to take its toll on the inability of poorer countries to invest in bigger water supplies as these countries are already grappling with problems in the process of meeting present water demands.

African nations also have undergone the process of urbanisation and face an urban crisis today. Unable to provide for the infrastructural needs of their cities, and faced with a break-down of the centralised system of providing infrastructure when most of the functions of city administration are taken over by central or higher levels of government, further urban reforms have become a compelling priority for Africa.

Urban areas tend to be characterised by high population densities (e.g. Nairobi which has an average population density of 3040 residents per km^2), intensive land use patterns and fast settlement dynamics. Urban planning and development generally centres around residential, industrial, commercial, social, cultural, institutional or recreational needs and uses, and water demand tends to be high for most of these urban components. (Karingi, 1994). Traditionally, as the city or urban centre grows, so do the water sources get further and further from its boundary. Many cities find a limit to expansion due to lack of water sources. Yet others situated along coastal areas lack freshwater or non-saline water sources. Some cities are faced with land subsidence due to over abstraction of groundwater and some have to practice conservation and recycling of treated wastewater. In spite of this, rainwater catchment and utilisation in urban areas has yet to be taken seriously.

The most striking change in Africa in general, and East Africa in particular is as Karingi (1994) states, the rapid growth of existing and newly established population agglomeratoins ranging from trading centres to small towns. The estimated current rate of urbanisation in Africa is 6% per annum and water provision in these growing towns and urban centres has tended to be the responsibility of local authorities ranging from City Councils to town councils. Their constraints in meeting water supply responsibilities have encompassed financial, technical, institutional and political incapabilities as well as social and cultural insensitiveness.

Rainwater catchment systems have been used in the urban areas since ancient times. Evidence of roof catchment systems in Rome for instance date back to early Roman times (J. Gould, Crasta et al, 1982). Roman villas and even whole cities were designed to take advantage of rainwater as the principal water source for drinking and domestic purposes. The largest rainwater storage tank is probably the Yevebatan Sarayi in Istanbul, Turkey. Constructed under the rule of Caesar Justinian (A.D. 527 - 565), it measures 140 m by 70 m and has a capacity of 80,000 cubic metres (Hasse, 1989).

In Africa, the earliest known evidence of rain water catchment technologies comes from Northern Egypt, where tanks ranging from 200 - 2000 m^3 have been used for at least 2000 years and many are still operational today (Shata, 1982 and J. Gould 1994).

Water related problems in urban areas arise from two sources: water demand and water supply; On the demand side for urban water, pressure systems are created by population increases, increased per capita consumption of water and wastage as well as mismanagement of water. The supply problems are related to scarcity of water sources, degradation of water quality, poor cost recovery due to the unwillingness of consumers to pay for the water and inability of various central urban authorities to provide water infrastructure at the required rate. Water shortage inadequacy in urban areas can be alleviated in two ways: development of new water sources or conservation of existing sources. Rainwater catchment is useful for both of these.

There are many reasons for developing rainwater catchment systems in urban areas:

- Cities have many well developed catchment surfaces (roofs, parking lots, playgrounds, parks, ponds, swimming pools, flood plains etc.)
- Rainwater tends to be relatively clean and of good quality and thus requires little treatment
- Users of rainwater also own the catchment systems resulting in efficient use of the water as well as increased levels of water conservation.
- Sources of rainwater are located close to storage devices so that transmission costs are reduced.
- Rainwater harvesting reduces stormwater run off and hence assists in flood control, preventing natural disasters due to flooding.
- Rainwater catchment systems provide a diversified and useful water supply during emergencies such as earthquakes and fires.
- The rainwater catchment systems are easy to construct in a short time and to suit the users taste and requirements.

However, it is also true that,

- Catchment areas and storage devices (which are expensive) tend to be limited so that during prolonged drought the storage tanks may dry-up.
- Maintenance of water quality is a problem for the users.
- Extensive development of rainwater catchment systems in the city may reduce income from public water supplies.
- Rainwater catchment systems have yet to be recognised as viable water supply alternatives in most urban areas.

URBAN RAINWATER HARVESTING - THE CASE OF KENYA

A review of the literature available shows that Kenya which leads the way in rainwater utilisation in rural Africa has no significant application of this technology in urban areas. The only aspects of urban rainwater utilisation that have been investigated for Kenya relate to storm water control or possibilities of involving low income communities in rainwater harvesting.

In urban areas, rainwater catchment systems are used to collect water for domestic use or for flood control and regulation of rainwater infiltration. Within these categories of urban rainwater utilization techniques, further sub-divisions can be made on the basis of cultural and social traditions and economic conditions of the users.

The constraints facing promotion of rainwater harvesting technologies and principles are of a varied nature and range from policy issues, to involvement of communities and households in planning these systems. Included in these are:

- Policy constraints: Water issues need to be linked to sectoral and overall strategies to achieve sustainable settlements and national socio-economic developments and an integrated planning and management approach is needed that will work at the whole water cycle including distribution of rainfall, conservation of water, systems of water supply and interactions between land use and the environment. Unfortunately, national policies which should be initiated by the citizens in collaboration with the government, following the processes defined in law do not yet encompass water resources management. Most policies follow a centralised government control approach to water resources development. Policy is therefore a major constraint to the promotion of rainwater catchment in the developing countries in general and urban areas in particular.

- Economic Constraints: Implementation of urban or indeed any rainwater catchment system, although affordable, still faces a serious financial constraint, if the facility is to provide adequate storage. The size of the storage facility necessarily implies a high investment cost. Consequently most rainwater harvesting projects focus on community and institutional solutions where rainwater harvesting is included in policy statements as being applicable at the household level and governments invariably have to subsidize the construction of these systems.

- Community Participation: A major constraint to promotion of rainwater utilisation has been the failure of public and private sector institutions to adjust to the peculiar patterns of project execution imposed by the irregular processes of community participation.

- Technological Constraints: While there is knowledge at present of an array of rainwater utilisation techniques and technologies for urban areas, their application is greatly hindered by official norms, and standards and administrative practices of local, national and international agencies. In general, standards and norms tend to stress importance of products rather than functions and the performance that these products are expected to provide. This, not only tends to inhibit the search for technological solutions, but also hinders the application of technologies that allow for incremental improvement of service standards. Thus in addition to subjecting water supply development to investment indivisibilities, the norms and standards tend to stress optimisation of costs and use of resources without proper consideration of the inputs required to operate and maintain these systems.

- Institutional Constraints: Formal and traditional institutions vested with water supply planning and management, have not been able to develop and accommodate approaches required to integrate the multi-faceted requirements and plans for urban development, industrial activities and other sectors. New, more flexible, institutional structures need to be developed to overcome the many constraints to rainwater harvesting that arise from these weak, sector based and traditional institutions.

- Information: There is a strong need for information systems to create awareness of the potential of rainwater utilisation. A major problem facing promotion of rainwater catchment systems is that of elevating the status of this technology among technologists, politicians, policy makers and administrators, who are today mainly involved with design, implementation or planning of complicated and expensive piped water supplies. Rainwater catchment often does not seem "glamorous" enough to these interest groups - much work needs to be done to sensitise policy makers and others through appropriate awareness raising campaigns. Information centres are needed at the national and regional levels to compile and disseminate technical information on rainwater catchment systems, techniques and technologies.

- Legislation: Despite availability of information on how to design, build and maintain a rainwater catchment system for adequate supplies of water at the household, institutional and community levels, little has been done to develop legislation or guidelines for rainwater quality control and assessment. State and municipal authorities should be vested with the responsibility of developing, monitoring and regulating domestic use of rainwater.

STRATEGIES FOR PROMOTION OF URBAN RAINWATER UTILISATION

A strategy for promotion of rainwater utilisation in urban areas calls for:

- an integrated approach to water resources management;
- a policy statement on rainwater utilisation within the national water policy or masterplan;
- development of legislation and guidelines relating to user requirements, participation and quality and service requirements;
- community participation and involvement from formulation to implementation, management, operation and maintenance of rainwater utilisation systems.
- research, development and assessment on/of technological options for this purpose; including resource inputs, expected benefits and environmental, social and cultural impacts;
- awareness creation and information dissemination through creation of appropriate institutions and materials, training, awareness campaigns and discussion fora.

In keeping with these requirements a strategy for promotion of rainwater utilisation in urban areas should comprise the following:

- Initiation of dialogue with policy-makers and relevant government institutions/ departments to promote and establish a policy statement/plan on rainwater utilisation in general and for urban areas in particular, where this does not exist already.
- Assessment of potential for rainwater utilisation in urban areas in each region or country.
- General delineation of responsibilities as regards various interest groups, government and national agencies, local authorities, international agencies, private and public sector bodies, NGO's, CBO's and individuals.
- Facilitation of urban water user associations and their collaboration with local authorities.
- Facilitation and creation of flexible and appropriate financial and material support structures.
- Standards, legislation and by-laws to control rainwater quality for potable purposes.
- Promotion of private sector involvement in rainwater utilisation.
- Information and reference centres to promote urban rainwater utilisation through the production of training materials and manuals, training workshops and participatory schools etc.
- Training facilities for water user associations, small-scale construction initiatives and technical manpower in local authorities as well as NGO's, CBO's and private enterprise.
- Involvement of local business, industrial, and private sector institutions in rainwater utilisation initiatives.
- Monitoring and evaluation of national/regional rainwater harvesting programmes.

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Section 8

WOMEN ACTIVITIES IN RAINWATER USE

WOMEN ISSUES IN RAINWATER COLLECTION PROJECTS

By Jessica Calfoforo-Salas*

ABSTRACT

The paper presents women issues discussed during the 6th International Conference of the International Rainwater Catchment Systems Association held at Nairobi, Kenya in 1993.

Reactions to the impact of a supply-driven program for women as in the case of rainwater collection projects, were discussed. It was pointed out that the alienation of men further established a gap in understanding gender roles in development.

The need for women specific projects was discussed sin the paper as an opportunity for women to participate in their own development, for women organizations to foster solidarity, and to help tip back the balance of power that rules the expectation of society.

An integrated approach to bring about gender awareness was recommended for rainwater projects. Methodologies for integration are also discussed.

INTRODUCTION

Do rainwater collection projects promote gender sensitivity, thus responding to the issues of women in development? Or do they simply reinforce stereotyped roles of women as domestic water carriers in the mind of the planners, the implementors and even the women themselves?

Differing and supporting views on how to tackle a host of women issues surfaced during the sixth conference of the International Rainwater Catchment Association (IRCSA). One achievement of the conference, though, was that questions were raised. Focus then was directed to thoughts on women and development programs.

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The IRCSA, an offshoot of the UN decade for water, is a 12-year old organization of scientists, project managers, and community organizations representatives who study and practice the technology of collecting rainwater. It meets bi-annually to review and publish papers on new studies and experiences in rainwater collection. The 6th international conference was held in Nairobi, Kenya last August 1 to 6, 1993.

The richness of the experience of organizing women for rainwater collection, particularly among the African states, has reached the conference in the form of technical papers, photo exhibits and slide presentations. Comments and reactions showed pitfalls in impementing rainwater collection projects as well as a realization of varied opportunities.

ISSUES RAISED

The issues on women which surfaced during the conference served as a springboard for more discussions in and out of the conference hall and long after the conference ended. The issues about a supply-driven program for women, perspective on partnership, women's benefits from technology improvement and how women programs are delivered/ implemented will have to be further explored by scientists and practitioners of rainwater catchment systems. It is important for IRCSA members and conference participants to have a holistic view of a sustainable rainwater catchment systems development program.

A Supply Driven Program. It was mentioned in the Kenya Conference that there is an "automatic" response on the part of policy planners to involve women when the project is about domestic water without much thought on the why. It is a fad! they said. One development manager was saying "...we cannot get money for water projects without involving women because that is what the donors want." Worst still is the thinking that the sole reason for giving the water project to women is that it is their role and domestic duty to fetch water.

It was felt that implementing water projects in this manner could be counter-productive to women empowerment. The effort could reinforce certain oppressive role-prescriptions of society. Instead of continuously examining how roles affect persons, the project will continue to stereotype women as domestic water gatherers.

Participatory project development could clarify issues raised by project managers. Even at project conceptualization, project beneficiaries or partners - especially the women - should participate in the process.

The Perspective of Partnering. During the conference, men expressed the feeling of being alienated from water projects. It was pointed out that the search for a better understanding of gender and development is obstructed in several project implementation because there is no information and insights on what happened to women when they organize themselves and build their own tanks. What men see are women simply doing the work that men used to do and could not understand why.

The purpose of the program for women was not known to them. They have not appreciated the need to be aware of the potential in women as partners in various aspects of development.

It should be clarified that the focus on gender and development does not sow competition between men and women. There is no race for political power and control over family and community decisions. What is facilitated is a collaborative effort or partnership. The need for both male and female mind, perspective, attitudes, and skills for the development of home and community has to be recognized.

Gender sensitivity exercises and baseline disaggregated data may be considered as part of the project development process. Data obtained from these schemes could be the basis for planning the integration of women's program.

Benefits from a New Technology. No doubt, women will upgrade themselves is technology, that is, from carrying jars and bamboo water poles, they build ferrocement water tanks. The thinking expressed during the conference was that women needed the new technology in rainwater catchment so that they will have more time to do other jobs at home, be more productive, or have time to rest.

Many felt that women's participation in development of technology is more than that. The women of course benefitted from the technology in many ways but more thought also should be given to the gender issues, otherwise, the opportunities provided for by involving women will not be optimized. For example, women should be encouraged to participate in technology development or technology evaluation and application.

IMPLEMENTATION ISSUES.

While the intent of the gender and development is appreciated, another pressing issue is on how to plan and implement intervention schemes along this line, particularly in development projects like a rainwater catchment system. Two general approaches on how to plan for and manage a program for women are explored in this paper. These are the use of women-specific projects and the integration of gender awareness in project activities.

Women Specific Projects. The advocacy for the integration of gender into development efforts does not exclude the need for women-specific projects.

In a male-dominated situation where manipulation and the show of bias against women are pervasive, there is a need to give women a positive discrimination, a focused attention, a special push. A movement of resources (physical and psychological) ought to be directed to the disadvantaged group -- the women in this instance -- in order to tip the balance back to minimize the skewness of power distribution. If power is viewed as emanating from material wealth and there is a cry for an equitable distribution of wealth among people and nations, there is also a cry for equitable distribution of *opportunities* between sexes as power is nestled in information and influence for acquiring these.

Women-specific initiatives like rainwater catchment projects, livelihood projects, building organizations, and the like, give women a preferential treatment -- the much needed preference to tip back the balance. Through these, women discover themselves, their strength and identity. They find opportunities to prove their self-worth and a hundred capabilities. They blossom, they see a new world, they find meaning in both small and big things, they discover joy (sometimes for the first time in their lives). When such happen, there is no stopping the energy surge to create, to discover new initiatives, build new alternatives and design another paradigm. New things happen -- even the capacity to understand men. The paradox in fact is -- women cannot truly relate with men unless they first recognize and like themselves.

The change in the individual must be supported by a permitting structure at the macro level. An oppressive structure could easily put-off a flicker of light from a struggling, even a doubting effort. Structures and systems are not conscious and have no feelings. The run of the mill, the force of habit and ways of doing things easily discourage effort to change. Women find solace in being together. In situations where fear is so strong, women have to be militant to protect themselves and their solidarity. Through women-specific projects and all women organizations, women find themselves and gain the community recognition they rightfully deserve.

A rainwater collection project is a good opportunity for a women-specific component. It could start with the existing situation that it is the women's job to fetch water. However, it should not stop there, but rather open doors for new realities.

Integration of Gender Awareness. The challenge is how to make participants in the rainwater collection project, and the community as well, become aware of gender roles with the hope that change could be facilitated, even gradually, as a result of the awareness. The rainwater project could facilitate data gathering to know the status of role predominance in productive, reproductive, and community tasks. A time structure study could help clarify the activities of men and women and the time spent on them. A workshop to analyze these data could make beneficiaires and the larger community aware of the situation.

Consequence and probable problems expected from a persistent condition could be discussed formally in groups or informally in the homes, in recreation areas, or in the market place. The project could institute policies or procedures to facilitate change consciously on the part of individuals or groups.

Household cases, prepared and discussed with the beneficiaries from time to time could further the appreciation of a need to review gender relations. The effect of the introduction of a new technology, the rainwater catchment system in this instance, could be examined by making a post implementation case study and analysis. Have roles changed because of the technology intervention? How?

Changing of roles with regard to the technology is only the beginning. As the consciousness level is raised, women will be asking about their role in other areas of their private or public life. A rainwater collection project could bring a new realm in development. The project will not only be a compendium of objectives and activities but it will also be throbbing with life, touching the deepest desires and enabling persons to reach new heights in their aspirations.

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Present Situation and Potential Development of Women's Role in Rainfed Farming: A Rural Survey in Hebei Lowland Plain

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ABSTRACT

A rural survey was conducted in two locations of different economic development levels in Hebei Lowland Plain. The results showed that the main features of the agriculture practice in the area were as follow: 1. As natural rainfall was the major water source in local agriculture production, the extension of rained farming technique was essential to further development of agriculture. 2. Undertaking about 70% of the farm work, women were the main forces to maintain the agriculture development and determined the productive level of rainfed farming. 3. Compared with men, the education level of women was much lower. Closely related to agriculture development, wemen's education level was the major limitation of the agriculture production in the area. Some suggestions were put forward to develop women's potential in rainfed farming practice. More attention should be payed to rainfed farming. Women's education must be emphasized and the intelligence investment should be increased to extend the new rainfed farming technique and improve women's scientific quality. The method of combining basic principles with practical skills of rainfed farming can be used in women's education.

Key words: women, rainfed farming, rural survey, potential development, female education

Drought is a widely existing problem in the north part of China. The shortage of water resources is one of the most important factors limiting the agriculture development. Hebei Lowland Plain (Heilonggang Area) is the drought centre of Huanghe-Huaihe-Haihe Plain. For lack of irrigation conditions, rainfed farming is of great importance in this area.

It is noticed that in recent years, different sexes play different roles in local economic development, and women contribute more to agriculture development than men. In order to study the current situation of women's role in rainfed farming and rainfall utilization, and find the way to develop women's potential, a survey form was designed to investigate the rural general situation in two typical locations in the area. Both in Hengshui Prefecture, the centre of Hebei Lowland Plain, the two locations were chosen according to their different economic levels. One is Tanzhuang Township, Hengshui city, which is relatively developed in economic. The other is Longdian Township, Wuyi county, relatively underdeveloped. Totally 150 sheets of forms were delivered while 120 sheets available returned, of which 59 from Tanzhuang, 61 from Longdian. The main contents of the form included: family members and labours, rainfed and irrigated field area, annual income, the major careers that men and women respectively engaged in, the proportion of women in total farm work, male and female labours's education level etc.

1. Current Situation of Agriculture Development in Hebei Lowland Plain

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Hebei Lowland Plain (Heilonggang Area), which is in the southeast of Hebei Province, is a traditional rainfed farming area. The total land area is about 37800 km^2, and cultivated area is 2.4 million ha. With its 500-600 mm annual precipitation and 1000mm evaporation, it is the drought centre of Huanghe-Huaihe-Haihe Plain. Because of water shortage and poor irrigation conditions, rainfall is the most important water source in agriculture. Compared with irrigated farming area, the crop yields are still in middle-low level. The yield level of winter wheat is about 3-4t/ha, and the rainfall productivity is 7.5Kg/ha mm, which is much lower than irrigated area. Rainfed farming must be emphasized to increase the rainfall use efficiency and keep sustainable agriculture progress.

According to the survey, more than half the cultivated area was non-irrigated land. Per capita arable field was about 0.12 ha, of which the irrigated field was about 0.055 ha, non-irrigated field was about 0.065 ha, accounting for 44.6 and 55.4% respectively.

The non-agriculture income is increasing rapidly in recent years, but agriculture is still the major income source of the farmers. Out of the 120 returned sheets, 78 families answered that the family income was mainly from agriculture, accounting for about 65%, and only 42 families (35%) from non-agriculture income.

Per capita income (PCI) in the area was 650.1 yuan, per capita agriculture income (PCAI) 329.6 yuan, per capita non-agriculture income(PCNI) 320.5 yuan. The ratio of PCAI/PCI was 50.7%. More than half the income was directly from agriculture. (Table 1)

Table 1. Average annual Income and income sources of the farmers

Income sources	income (yuan)	Percentage in PCI
per capita income (PCI)	650. 1	100%
per capita agriculture income (PCAI)	329. 6	50. 7%
per capita non-agriculture income (PCNI)	320. 5	49. 3%

2. Present Position and Role of Women in Local Rainfed Farming Practice

(1). Women's position in local agriculture production

The survey showed that women played more important role than men in local rainfed farming practice.

When asked the major career the male and female labours were engaged in, 86% of the female labours answered "agriculture," 14% answered "non-agriculture work"; and only 57% of the male labours answered "agriculture," 43% answered "non-agriculture work." When asked the proportion of female labours in total farm work, above 90% answered that they undertook more than half of the farm work; while only about 10% answered that the proportion of farm work they undertook was less than 50%. Accordingly, it was estimated that about 70% of the agriculture activities was undertaken by women. Additionally, almost half men in the area were engaged in non-agricultural work (such as household sideline production, industry, and seasonal job etc.). The release of men from agriculture strengthened the position of women in agriculture production.

As above mentioned, because more than half the income was directly from agriculture, and women were the main forces engaged in agriculture activities, women's role in local rainfed farming practice was determinative. The contribution of women to rural economic development was primarily through agriculture.

(2). Women's education status and its relation to economic development and rainfed farming level

Women's education level was much lower than that of men in the area. In the form, every labour, either male or female, was required to fill the form about the level and years of education. According to the survey, the men's average education years were 7.3, while the women, 5.45. The women's education years were 1.85 years lower than that of the men. The proportion of women graduated from senior middle school or above was only 10.9%, while that of the men was 21.6%, almost twice as the women. The illiterate proportion of women was 12.2%, while that of the men was zero.

The relationship of male and female labours' education years and annual income was analyzed using partial correlation. The correlation coefficients were listed in Table 2.

Table 2. Partial correlation coefficients between education years and income

sex	per capita income (PCI)	per capita agriculture income (PCAI)	per capita non-agriculture income (PCNI)
male	0.0956	0.0425	0.1905*
female	0.2045*	0.1847*	0.1654

*: significant at 0.05 level.

As all of the coefficients were positive, it was concluded that the higher the labours's (either male or female) education level, the higher the annual income. Furthermore, the agriculture income was primarily determined by female labours's education level, whereas the non-agriculture income was primarily determined by male labours' education level.

The regressive quotation of PCI to male and female labours's education years was :

$$Y = 158.2 + 32.76 X_1 + 62.62 X_2 \quad (P=0.0320)$$

Y: PCI

X_1: male labours's education years

X_2: female labours's education years

(3). Male and female labours' attitude to the acceptance of agricultural knowledge

According to the survey, 22.5% of female labours **often** read, listen or receive the books, magazines or TV programs concerning agricultural science, and 48.3% **seldom**, 29.2% **never**. As for male labours, 16.7% **often**, 49.2% **seldom**, 34.1% **never**. When asked "whether you are eager to accept the reeducation of rainfed farming skills," 96.7% of women answered "yes," and the proportion of men was 81.7%. It was suggested that women were more active to accept the reeducation of agricultural science and technology.

(4). The differences of women's role in the two investigation Locations

Women's role and position in the two investigation locations were quite different because of the different economic development levels. As listed in Table 3, the annual PCI of Tanzhuang was 37.8% higher than that of Longdian. In Tanzhuang, 48% of the total income was from agriculture, and in Longdian, 54.2%. It was evident that in underdeveloped area, the proportion of agriculture in rural economic was higher than developed area.

Table 3. The income and education years of the labours in two Locations

Locations	PCI (yuan)	PCAI (yuan)	PCNI (yuan)	education years of men	education years of women
Tanzhuang	758. 1	363. 6	394. 5	7. 4	6. 1
Longdian	550. 2	298. 1	252. 1	7. 2	4. 8

The labours's education level was also higher in Tanzhuang Township than Longdian Township. It should be noticed that the education years of men in Tanzhuang were very close to that in Longdian, but the difference of women's education years between the two locations was significant, revealing that it was mainly the inadequate women's education status limited the economic development in developing area. In Tanzhuang Township, the ratio of women who were mainly engaged in agriculture was 82.8%, men, 52.3%; and in Longdian, 89.2 and 62% respectively. There were more women released from land to non-agriculture work in relatively developed area.

3. Some Suggestions to Develop Women's Potential in Rainfed Farming

The development of women's potential is essential to improve the agriculture production to a new level. Up to now, women's potential in local rainfed farming practice has not been fully brought into play. Based on above analysis, some suggestions were put forward for the fully development of the women's potential in rainfed farming and rainfall utilization.

1. Considering the importance of rainfed farming and the fact that more than half of the cultivated land was lacking of irrigated conditions, the administrative and agricultural technique extension agencies should pay more attention to rainfed farming. The new technique of rainfed farming should be widely extended to the farmers, especially, the female farmers.

2. The well educated, qualified technique acceptors are necessary for the spreading of new knowledges and technique of rainfed farming. According to above analysis, the main acceptor should be women in this area. Meanwhile, women have showed their thirst to learn the agricultural knowledge. The major factor limiting the development of women's potential is their low education level. From now on, rural women's education must be emphasized. Women's illiterate proportion must be reduced and the quality of science and technology improved.

Since women are mainly engaged in agriculture, much capital should be invested to improve their general qualities and practical skills in agriculture production. The development of women's potential in rainfed farming is above all the development of intelligence. It has been reported that the intelligence investment is the most efficient investment. The profit / investment ratio in developed countries is about 10-20:1. In China, the ratio is about 7:1, a bit of lower than developed countries, but much higher than that of the substance, energy and active labour input.

3. According to the features of local agriculture production and the current status of women's education, the combination of basic principles and practical skills can be used as a primary method in women's education.

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ROLE OF WOMEN IN WATER AND SANITATION DEVELOPMENT

John M Erskine

Abstract

The low educational status and high rates of illiteracy among women living in the less developed rural areas of South Africa, their expanding responsibility for family and community welfare, the continuing increase in female-headed households, and the consequent vital role of women in development, all point to the need for special attention and high priority to be given to ways and means of involving women in, and training them for, all important development activities.

Bearing in mind the critical importance of water and sanitation in community life in these rural areas, where water resources are often meagre and undeveloped and proper sanitation non existent, the importance of involving women in the process of promoting and establishing water and sanitation systems cannot be over-emphasised. A description is given in this paper of suggested approaches for encouraging this involvement through the establishment of innovative programmes based on recognition of economic imperatives and the training needs of women. A logical series of steps for involving women in water and sanitation development in the less developed rural areas of South Africa is described, with particular attention being directed to rain water catchment systems and much emphasis being placed on data collection, capacity building, and close monitoring and evaluation.

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Introduction

In any exploration of the present and future roles of women in development and application it is perhaps appropriate to begin with a definition of gender. Thus, gender is a concept that refers to learned, culturally determined (as opposed to biologically determined) differences in the behaviour patterns of women and men in relation to each other and to their social context. Activities, rights and obligations are considered feminine or masculine by a given society or social group; members of that society learn to play gender roles in accord with these expectations. The norms and values that create gender roles are present in the society as a whole and in the household. Gender roles, which increasingly are being critically examined in societies worldwide, greatly influence the position of women and their prospects in life.

Hilhorst and Oppenoorth (1992) describe how gender roles affect the division of labour and how they also affect access to and control over the allocation of resources, benefits and decision making. This contributes to inter-dependence between women and men, which is complex, subtle, flexible and involves power relations. It also has implications for women's income generating opportunities. Women often have less access to resources than men, and less control over their own labour. Access to certain sub-sectors and sources of employment may be restricted, and support services may be harder to obtain. Finally, they may have difficulty exercising control over their income.

Gender-specific characteristics are thus important variables to consider in planning and policy making. The impact of gender, however, is modified by other socio-economic variables, such as socio-economic status of the household, ethnicity, and age. Gender roles vary within a society and over time; 'women' are not a homogeneous group. Acknowledgement of this heterogeneity by planners is crucial. Women differ with respect to work, interests, and needs.

While a growing body of research and information now describes the roles of women and men in many different situations, there is little consensus on the nature of women's difficulties, the solutions needed, or the specific impact that economic change has on them. In particular, policies that target rural women are too often based on assumptions, ignoring the broader development context. There is also considerable ambiguity over the broader redistributional issues raised by assistance to poor rural women.

In this paper, an attempt is made to place the important potential role of rural women in the development of water resources, through catchment systems in particular, in the broader context of the advancement of women in general.

Women and development : the need for innovation

Over the last twenty-five years, it has become habitual in development literature to categorise the target population, for example, 'women' or 'the poor', thus enhancing fragmentation in societies already fragmented along lines of caste or other sociocultural concepts of merit or demerit, which have little to do with individual value, skills, or efforts.

Trends in women's development have, by and large, followed this pattern, as a result of which projects or programmes claiming to empower women or improve their status have ended up by marginalising women further.

Most of the work rural women do is directed towards maintenance and nurturance; it results in no monetary acquisition, and cannot be calculated in terms of economic value-added. This has led to the very real economic dependence of the majority of rural women on men, and consequently an inferior status. Hence, also, the emphasis on women as another underprivileged or 'fringe' group which receives skills' training for the purpose of 'income generation'.

Nevertheless, income generating projects have been shown to be quite successful in many less developed countries in terms of ameliorating women's status in their families and in the community. They have also been used as a means of delivering a number of other services to women and children.

We can see, therefore, that the challenge facing researchers, trainers and extensionists that deal with the problem of promoting rural development, and of involving women in the process as contributors (equal to men) rather than as 'beneficiaries', is that of designing innovative approaches that recognise, develop and reward the valuable contribution of women so that they are not further marginalised.

Many research studies in the past, conducted worldwide, have emphasised that women are the mainstay, in terms of labour contributed, to subsistence agriculture. Concentration on providing rural women with an opportunity to earn income in their 'spare time' without looking at time and environmental factors is the wrong approach. Rather we must look at ways and means of creating income generating opportunities in the rural areas for all members of the rural household; in some households it may be the men who engage in market orientated, income generating (and/or meeting family food requirements) farming activities whilst the women are involved in nonfarm income generating activities - in other households, the reverse will be the case depending on personal preferences and interests.

For a high proportion of rural women, life is drudgery; if men had to do the work that women do (collect water and fuelwood, look after subsistence crops, care for the family, etc), technological innovations would have been found long ago to decrease the drudgery and allow more time for leisure or recreation. The concept of recreation is missing from income-generating projects that 'train' women to make money in their spare time without attempting to develop income generating opportunities for the men in the rural areas, on the family landholding or nearby, so that much of the drudgery can be removed from women's lives. Research work in this field should focus on (a) examining to what extent innovations can be found to lessen the drudgery in women's work, (b) exploring the trade-offs involved in women's off-farm employment activities in the context of the importance of their contribution to agriculture, and (c) investigating ways of bringing more men into farming through the introduction of intensive, profitable farming systems.

The role of women in development in the 'new' South Africa

In South Africa, the new Government is promoting a Reconstruction and Development (RDP) programme throughout the country. In the rural areas its aim is to "improve the quality of rural life through (a) the transfer of land to those who wish to produce incomes through farming in a sustainable way; (b) ensuring access to affordable services (education, health, etc), welfare, the police and courts; (c) providing needed infrastructure; (d) the promotion of non-agricultural activities; and (e) providing support (financial services, etc) for entrepreneurship (including agriculture)".

Particular emphasis is placed on the need for development efforts to address the special position of women as they presently make up the majority of small-scale farmers and bear the brunt of poverty, overcrowding and hunger in rural areas. They take responsibility for all aspects of their families' lives, including the need to obtain food, fuel and water, often over long distances, but are excluded from decison-making structures. Their priorities include accessible water, sewage disposal, infrastructure, land rights, housing, training, local development committees, a disaster relief fund, markets for their production, and good representation in local government.

Girls and women are frequently denied education and training opportunities because they are female. Furthermore, they are often educated and trained to fulfil traditional roles which perpetuate their oppression. Campaigns and information should be aimed at opening up a wider range of learning opportunities and choices for women, which in turn should lead to a wider range of income-generating forms of employment. A special effort should be made to encourage women to obtain technical skills. In addition, special steps must be taken to give full recognition and value to the work and skills that are traditionally associated with women. Where appropriate, these should be recognised within the national qualifications framework.

Economic imperatives for women

Poor rural women are generally involved in a variety of low-return activities in which the combination of gender inequalities and poverty increases the adversity of working conditions. The search for ways to earn a livelihood becomes even more critical in times of economic recession. This is especially true for women, since the number of households they head - in which women and children can rely only on their own capacity to generate an income - is rapidly increasing. For these women, as for those who are not heads of households but whose families need extra income, the only option is often to generate their own income, via self-employment, despite the problems they face in gaining access to assets and resources. Opportunities and possibilities open to women are more limited than those for men, and frequently must be compatible with other obligations. Gender roles (that is, the culturally determined roles of women and men) affect the division of labour, as well as access to and control over the allocation of resources and benefits. Self-employed women, and even more so women employed in family-based labour, may have little control over allocation of their earnings or products; women are often subordinate, with limited control over their economic lives. Not only living conditions but also womens' position in the household and society, and the accompanying social change required for sustainability, are at issue; this has essential implications for the design of programmes offering financial benefits or services to women.

The involvement of women in promoting and developing rural water provision should be based on income generation for the women rather than on voluntary or subsidised work. Where women are subsidised by government to carry out work with little intrinsic value, they are in effect receiving welfare payments - not wages - in return for their labour. Somehow, payments made to women for community upliftment work must be designed to be economically sustainable and not to rely on external funds.

In examining ways in which women can contribute to water resources development and management, it is essential to understand their positions. It is often assumed, incorrectly, that women have time free to devote to additional activities. All too often, women are expected to undertake new activities without due regard to the impact of the increased labour burden on their existing activities. No attempt is made to measure the opportunity cost for women of involvement in activities that do not improve the performance of their own major economic (income generating or income substitution) ventures (for example, subsistence farming). The result is the diffusion of energy and time that might have been utilised more profitably in other ways.

It is worth commenting perhaps, in this context, that both aid agencies and women themselves tend to concentrate on economic occupations such as sewing, handicrafts, raising chickens (using extensive rather than intensive systems), or vegetable gardening. These are often economically unpromising, characterised by low levels of profitability and poor market prospects; more often than not, these projects have a negative economic performance. This situation is frequently exacerbated by agencies that encourage women to act collectively when there is no economic or social justification for doing so. Collective action is not appropriate in all contexts, and yet many programmes assume it is in some way automatically superior to individual initiative. Poorly conceived collective activities may merely accentuate women's labour burden without providing financial compensation.

Women and training needs

The importance of training to women in less developed areas should not be surprising in light of women's low educational status and high rates of illiteracy. Yet, women's responsibilities for family and community welfare are expanding, as female headed households continue to increase and women's vital roles in development - from providing basic health care to preserving the environment - are better understood.

Women who have been denied schooling cannot expand their roles, either as income generators and/or as contributors to community development, without access to new knowledge and skills. Most basic to effective training is the relevance of the subject matter to the trainees. Programmes need to develop out of a thorough understanding of women's needs and problems and of their views about them. What women need to learn should be defined by them, from their own perspective, rather than by technical experts. But this, in turn, requires that they know what there is to learn; that is, they must be offered a 'basket of choices' from which they can select the learning material most relevant to their own needs.

Even the best developed content, however, is affected by a range of contextual considerations. For example, time and location for training activities are particular concerns. Women's time use, both over the course of an average day and over the course of a year, must be taken into account so that women are able to attend a programme and apply new knowledge or skills after the programme. Likewise, training should be conducted in a convenient and friendly environment where women feel comfortable expressing their ideas.

Another critical factor is women's interface with men in the programme, a factor which varies greatly depending on culture. The support of husbands and community leaders may be needed for women to even participate in a training programme.

Programme planners sometimes underestimate or ignore the value women place on *how* learning takes place. In many cultures, traditional roles and responsibilities isolate women, giving them an inaccurately limited view of their potential and self-worth. Participatory methods, which catalyse dialogue within groups of women and involve them in "learning by doing", provide a means for women to gain a different perspective of themselves, their relationships with one another, and their options for taking action to improve their circumstances. This sense of personal efficacy and group support is the foundation on which new knowledge and skills can be built. When women are provided with the opportunity to appreciate their strengths and to realise they share common problems with other women, and usually with men as well, they are more likely to participate in development activities.

With regard to the question as to whether trainers need to be women to be effective in women's training programmes, it is clearly desirable in some areas due to cultural norms and to the need trainees feel for examining their situation from a gender perspective. However, whether the trainer is a man or woman, the ultimate selection criteria should be an individual's respect for women's potential and recognition of the structural constraints they face in their societies. In some cases, male trainers can be advantageous, since they can become advocates for women's participation and open doors to mainstream development programmes.

To get an idea of the need for training amongst rural women in South Africa, we can take the KwaZulu-Natal Province of the country as an example. In this Province, where the Institute of Natural Resources is located, we find that women constitute 52,2% of the region's population and make up 43% of the those recorded as being economically active. 59% of women between the ages of 16 and 60 live in the rural areas. Many of the 41% living in urban areas live in informal settlements. Of those women recorded as being economically active :

- 35% fall into the category 'activities not adequately defined' (informal sector)
- 34% are in 'community, social and personal services' (includes teachers, nurses, social workers, domestic workers)
- 13% are in the 'commercial and financial' sectors
- 11% are in 'manufacturing' (textile and food production)
- 7% are in 'agriculture and related' sectors (not including subsistence farming

There is general agreement in the region that particular attention should be paid to the training needs of rural women and self-employed women, since the majority of women are located in the rural economy and in the informal sector economy. Training requirements revolve around specialised skills (agriculture, craft production, etc) and business and marketing skills, as well as development (water provision, electrification, child care provision, education and health services). Skills training schemes related to infrastructure development should be designed fully to incorporate women. In general, training (including curriculum development) should acknowledge and accommodate the diversity of women's needs and experiences in every aspect of life.

Water resources development

South Africa is a water-scarce country. Ask any inhabitant of a poverty-stricken rural area what his/her first priority is and the answer will invariably be clean, fresh water. The existing limited water resources are also unevenly distributed, with 70 per cent of the country receiving 11 per cent of the rainfall. Presently, more than 12 million people do not have access to clean drinking water and 21 million people do not have adequate sanitation (toilets and refuse removal). Less than half of the rural population has a safe and accessible water supply, and only one person in seven has access to adequate sanitation.

In the Government's RDP programme, referred to earlier, it is stated that water should be made available to all South Africans in a sustainable manner. The RDP recognises the economic value of water and the environment, and advocates an economically, environmentally and politically sustainable approach to the management of the country's water resources and the collection, treatment and disposal of waste. The Government's water management strategy has three main goals : meeting every person's health and functional requirements, raising agricultural output, and supporting economic development.

In the short term, the RDP intends to establish a national water and sanitation programme which aims to provide all households with a clean, safe water supply of 20 - 30 litres per capita per day (lcd) within 200 metres; an adequate/safe sanitation facility per site; and a refuse removal system to all urban households.

In the medium term, the RDP aims to provide an on-site supply of 50 - 60 lcd of clean water, improved on-site sanitation, and an appropriate household refuse collection system. Water supply to nearly 100 per cent of rural households should be achieved over the medium term, and adequate sanitation facilities should be provided to at least 75 per cent of rural households.

Recognising that while the above-mentioned short and medium term goals may be achieved in urban areas, it is highly unlikely, bearing in mind the scattered settlement pattern common to most less developed rural communities in South Africa, that they will be achieved in the rural areas. In these rural areas, appropriate institutions, including village water committees, will be required to examine water provision and provide guidance to individual households on this subject; consultation (including the provision of advice and training) by the Government with these communities concerning the provision of water is essential.

There is no doubt that the single most important factor limiting the general development of the less developed rural areas in South Africa is water. The provision of piped water from boreholes, springs, or small catchment dams is an excellent way of immediately improving living standards and health by enabling the establishment of intensive agricultural production enterprises and eliminating or reducing the occurrence of water-borne diseases. Moreover, the whole infrastructure needed to support village life, such as clinics, schools, cooperatives and recreation sites, relies on a dependable water supply.

The collection of water in many rural areas, a task usually undertaken by women, frequently takes several hours, which could be far better spent on income generating and recreational activities. Contaminated water frequently causes illness (bilharzia, gastro-intestinal disorders, etc) which further reduces the economic activity of an extended family.

Accepting that (a) most rural families will not be provided with piped water and water borne sewerage systems for many years to come; (b) the development of clean water resources is inextricably linked with the introduction of improved sanitation, for only if the two needs are addressed together will there be any significant improvement in public health standards; and (c) women have a vital role to play in promoting and introducing suitable water supply and sanitation systems, reliance must be placed, in the short term at least, on simple technologies. Cost-effective rain water collection systems and suitable latrines have been developed in South Africa. The challenge facing development agencies, government and non-government, is to mobilise communities and individuals, women in particular, to introduce the technologies (with the help of welfare bodies if necessary).

Steps for introducing suitable water supply and sanitation systems

A supplier of information (extension agent), one or more local facilitators, and a community committee (water development committee, general development committee, or other) are the essential institutional/organisational components required to promote the introduction of rural water supply and sanitation systems. There are many reasons for maintaining that women should fulfil some or all of these roles and be involved in all the essential steps required for introducing appropriate systems; these include community mobilisation and organisation, data collection, training, planning, implementation (including establishment of demonstrations), monitoring and evaluation, as outlined below :

(a) Stages of a water project

At each stage of a typical water and sanitation development programme, the local community needs to be helped to develop certain skills and complete certain activities required for each of the four essential components of the process : the water system, the sanitation system, hygiene education, and community development (institutional and organisational strengthening). The important stages of a typical water and sanitation programme can be identified as follows : (a) Community interaction and capacity building, (b) community mapping and data collection, (c) community problem solving, (d) system construction, (e) system operation and maintenance, (f) monitoring and evaluation.

(b) Community interaction and capacity building

Interaction with the community includes : identification of interested groups and individuals; discussion with these people to explain the benefits of water and sanitation development; establishment of a water and sanitation development committee; motivation of the committee and preparation of the committee for its responsibilities; selection of one or more women who will serve as facilitators and take on the task of organising and implementing the programme and who will receive monetary compensation for their inputs; and organisation of training for the facilitators and selected community members.

Community management capability enhancement includes formation of the committee, construction of facilities, financial management (including fee collection where appropriate), the daily functions of safeguarding water supplies, regular maintenance procedures, and environmental hygiene improvements.

Community participation "behaviours" that are improved through the development exercise outlined above include membership and participation, decision-making capability, leadership, and knowledge and support.

(c) Community mapping and data collection

The purpose of this programme component is for the facilitators to develop, with those community members interested in water and sanitation development, the physical characteristics relevant to water resources and environmental health issues as perceived by the community, and to assemble data relating to possibilities for water and sanitation development. The process involves getting the community members to draw a map of their area depicting existing infrastructure, water sources, etc, and to record information about health problems, etc.

(d) Community problem solving

Participatory problem analysis and classification involves the facilitators in getting the community members to (a) identify and prioritise the problems relating to water and sanitation development, and (b) discuss ways and means of overcoming the problems. This will include giving attention to community health problems and environmental hygiene.

(e) System construction

Once agreement has been reached about how community groups and individual households can solve their water supply and sanitation problems, the facilitators mobilise resources (financial, advice, etc) for the groups and individual households to construct the systems judged to be most suitable (with reference to affordability, technology availability, etc).

(f) System operation and maintenance

The management of operation and maintenance (O&M) will depend on the type of system established, and on whether it is a group or individual household system, but is nevertheless based on certain fundamental premises. The first premise is that the responsibility for O&M should be in the hands of the community or individual household wherever feasible. Since the community or household benefits from the water supply and sanitation facilities, they have an inherent interest in keeping the system operating. For many rural systems, particularly rain water harvesting systems that employ relatively simple technology, communities and individuals are capable of undertaking all O&M. In other cases, local or regional repair persons, either as private entrepreneurs or from a government agency, may be required; the development of private entrepreneurs should certainly be encouraged whenever possible.

(g) Monitoring and evaluation

The various systems established by community groups and individual households should be monitored by the facilitators through visits from time to time. The success or failure of the systems should be evaluated (in terms of physical performance, economic sustainability, environmental impact and social acceptance criteria) once they have been in operation for a reasonable time.

Conclusions

In projects in which community management (individual or collective) is the norm, as is the case in most water and sanitation development projects in the less developed rural areas of South Africa, an extension agent (ideally a woman) will react with the members of an interest group or committee (ideally comprising women). Not only must the extension agent train the group members but she must also give them the skills to establish appropriate demonstrations and manage their own water and sanitation systems (household and community). In addition, there is a need to make motivators, publicity agents and trainers out of the group members, for it is they who will be responsible for persuading the local rural dwellers to introduce water and sanitation systems and to provide them with the necessary advice and training. The extension agent is thus a trainer and a trainer of trainers; she is a facilitator, not a doer.

An important point to make is that if local women are to take on the tasks of trainer, demonstrator and extensionist, some system must be put in place to ensure that they are rewarded for the service they provide. It is desirable that local or regional government should bear the cost of training, remunerating and supporting these women. Another important consideration is the need for local communities to understand (through appropriate information dissemination) that public health improvement is the main reason for water and sanitation development and that the two must always be linked; clean water without sanitation (appropriate disposal of faecal matter and other waste materials that have a negative impact on environmental hygiene) will help very little in improving health.

References

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PAPER TITLE: THE ROLE OF WOMEN IN THE ROOF CATCHMENT WATER TANK PROJECTS IN THE CATHOLIC DIOCESE OF NAKURU-KENYA

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ABSTRACT

In the Catholic Diocese of Nakuru-Kenya, the need of involving women in roof catchment tank projects has been stressed especially the ability of women to play leading roles in planning and implementation. In the area covered by the Diocese women form more than 50% of the rural population. These women are the providers of water for domestic use, watering livestock and sometimes for watering small kitchen gardens.

The main project that attracted women is the rain water harvesting from roof tops, stored in ferro cement tanks - 15,000 litres storage capacity.

The Diocese earmarked women as the target group for this type of rain water harvesting since they are the key actors and it has been proved that sustainability of the project is possible since women have a sense of responsibility and ownership, the main ingredients of a successful water project.

Women in this area had well organized groups long before the Diocese initiated a water programme. The Diocese has been helping women groups with "pushes" and strengthening their leadership capacity.

Roof catchment demonstration tanks were constructed in parishes to entice women to change from masonry tanks to ferrocement tanks popularly known as "Wanyororo type". Wanyororo is one of the Parishes where roof catchment rain water harvesting has taken an exemplary role having more than 51 women groups with an average of 20 members each.

This paper underscores how involvement of women in roof catchment water harvesting can produce quick and tangible results.

INTRODUCTION.

The Catholic Diocese of Nakuru (CDN) -KENYA receives financial aid from MISEREOR (An Episcopal Church Organization in Germany) to assist rural folks in their struggle to get safe water nearer to their homes.To realize this noble cause,the Diocese set up a Water Programme in 1986 when it was recognized that people in rural areas within the confines of the Diocese faced diverse constraints as far as supply of water was concerned.

For a project to get assistance from Catholic Diocese of Nakuru Water Programme it has to be self-help community based. Before 1990 most projects assisted by CDN Water Programme e.g gravity schemes, shallow wells fitted with hand pumps were administered by water committees consisting of 90% men.This projects did not include women in decision -making,planning etc.

Since the inception of the Diocese in 1969,there has been vigorous mobilization about "Women in development" and many women's groups have been formed for specific women projects.One of the objectives of these groups is to have water nearer to their houses. Harvesting of rainwater through roof catchment is one of the ways that these groups did identify.

In 1992 the CDN water programme, introduced ferrocement tank of 15m3 (15,000 litres) capacity for roof catchment systems. Demonstration tanks were constructed at strategic locations in some parishes so that women could examine them and make decision to whether it was a better design than the previous types. This design received acclaim and women started making plans as soon as they visited the demonstration tanks.

In the history of the Diocese, women have always initiated the construction of the tanks in the next to house inorder to ease their workload of fetching water from long distances.

The Diocese realized that involvement of women in the planning as well as in implementation was vital.Women were left to make their own decisions and seek assistance from CDN water programme.

Since 1992 to date (Dec. 1994) 2,216 have been constructed for women's groups,each tank serving an average of 6 people in the household.Before May 1994,the group had to construct 1 tank before the water programme constructs one for the group,but due to dwindling finances from the donor,the system has changed and women's group has now to construct 2 tanks before the water programme gives 1 tank as a "push".

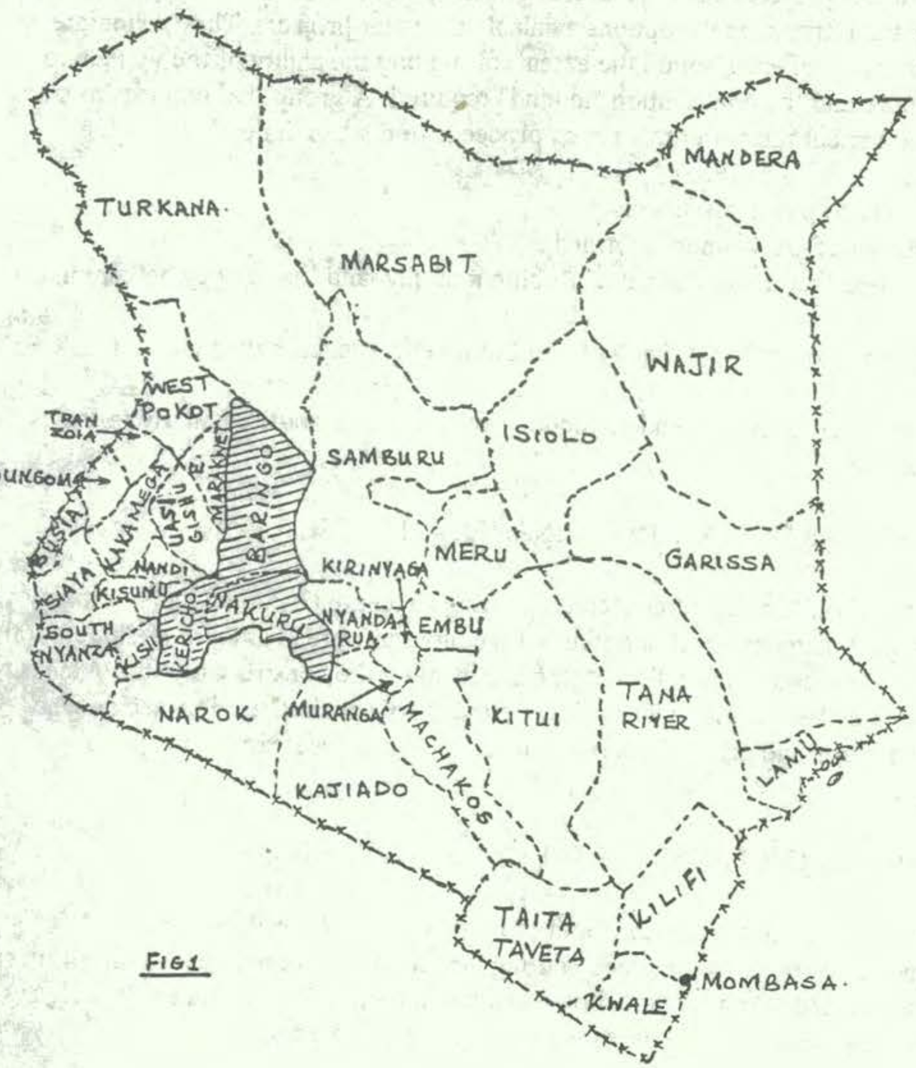

FIG 1

LOCATION OF THE DISTRICTS THAT CONSTITUTE C. D. N. (NAKURU, BARINGO, KERICHO)

INVOLVEMENT OF WOMEN IN PLANNING

CDN has employed a "Women in Development" co-ordinator who is a woman to deal with all projects aimed at assisting women in the rural areas. She meets with a group and introduces the options available on water projects. They deliberate on the suitability of each option,the extent of funding,the ability of the women to contribute and the contribution "in kind" required. A group that chooses to start roof catchment rainwater tanks then proceeds to discuss in depth about the project.

-the ability to pay is discussed

-a group of 15-30 women is formed.

-it is agreed that members will contribute monthly and that money be kept in a central pool.

-the registration of the group with the Community Development Office (GoK) is done.

-all members agree to attend communal work and contribute regularly to the central pool.

WOMEN PARTICIPATION IN FINANCING PROJECT.

After the group has been registered,the design accepted by all and ability to pay ascertained,members start contributing the monthly agreed amount (Ksh.200-400) $ 5-8 . When enough is collected ,the group starts the construction of two tanks for two members who are lucky to win the lottery (method used to decide who gets the tank).The group prepares all local materials necessary,and pays for transport.

WOMEN PARTICPATION IN THE CONSTRUCTION

Women provide the unskilled labour required by the Water Programme artisan,they provide water needed during construction (sometimes walking 1km to the water source) and provide food and accomodation for the artisan. It is always a pleasure to see happy dancing women as they help the artisan.

WOMEN INVOLVEMENT IN MAINTENANCE AND REPAIR

After a new group has constructed a few tanks the Women's groups co-ordinator arranges a meeting with the group to be addressed by the Medical co-ordinator (CDN) or a Health officer from the Ministry of Health(rarely) on the "relationship between water and health".It is in such meetings where the women are taught the need to clean roofs regularly,why it is important to drain all stagnant water around the tank,need to clean the roof area,need to clean the tank and remove overhanging tree branches etc.

TRAINING.

The women select one "fundi" to be trained by the CDN artisan. When this "fundi" is fully trained he starts constructing tanks for women's groups within his locality and who proposed his training.It is the duty of this fundi then to teach the groups how to do minor repairs e.g mending leaking taps and patching cracks. Since the fundi is within and a member of this community he can be contacted by individual tank owners for any repair of tank. It is important to note that cost of repairs is borne by the household owning the tank. CDN assists women by paying the salary of the "fundi" during the construction stage only.

CONCLUSION

Are women better managers than men ? Altough this paper deals with"the role of women in rainwater catchment projects" I wish to digress and share with you the deliberations of a meeting held between water programme personnel and 156 men and 450 women in one of the parishes in CDN. This number came from 19 borehole water projects.

Tank groups are organized and implemented by women only.Other projects are mostly organized by men with inclusion of one or two women.The water programme officers have been observing some major differences in organization,implementation and maintenance of various projects.Projects implemented by women groups give satisfaction to the whole group and a lot of commitment can be seen from committee members.Now the issue is ; despite the high cost, the tanks projects are implemented smoothly. Projects where men are more in the committee, are slower in implementation.

A strategy to introduce Rain Water Collection among the Urban Low Income Settlement's of Bangladesh.

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1.0 URBANISATION AND THE URBAN POOR

Over the decades in the recent past, Bangladesh's urban population has grown very rapidly. In fact its growth rate of 7 percent is among the highest in Asia. If this trend continues, the urban population which was 23 million in 1991 will exceed 37 million by the end of the century. Table 1 below shows the estimated growth rate of the population of Bangladesh from 1990 to 2015.

Table 1 : Urban Population Projection in Bangladesh 1990-2015

Year	Total Popn. (m)	Urban Popn. (m)	Rural Popn. (m)	Urban growth (% p.a.)	Share of Urban Popn. (%)
1990	113.7	22.9	90.8	5.4	20.1
1995	126.8	29.4	97.4	5.0	23.2
2000	141.1	37.3	103.8	4.8	26.4
2005	155.8	46.4	109.4	4.4	29.8
2010	170.5	56.8	113.7	4.0	33.3
2015	184.6	67.9	116.7	3.6	36.8

Source: World Bank, Bangladesh Economic and Social Development Prospects, Vol.III (Report No. 5409) April 1985, p. 126, Table 9.8.

This rise in the volume of urban population is attributed largely to natural growth and continued migration from rural areas mainly by low income groups. It is a fact that rural urban migration alone accounts for 70 percent of urban growth in Bangladesh. This increases pressure on urban land, services, and infrastructure which in turn deteriorates socio-economic and environmental conditions of the metropolises as well as secondary towns and cities. The situation is very critical in the capital city Dhaka which has already had to absorb almost 30 percent of the country's total urban population.

The urban population of four major metropolises of 1991 is shown in Table no. 2.

Table 2 : Urban Population of 4 Metropolitan Cities

Name of Metropolitan	Total Urban Popn. 1991	% of total National Urban Popn.	Total Urban Popn.	% of total National Urban Popn.
Dhaka	6537308	28.51	3440147	26.15
Chittagong	2342662	10.21	1396684	10.50
Khulna	966096	4.19	652000	4.71
Rajshahi	560013	2.44	253726	1.30

Source: Statistical Year Book, 1992.

Urban poverty in the country has by now assumed an alarming magnitude. The explosive growth of landless and jobless migrants in the cities has meant that they have to live in substandard conditions in slums and shanties. Not surprisingly, environmental degradation and a variety of social problems are common features of city life.

2.0 LOW INCOME SETTLEMENTS IN THE URBAN AREAS AND WATER SUPPLY

In the backdrop of the countries large population, limited land supply and high density and other physical resources the environmental issues resulting from urban expansion are getting critical. Scarcity of available land along with low affordability of the majority of population plus a poor and expensive transport system have caused development of extremely high density settlements in central parts of the city.

The poor have very little access to the urban land for their shelter. In Dhaka about 70% of the population belong to the low income group who have access only to 20% of cities residential lands, while 80% of the land is occupied by the remaining 30%. The urban poor hardly own any house, except the slum and squatter built home which is mostly built illegally. The shelters which the urban poor call home are nothing but make shift structure of bamboos, straw mats, even paper boards and plastic sheets. 64.18% of the low income dwellings are simply thatched houses, of temporary materials, causing a constant recurring cost of repair and replacement.

The state of infrastructure and social services is almost non-existent. The situation of life is aggravated during natural disasters like flood, cyclones, draughts etc.

Water Supply for the Urban Poor

The Urban Housing Demand Survey of 1970 collected data on sources of water supply in the urban areas indicated that nearly 90% of the low income people did not have piped water facilities inside their houses. One survey found that in some locations, slum dwellers buy water for drinking purpose from local taps spending Taka 0.50 per jar. Only 37% of slum dwellers get sufficient quantity of safe drinking water (CUS, 1983). The average distribution of population per tap/tube well was about 1000 (CUS, 1979). The percent of the slum households get their drinking water from wells, ponds etc. is shown in (Table 3). Even water from road ditches and potholes are used by the squatter for washing utensils. In small towns also most of the poor households use water from public tube wells and other's tube wells and municipal pipelines (Table 4).

Table 3 : Sample Information Derived from 5 Studies on Urban Poor.

Bastee of Dhaka 1975	Urban Poor in Bangladesh 1979	Islambag Bastee 1981	Slums in Dhaka City 1983	Destitute 1984-85	
				Dattapara	Mirpur
Source of Drinking Water: 1% tap, 2% well, 63% tube well	6% own tap or tube well	15% tap water 4.5% river water	37% tap and tube well	100% tube well	89% tubewell 11% pond
Other Purpose: 84% pond water		7.14% tap and tubewell 92.86% river	10% well & pond		
Source: Roushan Kader 1978, (Babupara Nayapaltan, Lalmatia).	CUS, 1979 Dhaka, Chittg. Khulna. Rajshahi City.	Hussain, Md. Imtiaz J.U., 1981 Thesis	CUS, 1983 40 slum cluster from Dhaka Municipality.	Khatun Mariyam J.U., 1984-85 (Thesis).	

Table 4 : Source of Drinking Water : A Comparison of Total Population and Low Income Population of Small Towns.

Source of drinking water	Town Total Population (Percent of Population)	Town Poor Population (Percent of Population)
Private Well	2.27 - 18.24	7.00 - 28.0
Private tube well	1.43 - 42.46	0 - 31.0
Public tap	1.45 - 23.02	10.0 - 30.0
Public tubewell	5.01 - 24.46	4.0 - 67.0
Municipal pipe line	6.01 - 51.40	3.0 - 36.0
Supplied by trade	0 - 13.06	-
Tank/Pond	0 - 28.08	0 - 36.0
River	0 - 1.43	0 - 5.0

Source: Compiled from Table 3.A. 10 of main Section Report on Water and Environmental Sanitation. The Urban Poor in Bangladesh - Phase I. CUS, 1989. p. 38.

In general communicable diseases arising out of poor environmental conditions and poor personal health practices are the most prevalent diseases of the urban poor. Scabies. Diarrhoeal diseases, Respiratory tract infections, Helminthiasis, Gastritis, Typhoid and Measles are the most common diseases. The most common causes of these diseases are related to quality of water and the use of water. Water the most necessary basic services is totally out of reach of the poor city people. How to provide safe water and adequate water to the urban poor remains a dilemina to those who are concerned about their welfare.

3.0 A strategy to introduce Rain Water Collection among the Urban Poor.

It is now a established fact that there is no short term possibility of providing even the most basic of services to the large number of urban poor. Yet strategies must be taken to develop low cost technologies and sustainable means for survival and improvement of the environment. Of these access to safe and adequate water is one of the rimary requisites. The information from various surveys and studies on urban low income show that already the supply of water is inadequate and unsafe. In such circumstances the introduction of Rain Water Collection and use can go a long way to meet the water needs of the urban low income group. Rain Water Collection already has widespread use in many countries both in the urban and rural areas. In Bangladesh at the moment UNICEF is trying to launch two Rain Water Collection Projects in the rural areas. However taking the example of so many countries where Rain Water Collection and use meeting the needs of the urban low income it is urgent to implement a similar strategy for the urban low income group of Bangladesh.

The main problems concerning water supply among the urban low income settlements are;

i) As there is no organised housing areas there is no services for the poor. The slums are temporary structures in a high density condition where as squatters are mainly on the low land areas and public land such as embankments, railway sides, road sides. Water is usually collected by the women from nearby sources i.e. drinking water is collected from tubewells or house supplies for other purposed water normally is used from ponds, ditches etc. The overall use of unsafe and inadequate water renders these large segment of population victims to wide number of diseases and the women and children are the worst sufferers.

ii) In the recent years the public authorities, NGO's and various donor agencies have been trying to provide the basic social and physical services to the poor through community and organised slum upgrading techniques. Health, education, credit schemes etc. are now provided in cooperation among these agencies to many of the low income communities. The success of EPI programme, free primary education, credit schemes for women etc. are some of the successful programmes bringing relief to the poor.

iii) In the back drop of these programmes it is the opportune moment now to introduce rain water collection as a source of safe water for various uses. Particularly during the rainy season rain water can serves as a source for domestic tasks such as wasting, cleaning and personal hygienic. It may even be used for cooking purposes. During floods rain water may also be used as a source of drinking water. A scheme on how to start such a programme is outlined below;

For the low income communities living in kutcha and semi-pucca (tin roof/thatch roof) structures in slums water source are normally street hydrants or shared tubewells. The amount of water gathered per household is always inadequate. If a scheme of rain water collection can be introduced in these areas all families can collect rain water to use it for domestic tasks such as washing dishes and clothes, house cleaning and personal hygienic such as bathing, toilet use etc. Income earning credit schemes are already operating in many of the low income communities. To link to these schemes credit for house improvement and also rain water collection can be an added dimension for health and sanitation improvement. A program that loans money to small land owners and house owners for such schemes will go a long way in providing this very basic need as well as health and sanitation improvement.

For the squatter population of the urban poor in Bangladesh who are living in the most temporary and unplanned way it is not possible to introduce household rain water collection. The only possibility is to provide community system whereby rain water will be collected in community used structures such as schools, mosques, community center buildings etc. These are at the moment being widely constructed and are present in all areas. The opportunity to start the system of rain water collection in these centers should be taken and to allow the poor people of the community to use it. The method of introduction and use will have to be worked out in cooperation with the agencies who are already providing the social services. The use of the water by the individuals or families would be worked out by the community itself.

In conclusion, the author would like to mention that in Bangladesh where 80 percent of the people are poor and living at a substandard level large scale programmes of providing health and sanitation services are being implemented both in the rural and urban areas. Housing supply and upgrading schemes are also being practiced to some extent though more in the nature of pilot schemes and test cases. It is at this stage that the need to link these programmes with a rain collection system will go a long way provide a better standard of living and help achieve a more sustainable urban environment.

ABBREVIATIONS

EPI - Expended Programme for immunisation

NGO - Non Government Organization

CUS - Centre for Urban Studies

INVESTIGATED REPORT ON THE RAIN-WATER CONVERGENCY TECHNIQUES IN CENTRAL HUNAN OF CHINA

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1. INTRODUCTION

CENTRAL Hunan refers to the hilly land and mountain areas in the middle part of Hunan Province of China. Zishui river is one of the four biggest rivers in Hunan, and also is a big tributary of the Yangtz river. It belongs to subtropical zone and monsoon climate. The annual precipitation is about 1000 to 2000 mm. Anhua County investigated lies in central Hunan Zishui river basin. The economic development to a certain degree was limited by the poor transportation in out-of-the-way mountainous areas.

IN the study and development of the water resources of reservoirs, lakes and rivers we also found that there are many valuable original techniques and experiences of rain convergence (RC) in the mountain areas. RC is the major form of water supply for local people in middle Hunan, almost every family utilizes the RC equipment. We also found some notable problems and phenomena, such as on the rain water management, waterline materials etc. Finally, some proposals ,esp. to play the part of the main force of women in RC techniques at remote mountainous district, are presented in this paper.

2.SEVERAL RC TECHNIQUES

SEVERAL typical RCs and their applications are presented here briefly, in order to illustrate the actual RC techniques. In general, RC techniques include some parts as follows

a. Optimization choices for the sources of water. in the mountain areas, they are determined by the conditions of the actual geographical position,the storage of water source, water quality and water quanity needed etc.

b. Optimal designs for water transmission forms and line materials. Because the relative distance and altitude (or waterhead)are different between the water source and users, and because of the different water quatity needed, the transmission forms should be designed perfectly and the line equipment including the conjunctions of two lines ought to be selected carefully.

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c. Choices for the rain water storage utensil. These choices are based on the water sources, quantity used and economic bases. There are many kinds of storage implements, such as bucket, earthenware pail, tank, cement cisten and so on.

d. Source of water conservation, water quality and its purifying tecniques, line materials and implements protection etc.

NOW we present the details of RC techniques in their scales.

2.1. Single-user RC Techniques

SINGLE RC user refers to a family or a small clan with about 10 persons. Generally, it can be defined as one which is used by the people with blood relationships or consanguinities.

Mr. Zhou,35 years old, is a bus driver. There are 5 members in his family, his mother,younger sister,wife and his little daughter. His living ambiment is shown in Fig.1., where ① is bamboo pipe, ② is rubber pipe in diameter 2 cm, ③ a small water earthenware pail, ④ a support of ②, ⑤ junctions between ①and②. It is the simplest RC form with only one flow direction. Above the point of water source. the vegetation is good so the RC can supply the dominent water for his family, sometimes water his private plot.

Fig.1

2.2. Multi-user RC Techniques

MULTIUSER RC means up to 7 or 8 users utilizing the rain-water convergency techniques for the dominent water-supply. Mr.Qius' RC equipment, shown in Fig.2., is the typical one of the 8th Group.Guangyi Village. There are two source points of water and througn the Phoebe bamboo (Nanzu) pipe and bamboo ditch with luunar section.the current may flow into a dispatching pool. The volume of dispatching pool is about 1 m^3, and it is connected to a storage tank by iron pipes and rubber pipes througn a valve. The storage tank is about 1.5 m^3. Between the dispatching pool and the users, the distance is about 100 m, waterhead is about 30m. It is said that the RC system can offer the drinking water for 20 to 50 people. In his father's generation the transmission implements were made of bamboos, but now some iron pipes or aluminum pipes and rubber, plastic pipes can be used too. It is noted that he has used washmachine connected by a tap from the tank. This is not the ordinary thing in the out-of-the-way areas. The functions of the dispatching pools are (1) fluid convergencing from different water sources; (2) water filtering; (3) irrigating the vegetable land.

ANOTHER example is selected from the Qunyi-upper village, its structure is summarized in Fig. 3. ① is Nanzu pipe wound iron wire outside, ② is the conjunction between two Nanzu pipes, ③ ④ ⑤ are the plastic pipes of ϕ 0.8-2cm respectively, ⑥is the mounth of fluid, in which 6 tied soft plastic pipes are connected. The plastic pipe is widely used in local area as it's fine, soft and easy to be distributed. From Fig.3., you can see the sophisticated water line network. The number of waterlines are more than that of the electric wires. To a greater or lesser degree, the people can not live without waterlines in the dry years, so they are also called " lifeline" of the people in mountain area.

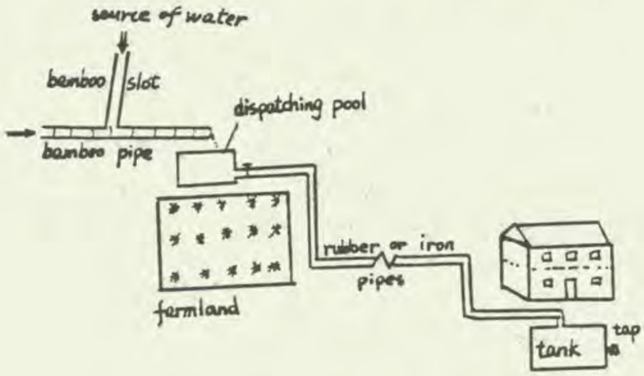

Fig.2.

A storage tank used in this RC is summarized as Fig 4 , where ① is the pole for removing deposits; ② is water intake,maybe connected by a tap; ③ is the spillway pole where the discharge can flow into water closet or a waste water pond.

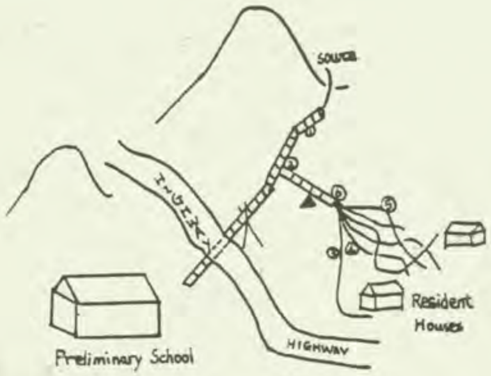

Fig.3

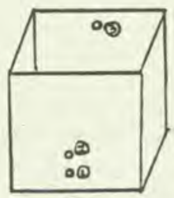

Fig.4

2.3. Integrated-user RC Techniques

IN this section we will emphasize on a RC, called integrated-user RC, which can supply for more than 10 users with about 50 people or over, especially it is the one established by the local government, or funded by the international fundation as well as other friendship and goodwill groups. Here is the example from the 6th Group of Qunyi Village in Anhua with 10km long from the Zhexi Hydroelectric Power Station. There are 102 people in this Group, their houses concentrate relatively. In 1989 the Anhua Water

Conservancy Bureau invested ¥8000 for developing a RC system, in order to solve the drinking water problems. Since then the people have had their own "waterworks" producing running water. It is also called Tianshui Supply System, i.e. the rain-water convergency system.

THE main departures of this system from the single and multiuser RCs are the two parts followed

a. a nearly 1000m long ditch, spiralled up the mountain with less 6cm depth and a lunnar section, covered by a thick growth of grass and convergencing the rain-water.Generally, the droplet and dew also can flow into the ditch by the surface from the vegetation, because of the big moisture and vapour in the high mountains. In Feb., when we visited to Anhua, there is a little current in canal with the depth of about 2cm. Then the Tianshui flows into

b. a large dispatching reservoir, with the volume of 3m × 3m × 4m, that is $36m^3$ In its upper lid , there is a window used to wash and clean the reservoir. It was made of blocks, mixed with cement. The scheme is shown in Fig.5.

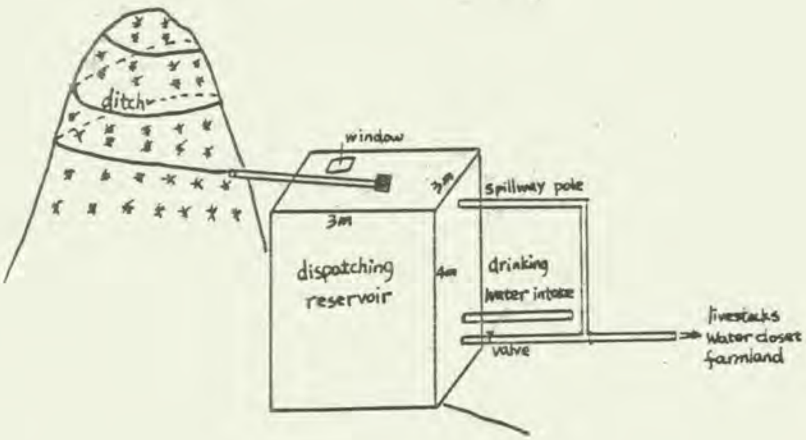

Fig.5.

3. THE RC'S FUNCTIONS AND ANALYSES

IT is very surprised that the rate of spread utilities of RC is almost up to 100 percent in the investigated areas of central Hunan. Therefore we visited on the local people. As a representative of the guests, Mrs.Qiu(Grandma Zhan, an illiterate person) who is 60 year-old and is the leading lady of multiuser RC in 2.2., can tell you why they have been using RC other than the stream in the gorge beside her family.

a. The stream is dirty. It was polluted by the excreta of man and livestocks ,and the chemical detergent of the waste water from the washing affairs, as a result of the poorer quality and lower envoirmental knowledge of local people.

b. The quantity of the stream varies by season. In summer mountain torrents often rush down, it is very dangerous to take water from the gorge. But in winter, there is low water and thus the stream is intermittent . It is the fact that the lower water the higher pollution.

c. Release the women's labour and pressure in their dayly lives. In mountain areas, the division of work is distinct. Men do the physical labour(mining etc.), or earn money in cities far away from their families. Women do the housework and have the heavy responsibility to take care of the whole things (including their children) in home. By using RC, it is more convinent for women , saves time and enhances the safety for the women.

d. RC may be used as a power , such as waterwheel, as well as for irrigating farmlands.

e. RCs have an additional outstanding function . Now they have become the ties of the adjacent people, enhanced the friendship among the users.

CN the other hand ,we should note the problems and phenomina in the RC's applications in central Hunan, such as

a. The conservation of water source. The recent situations show that the sources maybe destroyed with the expanded population and the economic development, people need more and more lands and woods. The forests are damaged rudely in some areas.

b. Water quality.

c. Line materials. Many waterlines used are the plastic oil pipes(ϕ 9mm), which are unsterilized and easy to be ageing . Bamboo pipes , in the case of high waterhead and high pressure or under the burning sun, will split easily. While using iron pipes are limited by the economic status for the long distance users.

d. Economize on water and the compositive rain-water utilities.

4. CONCLUSION AND PROPOSALS

THE flexibility, combined with the simplicity, low cost, and the advantages in geographical position of RC , guarantee it as the major form of water-supply both at present and in the future. Good prospects exist in the hilly lands and mountainous areas ,esp. in the out-of-the-way under developed regions and the areas of lacking water. It is no doubt that RC should be investigated further. Therefore some proposals are presented as follows

a. To play the part of the main force of local women at remote areas. Because not only women are the direct users of RCs, they are the main force of doing housework,irrigating private plots and feeding livestocks. but also women are the main guards and constructers of RCs, the design of RC should meet the requirements from women and must be safety, reliability, simplicity and easy to be repaired.

b. To improve the cultural quality of local people, esp. local women, with no illiterate person.

c. To publicize the general and specific policies of the water source conservations.

d. To ensure that people could drink the clean water, esp. in the work of supporting the development at mountainous areas.

e. To encourage that the local government and other goodwill groups invest to RC concentrately, and to enhance the management of the present RCs.

Section 9

RAINWATER QUALITY AND ITS PROTECTION

The Water Quality Problem of Rainwater UtiliZation in the Arid Region of Northwest China

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ABSTRACT

In this paper we have analyzed and assessed the water quality of the catchment and storage rainwater in the typical areas of Northwest China and made some conclusions that main factors exerting influences on the water quality are: air pollution, the building materials of catchment surfaces and water cellars, hygienic conditions, and that the water quality has seasonal and regional changes and the indices of rainwater commonly keep in accoudance with the national criteria of water quality of drinking and irrigation water. and that the most of the indices of the rainwater are superior to those of local spring and river water. Thus the catchment and storage rainwater is a new type water resource which is whole some and has much potential of solving the problem of domestic water in the arid areas

keywords: arid region in Northwest china, rainwater utilization, water quality problem.

INTRODUCTION

The arid areas in Northwest china lie in the interior Asian—European Continent, a few annual rainfall, serious shortrage of surface and ground water resources. Its extensive land, complicated topograph and sparsely habitated population make the diversion and lift project very difficult and less effective, which cost great investment. Therefore, the problem of water for drinking and irrigation has not been solved completely for a long time, which has become the limitation of the development of scocial economy and the improvement of local pepole's living standard.

With the revival and rapid popularization of the rainwater catchment technology around the world in the past ten years, rainwater has been proved to be a new type water resource of lower cost, higher effectiveness, reliability and much potential[6]. For example, the total area of the aridest sixteen counties in Gansu Province is 60,600 km^2, and its annual average precipitation is 330 mm, and the total rainfall volume is about 22.72 billion m^3, which equals the 75 percentages of the Yellow River annual flow through the Lanzhou discharge cross—section. But only two billion cubic metre of rainfall comes into runoff, and their runoff coefficiency is 0.05 to 0.1 and the rest is consumed through non—beneficial evaporation which is a great waste to the arid areas of little rain.

In some areas of Shahxi, Gansu, Ningxia, Qinghai, Xijiang provinces, the carring—out and popularization of the technology of "courtyard catchment and storage rainwater", which makes use of the solidized catchment systen such as concrete grounds, cement tile roof, rammed soil surfaces to promote the catchment coefficiency and to enlarge the storage water volume, opens a new way to solve the problem of drinking water in the arid region. Since 1990s, the fact that about ten thousand courtyard catchment and storage cellars and pools have been built in Gansu has proved the technology to be an effective, feasible and reliable measure.

Precipitation comes from the condensed vapour of meteoric water, and its water quality relys on local envirormental conditions to great extent. Rainfall in the interior continent may mix with the dust and bacteria in the air, smoke from burning coal and industrial powder in the areas of urban and industrial development. In general, rainwater is soft water of little impurity and low degree of mineralization. But the more and more serious atmospheric pollution with increasing industrialization, the different materials and the interaction between them and rainwater certainly have an increasing influence on the water quality of the catchment and storage rainwater.· In the course of water resoures exploitation and programming, the effective rainfall is not the only importat paramenter and its water quality is of same importance and particularly in the arid areas which rainfall contribute little to local natural water input, water quality may be more important. Thus, with the popularization and further development of the technology, it is a matter of great significance to carry out the water quality monitoring and assessment of the catchment and storage rainwater, and to research the avenues and measures of bettering the water quality.

In this paper authors have made use of the results of the chemical examination of the rainwater contained in water cellars, and tried to make some objective conclusions about the rainwater quality in Yuzhong and Tongwei two counties through the analyses and assessment which may provide scientific basis for rainwater utilization.

SAMPLES AND RESULTS

1. In order to make the samples comparable, we collected the samples under different conditions in Yuzhoug and Tongwei counties of Gansu province in January and September 1992[see Fig. 1 an Tab. 1].

The results of the chemical examination of water samples are listed in Tab. 2and Tab. 3.

ASSESSMENT AND ANALYSES

According to the national criteria of P. R. China: the standards of drinking water (GB5749—85) and water quality criteria for irrigation (GB5084—85)[4], consulting some related literature[3], authors have assessed main indices of water quality through comparison and analysis of the results [see Tab. 3].

1. The assessment of characteristic values of single index

Most indices of wate quality of the catchment and storage rainwater except the individual maximum conform to the national standards for drinking water : PH, arsenic, cadmium, chromium, copper, mercury, lead, selesium, zinc, degree of mineralization, total hardness, nitrates, chloride, cyanide, sulphates, anion detergent, among which the values or concentrations of degree of mineralization, total hardness, chloride, sulphates, nitrates and copper are much lower. Compared with the standards of drinking water ,the concentations of phenol and iron are higher in Yuzhong, and total coliform and total bacteria much too higher, respectively 3272 times and 17 times their standards, and the concentrations of iron and manganese in the rainwater in Tomgwei is higher, and total coliform and total bacteria greatly higher 2907, and 89 times of the standards respectively.

2. The comparison between the rainwater and local spring or river water.

Through the comparison of annual characteristic values of the catchment rainwater and spring and river water in the two counties Yuzhong and Tongwei, we could conclude the following:

In the rainwater in Yuzhong county, the concentrations or values of potassium, magnesium, sodium, calcium, lead, iron, copper, manganese, zinc, chromium (six valencies), nitrites, bicarbonate, fluoride, suspensoids, degree of mineralization , total alkalinity, total hardness, total bacteria, total coliform, anion detergent and conductivity are lower than those of local spring water. Moreover, the cocentrations or values of magnesium, sodium, chloride, sulphates, degree of mineralization, total alkalinity, conductivity are much lower, and only PH and the concentrations of selenium, ammonia as N are higher.

In Tongwei, the indices of river water exceeding those of rainwater are the following: chloride, sodium, sulpates, magnesium, iron, suspensoids, cadmium, nitrates, degree of mineralization, total hardness, conductivity ,fluoride, total coliform, 5—day BOD, arsenic, chromium (six valencies), lead, bicarbonate, ammonia as N ,dissolved oxygem, copper, PH except total bacteria, potassium, zinc, mangnese, selenium, phosphorus, anion detergent, total alkalinity and phenol.

In general, some toxic constituents in rainwater such as mercury and cyanide could not be measured and the concentrtrions or values of PH, suspensoids, arsenic, total alkalinity, chloride, total coliform are much lower than those of the Yellow River water in the same period.

The upper analyses indicate that rainwater is a new type water resource of tidiness, hygiene and fairly high quality, and rainwater is an suitable substitute water source for spring or river water of lower water quality in some areas. Long—term drinking roughly treated rainwater would play an important role in exterminating water—borne endemic disease, and in bettering the living conditions of resident in arid areas and in improving local people's health.

3. The comparison of water quality of the rainwater in different cellars in the same place at the same time

The following conclusions could be made according to Table 2 and Table 3:

PH, copper(Jan.), lead, selenium, zinc, potassium, total alkalinity, nitrites have higher values in the rainwater contained in the concrete water cellars with cement or grey tile catchment surfaces. The indices of arsenic, iron, calcium, magnesium, degree of mineralization, total hardness have higher values in the rainwater contained in soil water cellars. The indices of chromium (six valencies), cadmium, phosphorus, total bacteria and 5—day BOD have higest values in the rainwater in the cellars with natural or compound soils catchment surfaces.

Total coliform become fewer in the rainwater contained in the concrete cellars with tile or concrete catchment surfaces.

These conclusions may be the results from that the catchment surfaces and water cellars of different materials have different influences on the rainwater quality.

Therefore, clear concrete grounds or tile roots are the perfect catchment surfaces, and concrete water cellars could enhance their water tightness and lower the degree of mineralization and total hardness. What influences concrete soil water cellars exert on the other metallic and nonmetallic elements and organism need further research.

4. The comparison of the rainwater quality stored in the same type water cellars in the same place at the different time.

The following conclusions could be made from Table 4.

The values or concentrations of conductivity, 5—day BOD, chromium (six valencies), copper, sodium, magnesium, nitites, nitrates, sulphates, carbonate, bicarbonate and chloride are higher in January than these in September. Suspensoids, iron, calcium, zinc, total hardness, total alkalinity, fluoride and phenol have higher concentrations or values in September. The other water quality indices such as PH, total bacteria, total coliform, degree of mineralization change in different places with time and have no evident regulations to be after, These difference may be caused by the difference of original chemical composition of the rainwater at different time[10].

The rainwater sampled in January is the rest of the past year and has been long stored. The concentrations or values of nitrites and 5—day BOD which indicate the degree of pollution, and conductivity which indicates the concentrations of ions have evidently become higher, which may be related to the secondary pollution and the interaction between the materials of cellars and the rainwater in them in the course of rainwater utilization. However, the rainwater sampled in September is collected freshly in that year and generally the values or concentrations of suspensoids, total coliform and total bacteria are higher.

Of course, the chemical nature of the rainwater in water cellars is in a dynamic state and its water quality should be influenced by stocastic changes in physical situation and properties (Incl. time and space)[1]. Thus, the systematic asssessment of the trend of changes with time of water quality needs continual chemical examination of the rainwater in cellars, and synchronous tidy rainwater water quality monitoring, and some data about the rainwater before and after sampling, which would be beneficial to the utilization of rainwater resource.

5. The comparison of the rainwater quality in the same type water cellars of one kind in different places at the same time.

We have taken sample 1 and sample 5 in Table 2 to compare with sample 5 and sample 4 respectively and then concluded the following: on the one hand, the concentrations or values of ammonia as N, phenol, nitrates, nitrites, dissolved oxygen, 5—day BOD and sulphates have higher values in the catchment rainwater in Yuzhong, which should be related to its location near the air pollution source—the city of Lanzhou, on the other hand, the concentrations or values of maganese, selesium, potassium, calcium, degree of mineralization, toatal hardness, total alkalinity are higher in Tongwei, which should be related to the constituents of soil and building materials besides random man—made pollution.

6. There are none of some trace elements such as iodide, bromide, strontium, silver and nickel in the rainwater, and the concentrations of zinc, iodide, are less than the needs for normal phycological function and people's health in domestic water[9].

It is an essential part of the studies on rainwater uttlizaion how to change the concentrations of the constituents in the rainwater and to exterminate their disadvantageous influences, and to make the catchment rainwater more suitable for drinking.

7. The indices of PH, arsenic, cadmium, chromium (six valencies), copper, mercury, lead, selenium, zinc, phenol, chloride, fluoride, cyanide and total coliform in the sampled rainwater are all accord with the national irrigation water quality criteria of one class. Therefore, the catchment and storage rainwater is a good water source for developing rural courtyard economy and rainwater ecological agriculture.

CONCLUSIONS

The catchment and storage rainwater is a new water source of fairly high water quality which could meet the criteria of domestic water and irrigation water on the whole, and only total coliform and toatal hardness exceed their corresponding criteria for drinking and irrigation water too much. This problem could be solved through changing the building materials of the catchment surfaces and water cellars, improving hygienic conditions and taking some effective disinfectant measures. Comparatively, local spring and river water in the arid region is not fit to drink and irrigate and its main water quality indices such as degree of mineralization and total hardness have too high values, and even it contains toxic cyanide. The catchment rainwater should be chosen as domestic and irrigation water.

The different materials of the rainwater catchment systems exert different influences on rainwater quality which mainly depends on these local factors: atmospheric constituents, building materials, soils, hygienic conditions and geographic location of the rainwater catchment system. Therefore, the rainwater quality has seasonal changes and regional differences.

In brief, the study on rainwater utilization has a vast vista and its abundant content. Rainwater utilization has great potential and superiority both in the arid Northwest China and in the islands lacking river water and in the limestone areas in South China[5]. Moreover, rainwater quality is a very important aspect which should be payed much attention to in rainwater utilization, and since rainwater quality is changing continously to maitain physico—chemical equilibrium with its environment, more knowledge of the interaction between the catchment rainwater and its environment needs further research.

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Figure 1:Location of Sample Points

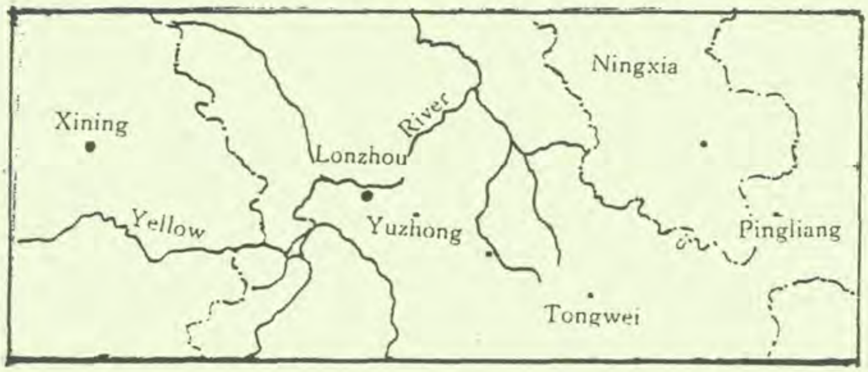

Table 1. The Conditions of Water Samples

place / sample / item	Yuzhong county						Tongwei county					
	1	2	3	4	5	6	1	2	3	4	5	6
material of catchment surfaces	concrete	rammed soil	cement tiles	soil	cement tiles	local spring water	concrete	natural ground	grey tiles	grey tiles	concrete	local river water
water cellar type	soil	concrete	concrete	soil	concrete		concrete	soil	concrete	concrete	soil	
the years of cellars being built	1958	1983	1980	1988	1991		1988	1988	1990	1991	1991	

Table 2: The Results of the Catchment Rainwater Chemical Examination in Yuzhong County

sample / data / item	1		2		3		4		5		6	
	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.
Tempereature(C)	4.4	11.4	5.0	12.0	1.4	14.0	5.9	9.6	3.4	11.0	2.8	16.8
taste and ordor	none	none	none	none	none	none	none	none	—	—	—	none
PH	7.9	7.4	7.8	8.3	7.8	8.1	8.0	8.2	9.6	9.4	7.5	8.2
conductivity ($\mu s \cdot cm^{-1}$)	251	229	177	157	219	148	185	181	286	141	5670	2141
suspensoids	104	367	76	93	409	45	60	74	100	264	548	341
As	0.005		0.009	0.007	0.017	0.005	0.011	0.009	0.004	0.013	0.007	0.011
Cd	0.0026	0.003	0.0042	0.001	0.0042	0.001	0.0042	0.003	0.0042	0.002	0.0074	0.005
Cr(+6)	0.009		0.015		0.005		0.006		0.021		0.007	
Cu	0.0115		0.0062		0.0168		0.0062		0.0168		0.0328	
Hg	0		0		0		0		0		0	
Fe	0	0.284	0.0045	0.102	0.2901	0.302	0	0.31	0	1.349	0.3496	0.416
Mn	0	0.037	0.005	0.02	0.0672	0.019	0.0258	0.025	0	0.114	0.1242	0.034
Pb	0.0618	0.014	0		0.0272		0	0.016	0	0.026	0.0618	0.055
Se	0.001		0.002		0.008		0.007	0.005	0.001	0.006	0.001	0.003
Zn	0	0.213	0	0.046	0.0799	0.073	0	0.151	0	0.238	0.0213	0.172
K	2.3464	2.287	3.0295	2.448	7.2628	2.414	1.204	1.315	7.448	5.727	3.8741	14.268
Na	9.5758	9.9	3.1397	3.702	5.1875	2.775	4.0173	6.956	22.62	7.255	[illegible]	33
Ca	[illegible]	[illegible]	23.5	26.1	27.8	22.3	24.4	26.6	11.1	16.[illegible]	219	41.1
Mg	[illegible]	[illegible]	3.45	1.97	5.19	0.61	7.92	2.95	2.98	2.46	258	[illegible]
P	[illegible]	[illegible]	0.075	[illegible]	0.203	[illegible]	0.067	0.016	0.056	0.113	[illegible]	[illegible]
phenol		0.002	0	0.024	[illegible]	0.024	0		0	0.002		
degree of mineralization	155	158	112	128	120	102	110	122	162	166	1460	1730
total hardness (as CaO)	[illegible]	59.1	45.5	73.9	56.9	58.2	22.4	78.5	22.5	50.1	991	389
total alkalinity (as $CaCO_3$)	44.1	129	40.3	148	43.6	113	43.2	128	53.8	123	145	178
HCO_3^-	56.1	78.9	37.7	73.9	91.9	69.1	94	78.1	63.0	41.4	710	109
dissolved oxygen	[illegible]	7.1	6.75	[illegible]	3.34	6.9	5.01	5.8	8.42	6.2	8.73	6.2
ammonia as N	0.18	0.15	0.02	0.13	0.06	0.09	0.10	0.23	0.16	0.3	0.2	0.14
nitrites	0.123	0.017	0.015	0.003	0.044	0.005	0.05	0.005	0.203	0.057	0.024	0.286
nitrates	0.65	0.349	0.215	0.487	0.956	0.361	1.265	0.751	1.147	0.609	7.475	0.273
chloride	7.13	8.92	5.35	3.57	5.35	8.92	4.99	0.13	27.1	4.28	1029	369

fluoride	0.32	0.52	0.19	0.57	0.43	1.29	0.34	1.44	0.62	2.85	0.34	1.69
cyanide												
sulphate	51.0	36.5	12.8	10.7	36.2	13.9	25.6	21.9	33.3	10.2	94.4	399
5-day BOD	4.94	5.0	5.3	1.0	3.16	2.3	4.73	3.2	6.52	3.5	7.78	3.6
corrosive CO_2	–	6.49	–	3.69	–	3.74	–	4.78	–	0.0	–	0.0
anion detergent	–	0.037	–	0.047	–	0.05	–	0.04	–	0.053	–	0.062
total bacteria	1800	1200	740	300	420	1300	9800	700	287	400	6200	8200
total coliform	23800	9600	9600	940	1800	230	23800	2300	23800	2300	23800	230

Table 3: The Results of the Catchment Rainwater Chemical Examination in Tongwei county

sanple / data / item	1		2		3		4		5		6	
	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.	Jan.	Sept.
Temperature(C)	6.2	17.6	6.0	13.2	5.4	16.8	5.5	17.0	5.6	14.0	2.3	25.8
taste and ordor	none		none		none		none		none		none	
PH	7.5	7.9	7.6	7.5	7.6	7.8	9.7	7.9	7.6	7.8	7.5	8.3
conductivity ($\mu s.cm^{-1}$)	339	272	372	339	377	333	236	260	422	302	9760	8994
suspensoids	14	21	12	24	4	15	12	453	212	39	1294	361
As	0.008?	0.014	0.01	0.025	0.006	0.013	0.001	0.01	0.012	0.015	[illegible]	0.017
Cd	[illegible]	0.002	0.0026	0.003	0.01	0.001	0.001	0.001	0.0042	0.004	[illegible]	0.015
Cr(+6)	0.011?		0.014	0.008	0.005		0.008		0.004		[illegible]	0.007
Cu	0.0168?		0.0062		0.0062		0.0115		0.0062		[illegible]	
Hg	0		0		0		0		0		0	
Fe	0.0164?	0.401	0.373?	0.501	0.1632	0.307	0.1672	0.386	0.373?	1.214	[illegible]	2.872
Mn	0	0.2	0.0465	0.214	0.2951	0.146	0.0517	0.141	0.2641	0.487	0.5645	0.132
Pb	0.0272	0.045	0	0.038	0	0.038	0.0618	0.036	0	0.053?	[illegible]	0.168
Se	[illegible]	0.009	0.005?	0.007	0	0.007	0.009	0.011	0.002	0.009?	[illegible]	
Zn	0	0.147	0	0.172	0	0.476	0	0.234	0	0.256	0	0.121
K	18.511	23.568	9.576	28.5	15.175	32.261	7.448	22.19	10.063	17.28	[illegible]	11.65
Na	12.501	7.788	2.5546	5.026	13.086	9.419	20.400	8.65	18.645	5.009	613.[illegible]	1758.1
Ca	15.3?	[illegible]	49.2	44.6	34.9	35.7	18.4	30.2	56.1	42.6	[illegible]	451.2?
Mg	10.5	2.09	3.11	2.21	7.66	1.72	0.91	1.72	9.47	1.48	551	144
P	0.092	0.28	0.25	0.232	0.121	0.11	0.089	0.096	0.288	0.505	0.251	0.096
phenol	0		0		0	0.002	0.001	0.002	0	0.001	0	0.001

degree of mineralization	204	192	254	244	228	226	304	174	346	212	8560	8660
total hardness (as CaO)	51. 2	87. 1	76. 1	121	66. 5	96. 2	27. 9	82. 6	100	112	1870	2955
total alkalinity (as $CaCO_3$)	95. 5	241	88	315	88. 3	249	112	241	93. 8	257	110	239
HCO_3^-	208	147	192	192	192	152	129	147	204	156	240	107
dissolved oxygen	6. 35	3. 9	5. 9	4. 8	5. 9	1. 7	7. 2	3. 2	6. 0	3. 6	5. 9	4. 7
ammonia as N	0. 38	0. 47	0. 05	0. 09	0. 06	0. 01	0. 09	0. 11	0. 06	0. 03	0. 24	0. 12
nitrites	0. 017	0. 011	0. 013	0. 015	0. 001	0. 115	0. 364	0. 005	0. 013	0. 005	0. 035	0. 083
nitrates	1. 0	0. 248	0. 903	0. 405	0. 39	0. 239	0. 168	0. 112	0. 183	0. 407	3. 493	0. 327
chloride	22. 1	10. 3	13. 6	17. 5	19. 3	19. 6	9. 27	12. 5	28. 5	12. 1	2390	2388
fluoride	0. 40	0. 31	0. 32	0. 45	0. 26	0. 30	0. 42	0. 40	0. 31	0. 63	0. 85	1. 55
cyanide	0		0		0		0. 002		0. 003		0. 002	0. 007
sulphate	31. 3	3. 4	7. 18	1. 94	14. 1	14. 1	27. 2	1. 46	28. 2	5. 59	592	1247
5-day BOD	5. 0	2. 2	2. 3	3. 1	2. 9	0. 1	1. 6	2. 4	0. 3	1. 8	3. 1	2. 2
corrosive CO_2	—	6. 6	—	3. 9	—	0	—	1. 38	—	1. 90	—	0
anion detergent	—	0. 037	—	0. 078	—	0. 037	—	0. 074	—	0. 05	—	0. 028
total bacteria	225	28600	2510	2250	216	26500	198	25500	340	2500	496	1800
total coliform	230	23800	2300	9600	230	2300	230	23800	920	23800	920	23800

Table 4: The Characteristic Values of the Water Quality Indices

characteristic / values / item	drinking water standards	irrigation water criteria	Yuzhong mean value Jan.	Yuzhong mean value Spt.	Yuzhong mean value year	Yuzhong max.	Yuzhong min.	Yuzhong spring	Tongwei mean value Jan.	Tongwei mean value Spt.	Tongwei mean value year	Tongwei max.	Tongwei min.	Tongwei river	Yellow River
temperature(℃)		35°	4.0	11.6	7.8	14.0	1.4	9.8	5.70	15.7	10.70	17.6	5.4	14.0	
taste and odor	none	none	none	none	none	none	none		none	none	none				
PH	6.8－8.5	5.5－8.5	8.22	8.28	8.25	9.6	7.4	7.85	8.0	7.78	7.89	9.7	7.5	7.9	8.5
conductivity ($\mu s \cdot cm^{-1}$)			223.6	171.2	197.4	286	141	3905.5	349.2	301.2	325.2	422	236	9377	
suspensoids			149.8	168.6	159.2	409	15.0	114.5	50.8	110.4	80.6	453	4	827.[illegible]	170
As	0.05	0.1	0.0092	0.0068	0.008	0.017	0	0.009	0.0074	0.0154	0.0114	0.025	0.001	0.011	0.012
Cd	0.01	0.005	0.0039	0.002	0.003	0.0042	0.001	0.0062	0.0018	0.0022	0.002	0.0042	0	0.0128	0
Cr(+6)	0.05	0.1	0.0112		0.0056	0.021	0	0.0035	0.0084	0.0016	0.005	0.014	0	0.009	0
Ċu	1.0	1.0	0.0115		0.0058	0.0168		0.0164	0.0094		0.0047	0.0168	0	0.0161	0.009
Hg	0.001	0.001	0		0	0		0	0		0	0		0	0.002
Fe	0.03		0.0589	0.4694	0.2642	1.349	0	0.3828	0.2187	0.5618	0.3903	1.211	0.0164	1.8944	
Mn	0.1		0.0196	0.043	0.0313	0.258	0	0.0791	0.1315	0.2376	0.1846	0.487	0	0.1981	
Pb	0.05	0.5	0.0178	0.0112	0.0145	0.0618	0	0.0581	0.0178	0.0124	0.0301	0.0618	0	0.1323	
Se	0.01	0.02	0.0038	0.0022	0.003	0.008		0.002	0.0044	0.0086	0.0065	0.011	0	0.003	
Zn	1.0	2.0	0.016	0.1442	0.0801	0.238	0	0.0967	0	0.257	0.1285	0.476	0	0.0605	
K			4.2581	2.8382	3.5482	7.418	1.204	10.0711	12.1145	24.7596	18.4371	32.26	7.448	8.5697	
Na			8.908	6.1176	7.5128	22.62	2.775	405.199	13.4574	7.1784	10.3079	20.4001	2.5546	1185.84	
Ca			23.78	24.74	24.26	32.4	11.1	150.05	35.58	36.9	36.24	56.1	18.4	138.[illegible]	

Mg			5.814	1.992	3.903	7.92	0.61	175.85	6.33	1.844	4.087	10.5	0.91	191.5	
P			0.0984	0.0742	0.0863	0.203	0.046	0.159	0.168	0.2116	0.2063	0.505	0.089	0.1735	
phenol	0.002	1.0	0	0.0144	0.0052	0.024	0	0	0.0002	0.001	0.0006	0.002	0	0.0005	0.003
mineralization	1000		134.4	135.2	134.8	168	102	3065	267.2	209.6	238.4	346	174	8610	
total hardness (CaO)	450		46.72	69.96	58.34	89.1	22.5	745	64.34	99.78	82.06	112	27.9	2412.5	101
totalalralinity			45.0	128.2	86.6	148	10.3	169.5	95.52	260.6	178.06	315	88	174.5	
oatal alkalinity (CaO_3)			87.14	69.28	78.21	96.1	11.4	209.5	185	158.8	171.9	208	129	173.7	
ammonia as N			0.104	0.18	0.142	0.30	0.02	0.17	0.128	0.112	0.135	0.47	0.01	0.18	0.19
nitrite as N			0.087	0.0174	0.0522	0.203	0.003	0.155	0.0816	0.0302	0.059	0.364	0.001	0.059	0.011
nitrate as N	20		0.9066	0.5114	0.709	1.447	0.215	3.8745	0.5288	0.2822	0.4055	1.0	0.112	1.91	0.84
chloride	250	200	9.984	5.164	7.574	27.1	0.13	694.5	18.554	14.4	16.477	28.5	9.27	2389	23
fluoride	1.0	2.0	0.38	1.334	0.857	2.85	0.19	1.015	0.342	0.418	0.38	0.63	0.26	1.2	
cyanide	0.05	0.5							0.001		0.0005	0.003	0	0.0015	0
sulphates	250		31.78	18.64	25.21	51.0	10.2	246.7	21.6	5.3	13.45	31.3	1.46	919.5	
dissolved oxygen			5.764	5.90	5.832	8.42	3.34	7.465	6.27	3.44	4.855	6.35	1.7	5.3	
5−day BOD			4.93	3.0	3.965	6.52	1.0	5.69	2.42	1.92	2.17	5.0	0.1	2.65	1
corrosive Co_2			--	3.74	3.74	6.49	0.0	0.0		2.756	2.756	6.60	0.0	0.0	
anion detergent	0.3		--	0.0454	0.0454	0.053	0.037	0.062	--	0.0552	0.0552	0.078	0037	.0028	
total bacteria	100		2609	780	1695	9800	287	7200	698	17070	8884	28600	198	1103	
total coliform	3	10000	16560	3074	9817	23800	230	12015	782	16660	8721	23800	230	12360	31400

* The blanks indicate that the items could not be measured.

* * All concentrations are reported by weight −per− volume units of milligrams per liter (mg/l), and total bacteria and total coliform are given in numbers per liter, and conductivity is measured in microsiemens /cm (μs/m).

THE RAINWATER CATCHMENT SYSTEMS IN CENTRAL& REGION OF BENIN (WEST-AFRICA), WATER POLLUTION AND ENVIRONMENT SAFEGUARD.

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INTRODUCTION

The Central region of Benin is a hilly area extending in latitude between 7°30' and 8°30' N, and in longitude from 2° to 2°30' E. It covers the territorial subdivisions of Dassa-Zoumé, Glazoué, Savalou, Bantè, Savè and Ouèssè, with about 339,000 inhabitants. Our paper deals with only two subdivisions, Dassa-Zoumè and Glazoué. The population constituted with Idatcha, Itcha, Tchabè and some Fon, Mina and Bariba... is essentally rural. In this precambrian peneplain cristalline rocks make water not continously available. Streaming exceeds infiltration and sane rocks do not permit to bore many deep wells to get water permanently. Since the end of rainy season, water shortage becomes more and more prejudicing and especially in the depth of the dry season. This situation obliges people to adopt very soon rainwater catchment and preservation systems.

What are those systems and water quality ?
How do traditional practices participate in safekeeping of environnement ?

I - THE REGION OF HILLS

Fig. 1 : Location of the region (p.2)

The hills of the Precambrian peneplain are constituted with cristalline rocks of dahomeyan (granite, gneiss, rhyolite). It is a whole of plateaus with 200-300 m high surmounted by residual reliefs of North-South orientation. The altitude is about 350-465 meters high in the sector of Dassa-Zoumè-Itangbè).

Fig.2 : Geological map of the region (p.4)

Thin soil layers : nearly everywhere rocky material is subcoming to the surface. This fact limits the number of traditional wells and if they exist, they dry out before the end of the dry season. Thus, populations exploit with difficulty superficial waterbodies. Their situation is all the more worrying as rainfalls are irregular from year to year in this transitional zone between sudanese climate of North (one rainy season and one dry season) and guinean climate of South (two dry seasons and two rainy seasons).

Fig. 3 : Graph of interannual rains evolution(1961-1990) of three stations in the middle region of Benin (p.5)

Let us add the high evaporation of no renewable surface waters : Physical evaporation (decade) of march 1992 is : 55,4 mm ; 70,4mm ; 87,1mm .

What shows the importance of rainwater catchment.

Fig. 2 GEOLOGICAL MAP OF THE REGION

(Adapted from R. Pougnet, 1955)

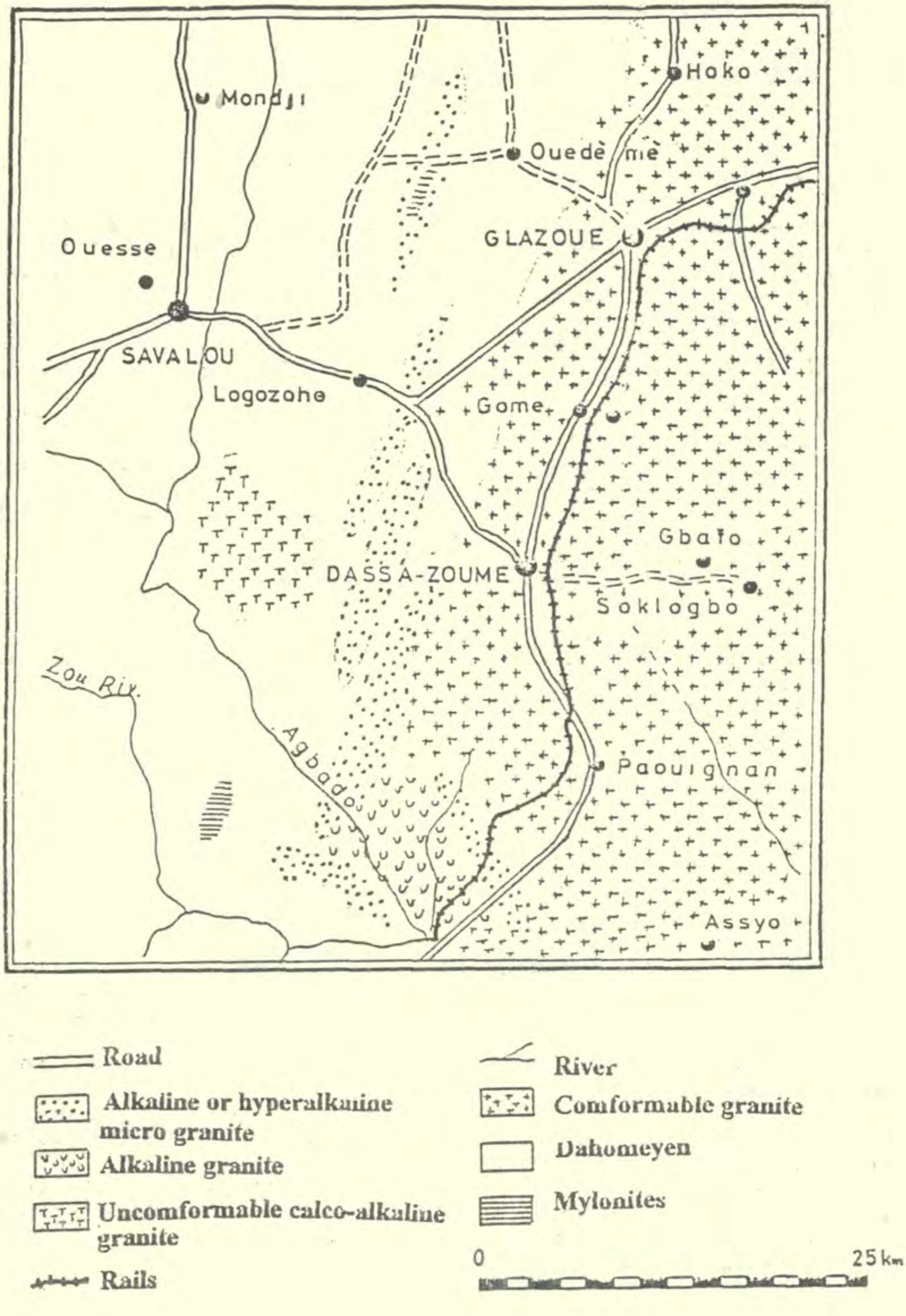
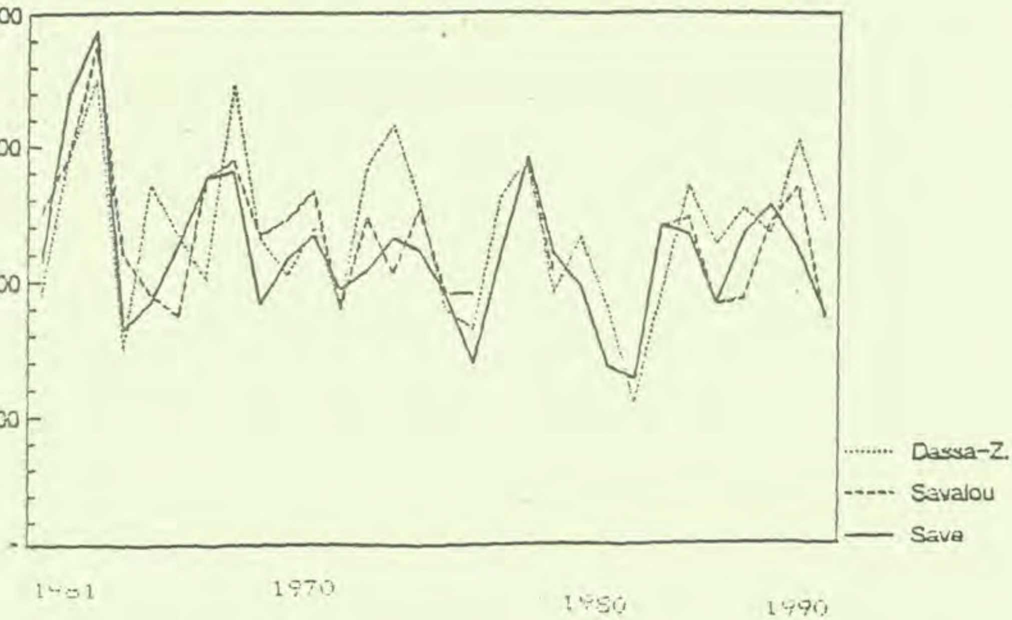


Fig. 3 Interannual rains evolution (1961-1990) of three stations in the middle region of Benin.



II - RAINWATER CATCHMENT METHODS

There are two systems of catchment: rooftop from and natural or boreholes.

- The rooftop water system

For this purpose jars, barrels and citerns are used. Their existence is due to the adoption of the sheet-ironed Roof. The thatched roofs don't permit this recuperation. In this case, recuperated water is no utilizable. Those means being recent, they are notsubjected to weight of tradition. Rooftop waters fall down a sheet-ironed instrument in form of drain . This drain brings water toward utensils of catchment :

- Jars in cooked clay are the most used because they were already the mean of conservation of water drawn from wells or holes. Their contents is very limited about 20-60 litres, and water is used for dayly needs supply.

Fig. 4a,b,c. Figures of some utensils[p.6]

- Barrels in steel (about 200 litres) are less utilized than jars because of their high cost 20 $ U.S. for the purchase power of the population.

- Water from citerns serves to need suppy when wells or holes are dried out. Their number is reduced because they necessitate a high investment (about 200 $ U.S.exceeding annual income of the peasant community. The countenance of citerns depends on their size and varies whith the village.

Fig.5 : a citern p.7

Fig. 4 **FIGURES OF SOME UTENSILS**

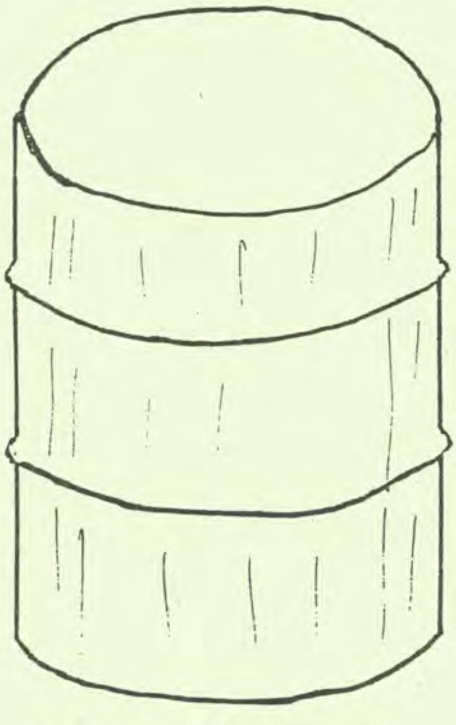
a

Jar

b

Jar of oval form

c



Barrel

Fig. 5 A CITERN

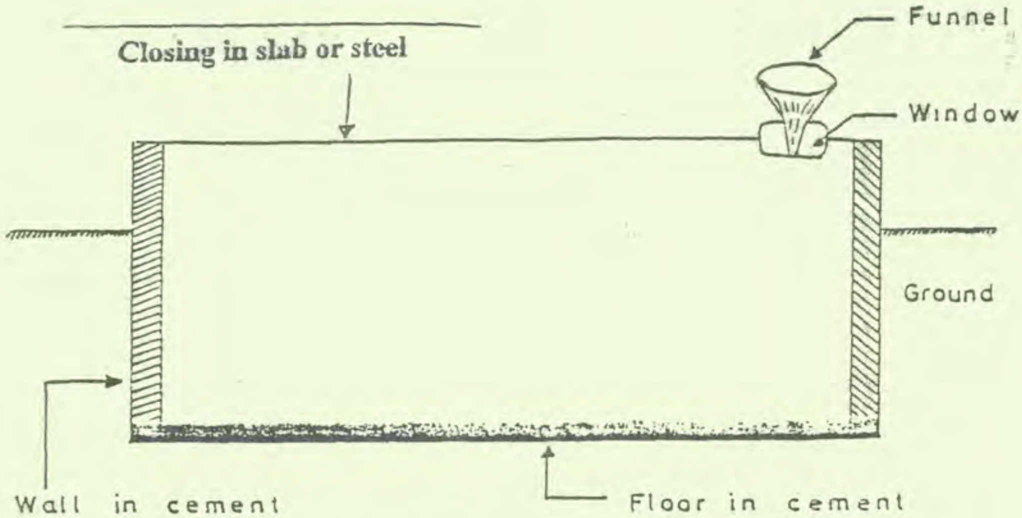
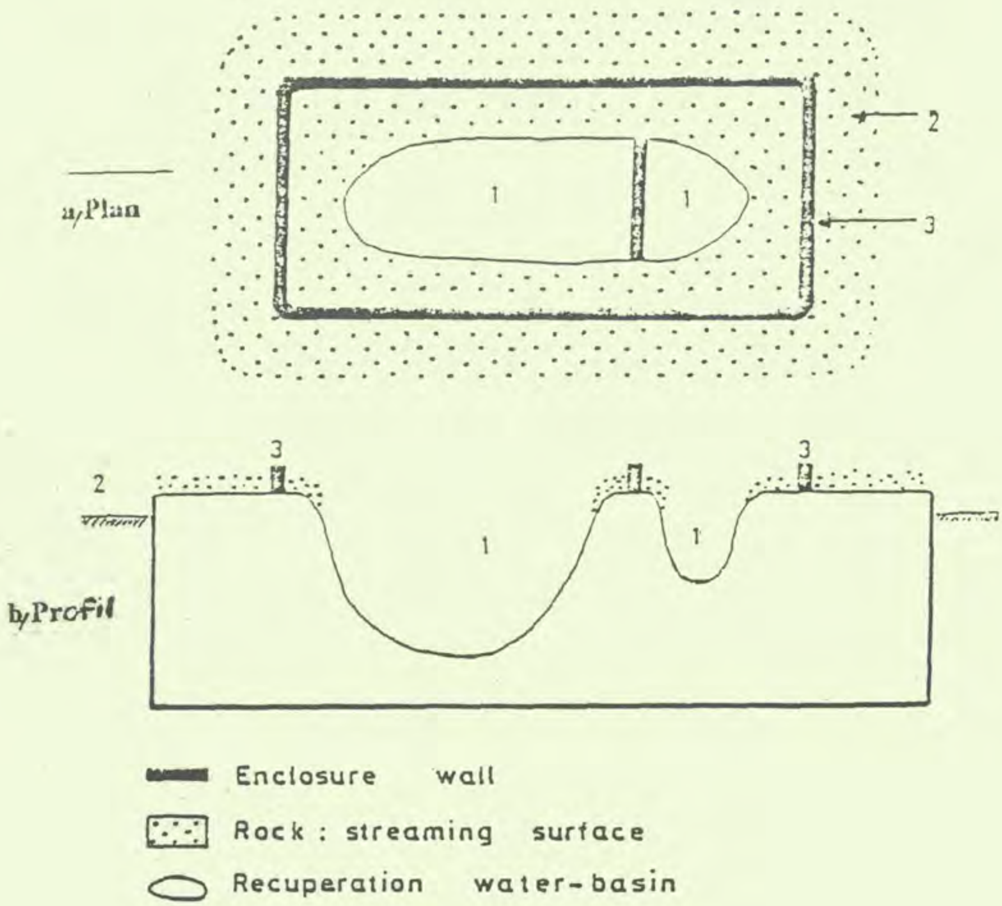


Fig. 6 THE KPATELE POOL



* HOLES OR POOLS

It is the older system to catch rainwater Water is taken in gourds and poured out into jars. We find them on lowlands and on hill. Sometimes they arearranged by people. They are subjected to the weight of tradition.

The pools of lowlands are situated at oneor two km from villages.There are the most frequented. For drawing water population puts feet in it and even they washon pool margin.

On hill ditches are natural. Generally , people go to it when lowlands pools dried out. They are often situated far from villages above two km. but this onethat we want to describe,kpatele, is on the top of a hill where the village of Tchatchegou extends. This natural ditch has been arranged by population.

Fig. 6 : The Kpatélé pool (a, b) (p.7)
Photo 1 : Housse, rocky reservoir on "Lissa so" (p.9)

In those figures, we notice a close wall which determines a surface for rainwater recuperation. On streaming area of this pool, animals or birds (dog, sheep, goat, hen) strut. That doesn't garanttee water quality.

Table 1: Nature and number of rainwater catchment utensils in some villages. (p.9)

Fig.7: . Location of concerned villages by inquiry (p.10)

+ WATER QUALITY AND ITS CONSEQUENCES ON HUMAN HEALTH

Water is polluted and often coloured. It countains a lot of micro-organisms.

Water analysis in laboratory results are shown in table 2

Table 2 : results of water analysis from two villages. Ouedeme et Paouignan.

Nature Localités	mg++		Po4		SiO2		Germs (nber/100ml)		
	NR	T	NR	RT	NR	RT	E. Colis	streptococcis	klebsiella
Ouedeme	pas	10,2	pas	0,95	10 mg/l	67,7	200	90	-
Paouignan							1500	580	+

Origine : KOUKPONOU,1994

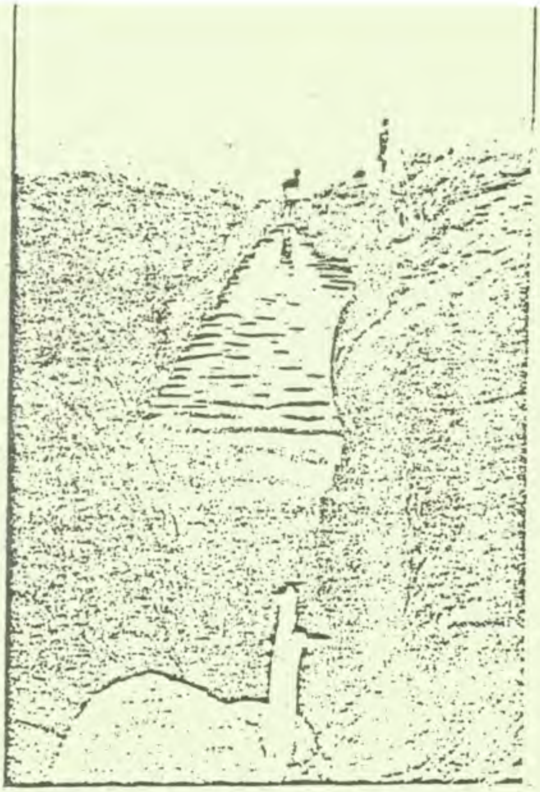


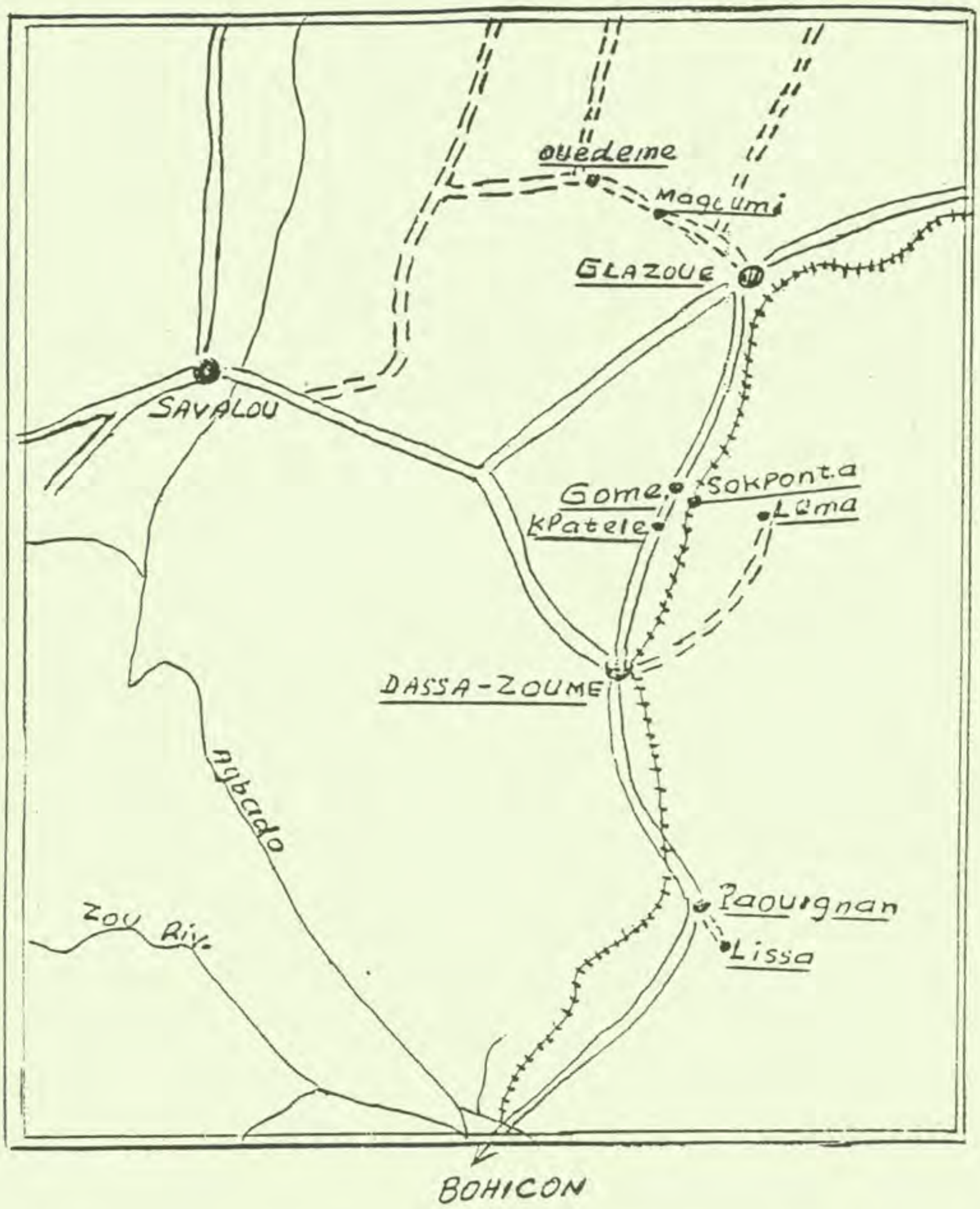
Photo 1 : "Housse", rocky reservoir on "lissa so"

Table 1 : Nature and number of rainwater catchment utensils in some villages

Nature / Localities	Citerns	Jars	Barrels	Pools
Dassa-Zoume	100[1]	1500	150	9
Paouignan	103[1]	400	150	11
Lissa	-	200	15	02
Lema	5	105	10	05
TchatchégouKpatélé	30	300	50	04
Gome	12	350	30	05
Sokponta	20	800	50	03
Glazoue	60[1]	1000	30	02
Magoumi	21[1]	850	60	01
Wèdème	13[1]	700	100	0
Total	364	6650	645	32

Origin : 1: KOUKPONOU, 1994
20 : inquiry

Fig.7 Location of concerned village by inquires



Road
Path
Rails
River

Lema: Concerned village

Fig.8: people of cyclopides of Lissa (september1986-august 1987) (p.11)

" Cyclopides" are crustaceans which transmit dracunculosis when man drinks water. Their number in water of Lissa is various: about 10,000 by 10 litres of water in september and november 1986, may and august 1987; but a lower number in february 1987 about 10 by ten litres of water.

The causes of water pollution are : The people for drawing water put feet into the pools . Often feet are dirty. The utensils for water drawing are not washed and sterilized. Atmospheric dust,many insects,dead leaves,birds and animals excreta drop into the water. Also streaming water often drains human excreta (peole does their excreta in the bush), many insects , dead leaves and blades , birds and animals excreta and carcases, and other things (steeled,ironed or plastic objects) toward the pools. All thing which favour diseases.

Some waterborne diseases are known in this region

Table 3 : some waterborne diseases from some health centers of this region (1991,1992

Diseases / H. Centers	Dracontiasis is		schisto somiasiS s		Intesti nal worms		Cholera
	1991	1992	1991-	1992	1991-	1992	1992
Paouignan	79	30	0	3	122	218	0
Dassa-Zoumè	11	2	11	7	843	1444	0
Glazoué	5	1	0	16	752	1732	0
Magoumi	11	3	4	3	125	121	1
Wedèmè	-	-	2	0	141	189	1
Gomè	-	-	0	21	132	189	1

Origin : health centers

The most frequented diseases of water in this region are intestinal worms, dracontiasis and schistosomiasis.

III - TRADITION AND ENVIRONMENT SAFEKEEPING

In this region only some pools are sacred. African pantheon countains forces of nature, ancestor manes, twins, and snakes. Snakes is sacred and considered as guardian of water and inhabitants of conserned villages, water is life.

The animals living in a sacred pool or near by are also sacred and can not be hunted or fished. They are property of God, guardian of water. Snake has a will and therefore many prohibitions are attributed to it and must be respected by the population. It is the base of tradition.

+ Prohibitions are different from a village to another so they are numerous . It is prohibited to:

* wash at the margin of pool.
* draw at noon or in the night : this act, according to the tradition, disturbs the rest of water inhabitans.
* fish or hunt wild ducks which come to drink.
* take away water plants which cover water surface.
* Cut the trees at the edge of pond.
* A unwell woman to go to the pond.
* Wear red clothes or object ; to bring black jar to the pool.

-* <u>For Kobèdjè on Okèlè hill in Lèma village</u>

It is the same things.

-* <u>For Kpatélé in Tchachégou village,</u> it is prohibited to fish tortoises in this pond.

Each misrespect of those prohibitions implies punishments and expiatory rites.

+ Punishment and expiatory rites

Punishments concern community or person who doesn't respect the interdicts. Those can be :

The pools dry up ;the community is struke by a great drought;the village enregisters successful death of youngmen or youngwomen; a great epidemic falls down the village; the concerned person falls ill. All thing which can threaten community life.

When such a situation occurs anciants consult guessman who purposes the solutions.

The rites serve to propitiate the God.The concerned community or person gives the necessary for rites. That can limits the misrespect of prohibitions. None wants to do this experience : the concerned person is considered by villagers as a disturber of social order.

Probibitions and punishments particip to the safeguard of environment . Also trees boundering the pond and plants covering the water, by their shadow, prevent it from high evaporation. Rare animals like wild ducks, tortoises etc.are in that preserved. Among the safekept plants or trees certains are medecinal and they are utilized for curing diseases.

CONCLUSION

In this region life is governed by seasons and fatality even if reality is other.

The drying of such pools can be due to demographic load.

Epidemic is often linked to unadequate hygienic conditions or to weakened organism by the way of life.

Drought is due to unfavourable climatic or meteorologic conditions : thin monsoon, few humidity of air...

Since ten years, the officials tray to bore deep wells and to install pomps in this region of Benin However population hasn't abandoned traditional rainwater catchment and preservation systems.

Pools are always at the honour. Consequence certain diseases like dracontiasis are actual even if it is in weak proportion.

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FLUCTUATION OF THE QUALITY OF CONTAINER-STORED RAINWATER DURING STORAGE

Ichiro KITA* and Kunihiko KITAMURA**

ABSTRACT

Rainwater cistern systems have been popular and useful around the world. In Japan, they have come to attract people's interest as a new source of water to mainly save tap water in urban areas. On the other hand there are many regions such as isolated islands where rainwater is the main source for drinking water or water for domestic purpose.

In Japan precipitation during the rainy season is abundant enough that if it could be collected and stored, then it could be utilized for the following dry summer season. For its safer use, there is a need to investigate fluctuation in the quality of rainwater during storage. For this purpose, rainwater is collected through the gutter of a greenhouse roof with an area of about 80 m^2 and stored in a polyethylene container. In order to investigate the state of its fluctuation, the quality of the stored rainwater was tested at intervals of one week from the end of July to end of October. The results are shown in this paper.

INTRODUCTION

Rainwater cistern systems have been popular and useful around the world. In Japan, they have come to attract people's interest as a new source of water to mainly save tap water in urban areas. For example, a building is equipped with a large scale rainwater cistern system in which rainwater is collected and stored to utilized as a cooling water and a flushing water. On the other hand there are many regions such as isolated islands where rainwater is the main source for drinking water or water for domestic purpose. In this case its scale is smaller for a household use and more care must be taken of water quality for a safe use.

Although there are not distinct rainy and dry seasons in Japan, a precipitation is abundant during about one month at the beginning of summer and subsequently little precipitation period last to the end of summer. Therefore if rainwater could be collected and stored at the beginning of summer, then it could be utilized for the following dry summer period. For its safer

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use, there is a need to investigate fluctuation in the quality of rainwater during storage. For this purpose, rainwater is collected through the gutter of a greenhouse roof and stored in a polyethylene container. In order to investigate the state of its fluctuation, the quality of the stored rainwater was tested periodically during the summer dry period.

The results are shown in this paper.

METHODOLOGY

Collecting and storing rainwater

Rainwater is collected through the gutter fitted to a greenhouse roof with an area of about 80 m^2 and stored in a polyethylene container with a volume of 0.3 m^3. The gutter is fitted to the low end of the roof around the middle of July. Because this year precipitation is very little, at the end of July we have enough rain to be collected and stored. Rainwater is collected and stored about two weeks later after the gutter is fitted. During the period grains of soil, feces and dead bodies of insects accumulate inside the gutter. They also accumulate on the roof. When rainwater is collected and stored, rainwater which is collected for a while after it begin to rain is not stored so that they can be washed away in order not to be mixed with rainwater. Collected rainwater begins to be stored into the container at the time when its appearance is clear. The container is located indoors and it is not exposed to the direct sunlight. Underground water is stored in another container to compare a state of fluctuation in water quality during storage.

Water quality parameters and Methods for analysis

Water is analyzed for pH, COD, NH_4, NO_2, NO_3, turbidity, color, coliform and bacteria. pH, COD, NH_4, NO_2 and NO_3 are measured using Pack Test (simplified chemical analysis products for water). Turbidity and color are measured using comparator set. Coliform and bacteria are measured using test paper which indicates only their presence. Water is taken from approximately 10 cm below from surface without stirring. pH, COD, NH_4, NO_2, NO_3, turbidity and color are measured from 7/28 to 10/26 at intervals of one week. Coliform and bacteria are tested at intervals of four weeks.

RESULT AND DISCUSSION

1. pH

The state of the fluctuation in pH is shown in Figure 1. pH is measured at interval of 0.2 pH. All through the periods, pH fluctuates around 5, increasing and decreasing. In contrast, pH in underground water is gradually increase.

2. COD

The state of the fluctuation in COD is shown in Figure 2. Measurement scales of COD are 0 mg/l, 5 mg/l, 10 mg/l and 20 mg/l. The amount of COD in 7/28 and 8/18 water sample is 5 mg/l.

Its amount in the others is 0 mg.

3. NH_4

The state of the fluctuation in NH_4 is shown in Figure 3. NH_4 is measured at interval of 0.5 mg/l. In 7/28 water sample 0.5 mg/l is contained. The amount of NH_4 increase to 1 mg/l in 8/4 and 8/11 water sample. It decreases to 0.5 mg/l in 8/11 and 8/25 water sample, finally 0 mg/l in 9/1 water sample. Subsequently, it remains 0 mg/l during the rest of periods. NH_4 is provably yield by decomposition of the dead body of insect that is on the roof and the gutter and mixed with rainwater by bacteria.

4. NO_2

The state of the fluctuation in NO_2 is shown in Figure 4. Measurement scales of NO_2 are 0 mg/l, 0.02 mg/l, 0.05 mg/l and 0.1 mg/l. In 7/28 water sample 0.02 mg/l is contained. The amount of NO_2 increase to 0.05 mg/l in 8/4 and remains the same amount during for five weeks. It decreases to 0 mg in 9/15 water sample and subsequently remains 0 mg to the last period. NO_2 is provably yield by nitrification of NH_4.

5. NO_3

The state of the fluctuation in NO_3 is shown in Figure 5. Measurement scales of NO_3 are 0 mg/l, 1 mg/l, 2 mg/l, 5 mg/l and 10 mg/l. The amount of NO_3 remains 2 mg/l all through the periods. Though it is considered that NO_3 is yield by nitrification of NO_2, it can not be seen clearly for difference of measurement scale.

6. turbidity

The state of the fluctuation in turbidity is shown in Figure 6. Measurement scales of turbidity are 0, 1, 2, 3 and 5. Measure of 7/28 water sample is 3 and remains 0.5 during the rest of periods. This is because particles that are collected and stored with rainwater are floating and they settle gradually.

7. color

The state of the fluctuation in color is shown in Figure 7. Color is measured at interval of 2. The measure of color remains 2 all through the periods.

8. coliform group and bacteria

The results of coliform group and bacteria test are shown in Table 1. All through the period the results of coliform group are positive. It is considered that feces on the roof and gutter are mixed with rainwater when rainwater is collected and stored. The results of bacteria are positive all through the period.

CONCLUSION

The fluctuation in the quality of rainwater stored in container during storage is investigated.

The results are as follows:

(1) pH remains almost constant during storage.

(2) COD remains almost constant during storage except two periods.

(3) NH_4 first increases, then decreases and finally remains 0

mg.
(4) NO_2 first increase, then remains constant for six weeks, then decreases and remains 0 mg/l.
(5) NO_3 remains almost constant during storage. However, it can not be seen clearly for difference of measurement scale.
(6) Turbidity remains constant during storage except first period.
(7) Color remains constant all through the period.
(8) The results of coliform group and bacteria are positive all through the periods.

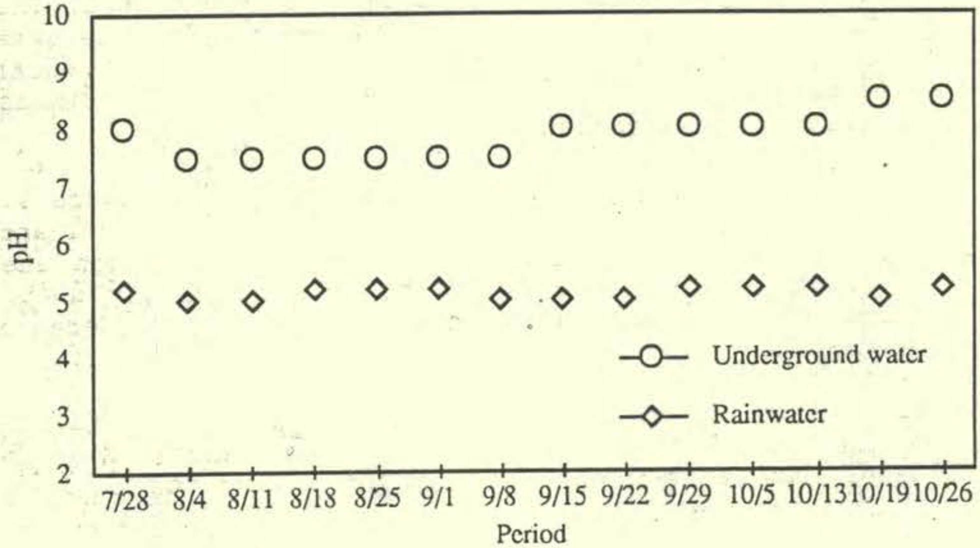

Figure 1 The state of the fluctuation in pH

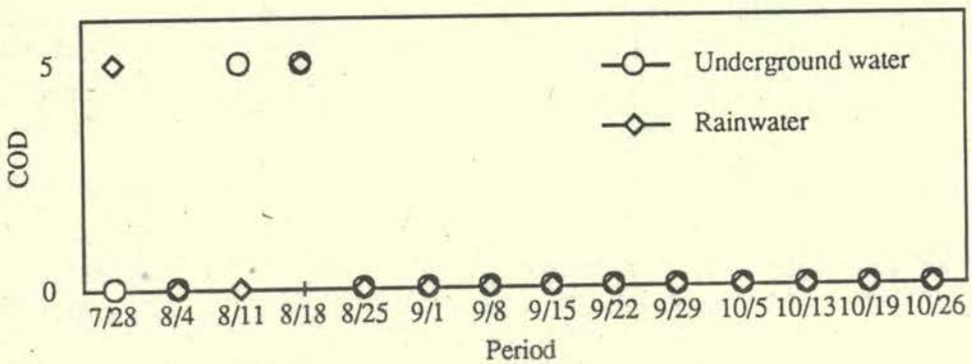

Figure 2 The state of the fluctuation in COD

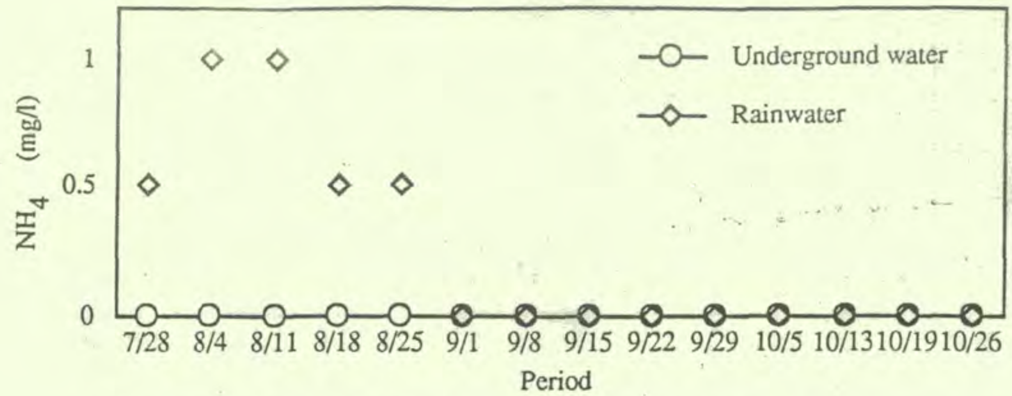

Figure 3 The state of the fluctuation in NH_4

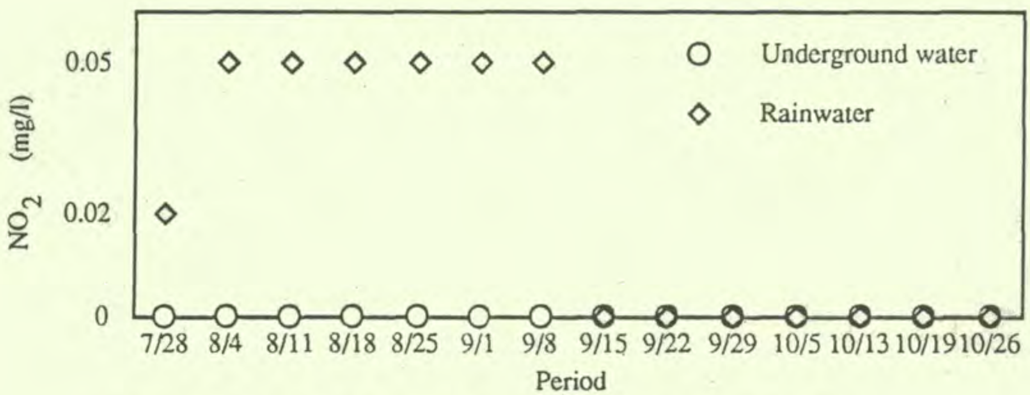

Figure 4 The state of the fluctuation in NO_2

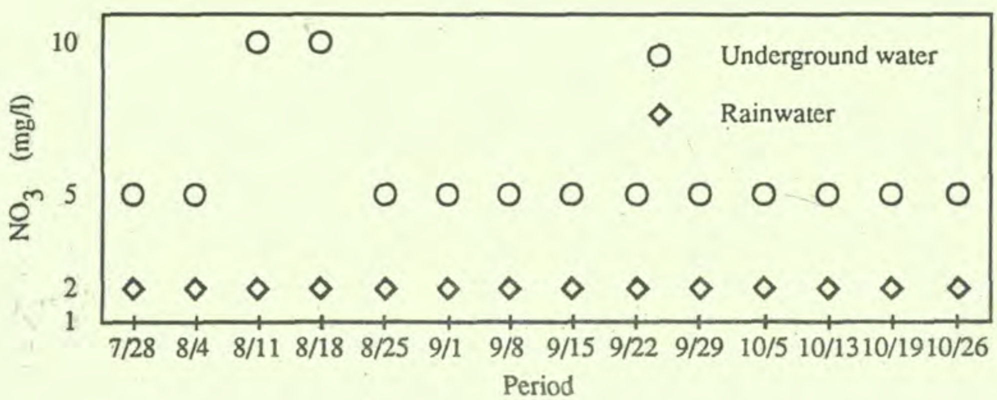

Figure 5 The state of the fluctuation in NO_3

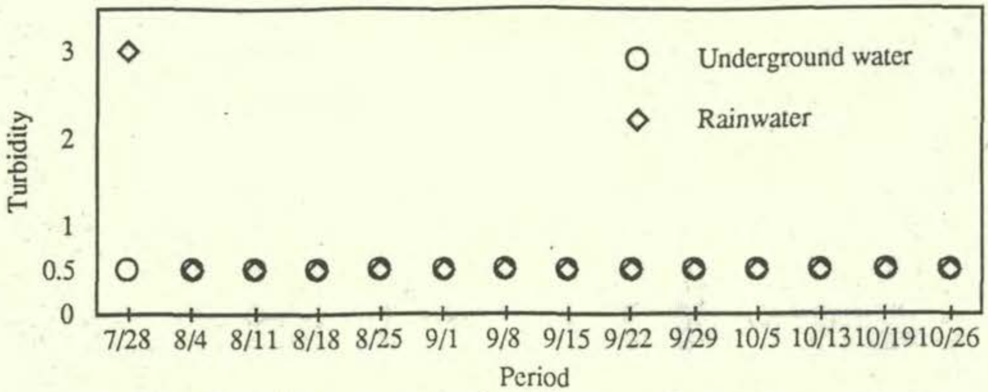

Figure 6 The state of the fluctuation in turbidity

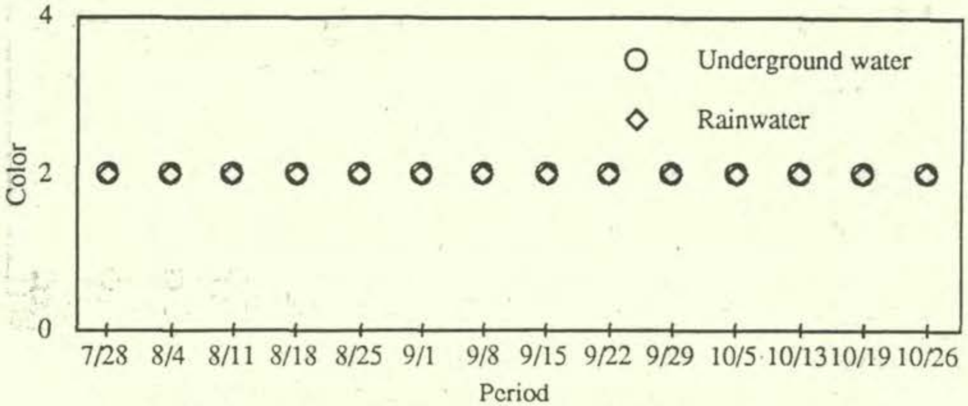

Figure 7 The state of the fluctuation in color

POTABILIZATION OF RAINWATER

By
Otto F. Joklik *)

ABSTRACT

A rainwater potabilization plant with a design capacity of 2000 litres of safe potable water per hour is described. The plant uses ultraviolet short wave UV-C radiation of 253.7 nm for rainwater disinfection without the use of chemicals. The rainwater is collected from the roof into a rainwater cistern and then proceeded to a combined filtration unit consisting of a pre-filter, a coarse filter and a fine filter for the removal of mechanical impurities and then passed to an activated carbon filter fpr the removal of dangerous chemicals and for taste and smell improvement. The filtered and activated carbon treated water is then proceeded to a photoreactor with a coaxilally arranged UV-C irradiation device. The ultraviolet radiation is controlled by an UV-C sensor and all the process data are recorded on an UV-C data logger. The disinfected water is finally passed onto a hardness increase filter and a microdosage unit for the addition of essential minerals, vitamins and trace elements to obtain a healthy drinking water of excellent quality.

INTRODUCTION

In developing countries households depend on water supplies from rainwater cisterns, commonly referred to as roof catchments, for their drinking or wash water, or both.

Because of the cistern's inherent susceptibility to contamination and their status as an unregulated water supply, the cistern's raw water has to be disinfected by a suitable process to obtain drinking water in a quality corresponding to the standards established by the World Health organization WHO for safe potable water.

Water cistern contaminants come from natural and artificial sources, including, but not limited to: manufactured building materials; animals; acid rain, which is generated by the transformation of volcanic emissions and water into sulfuric acid. Water cistern contaminants can include lead, mercury, copper, algae and pathogenic microorganisms.

Cistern water quality can be degraded by the excrement and animal matter of mice, geckos, and birds that come into contact with the water system. Drinking water contaminated by the excrement of animals or dust particles carrying pathogenic organisms can result in severe gastrointestinal disorders or other water-borne illnesses.

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ULTRAVIOLET DISINFECTION SYSTEMS

It has been established over many years that the simplest and most reliable way to disinfect water is to expose it to ultraviolet light. The ultraviolet wavelengths of 200 to 290 nanometers (nm) penetrate cell membranes to disrupt the DNA-molecules, preventing cell replication with a maximum effectivenes around 254 nanometers - exactly 253.7 nm - depending on the organism. The ultraviolet shoert wave light UV-C generated artificially by low-pressure mercury vapour arc tube is particularly rich in the microbiocidal wavelength of 253.7 nm which is required for inactivation of all waterborne pathogenic microorganisms - bacteria and viruses.

There are no microorganisms known to be resistant to UV-C, which, unlike the chlorination, is highly effective against bacteria, viruses, algae, moulds and yeasts immediately upon exposure of these microorganisms to the ultraviolet radiation having of course the required intensity and exposure time necessary for inactivation. Of these, enteric viruses, hepatitis virus and legionella pneumophila have been found to survive for considerable periods of time in the presence of chlorine, but are eliminated readily by UV-C radiation treatment. Similarly, chlorine forms trihalomethanes in drinking water whereas UV-C treatment does not produce toxic and cancerogenous by-products at all.

Ultraviolet germicidal lamps are made of special quartz glass that will allow 70 to 90 per cent of the short wave ultraviolet radiation to pass. Ordinary glass is not transparent to wavelengths below 320 nm. The low-pressure / low-temperature mercury vapour lamp emits ultraviolet radiation that is predominantly at 253.7 nm. This is the region of the maximum germicidal effectiveness.

The germicidal ultraviolet lamp works on the following principle: An electric arc is struck through an inert gas carrier (mercury, mercury -argon or the like), in a sealed and evacuated quartz glass tube. Heat from the arc causes vapourization of the small amount of mercury contained in the sealed and evacuated tube. The mercury, when vapourized, becomes ionized and emits in the electric arc ultraviolet radiation.

GERMICIDAL ENERGY

The dosage necessary to inactivate a micro-organism is a product of time and intensity of radiation. An average bacterium will be destroyed, if exposed in air at a distance of five centimeters from a germicidal lamp for about two seconds.

Bacteria withstand considerably more ultraviolet irradiation in water than in dry air. E. coli, for example, require more ultraviolet exposure for the destruction in water than in dry air. In either case, the germicidal radiation must strike a microorganism to destroy it. This implies that the water be clear enough to allow transmission of an adequate quantity of ultraviolet radiation energy.

As the degree of microbial destruction is a function of both the time and the intensity of the radiation to which a given microorganism is exposed, a short exposure time at a high intensity is as effective as a long exposure time at low intensity, provided that the product of time and intensity remains the same. This dosage is normally expressed in microwatt-seconds per square centimeter or also now in millijoule per square centimeter (mJ/cm^2).

Any turbidity in the water reduces the range of transmission of the ultraviolet radiation. Water that is naturally turbid, or that becomes turbid from corrosion products formed during storage in steel tanks and lines, should be filtered before exposure to ultraviolet radiation.

The most advanced design of recent realization is a combined water filter with an integrated ultraviolet germicidal lamp - ensuring maximum efficiency and effectiveness.

The dosage required for common bacteria range upward to more than 20.000 microwatt-seconds per square centimeter. To allow for les than 100 per cent transmission, a water disinfection system should be designed in such a way to deliver 253.7 nm ultraviolet radiation energy in excess of 30.000 microwatt-seconds per square centimeter.

DESIGN PRINCIPLES

Several design features bear directly on the dosage deliveries of an ultraviolet water disinfection unit and have to be considered when designing a photoreactor:

1. Radiation output of the germicidal lamp.
2. Length of the germicidal lamp. When the lamp is mounted parallel to the direction of the water flow, the exposure time is parallel to the length of the lamp.
3. Design water flow rate. Exposure time is inversely related to the linear flow rate.
4. Diameter of the photoreactor - irradiation chamber. Since the water itself absorbs ultraviolet energy, the delivered dosage diminuishes logarithmically with the distance from the lamp as a radiation source.
5. Turbulence of the irradiated water flow. A sufficiently high Reynolds number must be maintained to ensure a turbulence of the water flow and to avoid laminar flow of the water in the photoreactor. Mechanical turbulence devices can be installed for this purpose.

SIZING

The main parameter required for the selection of an UV-C system is the peak flow requiring treatment. Other factors need to be taken into account. Those include the optical quality of the water - per cent of UV transmission - and the number of pathogenic microorganisms in the water to be treated. A level of UV-C dose is the determined that will achieve the desired kill. This will be used to size a system based on the worst conditions of transmission, flow and contamination.

UV-C SYSTEM EFFECTIVENESS

The dose of radiation required to achieve a 90 % kill of a specific microorganism is called the D_{10} - the dose at which only 10 % of the microorganisms survive.

Doubling the dose achieves an overall 99 % reduction. Typical D_{10} figures are shown for various species.

An UV-C disinfection system is normally sized to achieve at least a 99.999 % kill. Therefore a dose of five times the D_{10} is necessary.

Taking E. coli (D_{10} = 3.0 mWs/cm^2) as an example the dose needed to achieve a 99.999 % kill can be calculated as shown below.

E. coli - relationship between dose and kill

Reduction	Kill %	Dose (mWs/cm^2)
1 x D_{10}	90	3.0
2 x D_{10}	99	6.0
3 x D_{10}	99.9	9.0
4 x D_{10}	99.99	12.0
5 x D_{10}	99.999	15.0

Achievement of a specific level of kill depends on the UV-C dose received by the microorganism. In order to ensure satisfactory water disinfection, a reliable UV-C disinfection system is normally designed to achieve a minimum of 20 mWs/ cm^2. Operating doses can be greater to kill specific microorganisms with a high D_{10} or to increase the level of disinfection.

MICROORGANISMS	D_{10} DOSE
Serratia marcescens	2.52
Pseudomonas aeruginosa	5.5
Mycobacterium tuberculosis	6.0
Salmonella enteritidis	4.0
Salmonella paratyphi	3.2
Salmonella typhi	2.14
Salmonella typhimurium	8.0
Shigella dysenteriae	2.2
Shigella paradysenteriae	1.68
Escherichia coli	3.0
Proteus vulgaris	2.7
Bacillus anthracis	4.52
Bacillus megaterium (cells)	3.75
Bacillus megaterium (spores)	9.07
Bacillus subtilis (cells & spores)	7.1
Clostridium tetani	4.9
Staphylococcus aureus	2.18
Streptococcus viridans	2.0
Streptococcus pyogenes	2.16
Micrococcus candidus	6.05
Micrococcus sphaeroides	10.0
Sarcina lutea (M. luteus)	19.7
Micrococcus lysodeikticus ATTC12698	23.0
Legionella pneumophila	2.04
Yeast (average)	4.0
Brewers yeast	10.0
Saccharomyces turpidans	9.0

ADVANTAGES OF ULTRAVIOLET WATER TREATMENT

As a tertiary treatment of water, clorination offers the advantage of continued disinfection after initial teatment, since some chlorine remains in the water with residual germicida effects. The ultraviolet radiation method, however, has none of the folowing disadvantages of chlorine:

1. Chlorine treatment requires continuous attention with permanent surveillance with monitoring and maintenance, to avoid dosage errors with consequent under- or over-dosage, which both are undesirable.

2. In small installations, when chlorine gas is liberated from a chlorine cylinder or moistened crystals or pellets, the fumes are extremely toxic and may even be lethal.

3. Chlorine itself is a highly corrosive and toxic chemical.

4. Chlorine is an additive chemical material which may impart an undesirable taste to water and also a decrease of pH.

5. Chlorine is chemically reactive and can react with foreign ingredients in the treated water (e.g. in raw water and in industrial waste water) to form toxic and even highly carcinogenous compounds, a matter of increasing importance and concern to public health authorities. It may combine with ammonia to form chloramine which is acutely toxic to fish even at low concentrations. It may combine also with phenol to form chlorophenol, another toxic compound. Recent investigations in the USA have proved and confirmed the existence of other carcinogenous compounds in chlorinated potable water, where particularly trihalomethanes are a considerable health hazard.

6. The investment cost and operation and maintenance cost of a chlorination equipment or plant is substantially higher than that of an ultraviolet radiation treatment installation.

7. Importation of chlorination pellets causes continuous expenditure in foreign exchange in developing countries and the logistics of its distribution and supply may cause severe problems.

8. An ultraviolet radiation installation can easily be combined with the production of ozone from atmospheric oxygen by the same radiation source, thus increasing substantially the germicidal effectiveness of the combined ultraviolet/ozone disinfection process. The ozone treatment of water secondary to ultraviolet radiation is particularly interesting for low-cost permanent treatment of stored potable water in tanks.

9. Chlorination of water alone does not destroy all viruses, where as ultraviolet radiation and ozone do.

10. Chlorination requires a contact and reaction time of at least one hour to achieve a sufficient disinfection, where as the ultraviolet radiation and ozone have an immediate disinfecting effect upon the irradiated microorganism.

APPLICATION AND USES

The unique advantage of the ultraviolet radiation method of disinfection of water is that nothing is added to water. When chemical methods of treatment are used there may be handling and dosage problems, taste and palatability and odour problems, and undesirable chemical reactions with substances present in the water. This difference is most significant when producing water for drinking or swimming, processing foods and bottled beverages, manufacturing pharmaceuticals and cosmetics, use in hospitals and research institutions, microbiological laboratories, and tertiary treatment of municipal or decentralized supply water or municipal or industrial waste water.

The versatility of ultraviolet radiation water disinfection includes:

1. Ultraviolet disinfection of water produces germ-free potable water according to WHO-standards, for home, institutional or municipal use.

a) Water wells. Bacterial contamination of water wells is unpredictable and may occur from seepage of surface water or sewage.
b) Water cisterns. Most cisterns foster the proliferation of bacteria in untreated water. This can be eliminated by installing a water disinfection equipment on outlet side of water cisterns.
c) Water softeners (ion-exchange beds, etc.). All ion exchange resin beds foster the proliferation of bacteria. This can be eliminated by installing a water disinfecting unit on outled side of water softeners. This applies for reverse ormosis equipment, too.
d) Ice cubes and ice flakes are often contaminated by microorganisms present in the water fed to the ice cuber. Hygienically safe ice cubes or flakes can be obtained by installing an ultraviolet disinfection device on the inlet side of the ice cuber or flaker.
e) Water and beverage fountains and dispensers are often contaminated by hygienically impure water. Hygienically safe beverages and chilled water can be obtained by installing an ultraviolet disinfection device on the inlet side of the water and beverages fountain or dispenser.

2. Ultraviolet radiazion disinfected water provides bacteria and viruses-free food process water without the use of germicides, oxidants, algaecides or chemical precipitants and is therefore particularly applicable where chlorine adversely affects flavour and taste.

a) For the brewery, vinery, soft drink and water bottling industries, where biological purity of water must be absolutely maintained in order to ensure constant product quality.
b) For safeguarding against spoilage of dairy products, e.g. cottage cheese and butter. Certain psycrophillic bacteria are resistant to chlorine treatment.
c) For fish hatcheries, oyster and shrimps breeding and for aquaria where pure water is essential.
d) For the preparation of ORL Oral Rehydration Liquids with subsequent re-alimentation for infants and children suffering from cholera-like diseases caused by contaminated water. Also for the preparation of milk and soups, vegetables and other food products from dehydrated powdered materials.
e) For disinfected washwater. To guard against waterborne bacteria spoilage where vegetables, fruits, meats, fish and other products must be washed before canning or packaging.

3. Ultraviolet radiation disinfection is particularly useful in applications where chlorine-free, de-ionized and/or carbon filtered water is extensively employed. Unattended carbon filters and ion-exchange tanks act as incubators for bacteria accumulation and proliferation. Applicable also for reverse osmosis equipment.

a) For electronics. In conjunction with de-ionized and high purity water systems.

b) For pharmaceuticals and cosmetics. Strict water treatment standards are necessary for strict maintenance of product quality and control.

c) For biological laboratories. Disinfected water is provided for testing and research work.

d) For hospitals. To provide ultra-pure water on demand for abdominal surgery, for maternity labor and delivery, dialysis units, pathology laboratories, geriatry, intensive care, etc.

4. Ultraviolet radiation in industrial pollution control, for excellent end-treatment for positive protection in wastewater control systems.

a) For selective use as tertiary treatment for bacteria and viruses destruction after removal of chemicals and other objectionable ingredients.

b) For use in disinfecting domestic wastewater from septic tanks and sewage before discharge to avoid potantial contamination of the ground water.

c) For use in disinfecting cooling water in cooling towers, air conditioners and air humidifiers for control of Legionellaceae to prevent Legionellosis caused by contaminated aerosols.

5. Ultraviolet radiation, also combined with ozone treatment disinfects water in private swimming pools indoor and outdoor to reduce and in most cases considerable reduce chlorination to avoid eye abd skin irritation and to avoid costly procurement of chemical disinfectants.

6. Ozone generation. Generation of ozone from atmospheric oxygen by ultraviolet irradiation of the undried air.

a) Ozone treatment of water for additional disinfection.

b) Ozone treatment of industrial effluents, particularly phenolic industrial waste waters for pollution control and environment protection.

PATHOGENIC MICROORGANISMS IN WATER

Bacteria	Disease
Salmonella typhi	Typhoid fever
Salmonella enteritidis	Gastroenteritis
Shigella dysenteriae	Dysentery
Vibrio cholerae	Cholera
Escherichia coli	Gastroenteritis
Leptospira icterohaemorrhagicae	Leptospirosis (Weil's disease)
Mycobacterium tuberculosis	Tuberculosis
Legionella pneumophila	Legionellosis (Legionnaires disease)

Viruses	Disease
Hepatitis A Virus	Infectious hepatitis
Polio virus	Infantile paralysis, Poliomyelitis
Enteroviruses	Gastroenteritis

RAINWATER POTABILIZATION - EXAMPLE OF INSTALLATION

On December 19, 1994 a rainwater potabilization plant has been put into operation at the premisses of Messrs. Josef Freund in Seyring, Lower Austria, to obtain safe potable water for some 30 workers of the production plant for concrete prefabricated elements.

The rainwater potabilization plant has been developed and designed by the author. Its design capacity is 2000 litres of safe potable water per hour in a quality corresponding to the standards for safe potable water established by the World Health Organization WHO.

The rainwater potabilization plant consists of the following equipment for the individual process steps:

1. Rainwater is collected by means of a collecting pipe from the roof of the production plant and led to the rainwater cistern made of concrete and holding some 300.000 litres of rainwater. The collected rainwater is first allowed to settle in two settling compartments and then passed to the holding part of the cistern. A coarse filter is installed at the pipe conduit which leads from the roof to the rainwater cistern to prevent the introduction of leaves, dirt and other impurities into the cistern.

2. Rainwater from the cistern is pumped to the boiler room of the production hall where the rainwater treatment plant is installed.

3. A pre-filter - coarse - is installed at the inlet pipe of the rainwater treatment plant to protect the installation from coarse mechanical impurities.

4. A magnetic iron filter is installed after the pre-filter to eliminate rust, magnetite and any other iron particles from the water flow.

5. A pressure regulating valve is limiting the overall pressure in the rainwater treatment installation to 7 bars.

6. A water meter designed for the average flow of maximum 2000 litres of water per hour is installed for the general control of the water flow and water consumption. A manual regulating valve is connected to the water meter to regulate the maximum water flow in the system to 2000 litres per hour.

7. A combined filter group ensures a thorough filtration of the rainwater prior to the UV-C disinfection and also to reduce its turbidity.
The filter group consists of the following elements:
- Coarse filter for the pre-filtration of the raw water with replaceable and easily washable filter cartridges. Three types of filter cartridges are available, interchangeable, and may be chosen to the local rainwater quality, to remove mechanical impurities from the raw water:
  a) Vitrified quarzite with a filtration degree of 60 microns and of 20 microns.
  b) Milded-proof polyester fibre felt with a filtration degree of 50 microns.
  c) Stainless steel with a filtration degree of 80, 40, 20 and 10 microns.

  Each filter housing is provided with a vent, a manometer and a discharge ball valve at the bottom for drain. Completely manufactured with atoxic plastic material of high resistance. The transprent bowl enables the visual control of the clogging degree of the filter cartridge. With cylindrical male thread gas connections. The pressure loss is 0.2 bars.

- Fine filter for an additional fine filtration of the pre-filtered water with replaceable and easily washable filter cartridges with a filtration degree of 20 or 10 microns (as described above).
- Activated carbon filter for the absorption of dangerous chemicals from the filtered water. The taste and smell of the water treated by activated carbon can also be improved. The activated carbon is in a granulated form and contained in an easily replaceable and disposable cartridges, which must be periodically changed, according to the contamination degree of the filtered water, at least every six months. The housing is the same as described above.

8. A solenoid valve, connected to the control box of the UV-C disinfection unit is opened under current and ensures that only fully disinfected water can leave the water treatment plant. The solenoid valve is shut-off immediately and closes thus the flow of the water in the case of interruption of the electrical supply, breakdown of the mains or a fault of the irradiation device. The solenoid valve only opens under tension and has an LED indicator for its function.

9. A flow limiting device consisting of a precisely sized diaphragm is installed at the inlet of the photoreactor. It ensures that the water flow is limited to the calculated design capacity of the UV-C disinfecting device.

10. The photoreactor consists of a passivated and electropolisted stainless steel cylinder with an internal coaxially arranged UV-C irradiation device - an UV-C low pressure mercury lamp emitting short wave ultraviolet at 253.7 nm - protected by a quartz glass sleeve. Thus the UV-C lamp can be easily replaced by simply exchanging the UV-C lamp within the quartz glass sleeve and without the necessity to drain the water from the system during the UV-C lamp replacement. The rated useful life time of the lamp is 8000 hours.

11. The control box has an on-off switch with a green control lamp for the connection to the mains (220 V AC 50 Hz), a time counter 0-8000 h for the control of the useable life time control of the UV-C lamp which has to be replaced after 8000 hours of operation, a control lamp for the indication of the UV-C lamp's function and an UV-C meter indicating the UV-C intensity with a preset knob for an automatic shut-off of the solenoid valve in the case of a decrease of the intensity of the UV-C radiation emitted by the UV-C lamp. The UV-C intensity meter is connected to an UV-C sensor mounted on the photoreactor.

12. An UV-C Data Logger is collecting and registering all relevant process data. It can be connected to a PC and/or printer for a continuous documentation of all process data.

13. A water turbidity control - optoelectronic - as well as an electronic bacterial growth control are integrated in the system.

14. A water sampling valve is situated at the outlet of the UV-C disinfection device to enable an easy sampling of the disinfected water for periodical microbiological controls prescribed by health authorities. A similar sampling valve is situated also at the entry of raw water into the system for comparison.

15. A filter housing filled with fine marble pieces is situated after the UV-C disinfection device and the sampling valve to impart to the disinfected water, which is usually quite soft, the nececessary hardness.

16. A microdosage device is installed in the disinfected rainwater piping system for additional enrichment with minerals, vitamins, trace elements and other vital substances and thus converting the initial raw water - rainwater from the cistern - to a fully disinfected, mineralized and vitaminized healthy water of excellent quality.

17. The disinfected rainwater is distributed by a piping system to the hot water boiler and directly also as cold drinking water to the shower- and bath room of the plant's personnel.

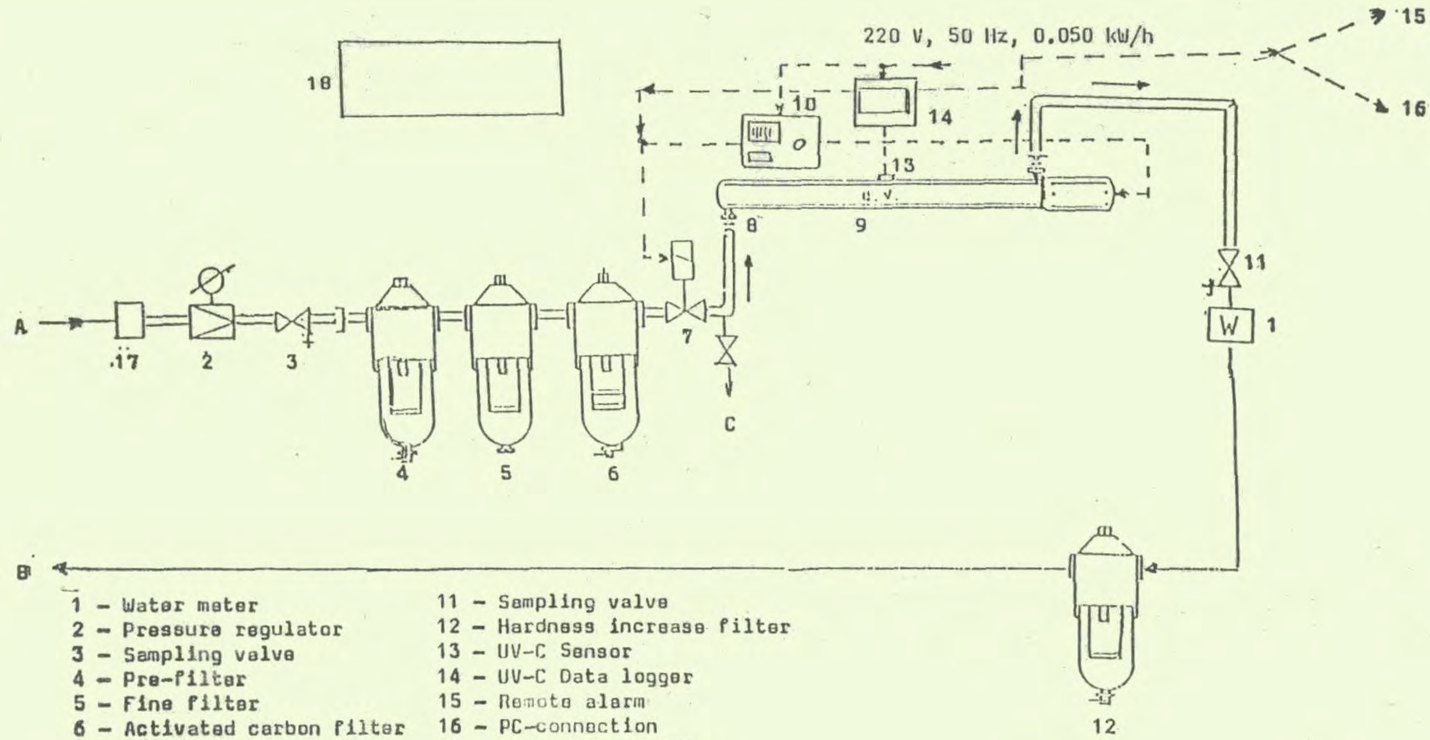
18. A stand-by diesel power generator is connected to the system to ensure a continuous power supply to the rainwater potabilization plant also in the case of a breakdown of the regular electricity supply from mains.

19. The power consumption of the UV-C irradiation device is very small - only 50 Watts per hour are required to operate the entire system - so that the rainwater potabilization plant can be operated independent from mains using solar energy via photovoltaic panels, solar battery and a load regulator.

20. Spare UV-C lamps, spare filter cartridges and activated carbon cartridges as well as the necessary tools required for maintenance are stored in a separate cabinet near the rainwater potabilization plant.

The rainwater potabilization system is shown in the attached flow sheet. Similar systems can be designed - based on the foregoing principles - also for complete rainwater potabilization plants of larger design capacities, either stationary or mobile.

The rainwater potabilization plant here described is the first of its kind in Austria and Europe and serves as experimental pilot plant for further development.



1 – Water meter	11 – Sampling valve
2 – Pressure regulator	12 – Hardness increase filter
3 – Sampling valve	13 – UV-C Sensor
4 – Pre-filter	14 – UV-C Data logger
5 – Fine filter	15 – Remote alarm
6 – Activated carbon filter	16 – PC-connection
7 – Solenoid valve	17 – Non-return valve
8 – Flow control	18 – Cabinet for spares
9 – UV-C Photoreactor	19 – Turbidity control
10 – Control box	20 – Minerals & vitamins addition

RAINWATER POTABILIZATION PLANT 50 W/h (220 V 50 Hz)

Q_{max} = 2000 l/h	Size:	2000 mm wide
p = 0.5 – 7.0 bar		1000 mm high
T = +5 – 35.0 °C		200 mm deep

Installed at the concrete prefabricated elements plant of Messrs. Josef Freund in Seyring, Lower Austria, to provide potable water for drinking, bath and shower for some thirty workers.

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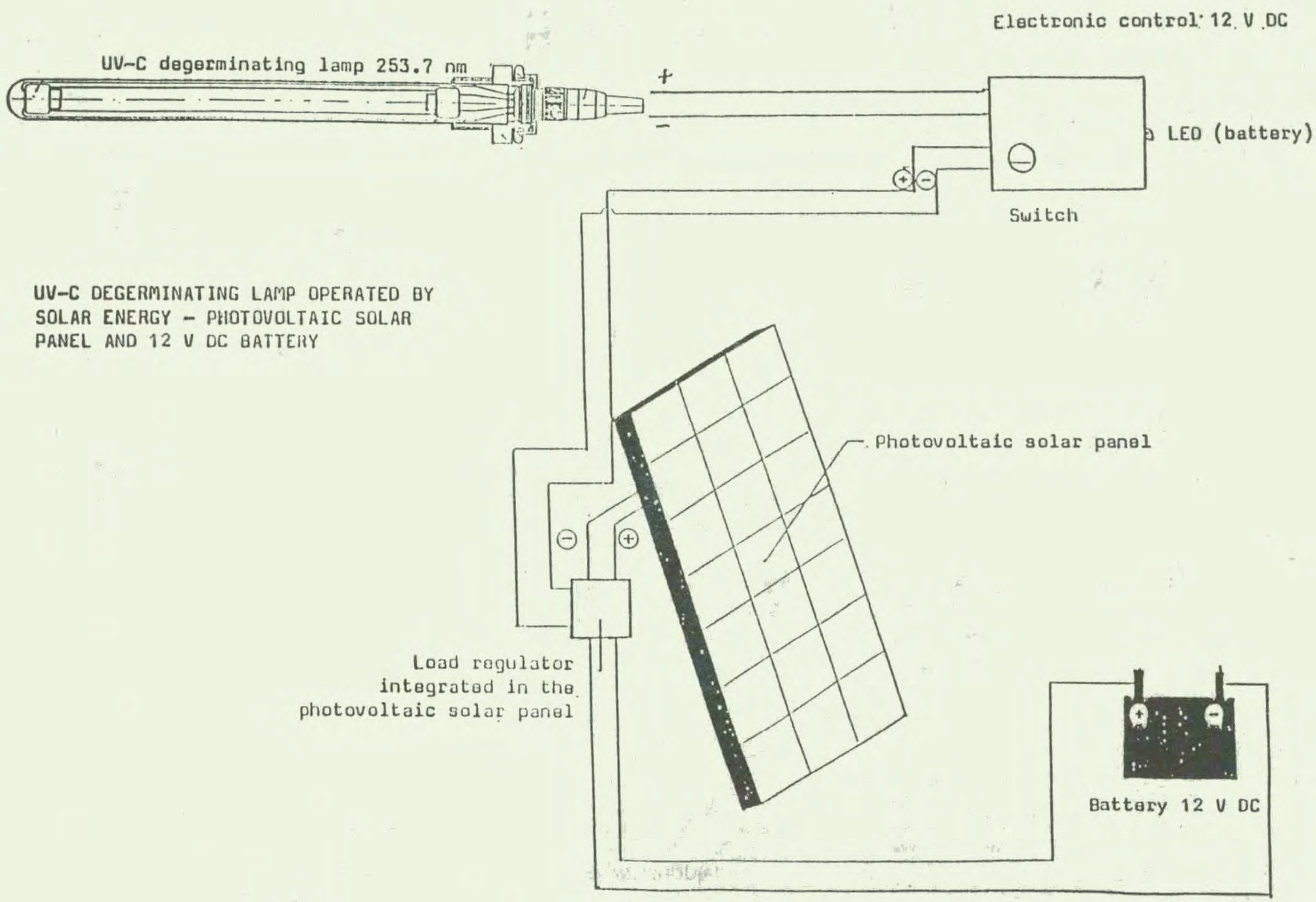
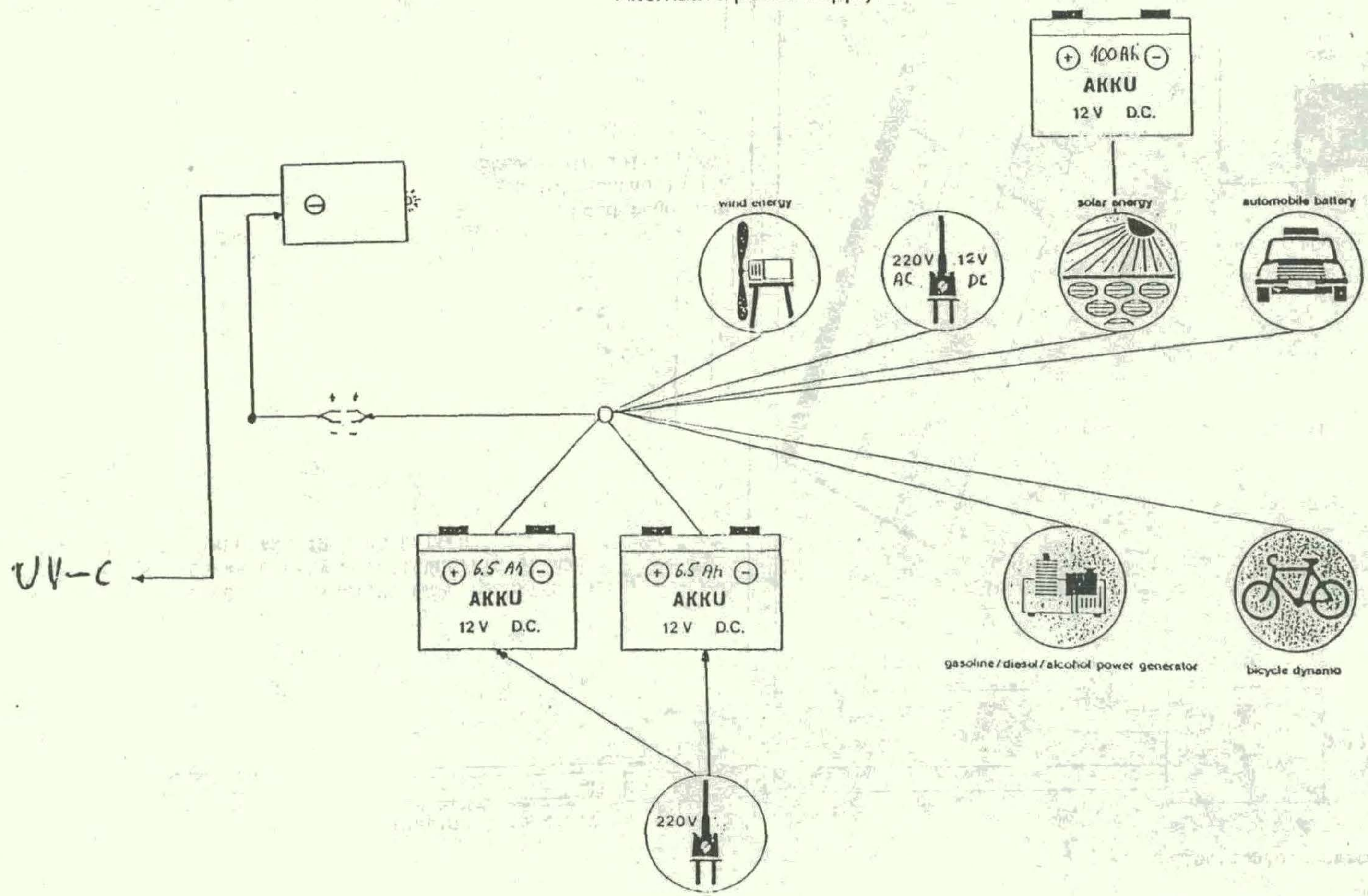
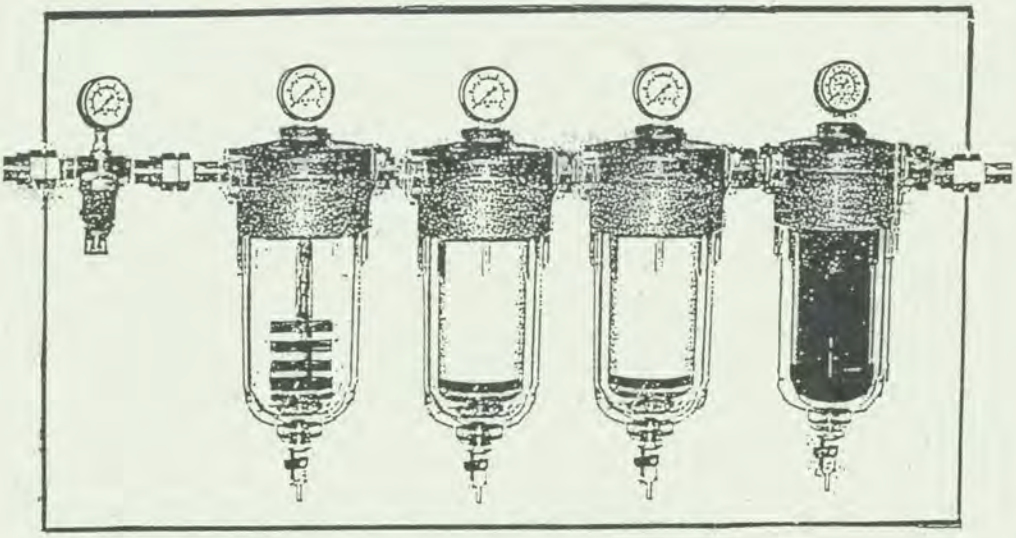


UV-C DEGERMINATING LAMP OPERATED BY SOLAR ENERGY - PHOTOVOLTAIC SOLAR PANEL AND 12 V DC BATTERY

Alternative power supply:





FILTRATION GROUP - TO BE INSTALLED BEFORE AN UV-C DISINFECTION UNIT

Pressure regulator	Iron removal filter (magnetic)	Coarse filter	Fine filter	Activated carbon filter

A pre-filter, a flow regulating valve and a water meter to be installed before the filtration group.

In rainwater treatment installations there has to be installed additionally a hardness increase filter and a microdosing device for the mineralization of the filtered and UV-C disinfected rainwater.

A Solar Powered UV System to Disinfect Cistern Waters

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ABSTRACT

Rainwater collected in cisterns are often used in rural areas of developed countries and in many villages of underdeveloped countries for household uses and as a drinking water source. However, we previously determined that even under favorable conditions, water in the cistern tanks contain high concentrations of total bacteria as well as fecal indicator bacteria, well in excess of drinking water standards. Chlorination to disinfect rainwater from cisterns has not been effective and often results in poor tasting water. There is a need for a simple-to-operate and reliable disinfecting system which can purify cistern water sources without the need for electrical power source and without changing the taste of the water. One such system is a small, solar-powered ultraviolet (UV) unit which uses gravity flow to process 1.5 liters of water per minute. The objective of this study was to evaluate such a system developed by Professor Otto Joklik of Austria and currently manufactured by Freund & Company. Several sources of cistern waters obtained from houses in Honolulu, Hawaii were tested for concentrations of various types of bacteria and viruses before and after treatment with this UV unit. This UV unit was shown to be effective in inactivating up to 99.9% of fecal indicator bacteria (fecal coliform, *E. coli*, enterococci) and up to 99.999% of total heterotrophic bacteria present in cistern water samples. This simple-to-operate, UV system which utilizes solar as a source of energy can be used in rural areas to purify the drinking water sources for an entire village.

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INTRODUCTION

Substantial populations in the world still do not receive a continuous supply of clean, safe water piped directly into their homes. In many developing countries, piped clean water is not available. Even in developed countries, piped water is not available to everyone because homes are too far away from a supplier or are in areas where the cost of piping is uneconomical due to low density of people, or due to the area's elevation. For many, the most feasible way to obtain water for household use is to use the roofs of their home as part of a rainwater catchment system and to collect this water in cisterns or tanks for future uses, including drinking. However, rainwater catchment systems are susceptible to bacterial contamination (Waller, 1984, Fujioka and Chinn, 1987, Yaziz et al, 1989, Lye, 1987,) and even under favorable conditions, most cistern waters cannot meet USEPA (1985) microbial drinking water standard established at 0 total coliform per 100 ml (Fujioka, Inserra and Chinn 1991, Faisst and Fujioka, 1994).

Over the years there have been numerous attempts to disinfect cistern waters by chlorination and this approach has not met with success for a number of reasons. First, new water is added to the cistern tank in an unpredictable way to recontaminate the reservoir tank. Second, the cistern tank material as well as the sediment in these tanks consume chlorine added to the system. Third, most cistern reservoir tanks are small and householder must rely on a manual system of applying chlorine which inevitably results in too much and then too little concentrations of chlorine in the tank water. Lastly, most cistern homeowners do not like the taste of chlorinated water. We recently proposed that only that portion of the cistern water used for drinking needs to be disinfected and that commercially available, electrically powered UV water purifier system can easily be used to disinfect cistern water used for drinking (Rijal and Fujioka, 1992). In that same study, we determined that it requires only a few minutes to disinfect the few liters of water needed for drinking per household per day. Thus, a single UV system can be used to disinfect the drinking water needs for many households or a whole village in a rural community. Since many areas in developing countries or isolated islands need to disinfect their water source but are also limited in not having electricity, we determined that there is a need for a simple-to-operate, reliable water disinfecting system which is not dependent on an electrical power source. The objective of this study was to determine whether a small, solar-powered UV unit which does not require electrical power for operation can be used to effectively disinfect cistern water sources so that these water sources can meet the microbial drinking water standards.

MATERIALS AND METHODS.

Study Site and collection of samples. Cistern water samples were collected in sterile plastic bottles from the kitchen faucets of nine homes in the Round-Top & Tantalus Community located on a hill in Honolulu, Hawaii. All samples were placed into an iced chest for transportation and all water samples were analyzed within four hours of collection. It should be noted that each home in this area utilizes their own rainwater catchment system and none of the cistern water is disinfected. The characteristics of the nine rainwater catchment systems are summarized in Table 1. Six of the nine homes used an in-line form of filter to filter the cistern water before it is pumped into the homes. Four of the cistern tanks had never been cleaned while the other cistern tanks were cleaned yearly or every five years

.Analysis of samples. The membrane filtration method as described in Standard Methods (APHA, 1989) was used to analyze up to 100 ml of water for fecal coliform on mFC agar, *E. coli* on mTEC agar, enterococci on mE agar, and for total heterotrophic count on mHPC agar. Up to 100 ml of water were also used in the analysis for *C. perfringens* using the method of Bisson & Cabelli (1979) and for male specific RNA bacteriophage by the method of Debartolomeis and Cabelli (1991). Hydrogen sulfide (H_2S) producing bacteria in water samples were monitored for by adapting the method as described by Manja et al (1982) to a presence/absence test method as well as a newly developed membrane filtration method. Water samples were also analyzed for UV transmittance using UV photometer (model P254, Trojan Technologies, Inc.).

UV System and experimental design. Freund & Co. of Vienna, Austria currently sells several models of Aquasan UV-C (253.7 nm) water disinfection system which was originally developed by Professor Otto Joklik of Austria. The UV system used in this study is the smallest, portable unit called "Water Boy" and was a gift from Professor Joklik for our scientific evaluation. This unit is packaged in an attaché case (length:44 cm, width: 33 cm; height: 11 cm) and contains a single 25 cm long UV lamp (12 V 8W, 12 khz), glass reaction vessel and tubing for the flow of water, as well as voltage regulator and a set of rechargeable batteries. A photovoltaic solar panel (360 X 330 X 35 mm) was used to charge the battery which powered the UV lamp. This system was designed to process water at the rate of 2.6 l/min. For our study we placed two reservoir containers at appropriate heights above the UV unit. The water sample was added to the higher reservoir jar and water flowed into the second, lower jar in which the water level was maintained. This enabled the water sample to gravity flow to the UV system at a constant rate of 1.5 l/m, without the need for electricity. The water treated in our study was being dosed at a higher rate of UV than was designed for this system.

The hygienic quality of cistern waters was based on the 10 fecal coliform standard as proposed by Fujioka (1994). However, all water samples were analyzed for six different fecal indicator microorganisms (fecal coliform, *E. coli, C. perfringens*, enterococci, H_2S producing bacteria, male specific RNA bacteriophage) as well as total heterotrophic bacteria which is an indicator of general water quality and nutrients in the water source. Use of multiple microbial indicators assist in the interpretation of water quality and especially on how well a system is functioning as a disinfectant.

RESULTS AND DISCUSSION

Hygienic quality of cistern waters Cistern water samples from nine households were collected on a weekly basis over five weeks and the samples analyzed for various microorganisms before and after treatment with UV. The hygienic quality of cistern waters from nine households were determined by assessing the concentrations of the various microorganisms but especially fecal coliform in the cistern water samples before UV treatment. The results summarized in Tables 2-10 show that the hygienic quality of water from Cisterns 3,4 and 5 ranged from excellent to good. Water from Cistern 3 was consistently free of fecal coliform over the five sampling periods while fecal coliform was recovered only once from water samples obtained from Cistern 4 (8 CFU/100 ml) and from Cistern 5 (1 CFU/100 ml). Thus, waters from Cisterns 3,4, and 5 consistently met the cistern water standard of < 10 FC/100 ml. Undetectable to low concentrations of all other fecal indicators were detected in water samples from Cisterns 3,4 and 5 substantiating the excellent quality of water from these cisterns.

The results (Tables 2-10) show that water samples from Cisterns 7, 8 and 9 were generally good but are vulnerable to contamination. For example, fecal coliform was detected in 3/5 samples from Cistern 7, and in 4/5 samples from Cistern 8 and 9. Most of the recovered concentrations of fecal coliform from these three cisterns were low (<10 CFU/100 ml) except during week two when the fecal coliform as well as other indicator bacteria counts increased dramatically suggesting a recent event such as rain just prior to sampling which would increase the concentrations of all bacteria in cistern waters.

Based on concentrations of fecal indicator bacteria, the hygienic quality of water from Cisterns 3,4,5 was determined to be very good while the hygienic quality of water from Cisterns 7,8,9 was determined to be good most of the time. Despite the good hygienic quality of water samples from these six cisterns, these same water samples often contained very high concentrations of total heterotrophic bacteria (>1000 CFU/ml) indicating that these waters sources are prone to contamination and most probably contain elevated concentrations of nutrients to allow the growth of bacteria.

Water from three cisterns (Cistern 1,2 ,6) consistently contain elevated concentrations of fecal coliform (Tables 2-10) and did not meet the recommended drinking water standard for cistern waters. Water samples from these same cisterns also contained elevated concentrations of all other fecal indicator bacteria as well as very high concentrations of total bacteria substantiating the poorer quality of water in these cisterns. The presence of high concentrations of fecal indicator bacteria in Cisterns 1,2 and 6 reflect the reality that some rainwater catchment systems allow for more contamination and the reason for the high bacterial counts could not be absolutely related to a specific characteristic of the catchment system such as composition of roof, presence of trees, lining material of cistern, frequency of cleaning cisterns or use of in-line filters. Cistern waters with high concentrations of bacteria should be disinfected before the water is used for drinking.

Disinfection of cistern waters. One of the major objective of this study was to determine whether cistern waters can be effectively disinfected by a solar powered UV system which does not require electrical power. The effectiveness of the UV system was evaluated by determining the residual concentrations of the various bacteria in the cistern water samples after UV treatment. The results summarized in Tables 2-10 show that most cistern waters are characterized by high UV transmission (range: 59-96%) and that UV treatment consistently reduced the levels of all five fecal indicator bacteria and especially fecal coliform and *E. coli* to undetectable levels (0 CFU/100 ml). These results clearly showed that the UV treatment inactivated at least 99.9% of the fecal indicator bacteria in all cisterns and the treated water easily met the cistern water quality standard. The UV treatment was also shown to greatly reduce the elevated concentrations (range: 188 - 896,000/ml) of total heterotrophic bacteria to 0.07 to 12 CFU/ ml. These results show that the UV treatment inactivated up to 99.999% of the bacterial population in cistern waters. This high rate of UV disinfection indicates that most of the pathogens which may be present in cistern waters would also have been disinfected.

SUMMARY AND CONCLUSIONS

In summary, the analysis of cistern water for many bacteria helped in assessing the quality of the water and the efficiency of disinfection by the UV system. First, RNA phage was not detected in any cistern water samples and therefore this data was not included in the Tables. Moreover, *C. perfringens* was generally not detected in these cistern waters. The absence of RNA phage and *C. perfringens* indicate that the source of the contamination for indicator bacteria is not human feces or sewage and therefore cistern waters are not likely to contain human fecal borne pathogens. The results suggest that soil or fecal droppings of birds as the most likely source of fecal contamination of cistern waters. These sources pose less of a health risk than human feces or sewage. The concentrations of H_2S producing bacteria in water samples as determined by the presence/absence test and the quantitative membrane filtration method closely paralleled the concentrations of fecal coliform bacteria before and after UV treatment. Since the method to assay for H_2S producing bacteria is simple and can be completed without the use of special equipment, it is the simplest method for homeowners to use to determine the quality of their water, the need to disinfect their water and the assurance that their water has been properly disinfected. Finally, this study showed that a solar powered UV system which was operated without the use of electricity, effectively disinfected cistern waters and the treated water met cistern drinking water standards based on reduced levels of fecal coliform bacteria. We propose that this UV disinfecting system be used to disinfect water for individual homes but will be especially useful for a whole village which does not have electricity and uses common sources of water such as rainwater collection systems or even a well. For practical reasons such as to prevent abuse and to ensure that the system will work, someone in the village should be assigned to operate this system.

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Table 1
Characteristics of Nine Rainwater Catchment Systems at Round-Top and Tantalus, Honolulu, Hawaii.

Household & Cistern Number	Household Roof Composition	Trees Around Roof	Cistern Tank Material	Number of Tanks : Volume (gallons)	In-line Filter	Cistern Cleaning Schedule
1	Enamel Steel	Yes	Redwood Vinyl Lined	two:5,000-10,000	No	every 5 years
2	Enamel Steel	Yes	Redwood Vinyl Lined	one:10,000	No	every 5 years
3	Asphalt Tile	No	Two cement lined & two metal lined	four:20,000-30,000	Fabric Rainbow Polyester filter: pore size 30μ.	once a year
4	Asphalt Tile	No	Galvanized Steel & Vinyl Lined	one:20,000-30,000	Fabric Filter : Rainbow Polyester filter pore size 30μ	once a year
5	Galvanized steel	Yes	Redwood Vinyl Lined	one:10,000-20,000	Stainless steel filters :Polyester filter pore size 30μ.	never
6	Galvanized steel	Yes	Galvanized Steel Tank & Vinyl Lined	one:10,000-20,000	Stainless steel filters :Polyester filter pore size 30μ.	never
7	Tar & Gravel	Yes	Redwood Vinyl Lined	one:10,000	Cartridge Polyester filter :pore size 30μ.	never
8	Tar & Gravel	Yes	Redwood Vinyl Lined	one:10,000	Cartridge Polyester filter:pore size 30μ.	never
9	Enamel Steel	Yes	Galvanized Steel tank & Vinyl Lined	one:10,000 -20,000	No	every 1-2 years

Table 2

Concentration of Indicator Microorganisms Recovered from Cistern 1
Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94)		Week 2 (9-23-94)		Week 3 (9-30-94)		Week 4 (10-07-94)		Week 5 (10-13-94)	
	BUV	AUV	BUV	AUV	BUV	AUV	BUV	AUV	BUV	AUV
FC (CFU/100 ml)	168	0	128	0	68	0	968	0	1092	0
EC(CFU/100 ml)	60	0	112	0	60	0	1000	0	904	0
CP (CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
EN(CFU/100 ml)	89	0	125	0	18	0	60	0	120	0
H_2S(CFU/100 ml)	145	0	126	0	49	0	849	0	923	0
H_2S(presence/ absence/100 ml)	+	-	+	-	+	-	+	-	+	-
TB(CFU/ ml)	960	3.0	896000	4.6	18400	6.48	111000	7.4	33600	3.4
% UV(254 nm) Transmission	85		87		not done		88		85	

Table 3

Concentration of Indicator Microorganisms Recovered from Cistern 2
Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94)		Week 2 (9-23-94)		Week 3 (9-30-94)		Week 4 (10-07-94)		Week 5 (10-13-94)	
	BUV	AUV	BUV	AUV	BUV	AUV	BUV	AUV	BUV	AUV
FC (CFU/100 ml)	312	0	279	0	93	0	186	0	160	0
EC (CFU/100 ml)	212	0	205	0	87	0	130	0	145	0
CP (CFU/100 ml)	7	0	0	0	0	0	0	0	0	0
EN (CFU/100 ml)	119	0	172	0	36	0	140	0	130	0
H_2S (CFU/100 ml)	278	0	212	0	84	0	173	0	184	0
H_2S(presence/ absence/100 ml)	+	-	+	-	+	-	+	-	+	-
TB (CFU/ ml)	1056	3.14	22670	3.14	21000	6.52	2400	1.3	1300	1.2
% UV(254 nm) Transmission	83		85		not done		88		87	

Table 4

Concentration of Indicator Microorganisms Recovered from Cistern 3
Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94)		Week 2 (9-23-94)		Week 3 (9-30-94)		Week 4 (10-07-94)		Week 5 (10-13-94)	
	BUV	AUV	BUV	AUV	BUV	AUV	BUV	AUV	BUV	AUV
FC (CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
EC(CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
CP (CFU/100 ml)	1	0	0	0	0	0	0	0	0	0
EN(CFU/100 ml)	0	0	0	0	0	0	6	0	0	0
H_2S(CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
H_2S(presence/ absence/100 ml)	-	-	-	-	-	-	-	-	-	-
TB(CFU/ ml)	426	3.36	8400	0.56	8800	4.16	1200	3.4	1100	1.44
% UV(254 nm) Transmission	94		92		not done		93		92	

Table 5

Concentration of Indicator Microorganisms Recovered from Cistern 4 Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94) BUV	Week 1 (9-16-94) AUV	Week 2 (9-23-94) BUV	Week 2 (9-23-94) AUV	Week 3 (9-30-94) BUV	Week 3 (9-30-94) AUV	Week 4 (10-07-94) BUV	Week 4 (10-07-94) AUV	Week 5 (10-13-94) BUV	Week 5 (10-13-94) AUV
FC (CFU/100 ml)	8	0	0	0	0	0	0	0	0	0
EC(CFU/100 ml)	12	0	0	0	0	0	0	0	6	0
CP (CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
EN(CFU/100 ml)	0	0	1	0	0	0	2	0	0	0
H_2S(CFU/100 ml)	16	0	0	0	0	0	0	0	0	0
H_2S(presence/absence/100 ml)	+	-	-	-	-	-	-	-	-	-
TB(CFU/ ml)	188	0.2	504	0.22	4700	4.63	13200	10.4	2160	1.68
% UV(254 nm) Transmission	94		96		not done		95		96	

Table 6

Concentration of Indicator Microorganisms Recovered from Cistern 5 Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94) BUV	Week 1 (9-16-94) AUV	Week 2 (9-23-94) BUV	Week 2 (9-23-94) AUV	Week 3 (9-30-94) BUV	Week 3 (9-30-94) AUV	Week 4 (10-07-94) BUV	Week 4 (10-07-94) AUV	Week 5 (10-13-94) BUV	Week 5 (10-13-94) AUV
FC (CFU/100 ml)	0	0	1	0	0	0	0	0	0	0
EC(CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
CP (CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
EN(CFU/100 ml)	2	0	1	0	0	0	27	0	0	0
H_2S(CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
H_2S(presence/absence/100 ml)	-	-	-	-	-	-	-	-	-	-
TB(CFU/ ml)	1288	0.07	2800	0.13	3600	12	440	7.84	620	3.6
% UV(254 nm) Transmission	74		83		not done		82		81	

Table 7

Concentration of Indicator Microorganisms Recovered from Cistern 6 Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94) BUV	Week 1 (9-16-94) AUV	Week 2 (9-23-94) BUV	Week 2 (9-23-94) AUV	Week 3 (9-30-94) BUV	Week 3 (9-30-94) AUV	Week 4 (10-07-94) BUV	Week 4 (10-07-94) AUV	Week 5 (10-13-94) BUV	Week 5 (10-13-94) AUV
FC (CFU/100 ml)	476	0	140	0	272	0	216	0	328	0
EC(CFU/100 ml)	412	0	152	0	216	0	176	0	280	0
CP (CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
EN(CFU/100 ml)	20	0	126	0	126	0	69	0	123	0
H_2S(CFU/100 ml)	386	0	208	0	208	0	212	0	316	0
H_2S(presence/absence/ ml)	+	-	+	-	+	-	+	-	+	-
TB(CFU/ ml)	3400	3.04	4000	0.21	5200	2.6	536	4.32	22400	1.8
% UV(254 nm) Transmission	70		78		not done		77		79	

Table 8

Concentration of Indicator Microorganisms Recovered from Cistern 7 Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94) BUV	AUV	Week 2 (9-23-94) BUV	AUV	Week 3 (9-30-94) BUV	AUV	Week 4 (10-07-94) BUV	AUV	Week 5 (10-13-94) BUV	AUV
FC (CFU/100 ml)	0	0	168	0	0	0	3	0	12	0
EC(CFU/100 ml)	0	0	208	0	0	0	5	0	8	0
CP (CFU/100 ml)	0	0	0	0	0	0	0	0	0	0
EN(CFU/100 ml)	0	0	44	0	0	0	2	0	0	0
H_2S(CFU/100 ml)	0	0	145	0	0	0	0	0	0	0
H_2S(presence/ absence/100 ml)	-	-	+	-	-	-	-	-	-	-
TB(CFU/ ml)	332	0.1	1960	0.44	324	5.84	122	7.76	684	1.65
% UV(254 nm) Transmission	68		59		not done		71		69	

Table 9

Concentration of Indicator Microorganisms Recovered from Cistern 8 Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94) BUV	AUV	Week 2 (9-23-94) BUV	AUV	Week 3 (9-30-94) BUV	AUV	Week 4 (10-07-94) BUV	AUV	Week 5 (10-13-94) BUV	AUV
FC (CFU/100 ml)	6	0	12	0	4	0	0	0	10	0
EC(CFU/100 ml)	0	0	1	0	1	0	0	0	14	0
CP (CFU/100 ml)	1	0	0	0	0	0	0	0	0	0
EN(CFU/100 ml)	1	0	18	0	0	0	0	0	0	0
H_2S(CFU/100 ml)	0	0	21	0	10	0	0	0	0	0
H_2S(presence/ absence/100 ml)	-	-	+	-	+	-	-	-	-	-
TB(CFU/ ml)	1200	0.28	2060	0.28	15200	4.56	220	4.2	520	3.1
% UV(254 nm) Transmission	80		76		not done		78		81	

Table 10

Concentration of Indicator Microorganisms Recovered from Cistern 9 Water Sample Before UV Treament (BUV) and After UV Treament (AUV)

Test Performed	Week 1 (9-16-94) BUV	AUV	Week 2 (9-23-94) BUV	AUV	Week 3 (9-30-94) BUV	AUV	Week 4 (10-07-94) BUV	AUV	Week 5 (10-13-94) BUV	AUV
FC (CFU/100 ml)	6	0	12	0	4	0	0	0	10	0
EC(CFU/100 ml)	0	0	1	0	1	0	0	0	14	0
CP (CFU/100 ml)	1	0	0	0	0	0	0	0	0	0
EN(CFU/100 ml)	1	0	18	0	0	0	0	0	0	0
H_2S(CFU/100 ml)	0	0	21	0	10	0	0	0	0	0
H_2S(presence/ absence/100 ml)	-	-	+	-	+	-	-	-	-	-
TB(CFU/ ml)	1200	0.28	2060	0.28	15200	4.56	220	4.2	520	3.1
% UV(254 nm) Transmission	80		76		not done		78		81	

A Homeowners Test for Bacteria in Cistern Waters

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ABSTRACT

In some communities, rainwater catchment systems are used to collect water in tanks (cistern) for household use, including drinking. These sources of water are vulnerable to contamination by microbial pathogens and may result in waterborne diseases. The quality of cistern waters can be expected to vary considerably from time-to-time, and the quality of this kind of water is rarely monitored. In a previous study we determined that the hydrogen sulfide (H_2S) test is a simple, reliable test that homeowners can analyze cistern waters in their own homes without the use of special equipment. The objective of this study was to evaluate the reliability of the hydrogen sulfide test as compared to currently accepted methods used to determine the quality of water from five cisterns on five separate days. The concentrations of H_2S producing bacteria as determined by the MPN method closely correlated with the concentrations of total coliform as determined by the MPN method. For example, when total coliform as well as other fecal indicator bacterial counts dropped to zero so did the counts of H_2S bacteria. When the concentrations of total coliform by the MPN method increased, so did the concentrations of H_2S producing bacteria. Thus, the results of this study show that testing water for H_2S producing bacteria is as reliable and as sensitive as testing for total coliform by the MPN method. The H_2S test is the only test which could be incubated at room temperature and since the black endpoint is easy to read, this test can be feasibly conducted by homeowners at their homes. We recommend that the H_2S test be used by cistern owners to determine the hygienic quality of their own source of water.

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INTRODUCTION

Many households use the roofs of their homes as rainwater catchment systems and collect the water in reservoir tanks or cisterns for all their household needs, including drinking. Since cistern owners are not required to test their water, the quality of most waters stored in cisterns is not known. However, recent studies (Waller, 1987, Fujioka and Chinn, 1987, Yaziz et al, 1989), clearly show that rainwater catchment systems are susceptible to bacterial contamination and cistern waters cannot be relied on to meet USEPA (1985) drinking water standard of 0 total coliform/100 ml (Fujioka, Inserra and Chinn, 1991, Faist and Fujioka, 1994). As a result, it is generally recommend that cistern waters be chlorinated (Krishna , 1994). However, it is difficult to successfully chlorinate individual cistern systems without greatly affecting the taste of the water. Recently, we (Rijal and Fujioka, 1992) proposed that UV light be used to disinfect cistern waters because UV can effectively disinfect bacteria in cistern waters without affecting the taste of the water.

Despite the many recommendations given to cistern owners, the homeowners are never sure that their cistern waters are not contaminated with microbial pathogens which can result in water borne diseases. The only way to determine whether the water meets drinking water standard is to send their water to a water quality laboratory for testing, an inconvenient, time consuming, and expensive endeavor. There is a great need for a simple test that home owners can use to determine the bacterial content of their water and determine whether the water is safe to drink or should be treated. And if treated whether the treatment method has rendered the water safe to drink. Such a test is now available. We (Rijal and Fujioka, 1992) previously reported that the hydrogen sulfide test originally developed by Manja et al (1982) is simple and can be used by homeowners to test the bacterial quality of their water without the use of special equipment. The objective of this paper is to compare the reliability of this simple hydrogen sulfide test method to several USEPA approved methods used to determine the quality of drinking water.

MATERIALS AND METHODS

Study sites and collection of samples. Cistern water samples were collected in sterile plastic bottles from the kitchen faucets of five homes in the Round Top & Tantalus community located on a hill in Honolulu, Hawaii. None of the cistern waters were disinfected. All water samples were immediately placed into an iced chest, transported to the University of Hawaii and analyzed within four hours of collection.

Analysis of samples. Concentrations of several indicator bacteria were determined by membrane filtration method as described in Standard Methods (APHA, 1989) and summarized as follows:

Bacteria	Medium	Incubation
Total Coliform (TC)	mEndo	35°C/24 hr
Fecal Coliform (FC)	mFC	44.5°C/24 hr
Fecal Streptococci (FS)	KF	35°C/48 hr
E. coli (EC)	mTEC	35°C for 2 hr 44.5°C for 22 hr
Total Bacteria (TB)	mHPC	35°C/24-48 hr

The five tube MPN method as described in Standard Methods (APHA, 1989) was used to analyze water samples for total coliform and *E. coli* and H_2S producing bacteria as summarized below:

Bacteria	Medium	Incubation
Total Coliform	LTB Broth	35°C/24 hr
E. coli	EC+MUG	44°C/24 hr
H_2S Bacteria	H_2S Medium	Ambient (23°C/24 hr)

The H_2S method as described by Manja et al 1982) was adapted to the five tube MPN method by adding the dried paper strips impregnated with the reagents for the H_2S test into each of the MPN tubes. Water samples were added to the tubes with the paper strips and the tubes incubated at ambient temperature (23-30°C) for 24 hrs. Black coloration of the paper strip was considered a positive reaction.

RESULTS AND DISCUSSION

We previously determined that the H_2S test was the only feasible test by which a homeowner could test the bacterial quality of waters at home. However, simplicity of test is not the only criteria to use a method. The method must be reliable and must yield results comparable to existing acceptable tests. For drinking water, the five tube MPN method for total coliform and for *E. coli* has traditionally been used. To evaluate the reliability of the H_2S test, this test was adapted to a five tube MPN method and water samples analyzed for total coliform, *E. coli* and for H_2S bacteria using this MPN method. To further characterize the water, the same water samples were also analyzed for total coliform, *E. coli*, fecal coliform, fecal streptococci and total heterotrophic bacteria using the membrane filtration method. The hygienic quality of water was evaluated based on current USEPA standards (1985) which recommend 0 total coliform/100 ml and a more pragmatic standard for cistern waters of 10 fecal coliform/100 ml as recommended by Fujioka (1994). The overall quality of water was evaluated based on USEPA (1985) recommendations that drinking water should not contain more than 500/ml of total heterotrophic bacteria. For this evaluative study, water samples were obtained once a week over five weeks from five separate cisterns representing five different rainwater catchment systems. All water samples were analyzed for the various indicator bacteria using the MPN method and the membrane filtration method.

Cistern One All water samples from this cistern analyzed by the MPN method and the membrane filtration method were negative for of all the traditional fecal indicator bacteria (total coliform, *E. coli*, fecal coliform, fecal streptococci) as well as H_2S producing bacteria (Table 1). The absence of H_2S producing bacteria correlated well with the absence of all fecal indicator bacteria indicating that the H_2S test will result in negative test when the traditional fecal indicator bacteria test results are negative. Thus, the hygienic quality of water from this cistern is excellent. The presence of 118 to 450 CFU/100 ml of total heterotrophic bacteria in these same samples indicate that the water had not been disinfected and was of an acceptable general water quality (<500/ml).

Cistern Two. All water samples from this cistern were positive for all fecal indicator bacteria as well as H_2S producing bacteria as analyzed by the MPN method and the membrane filtration method (Table 1). The hygienic quality of this cistern water did not meet the drinking water standard (0 coliform/100 ml) as well as the cistern water standard (10 fecal coliform/100 ml). In these samples, the concentrations of H_2S producing bacteria by the MPN method were identical to that of total coliform concentrations as measured by the MPN method. The concentrations of all other fecal indicator bacteria were similar, although higher concentrations of total coliform were recovered by the membrane filtration method. Thus, the H_2S test results correlated especially well with total coliform but also with the concentrations of other fecal indicator bacteria. In these same water samples the concentrations of total heterotrophic bacteria ranged from 445 to 782 CFU/ml substantiating the poor general quality of this cistern water. These results indicate that water from this cistern should be disinfected before drinking.

Cistern Three. All water samples from this source were negative for all fecal indicator bacteria as well as H_2S producing bacteria during the first two weeks of sampling. However, the concentrations of fecal indicator bacteria and H_2S producing bacteria increased slightly during week 3, increased to a maximum during week 4 and decreased during week 5 (Table 1). Thus, the hygienic quality of water from this cistern was good during weeks 1 and 2 but deteriorated during weeks 3,4 and 5. It is significant to note that the rise and fall of the concentrations of H_2S producing bacteria matched the rise and fall of fecal indicator bacteria, especially that of total coliform counts determined by the MPN method. These results demonstrate the reliability of the H_2S test to determine the hygienic quality of water as measured by the traditional tests. It should be noted that the total heterotrophic bacterial concentrations in waters from this cistern exceeded >500/ml only during week 4 when the counts for all indicator bacteria in the cistern water sample were elevated. Thus, the general quality of water from Cistern 3 was good.

Cistern Four. All water samples from this cistern were negative for all indicator bacteria during week 1, increased to maximum levels during week 2 and fell to lower levels during weeks 3,4 and 5 (Table 1) Based on these results, the hygienic quality of water from this cistern met the USEPA drinking water standard only once in 5 weeks but met the cistern water standard three times in 5 weeks. In these samples, the concentrations of H_2S producing bacteria were similar in concentrations to total coliform as recovered by the MPN method. Elevated concentrations of total heterotrophic bacteria (>500/ml) were detected in cistern water samples collected only during week 2 indicating that the general quality of water from this cistern was good.

Cistern Five. All water samples from this cistern contained elevated concentrations of all fecal indicator bacteria as well as H_2S producing bacteria and total heterotrophic bacteria (Table 1). These results indicate that this cistern is highly susceptible to contamination and general quality as well as the hygienic quality of water in this cistern is poor. The elevated concentrations of fecal coliform bacteria in this cistern water show that this cistern water cannot be expected to meet the stringent USEPA drinking water standard of 0 total coliform/100 ml or the more pragmatic cistern water standard of 10 FC/100 ml. Significantly, the concentrations of H_2S producing bacteria closely matched the concentrations of total coliform by the MPN method. These results indicate that this cistern water should be disinfected before it is used for drinking.

SUMMARY AND CONCLUSION

Five different sources of cistern water were analyzed for four different fecal indicator bacteria, for H_2S bacteria and for total heterotrophic bacteria over a five week period. The concentrations of all fecal indicator bacteria were similar. The average MPN/100 ml for the 25 samples were >8.08 for total coliform (TC), >9.4 for H_2S producing bacteria, and >5.3 for *E. coli*

(EC). By membrane filtration method, the average CFU/100 ml for these same water samples were 64 for TC, 14 for EC, 22 for fecal coliform and 31 for fecal streptococci. It is significant to note that the concentrations of H_2S bacteria as determined by the MPN method closely correlated with the concentrations of total coliform bacteria as recovered by the MPN method. For example, when total coliform as well as other fecal indicator bacteria counts dropped to zero, so did the counts of H_2S producing bacteria. When the concentrations of total coliform by the MPN method increased, so did the concentrations of H_2S producing bacteria. Thus, the results of this study show that testing water for H_2S producing bacteria is as reliable and as sensitive as testing for total coliform by the MPN method. Analyzing the water for total heterotrophic bacteria also proved to be useful as the general quality of the water based on concentrations of total heterotrophic bacteria correlated well with the hygienic quality of water based on concentrations of fecal indicator bacteria. Analyzing the water samples for several indicator bacteria using the MPN method and the membrane filtration method greatly increased the confidence in the results obtained. However, the results of this study show that use of only one or two tests is sufficient for routine monitoring of cistern waters.

The results of this study point out again that some cistern waters consistently contain high concentrations of fecal indicator bacteria while other cistern waters contain high levels of fecal indicator bacteria sometimes but not at other times. These results indicate that some cistern waters may have to be disinfected and for some cistern systems, improvements can be made to improve the quality of the cistern waters. It is clear, that there is a need to test cistern waters to determine the quality of water so appropriate decisions can be made to improve on the quality of cistern water. Of all the tests, the H_2S test is the only one which can be carried out by the homeowner without the use of special equipment. Incubation of the test is at room temperature and the black end point is easy to read.

We propose to adapt the H_2S test to simplify its use to homeowners and to make it semi-quantitative by providing homeowners with a 10 ml test container and 100 ml test container to analyze each water sample. The homeowner will add 10 ml of water to the smaller 10 ml container to a line indicating 10 ml volume and add 100 ml of water to the larger 100 ml container to a line indicating the 100 ml volume. Both containers will have the appropriate dried test paper which includes all the necessary reagents. After filling the two containers with water, the homeowner will recap the two containers and hold them at ambient temperature (23-30°C). The containers will be observed for blackening of the test paper after 24 and 48 hours as a positive test result for H_2S bacteria. A cistern sample which is negative in the 10 ml and the 100 ml sample indicate that the quality of the water is good and need not be disinfected. A cistern sample which is positive in the 10 ml and 100 ml sample indicate that the water is heavily contaminated with bacteria and should be disinfected before drinking. On the other hand, a cistern sample which is negative for H_2S bacteria in the 10 ml sample but positive in the 100 ml sample, indicate only a low level of contamination. This kind of information is useful to the homeowner because it tells the homeowner that the quality of the cistern water is only marginally contaminated and may reflect improvement in the quality of water due to disinfection or cleaning of the cistern tank. This minimal level of contamination may also indicate that the water may still meet the cistern water quality standard as proposed by Fujioka (1994).

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Table 1. Concentrations of Various Indicator Bacteria Recovered from Cistern Water

Cistern Number / Sampling Week	MPN Index/100 ml			Membrane Filtration CFU/100 ml				Membrane Filtration CFU/ ml
	TC	EC	H_2S	TC	EC	FC	FS	TB
Cistern One								
03-19-91	0	0	0	0	0	0	0	360
03-28-91	0	0	0	0	0	0	0	118
04-04-91	0	0	0	0	0	0	0	289
04-13-91	0	0	0	0	0	0	0	450
04-18-91	0	0	0	0	0	0	0	175
Cistern Two								
03-19-91	16	9.2	16	78	4	12	23	567
03-28-91	16	9.2	16	45	4	9	27	519
04-04-91	16	16	16	108	18	35	49	782
04-13-91	9.2	2.2	9.2	36	4	23	19	445
04-18-91	9.2	2.2	9.2	23	2	12	10	476
Cistern Three								
03-19-91	0	0	0	0	0	0	0	213
03-28-91	0	0	0	0	0	0	0	102
04-04-91	9.2	5.1	5.1	34	10	21	26	336
04-13-91	>16	>16	>16	263	20	35	112	1642
04-18-91	2.2	0	2.2	12	4	12	8	214
Cistern Four								
03-19-91	0	0	0	0	0	0	0	72
03-28-91	>16	5.1	>16	285	66	114	221	1663
04-04-91	2.2	0	16	10	4	8	12	45
04-13-91	5.1	5.1	16	13	8	8	10	56
04-18-91	5.1	5.1	16	24	12	16	18	112
Cistern Five								
03-19-91	>16	>16	>16	129	35	60	41	1200
03-28-91	>16	5.1	>16	96	24	35	37	718
04-04-91	>16	>16	>16	248	92	96	102	945
04-13-91	16	16	>16	118	22	46	35	869
04-18-91	>16	5.1	>16	65	12	16	18	568
Average (25 samples)	>8.08	>5.34	>9.35	63.5	13.64	22.32	30.72	517.44

note: TC-Total coliform, EC- *E. coli*, H_2S-Hydrogen sulfide test, FC-Fecal coliform, FS- Fecal streptococci, and TB-Total heterotrophic bacteria

RAINWATER ROOF CATCHMENT SYSTEMS FOR DOMESTIC WATER SUPPLY IN SOUTH OF WEST BANK

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ABSTRACT

Rainwater chatchment system (RCS) is a system to harvest, store, an use rainwater as a primary or a supplementary water source. The system has been used in Palestine for thousand of years and evidence of roof catchment system. Nowadays, and inspite of the availability of water distribution systems in most cities of West Bank, the people continue collecting rainwater in an economically water cisterns, and this is due to the shortage of water. In the occupied West Bank, rainwater of cisterns have been used for domestic and irrigation purposes as a supplementary water supply where the major supply is from ground water.

This paper examines the most significant aspects of rainwater roof catchment systems for domestic water supply in south of West Bank. It discusses first the development of this old technology focusing on description of the whole system (appropriate design and construction methods to the system components) base on field data. The feasibility of using roof rainwater catchment systems as supplementary water source in south West Bank along with the maximum amount of rainwater that can be stored during each year were investigated by considering the regional rainfall characteristics. Water quality issues were discussed. Overall summary and conclusions are given.

Through the collection of field data and rational analysis, it is shown that rainwater roof catchment systems, are feasible and effective in partially alleviating water shortage. At the same time, the water is of high quality.

INTRODUCTION

West Bank is located in the east of Palestine. It has an area of approximately 5500 km2, the area is a mountainous with an average hight of 800 m with respect to sea level. The temperature is moderate in the Summer (20-30 °C) and Winter temperature is low. The annual average rainfall is around 550 mm and annual water consumption amounts 155 million cubic meter. The total Palestinian population in the West Bank is estimated at approximately 1.5 million. The study area represents the southern part of West Bank.

Water is indispensable to human life and is also a vital necessity of plant and animal life. From the beginning of life, people used to settle close to water resources. Demand of water constantly and rapidly increases with increasing population, better living standard, more irrigation facilities and industrial development.

The general situation in West Bank cities, villages and camps is causing an increase in amount of water consumption for domestic, public, irrigational and industrial water uses. In the West Bank, underground water is the main source of water, but the Palestinian people are prohibited from developing new water wells due to Israelis Occupation Authorities restrictions. Therefore, West Bank cities and villages face great difficulties in finding water quantities that is adequate to meet the demand.

In view of this, searching for new water resources starts with decreasing the amount present of water lost in the distribution systems. Equally important is the collection of rainwater in an economically feasible water wells (cisterns). In other words, rainwater catchment and storage are good option. It must be stressed that rainwater is the only source which is easy to obtain individually and with minimum cost, the only thing which the person need is the roof of the house to collect the rainwater and a place to store it.

Rainwater catchment systems have been used in Palestine since ancient times, from Roman times, especially roof catchment systems. Rainwater has been used for domestic and irrigation purposes. These days, and inspite of the availability of water distribution systems in most cites of West Bank, the people continue collecting rainwater in an economically feasible water cisterns, and this is due to the shortage of water.

The rainy season in West Bank starts usually on November and ends in April. The average annual rainfall under normal climatic conditions is 550 mm. About 30-40% of this quantity evaporates and the rest is stored as either surface water or ground water. So, the amount of rainfall which can be collected either by roof chatchment or surface catchment and stored in cisterns or reservoirs to use it for different purposes is appreciable. The amount of water which may collected from a roof of 100 m2 in the rainy season is about 150 m3.

There are two basic types of rainwater catchment systems used for domestic water supply (Gould 1991 and 1993), these are roof and surface catchment systems. Roof catchment systems (or rainwater cisterns systems) are the most common type of catchment systems used in West Bank for rainwater harvesting. Surface catchments are areas prepared to harvest rainwater to be used for supplying water for drinking, irrigation, industries etc. Small dam or reservoir are usually built in suitable places in the catchment areas for the purpose of storing rainwater for the dry season. Such structures are presently absent and the potential for such facilities must be investigated.

In roof catchment systems, rainwater can be harvested by using roofs as catchment areas and storing the water in storage tanks or underground cisterns for domestic use. So, the main components of the roof rainwater catchment systems are: roof, pipes and storage tank or cistern. A filter may be used to remove the undesired sediments. Also, a pump may be required to pump water from the cistern to desired height.

Similar to other engineering systems rainwater roof catchment system has advantages and disadvantages. The main advantages are: the quality of rainwater is usually good, collection of rainwater is simple, it is economically feasible for small communities, no energy costs are needed to run the system, ease of maintenance by the user, and convenience and accessibility of water. The disadvantages of the system are: high initial cost, water availability is limited, and mineral free water has a flat taste and may cause nutrition deficient diets.

In West Bank, rainwater of cisterns has been used as a supplementary water supply where the major supply is from ground water. It constitutes favorable alternative source of water. As a result of cost considerations and limitations in current supplies of water in West Bank with respect to quantity and quality, Cisterns or roof catchment systems have started to attract attention as viable and important sources of water.

Accordingly, the study presented emphasizes the importance of rainwater roof catchment systems for domestic water supply in south of West Bank and this is the overall objective of this study. It discusses first general domestic water storage patterns and rainwater harvesting (with roof catchment system) for domestic usage in south of West Bank. Second, the maximum amount of rainwater which may be collected and stored in cisterns using roof catchment systems along with the advantages and contribution of the whole system within the traditional water supply system in south of West Bank are calculated and discussed. Third, the study evaluated the quality of the collected rainwater including, chemical and biological characteristics. Finally, the study provides some suggestions and recommendations regarding cost, the improvement of both quality and quantity of rainwater collected, the construction of cisterns including type and size, and the management of the existing storage capacities to maximize water supply.

For the purpose of this study and in order to evaluate the practices of using rainwater roof catchment systems in south of West Bank, data from different areas and villages in south of West Bank were collected using a prepared questionnaire. The survey was covered the major villages and cities of south West Bank. The questionnaire includes general questions about the study area beside the questions related to rainwater roof catchment systems such as the method of collecting rainwater, design and construction of the cistern, rainwater use, water quality, etc. A total of 300 questionnaires of 300 homes were included in this study. The survey took three months to complete. All the questionnaire were studied and analyzed. The major results of the survey are presented in the following sections.

DESCRIPTION OF RAINWATER ROOF CATCHMENT SYSTEMS

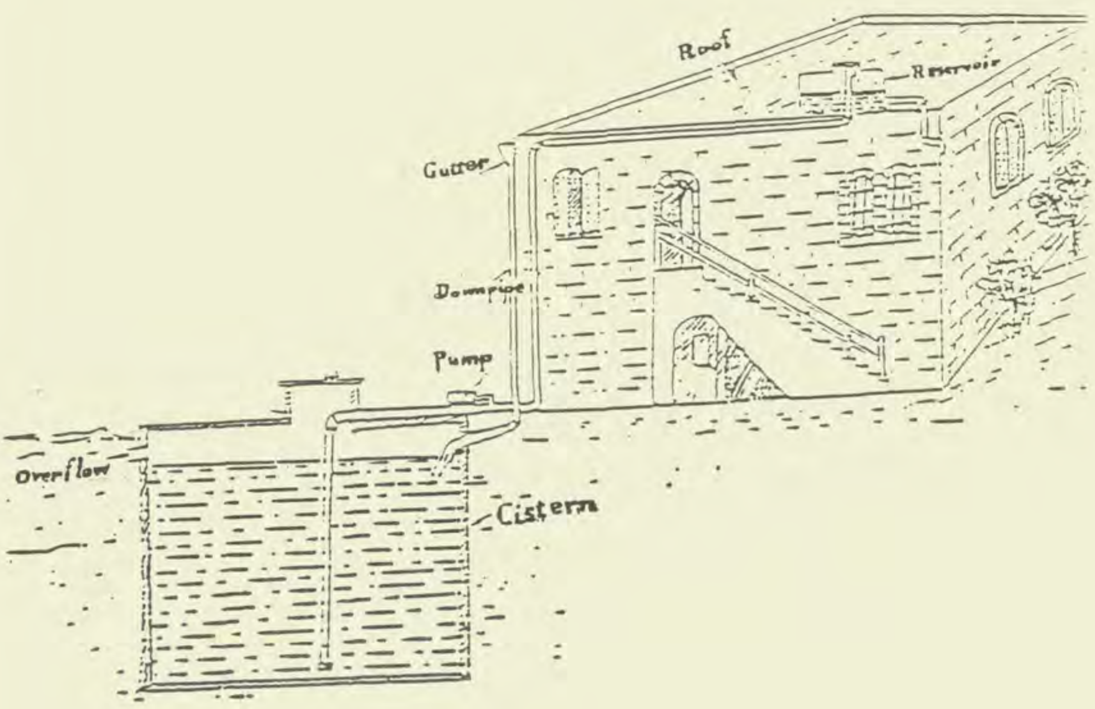
As shown in Fig. 1, a rainwater roof catchment system consists of three basic components (Latham and Gould 1986, Milne 1979).

1. A roof which is used as the catchment for collecting the rainwater.
2. A gutter and downpipe for conveying the rainwater to the cistern or storage tank once it is collected.
3. A cistern or tank for storing the water for future use.

In addition, some form of pumping system may be needed if the cistern is below the ground surface. If rainwater is used for domestic and drinking purposes, some type of treatment may be required (filtration or purification), it could be simple screen, sand filter or chemical treatment system.

FIG. (1)

RAINWATER ROOF CATCHMENT SYSTEM



Roofs

In rainwater catchment systems, rainwater has to be collected over impermeable surface areas. Many surfaces such as roofs, roads, and yards can perform the function of catching rainwater. Roofs are the most common catchments which is simply available in all buildings and has the advantage of providing good quality of water.

In south of West Bank, three types of roofing materials are used, they are sheet metal, cement, and clay. Cement roofs are the most common type in the area due to its durability, relatively low price, and provides good quality of water. Metal roofs are rare even it is easy to install and clean, it is seen on 3% of the roofs observed in south West Bank. Clay roofs is very common in rural areas, but it is generally not suitable because the collected water is not of high quality, less durability, and it is difficult to clean such roofs. In summary, cement roofing material are the most suitable materials for rainwater catchments in South West Bank.

The roofs of the building is usually flat, constructed with a slope of 1 to 2%, so that water is collected in one area. And in order to collect maximum amount of water, roofs are usually surrounded by a wall of 25 to 60 cm.

Generally speaking, water collected on the roofs is of good quality, the possible roof sources of contamination include air pollution, materials used in constructing the roof, and bird droppings (Milne 1979). Roofs should be very clean that will not add pollutants to the water. In West Bank, the roofs is cleaned manually before the first rainfall. The first precipitation flows from the roof through an outlet, thus cleaning the roof from dust. The outlet valve is then closed, and an inlet valve for the pipe to the cistern is opened. Both the inlet and the outlet valve are placed in the lowest part of the roof.

Gutters

The gutter is an important component in rainwater roof catchment system. A properly fitted and maintained gutter system is capable of collecting large volumes of rainwater (around 90% of all rainwater runoff). Gutters should not contain any material which contribute to the contamination of the rainwater.

In West Bank, gutters and downpipes are made of a variety of materials, such as metal, plastic, and bamboo. The gutter material depends mainly on cost and then on the availability and ease of installation. Metal gutters (especially Zinc gutters) are the most common type used in West Bank. Plastic pipes are also seen frequently in gutters. bamboo gutters are very rare seen. The durability and light weight of Zinc sheet metal and plastic makes both very suitable.

The size of gutters or downpipes is depend upon the amount of rainfall and the area of the roof. If the gutter is two small, considerable quantities of rainwater runoff may be lost due to overflow during the storms. The size of the gutters used is ranges between 2"-8" diameter.

The gutters and downpipes are usually installed in the wall of the building, and sometimes, the downpipes are fitted inside the wall while constructed.

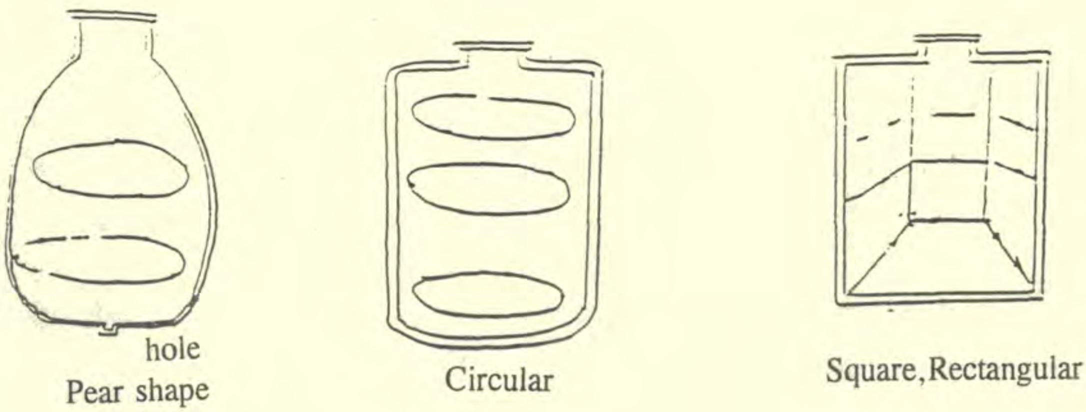
Cisterns

Cisterns are artificial reservoirs for collecting and storing rainwater from impermeable area (Alpaslam, Harmancioglu and Singh 1992). For a long time, Palestinians have been building cistern wells to collect and store the rainfall from the roofs of their houses. These cistern wells are still present in many Palestinian villages in which water is collected during Winter and used for domestic purposes throughout the year.

Many cisterns .or storage thanks, especially those that were constructed more than 50 years a go had a pear shape, were these days, cisterns are usually designed with circular, rectangular, and square plans, with depth around 3-5 m and of different materials (See Fig. 2). A cistern of a pear shape is excavated in rock were the opening of the cistern is narrow and then it is increased taking a circular-shape. It is usually needs less materials to build, excavation can be done manually and this is usually done by the owner and his family. Pear shape cistern is usually connected with small hole (60x60x20 cm) near the opening, the purpose of this hole is to treat water by sedimentation method before entering the cistern. Reinforced concrete cisterns of various sizes and rectangular or square shapes are the most common type of cisterns seen in south West Bank. It is constructed underground in clay or sand soil or on the ground under the building.

FIG. (2)

TYPES OF CISTERNS



Cisterns are usually located close to both the supply and demand points, either above or below the ground, inside or outside the building. Underground storage tank (cistern) has the advantages of collecting water from ground level catchments and the suprorting of the cistern's wall by soil. Cisterns are usually equipped with overflows and the opening is securely covered to prevent the entry of any pollutants which contribute to water contamination.

In past, a bucket on a rope or manual pump is used to use water from the cistern. These days, a small electric pump is usually used to pump water from a cistern to a small metallic reservoir on the roof of the house. Otherwise a rope with a bucket at the end is used, but the use of a bucket on a rope is not recommended, since this will possibly contaminate the contents of the cistern.

The cleaning of the cistern is done once a year, at the beginning of the Winter season. To facilitate the cleaning process, a small hole is made at the bottom of the cistern especially these of a pear shape.

In the case, when the rainwater does not cover a household demand for the whole year, water would be either purchased from vehicle tanks or brought from the springs and stored in the cistern to cover dry period. This is especially true in areas where there exist no distribution system (Helou and Shaheen 1993).

With regard to the economical aspects, the cost of constructing a cistern depends on the property of the soil and the type of the cistern. In many cases, this may be far less economical than buying water from the municipality or bringing it from a spring. Nevertheless, the use of rainwater cistern system as a mean to partially alleviate water shortage in the West Bank is feasible and recommended to overcome the shortage of water. Initial cost is an obstacle that can be overcome by some innovative technology (Helou and Shaheen 1993).

FEASIBILITY OF USING RAINWATER ROOF CATCHMENT SYSTEMS

The volume of water that any particular family can collect from their rooftop and store it in a cistern or storage tank depends upon the average annual rainfall and the catchment area it self. The volume of water can be calculated using the following equation (Brand and Bradford 1991):

$$\text{Volume } (m^3) = \text{Rainfall } (m) \times \text{Catchment Area } (m^2) \times 0.8$$

in which 0.8 is the runoff coefficient.

Rainwater roof catchment systems will be feasible if enough rainwater can be collected and stored. Feasibility of using rainwater roof catchment systems can be investigated by computing the minimum catchment area for a specified demand and determining whether the existing roof can provide this catchment area (Sciller 1982). Historical rainfall data can be used to determine the volume of water which can be collected and the tank's size needed to store the rainwater. The analysis of the data to determine the volume of water that can be collected, the size of the storage tank (cistern) required and the feasibility of using rainwater roof catchment systems are given below.

The average monthly rainfall in south West Bank for the last five years are listed in column number (2) of Table 1 (The data obtained from meteorological stations). Monthly water consumption per capita in the study area for domestic use is 2 m^3 (Abu-Sharekh 1994), the data are given in column (3) of Table 1. The catchment area that is necessary to collect the possible storage that stratifies the monthly consumption for one person (2 m^3) were calculated using the above equation, the figure 43 m^2 were obtained. The monthly rainwater supply which results from multiplying the monthly rainfall with the catchment area and the runoff coefficient are given in column number (4). The difference between the monthly supply and the monthly consumption gives the amount of water that can be stored (column number 5). The total Storage in column number (6) is the accumulation of the amount stored.

TABLE (1)

CALCULATION OF THE TOTAL WATER STORAGE (m^3/capita)AND THE SIZING OF THE STORAGE TANK (m^3) THAT REQUIRED TO SATISFY THE ANNUAL DOMESTIC WATER CONSUMPTION PER CAPITA IN SOUTH WEST BANK AREA

Months	Monthly Rainfall mm	Monthly consumption m3	Monthly supply m3/c	Amount Stored m3/c	Total Storage m3/c
October	7.9	2.0	0.3	-1.7	-1.7
November	60.5	2.0	2.1	0.1	-1.6
December	165	2.0	5.7	3.7	2.1
January	170.2	2.0	5.9	3.9	6
February	174.1	2.0	6.0	4.0	10
March	103	2.0	3.5	1.5	11.5
April	22.6	2.0	0.8	-1.2	10.3
May	1.2	2.0	0.1	-1.9	8.4
June	0	2.0	0	-2.0	6.4
July	0	2.0	0	-2.0	4.4
August	0	2.0	0	-2.0	2.4
September	0	2.0	0	-2.0	0.4

From Table (1), the total storage volume required to satisfy the annual domestic water consumption per capita of South West Bank area based on annual rainfall 704.5 mm and annual consumption 24 m3/capita is the difference between the maximum value of total storage and the minimum value. This gives a storage volume of about 13.2 m3/capita (11.5 - (-1.7)) coupled with the 43 m2 catchment area. This means that a household with five persons in south West Bank may take all its domestic water needs from rainfall using roof rainwater catchment system that has a catchment area of 215 m2 and a storage tank (cistern) of 66 m3.

WATER QUALITY CONSIDERATION

Although stored rainwater will not always meet WHO standards it frequently does, and generally speaking it is of a far higher quality than most of the traditional sources and many of the improved water sources found in the developing countries (Gould 1991).

Roof catchment system can provide a good quality of rainwater clean enough for any one to drink, so long as the points listed below are incorporated. Roofs should be very clean that will not add pollutants to the water. They should also be free from overhanging trees since these provide sanctuary for birds and animals which could defecate on the roof and thus contaminate the rainwater. The cistern should be securely covered to prevent the entry of dirt, animals and light, all of which contribute to biological contamination (Latham and Gould 1986). Provision should be made for cleaning the cistern on a regular basis. Implementation of a filtration unit at the entrance of the cistern may help to improve the quality of water.

A study of cisterns rainwater quality in south West Bank by (Abu Sharekh and subuh), examined chemical and biological contamination. Samples from 200 cisterns were collected, tested and analyzed.

The chemical analysis includes the determination of the concentration of major cations (calcium, magnesium, sodium, potassium) and anions (chloride, carbonate, bicarbonate). The analysis also includes measurement of pH, electric conductance, total dissolved solid, and total hardness. The chemical analytical results are presented in Table 2. The analysis revealed that none of chemical constituents exceeded WHO standards with the exception of some high and low values to some parameters. This mean that the cisterns water is of high quality and very suitable from chemical side for drinking and domestic purposes.

The study of biological contamination were limited to the investigation of the presence of total coliforms. Samples from 200 rainwater cisterns were tested. 54 out of 200 samples contained coliforms and 146 samples contained zero coliforms. The total coliform colony counts revealed through the test of samples are presented in Table 3. This mean that 27% of the cisterns water in south West Bank are contaminated by coliforms and did not meet with WHO drinking water standards, and 73% are not contaminated and meet WHO drinking water standards. Despite this finding it was still concluded that potentially cisterns water in general is safe and of good quality for drinking and domestic uses.

TABLE (2)
RESULTS OF THE CHEMICAL ANALYSIS OF
CISTERNS WATER SAMPLES

Constituents	WHO Standards in (mg/l)	Concentration Observed in (mg/l)		
		Minimum	Maximum	Average of 200
pH (dimensionless)	6.5-9.2	7.5	9	8.1
EC(μ mho/cm)	< 250	0.17	1.2	0.45
TDS	200-500	80	560	237.5
TH	200-500	70	423	182.6
Calcium	75-200	18.1	94.6	45.1
Magnesium	50-150	1.0	92	20.8
Sodium	100-200	5	41	11
Potassium	0-10	1	12	3.3
Chloride	200-600	18	138	41.7
Carbonate	0-50	1.2	67.2	21.1
Bicarbonate	0-500	41.6	315.5	146.9

TABLE (3)
TOTAL COLIFORM COUNTS IN 100 ML SAMPLES FOR STAORED RAINWATER IN
CISTERNS IN SOUTH OF WEST BANK

Total Coliform Counts in 100 ml Samples	Total Number of Samples	% Total Nnumber of Samples
0	146	73
1-10	10	5
11-20	15	7.5
21-30	12	6
31-40	7	3.5
41-50	4	2
>50	6	3
Total	200	100

SUMMARY AND CONCLUSIONS

In this paper the practices of using rainwater roof catchment system, in south West Bank were studied using field data which were collected by the research team. Description to the whole system were presented. The feasibility of using RWRCS as a mean to partially alleviate water shortage in the South West Bank has been investigated. Water quality consideration were discussed. The main conclusions drawn from the present study are summarized below:

1. In West Bank, Rainwater of cistern have been used for domestic and irrigation purposes as a supplementary water supply where the major supply is from ground water. It constitutes favorable alternative source of water. As a result of cost considerations and limitations in current supplies of water in West Bank with respect to quantity and quality, roof catchment systems have started to attract attention as viable and important source of water.
2. In the study area, Cement roofs are the most common type of the catchments due to its durability, relatively low price, and provides good quality of water. The roofs are usually flat, construct with a slope of 1-2%.
3. The gutter is an important component in rainwater roof catchment systems. In West Bank, gutters made of Zinc sheet metal or plastic are very suitable due to their durability and light weight. The size of the gutter used is ranges between 2"-8" diameter.
4. For along time, Palestinians have been building cistern wells to collect and store the rainfall from the roofs of their houses. Old cisterns had a pear shape excavated in rocks were the new cisterns are usually designed with circular, rectangular, and square plane, with depth a round 3-5 m and of reinforced concrete. Cisterns are usually located close to both the supply and demand points and a bucket on a rope or pump is used to use water from cistern. The cleaning of the cistern is done once a year.
5. With regard to the economical aspects, the cost of constructing a cistern depends on the property of the soil and the type of the cistern. This may be far less economical than buying water from the municipality or lording it from the springs.
6. The use of rainwater roof catchment systems as a mean to partially alleviate water shortage in the West Bank is feasible and recommended to overcome the shortage of water. A household with five persons in south West Bank may take all its domestic water needs from rainfall using roof rainwater catchment system that has a catchment area of 215 m^2 and a storage tank of 66 m^3.
7. Chemical and biologically tests and analysis revealed that rainwater stored in cisterns in south of West Bank in general is of high quality and far better than water from other source such as municipal or springs. It is also most of the time meet with WHO standards for drinking and domestic uses.

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CISTERNS WATER QUALITY IN SOUTH OF WEST BANK

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Hebron- West Bank

ABSTRACT

Cisterns are artificial reservoirs for collecting and storing rainwater from impermeable areas. In the occupied West Bank, rainwater of cisterns have been used for domestic and irrigation purposes as a supplementary water supply where the major supply is from ground water.

Cisterns constitute favorable alternative sources of water supply. One of such important subject related to cisterns is water quality which must be good and meet World Health Organization (WHO) domestic water standards. Accordingly , the present work attempts to study the chemical and biological characteristics of cisterns water in south of West Bank. Samples from 200 cisterns were collected, tested and analyzed for chemical and biological parameters.

The data obtained reveals that, in general, cisterns can provide a good quality of rainwater, clean enough for any one to drink. The water quality of cisterns depend mainly upon the cistern environment, and the general cleanliness of the catchment area and the cistern. The results show that the concentration of major chemical constituents are well within the prescribed limits of WHO. It is also concluded that cisterns water generally meet microbiological standards set by the WHO for total coliforms in drinking water. Levels of total coliform contamination were found 27%.

INTRODUCTION

West Bank is located in the east of Palestine. It is a mountainous area with an average height of 800 m with respect to sea level. The temperature is moderate in the Summer (20-30°C) and Winter temperature is low. The annual average rainfall is around 500 mm. The present population is around 1.5 million. The area of study represents the southern part of West Bank.

The wide expansion and accelerated development of the West Bank cities and villages had led to an increase in amount of water demand for domestic, public, irrigational and industrial water uses. The water demand is mostly meet by ground water, hence, underground.

water is the main source of water. In spite of this, the amount of water is not sufficient to meet the present demand of water. Further, the Palestinian people are prohibited from developing new water wells because of the Israeli Occupation Authorities restrictions.

In view of this prevailing condition, there is no alternative but to make most efficient utilization of the available water such as rainwater collection which is economically feasible for small communities. A rain water catchment system is a system to harvest, store, and use rainwater as a supplementary water source. Rainwater catchment systems have been used in Palestine since ancient times, rainwater has been collected and used for both domestic and agricultural purposes. These days, and inspite of the availability of water distribution systems in most cities of West Bank, the people continue collecting rainwater in an economically water cisterns, and this is due to the shortage of water.

There are two types of rainwater catchment systems: roof and ground catchment systems. Roof Catchement System (RCS) is the common type of catchment used in West Bank for rainwater harvesting. In roof catchment system, rainwater can be harvested by using roof as a catchment area and storing the water in storage tanks or underground cisterns for domestic use. The main components of the roof rainwater catchment system are: roof, pipes and cistern. Cisterns are artificial reservoirs for collecting and storing storm water from impermeable areas.

In West Bank, cisterns water has been used as a supplementary water supply where the major supply is from ground water. As a result of cost consideration and limitations in current supplies of water in West Bank with respect to quantity and quality, cisterns or roof catchment system has started to attract attention as viable and important source of water.

In the occupied West Bank, cisterns regaining their historical popularity and constitute favorable alternative source of water supply. One of such important subject related to cisterns is water quality which must be good and meet WHO drinking water standards. Therefore, the main objective of this study is to assess the quality of cisterns water in south of West Bank.

Although stored rainwater will not always meet WHO standards it frequently does, and generally speaking it is of a far higher quality than most of the traditional sources and many of the improved water sources found in the developing countries (Gould 1991).

The quality of water collected in a cistern varies with the quality of input rainwater and reaction that may occur during the retention period before use. The water quality of rain depends upon the atmospheric conditions of the area, the materials found in and on the collection and delivery surfaces, and the cleanliness of the cistern. Rainwater car react with air pollution to form acid rain. This problem can affect the color, odor, and taste of the harvested rainwater (Brand and Bradford 1991).

Roofs should be very clean that will not add pollutants to the water. They should also be free from overhanging trees since these provide sanctuary for birds and animals which could defecate on the roof and thus contaminate the rainwater. The cistern should be securely covered to prevent the entry of dirt, animals and light, all of which contribute to biological contamination (Latham and Gould 1986). Implementation of a filtration unit at the entrance of the cistern many help to improve the quality of water. Provision should be made for cleaning the cistern on a regular basis. Roof catchment system can provide a good quality of rainwater clean enough for any one to drink, so long as the points listed above are incorporated.

In the light of the above explanation, it is important to know the quality of cisterns water available for the home so as to choose the cleanest water, identify the origins of contamination, and control and monitor this contamination. Accordingly, an attempt is made to study and evaluate the quality of cisterns water in south of West Bank.

The first objective of this study is to determine the chemical and biological characteristics of stored rainwater in cisterns. The second objective is to evaluate the collected water in cisterns and see whether or not is safe to drink and use for domestic purposes. Finally, the study will give suggestion and recommendation regarding the quality of cisterns water and the ways of improving.

WATER SAMPLING

In order to study the chemical and biological characteristics of cisterns water, 200 samples were collected, tested, and analyzed. The samples covered all the places of the south West Bank.

For the purpose of study and in order to know the quality of cisterns water, determine the extent of purification necessary due to different pollutants, and to identify the possible sources of its pollution, simple questionnaire were prepared to take all the information about each cistern (see Table 1). The questionnaire includes many questions about the cistern such as address, volume, age, source of water, method of collecting water, shape and way of construction, environment, water use, etc.

In the questionnaire there is a question about the source of cistern water, if it is rain, municipal, spring or mix (rain and municipal). This question because the people in West Bank face great difficulties in water supply and the cisterns rainwater is some times not sufficient to meet with municipal water the demand of water for the whole year, and if it is so, the people in West Bank used to fill the cistern when it is empty with water from water networks or springs, and in most of the time they mix the rainwater in cistern with municipal water together. Of course, most of the cisterns tested were filled with rainwater only.

TABLE (1)

QUESTIONNAIRE

CISTERNS WATER QUALITY IN SOUTH OF WEST BANK

1. Cistern Number:
2. Address:
3. Cistern Volume (m^3):
4. Cistern Age (year):
5. Source of Cistern Water:
   - Rain - Municipal - Spring - Mix (rain & municipal)
6. Method of Collecting Water:
   - Roof - Roof and Area Round the Cistern
7. Shape and Way of Construction:
   - Concrete (rectangular) - Concrete (circular)
   - Under ground (conic) - Other (determine)
8. Cistern Environment (availability of):
   - Animals - Insects -Sewage -Trees - Nothing
9. Water Use:
   - Domestic & Drinking - Domestic - Animals Watering
   - Irrigation
10. Physical Properties:
    - Color - Taste - Odor

The questionnaires for all the cisterns were filled before water sampling, and all the information in the questionnaires were tabulated in a tabular form.

In sampling cisterns water for quality analysis, glass bottles 250 ml volume were used, one bottle for each chemical and biological analysis. After sterilizing the bottles in an ordinary oven for one hour at 170° C and rinsing them and the stoppers with distilled water, the samples are then collected and securely sealed, this is done by the help of cleaned bucket. Samples have been taken from the cisterns after shaking the water by the bucket to collect a representative samples. The bottle were usually stored in a cool place and transferred promptly to a laboratory for analysis. Water sampling were usually done in the morning time.

WATER QUALITY ANALYSIS

A complete water quality analysis was performed at the laboratories three times at a cistern during the course of the research to assess the cisterns water quality in south of West Bank. Tests for pH, conductivity, total dissolved solid, total hardness, and major cations and anions were conducted in the Palestinian Hydrology Group (PHG) laboratory in Gaza Strip. Tests for total coliforms were conduct in the Alia Hospital laboratory in Hebron city of West Bank. The laboratory analysis included the following tests which were performed.

1- pH value (pH)
2- Electric Conductance (EC)
3- Total Dissolved Solid (TDS)
4- Total Hardness (TH)
5- Calcium and Magnesium (Ca^{++}, Mg^{++})
6- Sodium and Potassium (Na^{+}, K^{+})
7- Chloride (Cl^{-})
8- Carbonate and Bicarbonate ($CO3^{--}$, $HCO3^{-}$)
9- Total Coliforms

RESULTS AND DISCUSSION

The present study of cisterns rainwater quality in south of West Bank examined chemical and microbiological contamination. Sampels from 200 rainwater cisterns were tested. The data obtained were analyzed. The purpose of the analysis is to evaluate the quality of stored rainwater, detect the processes controlling cisterns water quality and to assess the suitability of the cisterns water for drinking and domestic uses. Analysis and discussion of results are given below.

Chemical Characteristics Results

As mentioned earlier, the chemical analysis of a cisterns water includes the determination of the concentration of major cations (calcium, magnesium, sodium, potassium) and anions (chloride, carbonate, bicarbonate). The analysis also includes measurement of pH, electric conductance, total dissolved solid, and total hardness. The chemical analytical results of the 200 samples which were considered to be representative for the cisterns water quality are presented in Table 2. The values of minimum, maximum, and average concentration for each constituents are given in the table beside WHO standards.

TABLE (2)

RESULT OF THE CHEMICAL ANALYSIS OF CISTERNS WATER SAMPLES

Constituents	WHO Standards in (mg/l)	Concentration Observed in (mg/l)		
		Minimum	Maximum	Average of 200
pH (dimensionless)	6.5-9.2	7.5	9	8.1
EC(μ mho/cm)	< 250	0.17	1.2	0.45
TDS	200-500	80	560	237.5
TH	200-500	70	423	182.6
Calcium	75-200	18.1	94.6	45.1
Magnesium	50-150	1.0	92	20.8
Sodium	100-200	5	41	11
Potassium	0-10	1	12	3.3
Chloride	200-600	18	138	41.7
Carbonate	0-50	1.2	67.2	21.1
Bicarbonate	0-500	41.6	315.5	146.9

Pure water has a pH value of 7, below 7 it is acidic and above 7 it is a alkaline. The result of the chemical analysis reveal that cisterns water is alkaline in character, hence, the values of pH ranges between 7.5 - 9.0. All the values of pH are within the acceptable WHO standards.

The specific conductance for pure water is $5.5x10^{-2}$ micromhos/cm. However, water quality is considered to be very good if it's electric conductance is less than 250 micromhos/cm. Results of the tests indicate that electric conductance values are very low and ranges between 0.1-1 micromhos/cm, which means that the concentration of dissolved solids in water is very low and water quality of cisterns in terms of electric conductance is very good and meets the guideline of the WHO.

Total dissolved solid in water samples includes all solid materials in solution. Classification of the drinking water quality in terms of the total dissolved solid (TDS) published by World Health Organization (WHO) is given in Table 3.

TABLE (3)
CLASSIFICATION OF THE DRINKING WATER IN TERMS
OF THE TOTAL DISSOLVED SOLIDS (TDS)

Water Quality	Total Dissolved Solid (mg/l)
very good	<300
good	300-600
fair	600-900
poor	900-1200
not acceptable	>1200

In the present study of cisterns water quality in south of West Bank, the values of total dissolved solid ranges between 80 mg/l and 560 mg/l. The average of 200 samples is 237.5 mg/l, which means that water quality of cisterns in the study area is very good for drinking and domestic purposes.

Table (4) correlates between source of cistern water, method of collecting water, cistern environment and total dissolved solid to study the effect of these factors in the quality of cisterns water according to total dissolved solid content.

TABLE (4)
TOTAL DISSOLVED SOLID FOR CISTERNS WATER IN SOUTH OF WEST BANK ACCORDING TO SOURCEOF WATER, METHOD OF COLLECTING WATER,AND CISTERN ENVIRONMENT

General Information About the Cistern		Number of Cisterns	Total Dissolved Solid (mg/l)		
			Minimum	Maximum	Average
Source of Cistern Water	rain	133	80	370	192
	municipal	7	385	480	418
	spring	15	270	560	451
	mix	45	170	370	269
Method of Collecting Water	roof	88	80	480	221
	roof & area	112	110	560	251
Cistern Environment	very good	47	110	385	222
	good	82	80	480	227
	intermediate	43	120	510	237
	bad	28	150	560	299

Cistern environment:

- Very Good: not availability of animals, insects, sewage, and trees, and general cleanliness is excellent.
- Good: the availability of animals, insects, sewage, and trees is very rare and general cleanliness is very good.
- Intermediate: availability of some pollution causes such as animals, insects, sewage, and trees, and general cleanliness is good.
- Bad: availability of animals or insects or sewage or all of them, and the general cleanliness is very bad.

It may be noted from Table 4 that the total dissolved solids concentration is less when the source of cistern water is rain or mix (rain & municipal) were the averages are 192 mg/l and 269 mg/l respectively and water quality is very good. The average when the source of water is municipal or spring is 400 mg/l in which water quality is fairy good. When the water is collecting from area around the cistern it collect with it different materials which dissolved in water and increase the concentration of total dissolved solid, the data of Table 4 prove this conclusion. It may also be noted from the table the effect of cistern environment in the concentration of TDS and subsequently in the water quality, hence, good environment means low concentration of TDS and better water quality and bad environment mean more concentration of TDS and fair water quality.

The degree of hardness in water is commonly based on the classification listed in Table 5 (Hadad and Al-Hamidi 1991).

TABLE (5)
HARDNESS CLASSIFICATION OF WATER

Hardness (mg/l) as $CaCO_3$	Degree of Hardness
0-60	Soft
61-120	Moderately hard
121-180	Hard
over 180	Very hard

The averages of total hardness for cisterns water in south of West Bank according to source of water are presented in Table 6. The table also reveal the minimum and maximum values .

TABLE (6)
TOTAL HARDNESS FOR CISTERNS WATER IN SOUTH OF WEST BANK
ACCORDING TO SOURCE OF WATER

Source of Cistern water	Number of Cisterns	Total Hardness (mg/l)		
		Minimum	Maximum	Average
Rain	133	70	200	127
Municipal	7	255	377	331
Spring	15	232	423	344
Mix	45	84	312	245

The results of Tables 2 and 6 indicate that the values of total hardness varies from 70 to 423 mg/l, which are within the acceptable WHO standards (<500 mg/l). Even this, the values of total hardness are comparatively high, so, cisterns water in south of West Bank is considered generally moderately hard or hard. The reason may be because the study area is famous in rock industry and the atmosphere is full of dust contain calcium carbonates and calcium chlorides which causes hardness. It is natural that when the source of cistern water is rain or mix (rain & municipal) the hardness is less, .and this what the data of Table 6 emphasize.

The results of major cations (calcium, magnesium sodium, and potassium) given in Table 2 indicate that the cisterns water in south of West Bank is suitable of drinking and domestic purposes. The results show a low concentrations to these cations. The values of Ca^{++} and Mg^{++} ranges between 18.1-94.6 mg/l and 1-92 mg/l respectively, the values of Na^{+} and k^{+} varies from 5-41 mg/l and 1-12 mg/l respectively. These values are within the acceptable WHO standards. In some water samples, the values of major cation are comparatively high because the source of water is municipal or springs and because some cisterns are very old and the water is collecting to them through dirty area around them. The concentration of chloride is below the WHO standard (250 mg/l for drinking purposes) in the cisterns of south of West Bank. The values of chloride ranges between 18 and 138 mg/l. The concentrations of other anions (carbonate and bicarbonate) are within the WHO standards. The values of carbonate and bicarbonate varies between 1.2-67.2 mg/l and 41.6-315.5 mg/l respectively, and the water to be suitable for drinking purpose the cocentration of carbonate and bicarbonate should by less than 500 mg/l. So, the cisterns water in south of West Bank is, in general, suitable for drinking and domestic uses in terms of anions concentrations.

Biological Results

As mentioned earlier, roof catchment cisterns can provide good quality rainwater clean enough for anyone to drink, so long as the roof is very clean and free from overhanging trees. The cistern should be securely covered and far from septic tanks, and the availability of animals and insects.

Of two potential types of water biological contamination microbiological and bacteriological, the dicision were made to limit the study to the investigation of the presence of total coliforms in order to evaluate the quality of stored rainwater in cisterns in the south of West Bank. This is an important indicator of whether or not water is safe to drink and use for domestic purposes.

Samples from 200 rainwater cisterns were tested .54 out of 200 samples contained coliforms and 146 samples contained zero coliforms. The total coliform colony counts revealed through the test of samples are presented in Table 7. According to WHO drinking water standards water is contaminated by coliform if it contains more than 0 coliform / 100ml water sample. This mean that 27% of the cisterns water in south West Bank are contaminated by coliforms and did not meet with WHO drinking water standards, and 73% are not contaminated and meet WHO drinking water standards (See Fig. 1). Despite this finding it was still concluded that potentially cisterns water in general is safe and of good quality for drinking and domestic uses.

TABLE (7)

TOTAL COLIFORM COUNTS IN 100 ml SAMPLES FOR STAORED RAINWATER IN CISTERNS IN SOUTH OF WEST BANK

Total Coliform Counts in 100 ml Samples	Total Number of Samples	% Total Nnumber of Samples
0	146	73
1-10	10	5
11-20	15	7.5
21-30	12	6
31-40	7	3.5
41-50	4	2
>50	6	3
Total	200	100

FIGURE (1)
CISTERNS WATER QUALITY TESTING

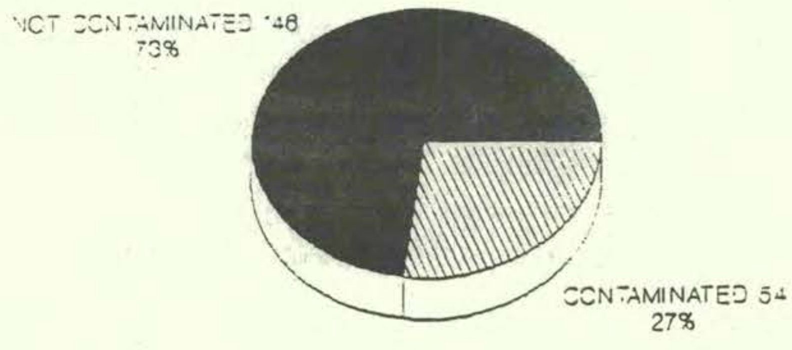

Table 8 presents the results of total coliform contamination in rainwater collected from various cisterns in south of West Bank according to cistern environment, cistern age, and method of collecting water to the cistern.

TABLE (8)
ANALYSIS OF TOTAL COLIFORM IN RAINWATER COLLECTED FROM VARIOUS CISTERNS IN SOUTH OF WEST BANK

General Information About the Cistern		Total Number of Samples	Number of Samples Contaminated by Total Coliform	% of total Coliform Contamination
Cistern Environment	very good	47	0	0
	good	82	7	8.5
	intermediate	43	23	53.5
	bad	28	24	85.7
Cistern Age	new	50	2	4
	old	85	25	29.4
	very old	65	30	46.2
Method of Collecting Water	roof	88	12	13.6
	roof & area	112	43	38.4

Cistern age:

- New : Age of the cistern is less than two years.
- Old : Age of the cistern is between 2 and 15 years.
- Very old: Age of the cistern is more than 15 years.

It may be noted from Table 8 that the cistern environment has big effect in the contamination of water with total coliforms. In case of good environments, the contamination is less and vice versa, the contamination is more in bad environments. Percentage of total coliforms contamination in good environments ranges between 0-10%, and in bad environment the percentage contamination reaches to a round 90%. So, to have safe, and good quality of water to drink the cistern environment should be very clean.

Cistern age and method of collecting water have less effect in the contamination of cistern water by coliforms. The analysis of Table 8 revealed that the percentage of total coliform contamination is 4% for recently constructed cistern and varies between 30-46% for old cisterns. When the roof is the only catchment, the contamination is low (13.6% and when the catchment include area around the cistern the percentage of contamination is slightly high (38.4%).

CISTERNS WATER QUALITY EVALUATION FOR DOMESTIC USE

Water is used for many purposes such as drinking, domestic water supply, irrigation, and industrial. Water quality standards are not same for all uses. The suitability of water for irrigation is not same for domestic uses and vice versa. In order to evaluate the suitability of water for different purposes, the World Health Organization (WHO) has laid down international standards for different uses. Some countries put their national standards. The WHO standards of quality of water for domestic and drinking purposes and for constituents tested are given in Table 2.

Cisterns water in south of West bank are mainly used for domestic and drinking purposes and sometimes for irrigation purpose. The domestic purposes for which water is used might include preparing and cooking food, washing dishes, bathing, washing clothes, cleaning the house, etc. Of course, water required for drinking and domestic uses must be colorless, odorless and tasteless. It should be of high quality biologically and chemically for protection against diseases. The questionnaire prepared for the purpose of the study has a question regarding water use in order to evaluate rainwater stored in cisterns in south of West Bank. The discussion of the evaluation of cistern water quality in term of chemical and biological characteristics and for domestic and drinking use are given below.

The chemical constituents analysed included pH value, electric conductance, total dissolved solid, total hardness, major cation, and major anions. The discussion of results are explained in the previous sections. The analysis revealed that none of these exceeded WHO standards with the exception of some high values to some parameter such as total hardness due to different reasons. This mean that the cisterns water is of high quality and very suitable from chemical side for drinking and domestic purposes.

Biologically analysis revealed that only 27% of 200 rainwater cisterns sampled contaminated by coliforms and did not meet with WHO standards (Fig. 1). Some of these cisterns are used for domestic purpose including drinking and some of them used for domestic purpose only, the other remaining cisterns are used for different purposes such as irrigation. Table 9 presents total number of cisterns contaminated by coliform and percentage of contamination according to water use in south of West Bank.

TABLE (9)
TOTAL NUMBER OF CONTAMINATED CISTERNS AND PERCENTAGE OF CONTAMINATION ACCORDING TO WATER USE

Water Use	Total Number of Cisterns	Number of Cisterns Contaminated by Coliform	% of Coliform Contamination
Domestic and drinking	140	26	18.6
Domestic	38	14	36.8
Other purposes	22	14	63.6
Total	200	54	27

It may be noted from Table 9 that 18.6% of tested samples are not suitable for drinking use and around 36.8% are not suitable for domestic use. As expected, rainwater for domestic uses is more contaminated than rainwater collected separately for drinking. The availability of contaminated cisterns and used for drinking purpose is dangerous matter because contaminated water by pathogens causes numerous water diseases, such as typhoid, dysentery, etc. Even this it was still concluded that cistern rainwater is the safest and most economical source for drinking water and domestic use in south of West Bank, since, generally the contamination was slight and the situation can be improved by taking care with the cleanliness of cistern environment and improving the method of collecting water.

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions drawn from the present study are summarized below:

1. Generally speaking, rainwater stored in cistern in south of West Bank is of high quality and far better than water from other source such as municipal or springs. It is also most of the time meet with WHO standards for drinking and domestic uses.
2. The water quality of cisterns in south of West Bank depend upon the source of their water, method of collecting water,cistern environment, and the general cleanlines of the catchment area and the cistern. The water is of high quality when the source of water rain only,the roof is the only catchment, the cistern environment is very clean,and the general cleanliness is very excellent.
3. The study reveals that the concentration of major constituents are well within the prescribed limits of WHO, except in few cases where the values of total dissolved solids, total hardness, and carbonate are comparatively high, and the values of electric conductance and chloride are very low.
4. Rainwater stored in cisterns and uses for drinking and domestic purposes is generally meet microbiological standards set by the WHO for total coliform in drinking water. Levels of total coliform contamination were found in cisterns water 27% > 0 coliform. Despite this, water in general is safe and of good quality .
5. Chemical and biologically analysis revealed that cisterns water in general is suitable for drinking and domestic uses. It is the safest and most economical source for drinking water and domestic use in south of West Bank.
6. As expected cisterns water for domestic uses is more contaminated (37%) than water collected separately for drinking (19%).

On the basis of experiences and observations, the following recommendations can drawn for guidance:

1. Encouraging the people in West Bank to construct cisterns in their houses due to limited quantity of water coming through the water supply networks, and the higher quality of rainwater.
2. Guide the people in West Bank to the following guidelines:
    a. The cistern environment should be very clean and the cistern is far a way from septic tanks and animals.
    b. Testing the cistern water periodically.

c. The cistern should include solid secure cover and coarse inlet filter.

d. The roof surface must be very clean and kept free from excreta of birds and animals, dust and leaves.

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WATER QUALITY ISSUES IN RAIN WATER CISTERN SYSTEMS IN SOME SOUTH EAST ASIAN COUNTRIES

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ABSTRACT

The sole source of supply in roofwater cistern systems is rainwater. Rainwater, as it exists and before it reaches the ground, is believed to be free of pollution. This is not the case in some developed countries where acid rainfalls occur. In developing countries, the rainwater quality appears to be acceptable but the runoff which flows off different types of roofs is affected not only by the inherent quality of the roofing material but also by pollution in roofs by rodents, birds etc. Consequently, bacteriological quality levels, in terms of international drinking water standards, are exceeded though the collected rainwater is still used extensively for potable purposes. From samples collected in Thailand, Malaysia, Philippines, Singapore etc., a number of samples had positive Total Coliform (T Coli) and Faecal Coliform (F Coli) counts though, in terms of physico-chemical parameters, roofwater appears to be of a higher quality. Various causes from improper sample collection practices to poor individual hygiene have been attributed to the frequent presence of F Coli. However, it is warranted that the collected roofwater be boiled or, alternatively, disinfected by any other means. Simple disinfection with household bleach on regular basis is suggested. Radiation appears to have good potential to be an effective bactericide but more studies need to be done to arrive at a cheap, effective and easily adaptable system of disinfection. As salmonella species, which can cause gastro-intestinal problems have been found in a number of samples, it is recommended that simple testing methods be developed with a view to set standards and be used as the basis for roofwater quality assessment and acceptance. Besides, health education should be imparted to RWCS users with emphasis on location of the water tanks, cleanliness of the roofs and the water tanks, maintenance and an awareness of the need for disinfection of the collected water.

INTRODUCTION

The primary input in Rain Water Cistern Systems (RWCS) is rainfall. In the past, the quality of rainfall has always not been questioned till about a decade ago when it was noticed that acid rain was a realty. This can be attributed to high discharge levels of sulphur and nitrogen gases associated countries where industries are using large amounts of fossil fuels. However, in most developing countries rainwater quality appears to be one of the purest in nature though the quality of the collected water can be affected detrimentally. The main objectives of this paper are:

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(a) to outline RWCS available in the region with specific emphasis on the degree of propagation, type of roofs and material of the containers,

(b) to review and discuss, on country by country basis, the water quality in water cisterns in terms of physico-chemical and bacteriological parameters,

(c) to review some simple methods of disinfection and

(d) draw conclusions and make some recommendations for maintaining good RWCS practices.

DEVELOPMENT OF EXISTING RWCS IN SOUTH EAST ASIA

The types of RWCS being adopted at present are largely dependent on the location of the country, the available rainfall, the traditional methods of using rainwater and a host of other socio-cultural and economic factors. Some of the systems prevalent are as follows:

(a) **Thailand**

Having a rainfall of 1150 mm per annum, it is one of the countries in which RWCS are being propagated and used most fruitfully. The existence of rain harvesting and storage systems extends to more than 2000 years (Dept of Fine Arts, 1978). Jars have been used traditionally to collect rainwater (Thamrong, 1983). Even by 1987, more than 50,000 bamboo reinforced tanks had been built though there were a number of structural failures (Vadhanavikkit & Pannachet, 1987). Thailand has developed a policy for providing drinking water to rural areas and by 1990 about 9 million jars are to be built. These cement jars have a volume of 2 m^3 and weigh 450 kg (Fok, 1993). Besides, reinforced concrete tanks have also been established in abundance by self-financing schemes (Hayssen, 1983) and quite a few ferro-cement tanks have been built in the Khon Kaen area which has a much lower rainfall (Vadhanavikkit, 1983). In all these systems, the process involves the tapping of roofwater running followed by storage in containers made of various materials. After being stored, in most cases, the collected water is not disinfected. One of the precautions taken to safeguard the quality of water appears to have been diversion of first flushes as observed in Khon Kaen. It has also been reported that fish have been reared in the tanks to prevent mosquito breeding.

(b) **Indonesia**

The collection of rainwater for domestic purposes has been prevalent for several centuries in Kalimantan (Doelhamid, 1981). A systematic approach to build cisterns was pursued in 1978 using different materials like brick, bamboo, ferro-cement etc., in West Java. Finally ferro-cement was chosen and a construction manual prepared (Kerkvoorden, 1982). There is indication that considerable thought and effort were put into the maintenance and running of 300 of these systems in Java (Aji, 1983). Subsequently in 1975, a well-established non-government organization (Dian Desa), embarked on an extensive RWCS propagation program with emphasis on ferro-cement (9 m^3) and bamboo reinforced tanks (4.5 m^3) in the Gunong Kidul area where there was perennial water scarcity. It is in this project that, considering the economic status of the villagers, a unique financing system involving the lending of two goats to effect repayment was evolved. Following Dian Desa's success of RWCS, the UNICEF, World Bank, Indonesian Dept of Health and others have "literally built thousands" of tanks (Aristanti, 1983). The RWCS again primarily were containers in which roofwater was collected with no specific treatment provided within the system and no long term maintenance and operation programs outlined. It has been observed in the Jogjakarta area that a number of the bamboo-reinforced tanks have failed. Besides, fish was being reared within many tanks to prevent mosquito breeding.

(c) **Philippines**

Rainwater collection has been practised for a long time and particularly in the rural areas. The traditional concept is that rainwater is safer to use for household and human consumption rather than river waters. Rooftop collection through eaves is channelled to receptacles made of brick, cement, earth, heavy plastic or galvanized iron. In some cases, filtration is effected by filtering cloth or muslin attached to the inlet. Chemical treatment is rarely resorted to although sulphur has been used as a disinfectant and larvicide in the central provinces (Cuyegkeng, 1983).

The first attempt at systematically propagating 30 units of RWCS was undertaken in the Province of Capiz (Appan et al, 1989). Construction of such tanks was progressively extended to another 540 units in the same region (Lee & Appan, 1991). In all these projects, the prime goal was to get the people involved in making their own RWCS, paying for and maintaining them. The emphasis was on good management practices but the system did not include any treatment process whatsoever.

(d) **Malaysia**

Having an abundant annual rainfall of 2420 mm (Abllah, 1987) and relatively good conventional large-scale water supply systems, the activity on RWCS has been very limited. However, in rural areas water has been collected in jars, tubs etc. from very early time (Hodder, 1959). Experimentation on the use of RWCS commenced in East Malaysia in 1971 and by 1982 about 2700 tanks were built in Sarawak and Sabah. and a few tanks constructed in Perlis and Kedah in West Malaysia (Appan, 1983). Generally in West Malaysia RWCS are only considered as a stop-gap measure before extension or development of large scale systems (Malik, 1983).

(e) **Singapore**

The country has an abundant rainfall of about 2500 mm and is well supplied with drinking water though 40% of the water is imported from Malaysia. Feasibility studies have been carried out in urban high-rise buildings for dual-mode supply systems with emphasis on using rainwater for non-potable uses like toilet flushing (Appan et al. 1987). Roofwater has also been used successfully for aqua culture (Appan. 1989) and washing of quarry sand (Appan, 1991). A more recent study has shown the effective use of rainwater in an airport for non-potable uses like fir-fighting, toilet flushing etc. (Appan, 1993).

WATER QUALITY IN RWCS

By and large in the SE Asian region, RWCS are simple systems with the primary objective of having a container to store roofwater. The selected storage container has to be economically viable and durable. Treatment of the stored water is practically non-existent and, at the best, first flush diversion systems have been attempted. Even simple unit processes like filtration and disinfection are found only in isolation.

(a) **Factors affecting water quality**
The water quality in cisterns will be affected by a number of factors like quantity and quality of rainfall, roofing material, type and condition of gutters, type and location of storage containers, method of collection and usage and a host of other reasons.

(b) **Criteria for comparing water quality**
As most of these countries do not have well-defined standards for drinking water, the WHO Guideline values (1984) have been used (see Table 1) for comparison purposes.

Table 1 : WHO Guidelines for Drinking Water (1984)

Parameter	Guideline value*
Colour (TCU)	15
Turbidity (NTU)	5
pH	6.5 - 8.5
Hardness(as $CaCO_3$)	500
Iron	0.3
Manganese	0.3
Sulphate	400
Chloride	250
Total Dissolved Solids	1000
Nitrate	10
Arsenic	0.05
Cadmium	0.005
Chromium	0.05
Cyanide	0.1
Fluoride	1.5
Lead	0.05
Mercury	0.001
Selenium	0.01
Zinc	5.0
F Coli/100mL	0
T Coli/100mL	0

* **Note:** All units, except pH, in mg/L unless stated otherwise

Also, wherever feasible, the Faecal Coliform/Faecal Streptococci (FC/FS) ratios have been determined. These FC/FS ratios have been shown (Dukta, 1973, Geldritch & Kenner, 1969) to indicate hether the sources of pollution are of human (FC/FS >1 to 4) or animal (FC/FS <1) origin.

(c) **Summary of water quality in South East Asia**

A summary of some of the quality characteristics investigated and reported in different countries is presented and comparisons, made with WHO Guideline values.

(i) *Thailand:* In a study covering the whole country, 1292 samples were collected over a period of 4 years mainly from jars (Nantana, 1987). The results are shown in Table 2.

Table 2 : Roofwater Quality - Thailand (I)

Parameter	Satisfactory Values *
pH	83.66%
Colour	88.01%
Turbidity	90.00%
Iron	92.31%
Manganese	94.29%
Lead	59.26%
Cadmium	93.20%
T Coli	12.91%
F Coli	23.73%

*** Note:** Values are % of total samples.

In terms of physico-chemical parameters more than 83% of the samples were satisfactory in the above Table 3 except for about 40% of the samples exceeding the allowable limits of Lead. Hardness, Copper, Zinc, Chromium, Sulphate, Chloride and Nitrate levels were well within the WHO guideline values. In terms of Coli, more than about 76% of the samples had values exceeding the WHO guideline standards.

Table 3 : Roofwater Quality - Thailand (III)

Sampling Locations	Acceptable Quality			FC/FS	
	T Coli	F Coli	E Coli	>4	<1
Roofs & Gutters	10%	10%	22%	18%	79%
Tanks & jar	35%	30%	47%	17%	82%
In-house Containers	22%	22%	67%	47%	39%

In another series of tests conducted in three locations in Khon Kaen (Wonpen 1989), 709 water samples were collected from the roofs and gutters, containers (tanks and jars) and the point of consumption. The tanks were made of cement or galvanized iron whereas the jars were made of mortar and were about 2 m^3 capacity . A summary of the results is shown in Table 3. In terms of the three Coli groups, only 10% to 67% of the samples were within WHO's guideline values. Samples other than those collected from the container showed that not less than 79% to 82% of the contamination could have emanated from animal droppings.

In the same study, the heavy metal concentrations were also examined. It was noted that Cadmium, Chromium, Lead, Copper and Iron did not exceed the WHO values though Manganese (in 2% to 20% samples) and Zinc (in 4% to 26% samples) did not meet the guideline levels.

(ii) *Indonesia*: Though RWCS seem to have been practised with extensive experimentation using different types of materials, there is practically no available information on the quality of collected water. It has been observed that some measures like fish-rearing within the tanks have been practised so as to keep the water clean. Besides, it has also been reported that as the taste of collected and stored roofwater was not acceptable initially, the villagers, on occasions, have added river mud to give the water a more acceptable taste (Aristanti, 1986).

(iii) *The Philippines*: As a country that has adapted to the use of RWCS in a large scale relatively recently, there has been an awareness that the quality of water is of great importance. In a study spread over three villages in the Province of Capiz and involving 25 ferro-cement tanks, over a period of one year, it was shown that not less than 24% of the samples had T Coli exceeding the WHO guideline values.(Personal Communication, 1986).

(iv) *Malaysia*: The quality of water both from rainfall and from roofs has been monitored over a period of time (Yaziz et al, 1989). A total of 72 samples was collected from two types of roofs in West Malaysia and their analytical results are shown in Table 4.

Table 4 : Roofwater quality (Averages) - Malaysia

Parameter	GI roof	Concrete tiles
pH	6.6-6.4	6.8-6.9
Turbidity (NTU)	10-22	24-56
Total solids mg/L	64-119	116-204
Suspended solids mg/L	52-91	95-153
Dissolved solids(mg/L)	13-28	23-47
Zinc (mg/L)	2.94-4.97	0.05-1.93
Lead (mg/L)	1.45-2.54	1.02-2.71
F Coli /100mL	0-8	0-13
T Coli /100mL	25-63	41-75

The range of turbidity, Lead and F Coli values far exceed the WHO guideline values. The pH value of rainwater also has a tendency to lie towards the lower range of the guideline values.

(v) *Singapore*: Roofwater was monitored from a high-rise building in the Nanyang Technological University over a period of almost six years from May 1989 and the range of mean values are shown in Table 5.

The values appear to be acceptable in all the physico-chemical parameters except pH which is quite low. T Coli and F Coli values also exceed the guideline values.

Table 5 : Roofwater Quality - Singapore

Parameter	Range of Annual Means
Colour (Hazens)	3.3 - 5.2
Turbidity (NTU)	1.6 - 2.9
pH	4.2 - 4.3
Sulphate (mg/L)	2.9 - 10.0
Chloride (mg/L)	1.0 - 1.5
TDS (mg/L)	4.8 - 20.2
NO_3 as N (mg/L)	0.3 - 0.6
T Coli/100mL	18 - 46
F Coli/100mL	2 - 6

Earlier field investigations have also shown that during January 1974 to July 1983, the range of pH in 11 monitoring stations distributed throughout Singapore was 4.8 to 5.5 (Tan, 1984).

SOME SIMPLE METHODS OF DISINFECTION

There are simple and effective methods for disinfecting water so as to render safe for drinking purposes. Some of the methods are:

(a) **Physical methods**
Boiling, which is one of the safest methods, could result in a flat taste and hence is not favoured by some. The use of simple filters leads to clogging and often breakthrough of the filter. The maintenance of filters and their relative cost are major influencing factors.

(b) **Chemical methods**
The forerunner of these methods is large water treatment plants where disinfection process follows extensive coagulation, flocculation and filtration processes. For small supply systems, chlorine compounds in solution or tablet form have been used. These

will include sodium hypo chlorite solutions, organic chlorine and iodine compounds, iodine solution, tablets etc., Chlorine, in the form of household bleach, has been applied successfully over a two week period to collected roofwater retaining a residual level of 0.2 mg/L (Krishna, 1991). The use of very small volumes of colloidal silver has also been practised successfully in Mexico (Owen & Garba, 1987).

(c) **Solar radiation**
Solar radiation, especially the uv band of the solar spectrum, has been tested in Honolulu and found to be effective for the removal of T Coli, F Coli and F Strept when roofwater samples were kept in clear glass tubes (Fujioka & Chinn, 1987). Using two Erlenmeyer flasks filled with roofwater, it was noticed in Thailand that for radiation levels varying from 192 to 1028 w/m^2 (cloudy to clear days), there was a total destruction of F Coli within 1.5 to 3 hours (Wanpen, 1992). UV systems costing about US$ 200 have also been found to be effective in terms of removal of T Coli, F Coli, E Coli and F Strept (Rijal & Fujioka 1992).

DISCUSSION & CONCLUSIONS

Along with the discussion some conclusions are drawn and, in some cases, recommendations made.

(a) **Sampling and testing**
It is evident that available data of water collected from cisterns in the region are grossly inadequate. There is no systematic collection and testing which is an integral part of good water quality management practice.

It is suggested that wherever RWCS have been established, or are being planned to be established, the sampling program should be an integral part of the whole project and water quality should be monitored on a routine basis.

(b) **Physico-chemical parameters**
Generally, collected water appears to exhibit quality levels that are comparable to WHO's Guideline values and it is understandable as to why, in most cases, most rural folk prefer rainwater over river water for drinking purposes. However, pH range is on the acidic side in Malaysia and more so in Singapore and where it could reflect the level of industrial activities in the sampling location.

(c) **Bacteriological parameters**
There were quite a few samples that exceeded WHO values in terms of T Coli and F Coli counts. Besides, the FC/FS ratios indicated that the source of pollution was largely of animal origin (droppings of birds, rodents etc.). The few cases of human contamination can be attributed to poor handling practices.

There is evidence that bacteriological contamination (salmonella arechevalata) presumably from animal droppings, has led to gastro-intestinal problems (Koplan et al, 1978). It has also been well-established that animals and birds, both domestic and wild, are frequent carriers of salmonella (Osborne 1976, Quevadoet et al 1973). The presence of different species of salmonella in roofwater has also been reported my many researchers (Fujioka 1982, Fujioka & Narikawa 1982, Wanpen 1987, Fujioka et al 1991). Hence, with the frequent presence of F Coli and particularly salmonella, there is the need to research its impact on human systems. As it is known that infectious doses of most salmonella species have to be greater than 1000 (Fujioka, 1993), there is the need to develop simple and inexpensive methods to identify salmonella during routine sampling

(d) **Disinfection**

Roofwater has to be subjected to some form of disinfection. Boiling, though it has its limitations, is the easiest and surest way to achieve this. Alternatively, simple methods of adding any one of the halogens compounds should be practised. This would call for action by the individual owners of RWCS in which case simple systems like adding household bleach periodically could be recommended. The cheapest UV system could still be prohibitive to rural folk in many developing countries.

It is also recommended that, as most of the countries in the region have an abundant amount of sunlight, research be undertaken to study the possibility of using solar radiation as the sole means of disinfection.

(e) **Health education**

A basic difference between conventional large water supply systems and RWCS is the fact that the onus of treatment and disinfection is transferred from the central water authority to the individual householder (Appan 1984). Hence considerable effort has to be put to convey the need for disinfection to the individual users. Simple methods should be proposed, implementation overseen and results monitored.

Roofwater quality which is generally of a higher order than that of surface runoff is readily imbibed though it is apparent that bacteriological contamination could render it below the allowable level for drinking. Such information should be systematically conveyed to the users and good collection practices introduced. The roofs, gutters, pipes and cisterns should be frequently inspected. All these measures should form the basis of an integrated health education program that should go hand in hand with the RWCS building project.

(f) **Water quality study**

Most of the information on water quality appears to be carried out on an ad-hoc basis. Consequently, the information is scanty and the results not applicable to all locations. A systematic study should be undertaken on a national or regional basis taking into consideration rainfall patterns, types of roofing materials, rain and roofwater qualities, guttering systems, materials used for storage tanks, maintenance practices, sequence and frequency of collection, testing schedules and any other salient factors specific to the country or region.

(g) **Standards for roofwater quality**

With quality levels of drinking water being progressively upgraded and made more stringent in developing countries, it would be prudent to lower the acceptable level of bacteriological quality of roofwater, unless it can be established that roofwater that is contaminated only with animal faeces can adhere to a different set of standards based on research as outlined in (c).

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PROSPECT OF RAINWATER CATCHMENT IN BANGLADESH AND ITS UTILIZATION.

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1.0 INTRODUCTION:

Bangladesh is one of the south east Asian countries which emerged as an independent and sovereign state in 1971. Globally it is located between about 20° to 26° north latitude and about 88° to 92° east longitude. Bordered on the north and west by India, on the east by India and Burma and South by the Bay of Bengal, Bangladesh has an area of 143998 sq.km. It has a population of about 120 million with one of the highest density of population in the world.

Bangladesh is a riverain country and natural calamities like flood , cyclones, storms and tornadoes visit the landscape very occasionally which claim huge toll of lives and cause heavy loss to the properties. Tropical climate being the characteristic event, rainfall pattern of the country is not always uniform. In some years severe drought is experienced with no rainfall at all for a particular period. On the other hand excessive rainfall also occurs sometimes to invite occasional flood. July to Sept. is usually the period for monsoon rainfall. Between winter and summer the temperature varies from around 11° c to 36 °c.

Bangladesh is almost entirely an alluvial plain land with some hills on North East and South - East margin. The alluvial plain slopes north west to south east from an elevation of 90m to 3m in South east. Within the plain land there are some elevated tracts which range in height from 15m to 40m above MSL. The plain land and low lying areas are formed of alluvial deposits carried by three mighty rivers, namely the Padma, the

Brahmaputra & the Megna. The main land is also criss- crossed by numerous small rivers and natural canals.

2.0 WATER SUPPLY PATTERN IN BANGLADESH:

In Bangladesh the principal source of public water supply is ground water. Next resort is the surface water sources developed through treatment process where ground water extraction is not feasible/ economical.

The mode of supply differs from urban to rural areas. In urban areas the extraction of ground water is made through large diameter production wells & supplied through pipe net work.

On the other hand rural water supply is made by 38 mm diameter hand operated tube wells which are located sparsely in homesteads. In Bangladesh ground water source is rich and plain land (about 80% of the total area) being formed of alluvial deposits is ideal for installation of hand pump at cheaper cost utilizing low cost appropriate technologies. There are about 1 million public hand operated tube wells in rural Bangladesh i.e. on average one tube well for 112 persons and 90% of rural population have access to tubewell water within 150 meters of their homesteads. In addition to that there are more than 1 million private hand operated tube wells in the country. Hand operated tube wells are the common source of water supply in rural Bangladesh (about 80% areas) except in problem areas.

The salinity problem in ground water as well as in surface water is encountered in the southern part of Bangladesh. In order to cope with diverse stratigraphic problems and the effect of dry period on subsurface water levels, the following types of rural water supply systems operate in the country :

1. Suction mode hand operated tubewells in the shallow water table areas.
2. Deep set tubewells in low water table areas.
3. Shallow shrouded Tube well and pond sand filter in saline problem areas of costal belt.

3.0 COASTAL BELT OF BANGLADESH AND PROBLEM AREAS:

Bangladesh has a very long coastline and some 20,000 sq km. area forming the coastal belt is considered the problem- area in respect of the availability of potable water. This is because ground water in the coastal belt is uncertain, either suitable quiefer is not available or water is extremely saline. Of course in some particular areas hand operated deep tubewells are successful within 300 m from GL. Nevertheless over 10 million people living in the belt have one kind of problem or the other with usable water in many places. Therefore they run the risk of endemic or epidemic diseases due to consumption of contaminated water.

4.0 SYSTEM OF RAIN WATER CATCHMENT IN THE PROBLEM AREAS OF BANGLADESH, SPECIALLY IN COASTAL AREA :

The yearly average rainfall in Bangladesh is 2500 mm. Heavy rainfall is experienced in July to Sept. A 10 year rainfall pattern based on country's mean rainfall intensity in 28 stations for the period between 1981 to 1990 has been shown in Annex-A and in Annex-A1, it is seen that maximum rainfall occurs in the month of July. The histogram of rainfall intensity also shows that the minimum rainfall was recorded in Jan. - Feb. and Nov., Dec. period in that year.

This indicates that rainfall in Bangladesh is not uniform over the year. As such catchment or rain water in one season and using the same in the dry season is both in convenient and expensive in normal situation of Bangladesh. The catchment of rain water in surface pond (reservoir) and utilizing the same throughout the year is the common phenomenon in Bangladesh . This has been the practice in this region since time immemorial. Even now - a - days pond water is used mainly for bulk requirement such as washing, bathing and other multifarious uses and tubewell water is used mainly for drinking purpose. But scenario in problem areas of coastal belt of Bangladesh is different mainly in the zone shown in red mark in attached map (Annex-B) where ground water & surface water sources are both saline and the people have no other alternative to rain water stored in surface pond. They use rainfed pond water for all domestic purposes through out the year.

Catchment of rain water from roof is not widely practised because of hazard of collection & storage and the system is also expensive. But this system is, sometimes, practiced for shorter period. The problem of using the pond water for domestic use is attributed mainly to contamination. It is a matter of great concern that surface pond water is grossly contaminated which is one of the reasons for spread of diarrheal diseases.

To tide over the above problem simple low cost treatment process has recently been developed to treat the raw pond water through slow sand filtration system. On the bank of the surface pond a small brick chamber is constructed which is filled with coarse sand and brick chips and raw water is pumped there through hand operated tubewell and get it filtered through sand bed. This is known as pond sand filter(PSF). This system has been found very effective and suitable in the problem areas where no alternative source is available. The system provides safe drinking water to the consumers (Annex_c).

The community is supposed to look after the maintenance of the pond sand filter. Cleaning of pond sand filter & replacement of sand is required to be done off & on depending upon the quality of water. To decrease the pollution load the pond is kept reserved i.e. pond is not allowed for uses such as bathing, washing and other purposes except pumping water through hand operated tubewell to the pond sand filter. This helps maintain reasonably good quality of raw water in the reserved pond. Moreover, to avoid contamination surface run off is prevented by constructing embankment all around the pond. . Sometimes, fencing is also done for protection.

5.0 ONGOING RESEARCH PROGRAMME OF RAIN WATER COLLECTION IN BANGLADESH :

A study has been undertaken in the saline coastal belt of Bangladesh to collect rain water from roof of the rural houses. Attempts have been made to explore the traditional practice in the project area and develop innovative measures to improve the existing practice.

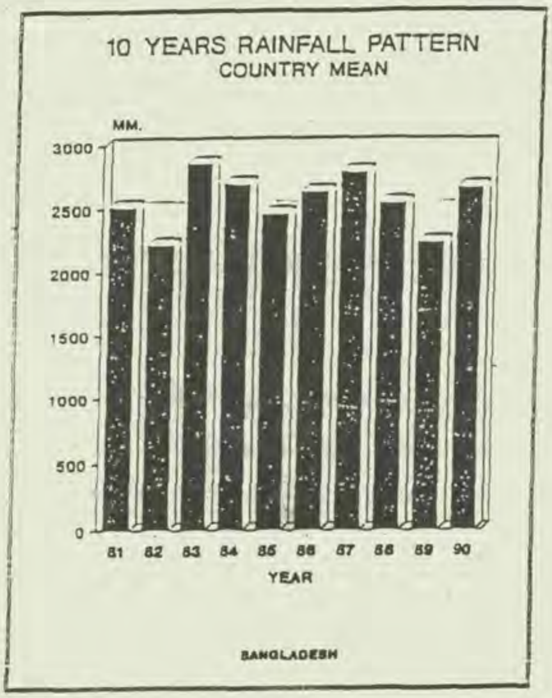
Bangladesh being thickly populated area, community based group collection and distribution system may also be tried through large rainwater overhead reservoir.

Rain water use in the urban area may also be popularized to cater the domestic need of water for washing, bathing etc. A project profile is under process.

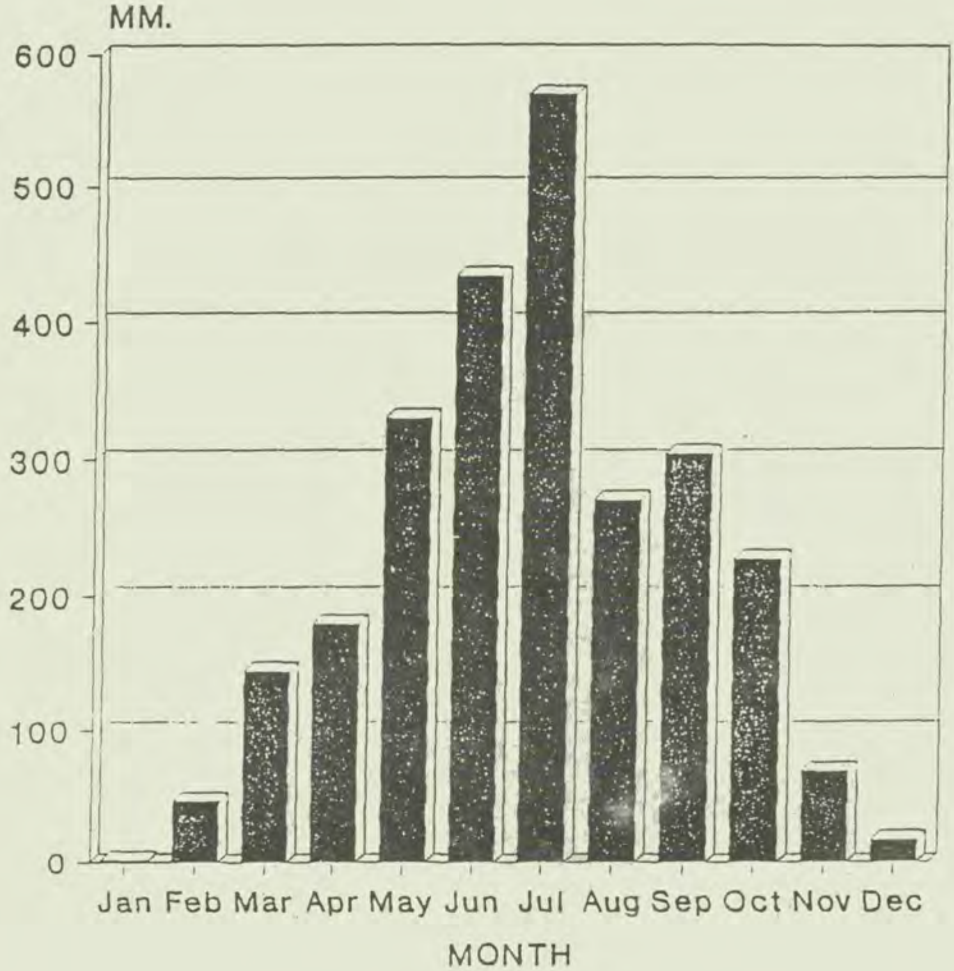
6.0 CONCLUSION :

In Bangladesh ground water availability is not so acute except in the saline coastal belt. Various water supply systems have been developed so far. Of them the pond sand filter (PSF) is dependent on rain water storage systems in surface pond. In the rural sector, homesteads are widely scattered and wherever there are surface water ponds these can be used to receive direct rainfall. There is ample opportunity to develop these ponds in order to augment potable water supply in the saline coastal belt through pond sand filters(PSF). There is also need for excavating greater numbers of surface water ponds in those areas for catchment of rain water and using the same all round the year.

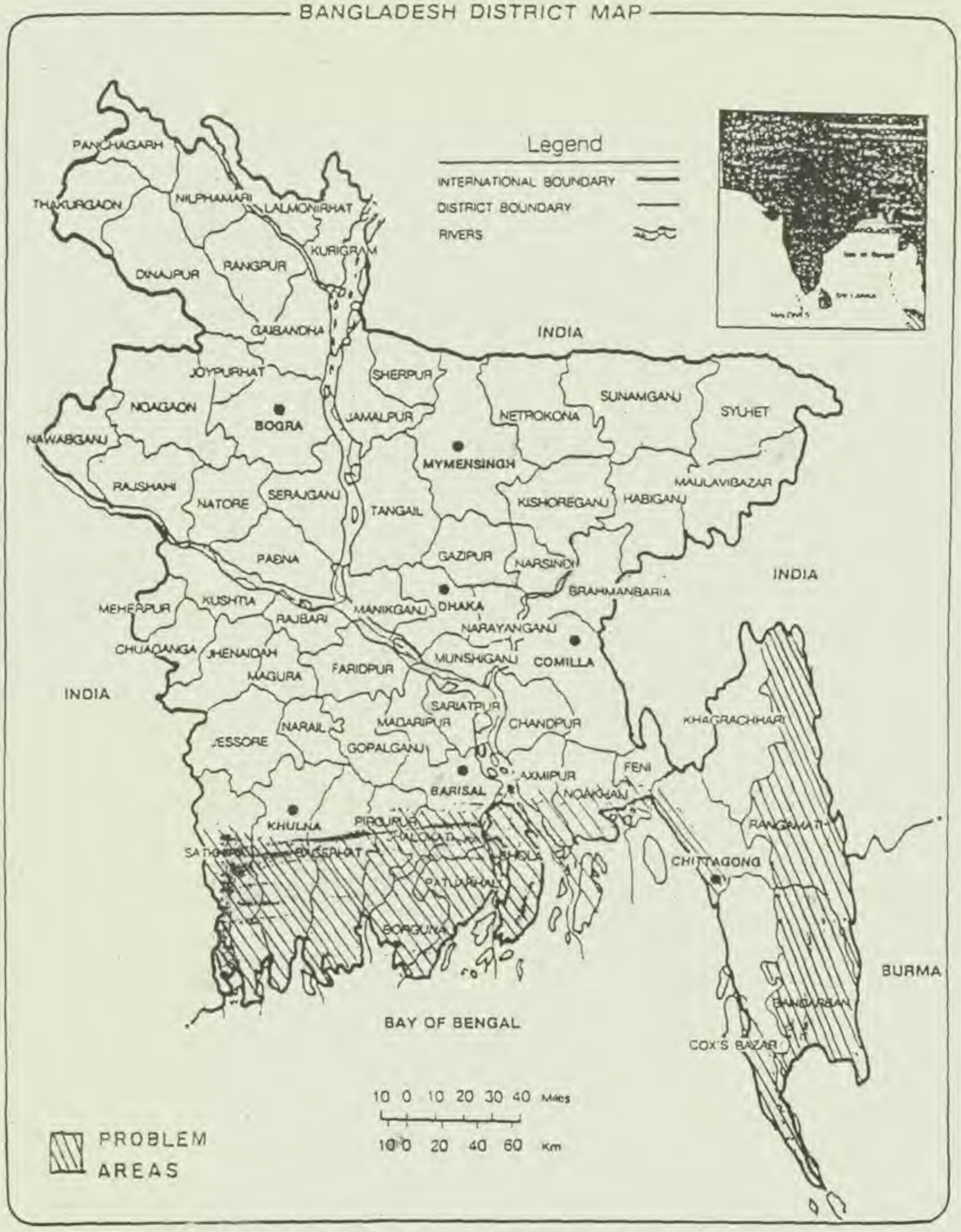
Recently some hilly regions where the availability of potable water is a problem, have been proposed to be brought under study of utilization of rain water. Rain water will be collected there in ferrocement reservoir and the same will be purified as required following simple technologies before use.

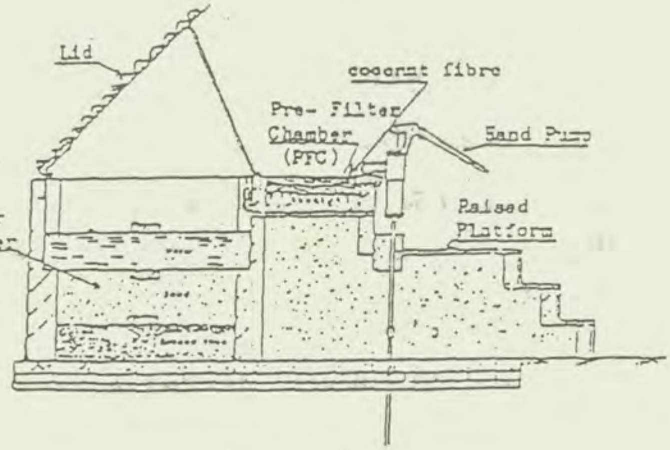


MONTHLY RAINFALL PATTERN
COUNTRY MEAN

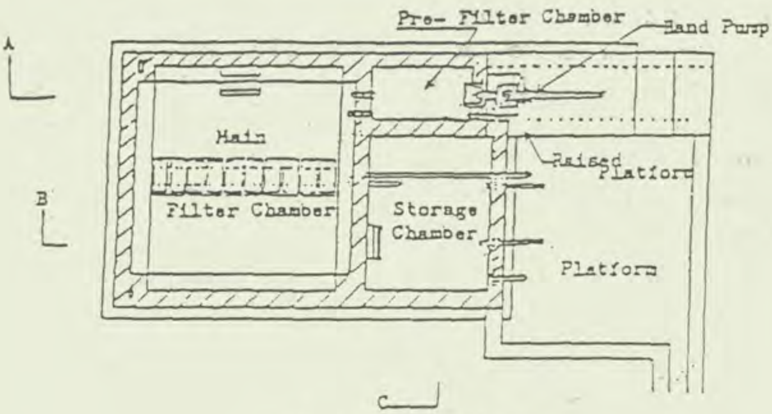


YEAR, 1990, BANGLADESH.

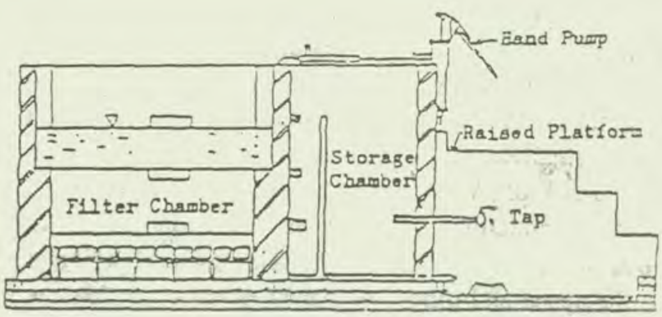

BANGLADESH DISTRICT MAP
Legend
INTERNATIONAL BOUNDARY
DISTRICT BOUNDARY
RIVERS
INDIA
BAY OF BENGAL
BURMA
PANCHAGARH
THAKURGAON
NILPHAMARI
LALMONIRHAT
KURIGRAM
DINAJPUR
RANGPUR
GAIBANDHA
JOYPURHAT
NOAGAON
BOGRA
NAWABGANJ
RAJSHAHI
NATORE
SERAJGANJ
SHERPUR
JAMALPUR
MYMENSINGH
NETROKONA
SUNAMGANJ
SYLHET
MAULAVIBAZAR
HABIGANJ
KISHOREGANJ
TANGAIL
GAZIPUR
NARSINDI
BRAHMANBARIA
PABNA
KUSHTIA
MEHERPUR
RAJBARI
MANIKGANJ
DHAKA
NARAYANGANJ
CHUADANGA
JHENAIDAH
MAGURA
FARIDPUR
MUNSHIGANJ
COMILLA
SARIATPUR
MADARIPUR
CHANDPUR
KHAGRACHHARI
JESSORE
NARAIL
GOPALGANJ
BARISAL
FENI
NOAKHALI
KHULNA
PIROJPUR
JHALOKATI
SATKHIRA
BAGERHAT
BHOLA
PATUAKHALI
BORGUNA
RANGAMATI
CHITTAGONG
BANDARBAN
COX'S BAZAR
10 0 10 20 30 40 Miles
10 0 20 40 60 Km
PROBLEM AREAS



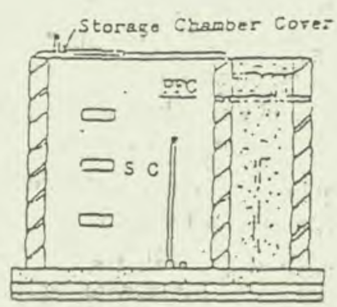
Sectional side view of large PSF diagram only



Plan view of large PSF without lid



Section B-B



Section C-C

Sectional view of large PSF

Fig-1

RATES AND CHEMICAL ANALYSIS OF OCCULT PRECIPITATION

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Abstract

The main objectives of this paper were to: (1) estimate the influence of occult precipitation on the water balance in the chosen mountainous regions of the Czech Republic; (2) characterize the chemical composition of this kind of water; and (3) determine if site-to-site differences exist. The methods used in assessing the fog water amount are discussed. Two of them (the method of water balance of forest canopy and a micrometeorological mathematical resistance model) were used for the estimation of cloud and fog water total. The chemical and hydrological significance of occult precipitation has been suggested for the higher elevation zones above the elevation of 800 m a.s.l. For the purposes of this study the foregoing studies of the Czech researchers (Milešovka Mts., Beskydy Mts., and Orlické Hory Mts.) were used and two new localities (Šumava Mts., and Krušné Hory Mts.) were established. Estimated gross deposition of cloud-water is about 10 % of the total annual precipitation. A wide range of concentrations were encountered, most typically exceeding concentrations occuring in rain by factor from 2 to 41 in the Šumava Mts. (the clearest region of the Czech Republic), and 7 to 97 in the Krušné Hory Mts. (heavy polluted area).

Introduction

Considering, that some 90 % of the Earth's surface remains with little rainfall and insignificant rivers, the exploit of water resources needs to adopt new techniques for rain-water catchment. The deposition of low clouds and fogs on the vegetation cover or capture of atmospheric water droplets by artificial fog collectors has long been recognized as input impotant both from hydrological and ecological point of view, especially in seacoast and mountainous regions. The so-called horizontal (occult) precipitation originated from fogs and low clouds is capable to produce substantial quantities of water for domestic, agricultural or forestry purposes. For these direct utilisations it is important to know the actual chemical composition of fog and cloud water since recent studies have shown that fog can be a source of high ionic concentrations and acidity. Since the concentration of chemical species is several times higher in cloud water than in precipitation, the chemical deposition associated with cloud and fog droplet interception by vegetation can be significant, or even predominant, with respect to deposition due to precipitations (Fuzzi and Orsi 1985; Vong, Sigmon and Mueller 1991).

Despite the importance of horizontal precipitations, estimates of the amount of cloud water deposition are still crude, because it is not easy to estimate the total annual horizontal precipitations, especially with regard to the space and time irregularity of their occurrence. The methods published in literature fall into four classes (Lovett 1988):

(i) **Micrometeorological methods** include the flux gradient, eddy accumulation, and other measurements of the cloudy air itself. These methods are often complicated and involve some unverifiable assumptions, but they can provide detailed information on water and ion deposition (Lovett 1984; Lovett 1988; Lovett, Reiners and Olson 1982).

(ii) **Method of water balance in the canopy;** stemflow and throughfall measurements involve the collection of the water captured by the vegetation and dripping to the ground. The interpretation of these measurements is complicated by evaporation from the canopy and by the chemical alteration of cloud-water by foliar leaching (Lovett 1988).

(iii) **Surrogate surface measurements:** wire screens or artificial foliage are used to capture cloud-water which subsequently drips into a collection bucket. This facilitates the chemical analysis of cloud-water, but an extrapolation of the results to actual vegetation canopies is difficult (Lovett and Reiners 1983).

(iv) **Method of streamwater chemistry** can be applied only if some assumption concerning the chemistry and hydrology of the watershed can be accepted. Rain and clouds are the only water inputs to the watershed of the sampled streams, and evapotranspiration and streamflow are the only outputs. Sources and sinks of the suitably chosen tracer within the watershed are negligible as compared to measured inputs and outputs. It may be possible to estimate the deposition at a single point in space and time with reasonable certainty, yet broader-scale estimates are associated with very high uncertainties (Lovett 1988).

The present study involves the first method (the mathematical micrometeorological resistance model) and the second method (water balance of the forest canopy - literature review over the Czech Republic) for the purpose of the estimate of cloud and fog water deposition total, and the third method with the use of the sample-taking device (Daube et al. 1987) - the so-called active cloud water precipitation (CWP) collector - for the collection of cloud and fog water samples and for the estimate of liquid water content..

Sites description

The chemical and hydrological significance of horizontal precipitation has been suggested for the higher elevation zones of the Czech mountainous regions (the Šumava Mts., Krušné Hory Mts., Orlické Hory Mts., Moravskoslezské Beskydy Mts., and Milešovka Mt.). These zones, especially above the elevation of 800 m above sea level, are characterized by high wind speeds, lengthy periods of cloud and fog immersion, and coniferous vegetation, all of which contribute to high potential rates of cloud droplet capture. The schematic location of testing sites for the estimates of the amount of the occult preipitation, for collection of samples and modelling of this sort of precipitation and for the collecting of bulk precipitation and throughfall (in the Šumava and Krušné Hory Mts.) is shown in Fig. 1.

The **Šumava Mts.** is the mountain range forming the border among SW Bohemia and Germany and Austria. The sampling site for the cloud and fog water collection is located at an elevation of 1123 m a.s.l. on the hilltop Churáňov (13°36'56"E, 49°04'08"N). The precipitation and throughfall network was installed in the Liz catchment (Fottová, 1995). This afforested watershed of mountainous type lies in the National Park Šumava at a distance of 4 km from the meteorological station Churáňov with the cloud water sampler. The completly forested Liz catchment (49°04' N, 13°41' E, 0.99 km², 828 - 1074 m a.s.l.) has been studied since 1975 (Tesař, 1990; Pražák et al., 1994). This watershed is covered by mature spruce forest.

The **Krušné Hory Mts.** (Ore Mts., Erzgebirge) is a mountain range adjacent to the one of the regions with the most severe air pollution worldwide, the North Coal Basin. This region is known since medieval times for mining of ore deposits. The samling site is located in the vicinity of Rudolice at an elevation of about 900 m a.s.l. The precipitation and throughfall network was installed in the Jezeří catchment (Fottová, 1995). This watershed (50°33' N, 13°29' E, 2.61 km², 420 - 925 m a.s.l.) has been studied since 1983 (Kinkor, 1988). The upper half of the catchment was covered by mature spruce forest which died before sampling started and today it is covered by a heterogenous mixture of spruce, birch, mountain ash and shrubs. The lower half of the catchment is formed by a steep valley covered by mature beech forest.

The **Orlické Hory Mts.** is the mountain range forming the border between NE Bohemia and Poland. Experimental areas were established in this region in non-mixed spruce and non-mixed beech stand (50°19' N, 16°21' E, 900 m a.s.l.). Very extensive research concerning the water balance of the forest canopy has been worked out (Kantor 1981, 1983).

The **Moravskoslezské Beskydy Mts.** is a mountain range forming the border among the Czech Republic, Slovak Republic and Poland. Two experimental watersheds Malá Rázto-ka and Červík were established in this region in 1953 (49°30' N, 18°15' E, 2.08 km², 602 - 1084 m a.s.l. and 49°27' N, 18°23' E, 1.85 km², 640 - 960 m a.s.l, respectively). The results of research concerning the water balance of these catchments were published (Zelený 1967; Zelený and Chlebek 1973).

The **Milešovka Mt.** is the hill 60 km NW from Prague with its top at an elevation of 837 m a.s.l. An analysis of basic characteristics of fog variation at the station on the tophill shows the importance of fog water deposition in this region (Koldovský 1968).

Methodology

For the purposes of the estimate of cloud water deposition amount in the Orlické Hory Mts. and Moravskoslezské Beskydy Mts. the water balance of the forest canopy method was used (Kantor 1981, 1983; Zelený 1967; Zelený and Chlebek 1973). Water that enters a forest canopy either as rain or cloud and fog water deposition is either evaporated as interception loss or drips to the forest floor as stemflow or throughfall. Measurement of rainfall, throughfall and stemflow over extended periods provides a simple and direct estimate of cloud water deposition to a forest. The obvious drawback is that interception loss must be estimated. This can be done by monitoring wind speed, temperature, relative humidity, and net radiation above the canopy and calculation evaporation rates when the canopy is wet. Even without the correction for interception loss, measurement of rain, stemflow, and throughflow provides a firm lower limit for cloud water deposition. While the measurements are only applicable to the stand in which they are made, replication is inexpensive and is not limited by complexities of terrain or vegetation cover.

A resistance model of the deposition of cloud droplets to a spruce forest canopy (Lovett 1984) was used for the prediction of cloud water deposition in the Šumava Mts. The model is composed of two submodels, the first simulating a turbulent diffusion of cloud droplets into the forest and their deposition onto foliar and branch surfaces, and the second simulating the evaporation/condensation process under cloud-immersion conditions in the forest. Both the cloud deposition model and the evaporation/condensation models have been described by Lovett (1982, 1984, 1988). Although these models depend on the estimation of a number of parameters whose accurate measurement is difficult (the leaf-area index, the droplet-size distribution and the cloud-liquid-water content), it represents a very instructive tool enabling us to estimate both gross and net deposition (total cloud-water deposition minus total evaporation) and examine their reactions to changes in meteorological and canopy-structure parameters. For calculating the ion deposition via cloud-water a direct estimate of gross water input is needed, and that is why we have applied the above-mentioned model. Some canopy-structure parameters are described by Thorne, Lovett and Reiners (1982) and Lovett and Reiners (1986).

In order to estimate the cloud-liquid-water content (LWC) and to gain cloud-water samples, the sample-taking device was constructed. Mountainous areas in the Šumava Mts. are frequently immersed in fog, but often do not have sufficient wind to propel the fog through a passive collector. Under these conditions, an active collector which provides relative motion between the collection surface and the fog droplets is required. The so called active CWP collectors as described by Daube et al. (1987) were installed in the Šumava Mts. (Churáňov station, 1123 m a.s.l.) and in the Krušné Hory Mts. (Rudolice station, 900 m a.s.l.). For this design, a propeller-type automobile cooling fan was chosen as a means of facilitating collection. Collector of this type have been used during a relatively extensive fog research in the U.S.A. (Weathers et al. 1988). The CWP active cloud-water collectors are constructed of chemically inert materials; the inlet is located on the bottom of the collector to avoid the collection of rain-water. The fan draws fog into a ventral inlet and through a bank of nylon strands. A strand diameter of 0.78 mm was selected (Daube et al. 1987). Satisfactory velocity through the strands, which is required for efficient collection, was achieved by reducing the internal cross-sectional area of the collector with a venturi.

Samples collected were stored in 500 or 1000 ml polyethylene bottles at 4 °C in the dark. Prior to use, storage bottles were washed with 6N HCl, followed by several distilled water rinses. Chemical analytical methods: pH of the samples was measured with a Radiometer CG-2401C electrode, fluoride was determined by ion selective electrode, chloride, nitrate and sulphate by non-suppressed single column ion chromatography, ammonia spectrophotometrically and metals by flame AAS.

Results and discussion

On the basis of the results of water balances of forest canopy in the Orlické Hory Mts. (Kantor 1981, 1983) it can be supposed that on the annual average horizontal precipitation increased water quantity supplied to soil in the spruce and beech stand by 100 - 120 mm (8 - 10 % precipitation total).

Results of water balances of forest canopy obtained in the Beskydy Mts. (Zelený 1967; Zelený and Chlebek 1973) prove that the interception is strongly affected by horizontal precipitation. The results show the relative difference from 18 to 38 % as compared with precipitation.

The results of model predictions for the Šumava Mts. region of gross cloud droplet deposition, net cloud droplet deposition and simulated cloud water deposition velocity (gross flux divided by the liquid water content) are $0{,}505.10^{-3}$ $g.cm^{-2}.min^{-1}$, $0{,}175.10^{-1}$ $cm.hour^{-1}$ and 20,9 $cm.s^{-1}$, respectively. Model predictions were made for canopy structure parameters in harmony with the literature (Lovett and Reiners 1986) for the similar state of growth of the chosen spruce forest. Furthermore the estimates were made for annual mean meteorological conditions during cloud and fog events according to Strnad et al. (1988), with wind speed 3,2 $m.sec^{-1}$, relative humidity 96 %, cloud-water content 0,4 $g.m^{-3}$, mean droplet diameter 10 um, net radiation 0,071 $cal.cm^{-2}.min^{-1}$ and air temperature -0,2 °C. If we assume that the spruce forest in the Šumava Mts. are immersed in clouds and fogs for 322 $hours.year^{-1}$ (only very heavy intensity 3) on the average according to Tesař and Eliáš (1990) and that, for 104 $hours.year^{-1}$, rime-ice accretion reduces the deposition rate by 50 % according to Lovett, Reiners and Olson (1982), then our estimated annual gross deposition of cloud-water is 81 $mm.year^{-1}$, while the net deposition is 47 $mm.year^{-1}$. If we take into account also the fogs with the intensity 2 (heavy intensity) then the cloud immersion lasts 758 hours per year and gross deposition represents 214 $mm.year^{-1}$, while the net deposition is 124 $mm.year^{-1}$. The first estimation is probably more realistic because the liquid water content of fogs of second intensity is small and in harmony with our field observations the cloud water deposition doesn't occur during these fogs. These estimates are admittedly crude, but they certainly are the best estimates available. The similar approach would be possible to use for the locality Milešovka Mts. The vegetation is immersed into the fog for 2708 $hours.year^{-1}$ (Koldovský 1968). However there is not a distinction the fogs events for the individual intensity. Nevertheless it is apparent that the influence of occult precipitation is very high in this region due to very long lasting cloud and fog immersion.

In the course of time period from October 1989 to September 1994 59 samples of fog water were collected at Churáňov station. During the autumn 1994 2 samles of fog and low cloud water were collected at Rudolice station. On the basis of chemical analyses of these fog water samples the so-called enrichment factors were determined. In Table 1 and 2 the comparison between calculated deposition due to fog and measured deposition via precipitation and throughfall both on an annual basis is shown for the Šumava Mts. and Krušné Hory Mts., respectively.

There is unsufficient number of chemical analyses of cloud water collected at Rudolice station in the Krušné Hory Mts. to be able to work out some deeper evaluation. These results are only preliminary but ionic concentrations in cloud and fog water are apparently higher with comparison to precipitation.

Conclusions

Without wishing to generalize the above reported findings, the results clearly show that in the examined mountainous regions of the Czech Republic the combined effect of high fog frequency and high ionic concentration of the solution droplets result in wet deposition rates for chemical substances which can be important to the environment. From the above results these conclusion can be drawn:

1. The obtained results of chemical analyses are in general agreement with the known pattern of the chemical composition of European horizontal precipitation (Fuzzi and Orsi 1985).
2. The cloud and fog water deposition is important delivery mechanism for pollutants both in relatively very clear part of the Czech Republic (the Šumava Mts.) and in very heavy polluted region (the Krušné Hory Mts.).
3. The gross water input via cloud and fog water represents about 10 % of the total annual vertical precipitation.
4. Concentrations of major ions in cloud and fog water are approximately 20 times greater (so called enrichment factor reaches values from 10 to 25) in the Šumava Mts. and 50 times greater (from 7 to 97) in the Krušné Hory Mts.
5. In the Šumava Mts. cloud water droplets deposition can increase wet deposition of SO_4^{2-}, NO_3^- and NH_4^+ by 121, 181 and 362 %, respectively. This transport represent 2292, 2178 and 887 $kg.km^{-2}.year^{-1}$, respectively.
6. In the Krušné Hory Mts. cloud water droplets deposition can increase wet deposition of SO_4^{2-}, NO_3^- and NH_4^+ by 82, 216 and 189 %, respectively. This transport represent 3340, 5736 and 1391 $kg.km^{-2}.year^{-1}$, respectively.
7. The estimated annual deposition of nitrogen and sulphur via horizontal precipitation for the same time period (1994) was 1.18 and 0.76 $t.km^{-2}$, respectively in the Šumava Mts. and 2.37 and 1.11 $t.km^{-2}$, respectively in the Krušné Hory Mts.

Acknowledgements

We would like to express special thanks to Dr.G.M.Lovett for kindly supplying us with the computer programme of cloud water deposition. We are indebted to staff of Geological Survey and Czech Hydrometeorological chemical laboratories for precise analyses of our cloud water samples, to Dr. Šantroch from the Czech Hydrometeorological Institute in Prague for making available the chemical analyses of precipitation in Ore Mts. for us. The special thanks belongs to Dr. Fottová from the Czech Geological Survey in Prague for making available the chemical analyses of precipitation and throughfall in Šumava and Ore Mts. (the Grant of the Grant Agency of the Czech Republic No. 205/93/0717) for us. Funding for the project came from the same Grant Agency (No. 103/94/0653).

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FIGURE CAPTION

Fig. 1 Map showing the experimental sites in the Czech Republic. 1- Šumava Mts.; 2 - Krušné Hory Mts.; 3 - Orlické Hory Mts.; 4 - Beskydy Mts.; 5 - Milešovka Mt.

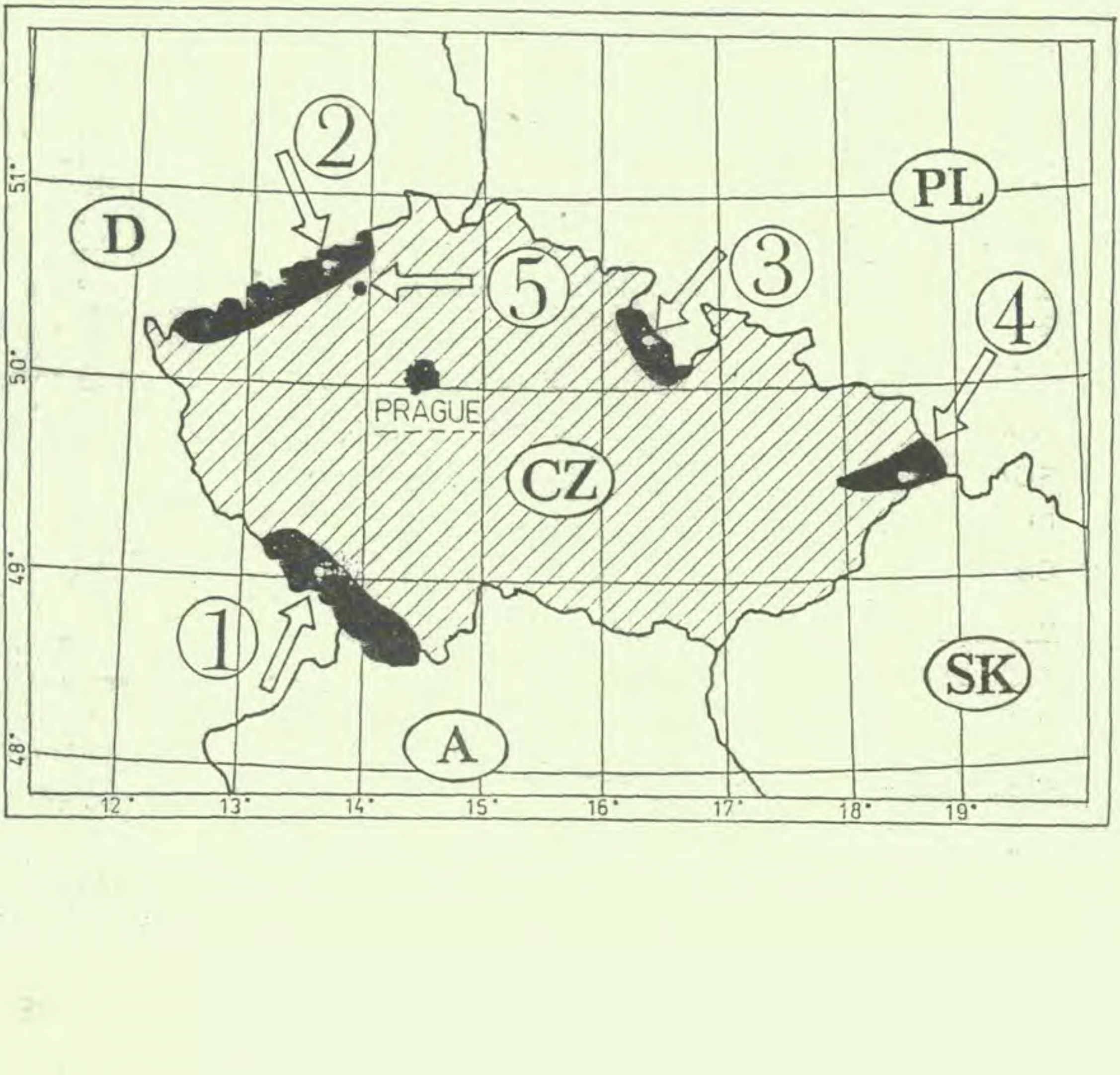

Table 1. Comparison between calculated deposition due to fog and measured mean weighted precipitation deposition at Churáňov and Liz in the Šumava Mts. Throughfall deposition and total water deposition in 1994 are also reported.

Ion	P [kg/km2.y]	TH [kg/km2.y]	F [kg/km2.y]	F/P [%]
Na	146.78	198.39	48.60	33
K	177.40	877.11	40.50	23
NH4	245.10	405.28	886.95	362
Mg	50.31	106.04	25.92	52
Ca	253.58	527.94	267.30	105
Mn	5.38	34.02	3.32	62
Zn	12.84	7.56	27.74	216
F	19.08	18.13	18.47	97
Cl	252.09	350.94	38.07	15
NO3	1204.40	1553.08	2178.90	181
SO4	1888.72	2652.40	2292.30	121
Pb			3.30	
Cd			8.02	
Ni			0.97	
Water dep.[mm]	892.9	401.3	81.0	9

P - weighted precipitation yearly deposition [kg/km2.y] (Fottová, 1995), Liz

TH - throughfall deposition [kg/km2.y] (Fottová, 1995), Liz

F - calculated fog deposition [kg/km2.y], Churáňov

Table 2. Comparison between estimated deposition due to fog and measured mean weighted precipitation dep. at Rudolice in the Krušné Hory Mts. Throughfall dep. in the Jezerí basin and total water dep. in 1994 are also reported.

Ion	P [kg/km2.y]	TH [kg/km2.y]	F [kg/km2.y]	F/P [%]
Na	122.13	566.00	1105.04	905
K	56.63	2201.00	133.00	235
NH4	734.89	1668.00	1390.80	189
Mg	42.56	296.00	225.72	530
Ca	296.56	1609.00	326.80	110
Mn	1.95	116.00	13.11	673
Cl	414.74	1134.00	487.92	118
NO3	2654.82	5518.00	5735.72	216
SO4	4066.57	13927.00	3340.20	82
Pb	6.07		3.97	66
Cd	0.19		0.33	179
Ni	1.76		2.32	132
Water dep.[mm]	833.10	702.10	76.00	9

P - weighted precipitation yearly deposition [kg/km2.y] (Šantroch, 1995) at the Rudolice station

TH - throughfall deposition [kg/km2.y] (Fottová, 1995) in the Jezeří basin

F - estimated fog deposition [kg/km2.y] at the Rudolice station

A Preliminary Study of Pellet-type Purifier

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ABSTRACT

Water purifiers employed to treat surface water sources in China may be classified into two categories. Conventional purifiers are limited by their ability to treat waters with turbidity < 500mg/l. The objectives of this paper are to: (1) Introduce the process of pellet-type water purifier, (2) present the results of a prototype study using this process, and (3) show a comparison of operational and economic date between the pellet-type and conventional purifiers. A pilot scale experiment using the pellet flocculation process was conducted in July and August, 1994 at the North China Institute of Water Conservancy and Hydroelectric Power, Hebei. The prototype worked well at high overflow rates (4.9mm/s to 6.4mm/s) with turbidity ranging from 46mg/l to 2100mg/l. The quality of finished water was excellent with turbidity prior to filtering <5mg/l. The addition of PAC and PAM are essential in maintaining optimum result. Pellet flocculation appears to be an attractive means of removing surface water turdidity. Pellet-type water purifiers can be more cost effective in treating water than conventional purifiers. A full scale demonstration of this process is warranted.

Key words: purifier, tubular coagulator, pellet reactor, turbidity

Background

Water purifiers employed to treat surface water sources to meet the demand for potable water make full use of the latest water treatment techniques. Their functions are similar to that of small surface water treatment plants. At present, water purifiers may be classified into two categories in China: type I and type II. Both types of purifiers deal with the removal of turbidity -producing substances (colloidal solids, clay particles, organics, bacteria and algae etc) . Type I consists of coagulation (including mixing) , sedimentation and filtration while type II incorporates only direct filtration. Generally speaking, type I should be used to treat surface water with turbidity between 100mg/l-500mg/l and type II for concentrations less than 100mg/l. Type II is less widely used than type I for the treatment of surface water in China. Because surface water turbidities are generally greater than 100mg/l and variable under normal conditions throughout the calendar year.

According to many researchers both in China and abroad, it has been found that flocs forming in type I purifiers are random flocs, which have the following characteristics.[1,2]

• Loose in structure resulting in flocs that have poor resistances to shearing stress.

• Low in density resulting in flocs that have low sedimentation velocities, and

• Catkin and porous resulting in a chemical sludge that has a high water content.

These characteristics limit the ability of type I purifiers. In order to overcome the above disadvantages, a new type of surface water purifier (pellet -type water purifier) is being developed in hina which is based on the latest water treatment theory of pellet flocculation.

The objectives of this paper are (1) to introduce the process of pellet flocculation, and (2) present the results of a prototype study using a pellet - type surface water purifier, and (3) show a comparison of operational and economic data between the two types of purifiers.

Introduction

The process of pellet flocculation used in theoretical research is based on the diagram shown in Figure 1.

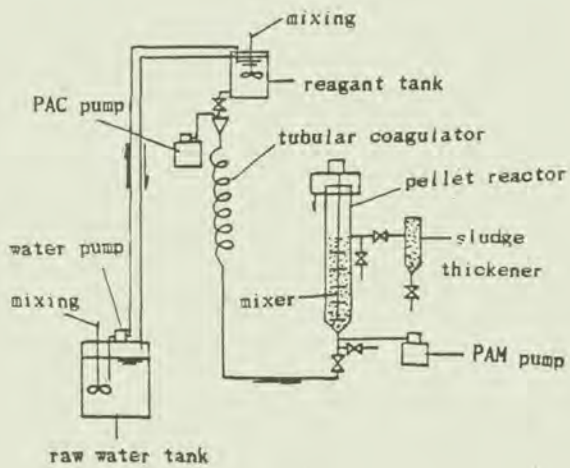

Figure 1. the process of pellet flocculation used in theoretical research

At the entrance of tubular coagulator, polyaluminum chloride (PAC) is introduced to the raw water to destabilize turbidity- producing substanes. By controlling the hydranlic index $(G/Re)^{1/2}$ T and the boundary parameter L/D within a certain range, the formation of micro -flocs will result. Where G=mean velocity gradient, Re=Reynods number, T=detention time, L=length of tubular coagulator, and D= diameter of tubular coagulator. Uniform and well- distributed micro-flocs are obtained at the end of the tubular coagulator. In addition to their size, the micro-flocs have characteristics of low water content and high density.

Polyacrylamide (PAM) is introduced into the process just before the entrance to the pellet reactor. In the pellet reactor (where pellet flocculation occurs) a mechanical mixer is installed to promote floc growth. PAM rapidly disperses in water and a flocculation reaction occures between PAM and the micro-flocs. Nuclei of pellet flocs begin to form by adsorption and interparticular bridging. However, it must be kept in mind that all particles (micro-flocs) don't immediately react with PAM before they enter the pellet reactor. What enters the pellet reactor is a mixtures of flocnuclei and micro-flocs. The moment water enters the pellet reactor, the velocity gradient rapidly decreases. This creates good conditions for the growth of pellet flocs. The mechanical mixer and upflow water in the pellet reactor perform important functions in the promotion of pellet floc growth. Pellet flocs in the sludge zone of the pellet reactor, unlike flocs in conventional purifiers, are in a state of motion. Two kinds of motions are present. One is microcosmic rotation of pellet flocs and the other is macroscopic spiral movement. In the pellet reactor, existing rolling frictions and extrudings among growing pellet flocs induce them to become spheroidal shape. The characterics of pellet flocs forming in the pellet reactor are quite unlike random flocs forming in conventional purifiers. The former has the following characteristics: [3]

* More compact and spheroidal in structure resulting in higher binding strengthes and resistences to shearing stress.
* Higher density and sedimentation velocities producing a higher overflow rate in the pellet reactor.
* Small porosity resulting in pellet flocs with low water content.

Mathods and Materials

A pilot scale experiment for treating surface water was conducted in July and Augest, 1994 at the North China Institute of Water Conservancy and Hydroelectric Power, Handan, Hebei, using the pellet flocculation process. A prototype of the pellet- type water purifier was constructed and a preliminary study was designed to test the effectiveness of turbidity removal under various conditions. In the design of the prototype, filteration was also incorporated, but operational data is not included in this paper.

Figures 2 and 3 show the configuration of the prototype and the flow diagram for the surface water treatment system used. The capacity of the prototype was initially designed to be 5 m^3 /h.

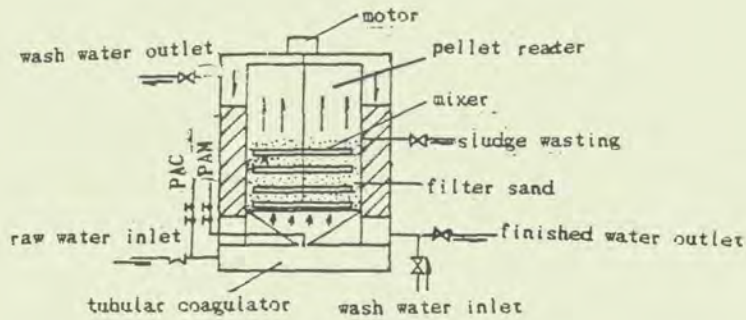

Figure 2. the configuration of the prototype

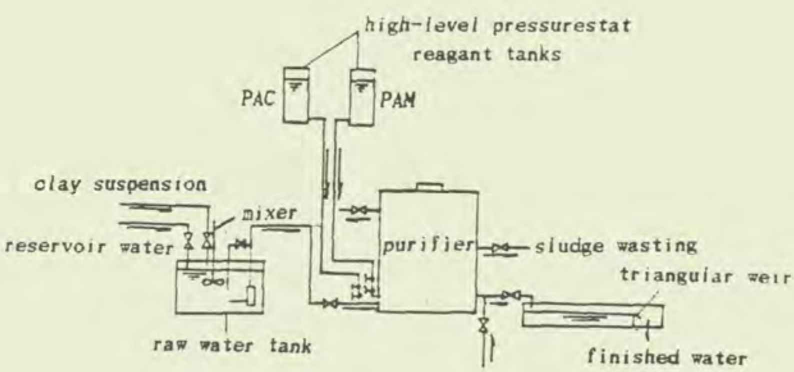

figure 3. the flow diagrom of the surface water treatment system

Figure 2 illustrates the prototype's three main parts (1) tubular coagulator (2) pellet reactor, and (3) filter. The tubular coagulator is in the shape of a circle having a length of 10.0m and a diameter of 50mm. PAC is added to water at the entrance of the coagulator. The pellet reactor, has a total height of 1.2m and a diameter of 600mm. It consists of a conical lower section and a cylindrical upper section. In the middle of the cylindrical section a pipe was installed for sludge wasting and accidental dischange. A vertical shaft mixer is mounted on the pellet reactor to promote the growth of pellet flocs. The filter was provided for nonsettleable flocs and impurities remaining after pellet flocculation. Finished water is collected and discharged through a triangular weir.

The study of turbidity removal involved experiments using raw water with initial turbidity values ranging from 46 mg/l to 2100 mg/l. The raw water was prepared using reservior water and concentrated solutions of the earth's surface soil. Temperature during the experiments was 20℃ —25 ℃. Turbidity of each water sample was measured by using a turbidimeter (Type GDS-3, made in China).

PAC is commercially produced in china and was supplied as yellow powder having a strength of 30--33% Al_2O_3 with alkalinity of 55-88%. A concentration of 4‰ was used during experiments. PAM(ZS-B, positive) is also commerially produced in China and was supplied as white power having a strength of 90% . A concentration of 0.24%. was used during experiments. Both PAC and PAM were added to the water by gravity using high-level pressurestat reagant tanks. The amount was measured by volumetric determination.

Results and Dissussion

The primariy objective of the pilot study was to evaluate the effectiveness of turbdity removal by a prototype water purifier. Table I summaries data obtained by taking the mode of continuous flow under different initial turbidity conditions.

The data clearly indicates that the prototype can work well at high overflow rate (from 4.9mm/s to 6.4mm/s). Although it was designed to treat $5m^3$ /h, it produced a good water product at 6. $5m^3$ /h. The overflow rate of conventional purifiers is about 1.0-1.2mm/s. Thus the high efficiency of pellet-type purifiers was demonstrated.

The quality of finished water was excellent, Water turbidity prior to filtering was generally less than 5mg/l. Much less than the filter demand of 15mg/l. The postfilter water turbidity was less than 0.5mg/l, conforming to the Sanitary Standard for Drinking Water(3mg/l) of People's Republic of China.

During the experiments, the addition of PAC and/or PAM was consciously terminated. This resulted in sludge bulking and a rapid decrease in water quality in the pellet reactor.

Table 2 compares some economic and performance data between a pellet-type and conventional water purifiers. Although little experience in long term operations has been gained from the prototype, it's clear from Table 2 that the pellet-type water purifier can be more cost effective for treating surface waters with high variabl turbidity (from 46 mg/l to 2100 mg/l).

Summary and Conclusions

• Two types of surface water purifiers used in China were reviewed in this paper. Conventional purifiers have some disadvantages and limitations for treating surface water with high variable turbidity due to random flocs formation.

• A prototype purifier was evaluated and found that pellet flocculation appears to be an attractive means of removing surface water turbidity. It was found in the pilot-scale research that with a overflow rate of 6.4mm/s and initial turbidity range of 46 mg/l to 2100 mg/l turbidity of less than 5mg/l can be achieved. Both PAC and PAM must be introduced to the process water at the same time for optimum results. The process of pellet flocculation provide a promising approach to water treatment which is both simple and economical to contruct and operate. A full scale demonstration of this process is warranted.

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Table 1 performace data for turbidity removal

capa-city	dosage (mg/l)		tubular coagulater		pellet	reactor		filter		mean turbidity (mg/l)		
(m^3/h)	PAC	PAM	G (S)	T (S)	overflow rate(mm/s)	detention time(min)	mixer (rpm)	depth (mm)	velocity (m/h)	raw water	pre-filter	post-filter
5	14.1	0.8	360	15.2	4.9	10.0	4.8	500	10.0	46	2.2	<0.5
5	15.0	0.9	360	15.2	4.9	10.0	4.8	500	10.0	81	2.4	<0.5
5	16.3	0.9	360	15.2	4.9	10.0	4.8	500	10.0	112	2.1	<0.5
5	16.9	1.0	360	15.2	4.9	10.0	3.5	500	10.0	169	1.9	<0.5
5	16.9	1.01	360	15.2	4.9	10.0	5	500	10.0	248	1.5	<0.5
5	17.1	1.03	360	15.2	4.9	10.0	4.5	500	10.0	540	2.6	<0.5
5	17.0	1.04	360	15.2	4.9	10.0	4.5	500	10.0	1030	2.8	<0.5
5	17.3	1.03	360	15.2	4.9	10.0	4.5	500	10.0	1560	2.7	<0.5
5	17.5	1.04	360	15.2	4.9	10.0	4.5	500	10.0	2100	2.5	<0.5
6	16.8	0.91	464	13.9	5.9	11.9	4.5	500	11.9	455	2.7	<0.5
6	16.1	0.9	464	13.9	5.9	11.9	4.5	500	11.9	398	3.4	<0.5
6.5	17.4	1.0	526	11.8	6.4	12.9	4.5	500	12.9	370	3.5	<0.5
6.5	17.4	0.9	526	11.8	6.4	12.9	4.5	500	12.9	1210	4.8	<0.5
6.5	17.3	0.9	526	11.8	6.4	12.9	4.5	500	12.9	1345	5.3	<0.5

Table 2 comparision between a pellet-type and conventional water purifier

item / type	capacity (m^3/h)	process	range of turbidity(mg/l)	dosage(mg/l) PAC	dosage(mg/l) PAM	turbidity of finished watera(mg/l)	total detention time(min)	pressure of inlet (kg/cm)	size (diameter×height) (mm×mm)	weight (kg)	production cost or market price (yuan)
pellet	5	pellet flocculation, filter	2100–46	14.1–17.5	0.8–1.04	<0.5	<17	⩽0.3	1000×1500	500	about 6,000 (production cost)
CW	5	coagulation, sedimentation, filter	⩽500	20-30	-	⩽5	38	⩽0.5	1000×2600	1100	about 50,000–70,000 (market price)
KG-L	5		⩽500	20-30	-	<5	40		1200×1500×3200	3000	
FXY	5		⩽500	20-30	-	<4		0.6-1.0	1150×2950	1000	

CATCHMENT WATER TO PUBLIC HEALTH STANDARDS

Harvey E FINCH

On the Island of Hawaii. the largest of all the Hawaiian Islands water catchment is a way of life for over 25% of the population.

There are active volcanos on this Island and evidence of their activity is that the Island has grown by 60 hectors in my lifetime.

The result of this volcanic activity is that on recent lava flows the rainwater percolates into the ground, and is not available in streams or shallow aquifers that would allow for public water systems to be developed.

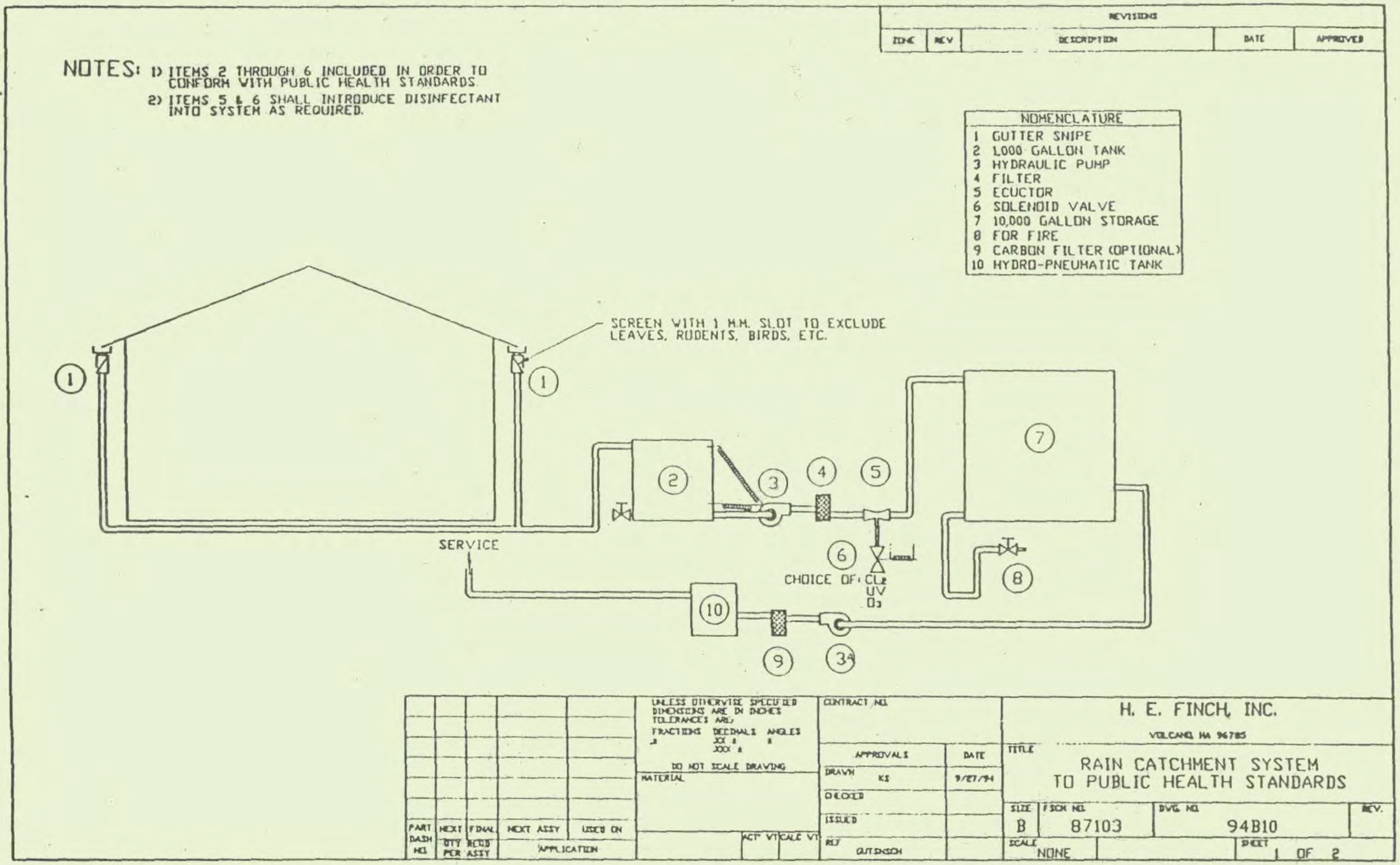
When I undertook to build my home on the Island of Hawaii in 1990, I decided to design a self cleaning screen for this catchment application. At the top of each downspout there is a self cleaning screen that excludes any material larger than 1 mm. The water system in service at my home has just these 1 mm screens in the line before the main 10,000 gal(37.8 m^3) storage tank. In all the tests that have been done, the coliform bacteria counts have been less than 1 (colonies/100 ml).

The current laws in Hawaii allow catchment systems to be used for individual homes but not for public facilities such as restaurants or hotels. I was asked to design a catchment water system that would conform to public Health Standards and the result is what is shown on Dwg 94B10.

The system includes:(1). the self cleaning, 1 mm screen at each downspout. (2). an interim 1,000 gal.(3.8 m^3) storage tank. Water will accumulate in this storage tank until the top sensor level is reached which will automatically turn on pump (3) and open solenoid (6). Pump (3) with a known flow rate will pump the water through filter (4) and educator (5) and administer a constant volume of disinfectant while the pump is on. If chlorine is the disinfectant selected, one would expect to administer 1 to 2 mg/ltr of chlorine to storage tank (7). Pump (3) and solenoid (6) will automatically turn off when the lower sensor level in tank (2) is reached.

The service pressure to the house is normally supplied by a hydro-pneumatic system including pump, filter and hydro-pneumatic tank. These could be eliminated since the system already is pumping the water from tank (2). If main storage tank (7) could be placed at a high enough elevation there could gravity fed service to the house.

An additional feature that would have to be included to meet Public Health Standards would be that all storage tanks must be designed to exclude contamination by insects or animals.


NOTES: 1) ITEMS 2 THROUGH 6 INCLUDED IN ORDER TO CONFORM WITH PUBLIC HEALTH STANDARDS.
2) ITEMS 5 & 6 SHALL INTRODUCE DISINFECTANT INTO SYSTEM AS REQUIRED.
REVISIONS
ZONE
REV
DESCRIPTION
DATE
APPROVED
NOMENCLATURE
1 GUTTER SNIPE
2 1,000 GALLON TANK
3 HYDRAULIC PUMP
4 FILTER
5 ECUCTOR
6 SOLENOID VALVE
7 10,000 GALLON STORAGE
8 FOR FIRE
9 CARBON FILTER (OPTIONAL)
10 HYDRO-PNEUMATIC TANK
SCREEN WITH 1 M.M. SLOT TO EXCLUDE LEAVES, RODENTS, BIRDS, ETC.
SERVICE
CHOICE OF: CL2 UV O3
H. E. FINCH, INC.
VOLCANO, HA 96785
TITLE
RAIN CATCHMENT SYSTEM TO PUBLIC HEALTH STANDARDS
SIZE B
FSCM NO. 87103
DWG NO. 94B10
REV.
SCALE NONE
SHEET 1 OF 2
APPROVALS
DATE
DRAWN KS 9/27/94
CHECKED
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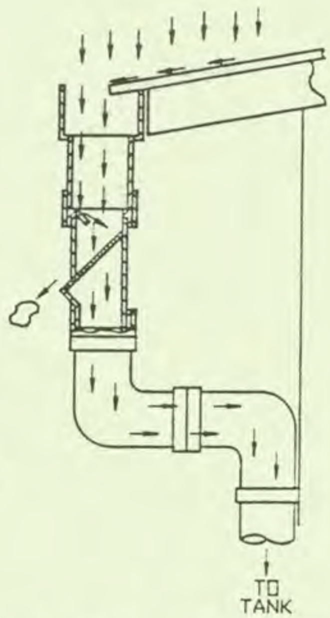
CONTRACT NO.
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
DO NOT SCALE DRAWING
MATERIAL
PART DASH NO.
NEXT QTY PER
FINAL REQD ASSY
NEXT ASSY
USED ON
APPLICATION

GUTTER SNIPE*

- KEEPS LEAVES, BUGS, DEAD BIRDS, AND OTHER DEBRIS OUT OF YOUR DRINKING WATER.
- DEBRIS IS REMOVED BEFORE IT BECOMES IMMERSED IN THE WATER SYSTEM AND DECOMPOSES.
- WATER TRAVELS DOWN THE ROOF AND ALONG THE GUTTER TO THE DOWNSPOUT WHERE THE GUTTER SNIPE IS INSTALLED. HERE THE WATER GOES THROUGH THE .040" SLOTS IN THE SCREEN, TO BE STORED, WHILE THE SOLID MATTER SLIDES DOWN THE SCREEN AND FALLS TO THE GROUND.
- THIS GUTTER SNIPE SYSTEM WAS INSTALLED AT THE INVENTOR'S HOME IN THE VOLCANO GOLF COURSE SUBDIVISION IN OCTOBER OF 1990, AND HAS BEEN OPERATING SINCE THEN BEYOND ORIGINAL DESIGN EXPECTATIONS.



CONTACT YOUR GUTTER CONTRACTOR FOR INFORMATION ON CONVERTING YOUR PRESENT CATCHMENT SYSTEM.

*PATENT APPLIED FOR

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Section 10

TECHNIQUES AND DESIGNING

THE FIELD TESTING OF A RAINWATER COLLECTOR

A Fewkes*

ABSTRACT

This paper describes some of the results from the preliminary field testing of a rainwater collector installed in a UK house. The rainwater collected from the system was used for WC flushing. The capacity of the collection or storage tank is critical in the design of such systems. Sizing models have been proposed by researchers but none of the models appear to have been verified or refined using field data.

The collected data was used to assess the sensitivity of a sizing model to the time interval of the rainfall and WC flushing time series. The analysis confirms sizing models should be based on a maximum time interval of one day. The refinement of models to utilize smaller time intervals such as an hour does not result in a significant increase in accuracy.

Rainfall losses from the catchment area were modelled. The inclusion of rainfall loss parameters into sizing models is required but a degree of latitude in their estimation is possible whilst preserving model accuracy.

INTRODUCTION

The general problem concerns the use of rainwater for WC flushing. In the United Kingdom 30% of the potable water supplied to the domestic sector is used for WC flushing and the transportation of foul waste. The use of rainwater for WC flushing is a simple and practical method of reducing the demand on both the public water supplies and waste treatment facilities. In the past there has been no financial incentive for UK consumers to conserve water because charges were not based upon the volume used. During the next decade the metering of domestic supplies is to be introduced and water conservation devices are likely to become financially viable.

The cost of the collector and its installation are related to its storage capacity because for a desired level of reliability this is the one parameter controlled by the designer. The paper outlines the results from the preliminary field testing of a collection system. The present work was undertaken to both identify and investigate the parameters relevant in the development of sizing models.

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RAINWATER COLLECTOR AND INSTRUMENTATION

A rainwater collector with a storage tank of 2032 litres was installed in a UK property and its performance monitored over a five month period. The system tested was supplied by Wilo Sampson Pumps Limited. The system was installed in a two storey house with a total pitched roof area of 85 m^2, surfaced with profiled, granular faced, concrete tiles. The property has two WC's, one on the first floor and the other on the ground floor. The occupancy of the house varied between three to five people.

The system monitored is available commercially and uses a pump and accumulator to distribute water to the WC (Figure l). Rainwater is collected from the house roof by gravity feed via a 100 mm diameter downpipe into a polythylene tank. A coarse filter fitted into the downpipe ensures debris such as leaves do not collect in the tank. An overflow is fitted to the storage tank which discharges into the household's surface water drain. Water is supplied under pressure from the accumulator. The system is pressurised by the pump which pumps water into the accumulator until the pressure switch deactivates the pump at a pressure of approximately 4 Bar.

When insufficient rainwater is available a float switch fitted near the bottom of the tank activates a magnetic valve which allows mains water to flow into the collector. To comply with the water by-laws the mains water is not connected directly to the tank but is fed via a funnel connected to the top of the collector.

A schematic diagram of the instrumentation system is included in Figure l. The water flow rate from the collector to the WC was measured using a positive displacement flow meter. The data logger recorded the total flow at intervals of a minute. The inflow of mains make-up water was monitored using the same method. The volume of rainwater inflow from the roof was determined by measuring the level of water in the collection tank at intervals of a minute using a pressure transducer. Water overflowing from the system was collected in a 250 litre spill tank. Discharge into the drain was via a 25 mm pipe fitted with a positive displacement flow meter. The data collected was used to determine the percentage of WC flushing water conserved each month.

At the test site a weather station was installed to monitor rainfall, windspeed and direction. The weather station data was used to quantify run-off losses due to wind effects and absorption by the collection area.

A detailed description of the instrumentation and justifications for the techniques adopted is reported elsewhere, Fewkes (1993).

RESULTS

Results for the first five months of a planned twelve month monitoring period are given in Table 1. The percentage of WC flushing water conserved each month ranges from 23% for August to 100% for September. Monthly rainfall data for the Nottingham area is given in Figure 2, which shows the fifty year maximums, minimums and averages along with the actual rainfall levels recorded at the test site. September, November and December received above average rainfall whilst August was drier than normal. October was an average month. The percentages of WC water conserved follow the monthly rainfall pattern.

WC flushing data is summarized in Table 2. The average daily WC flushing water demand varies between 163.5 to 192.5 litres/day which is equivalent to 18 to 21 flushes for the household. This represents 6 to 7 flushes per day per person based on an occupancy of

3 people. Domestic water usage in the UK has been researched by various workers, Thackray, Cocker and Archibald (1978) and more recently Butler (1993). Butlers survey estimated the average WC usage in a household was 3.7 flushes per day per person which is in good agreement with Thackrays figure of 3.3 flushes per day per person.

WC usage in the test house was higher than expected. The high usage rate may in part be attributable to the downstairs WC which usually required at least two flushes to clear the WC pan. The occupancy at the house also increased at weekends.

Rainfall loss during collection occurs due to absorption by the roofing material and wind effects around the roof. The rainfall loss was modelled using an initial depression storage loss (D) with a constant proportional loss (C_f) as suggested by Pratt and Parker (1987). The model is of the general form:

$$V_c = R \times A \times C_f - D \qquad (1)$$

where:

V_c = Volume of rainwater collected by roof (Litres)

R = Rainfall level (mm)

A = Plan area of pitched roof (m^2)

D = Depression storage loss (Litres)

C_f = Run off coefficient

It is worth noting that, D, can also be expressed in millimetres by dividing the depression loss by the collection area. Linear regression analysis was used to produce the rainfall loss parameters in Table 3. Pratt and Parker (1987) suggested undertaking the analysis for storm events with a peak 30 second intensity of less than and greater than 20 mm/hr; and with a rainfall duration less than and greater than 60 minutes to investigate any effects of storm characteristic upon rainfall loss. In this study sufficient data was not available for the analysis of events with a peak 30 second intensity greater than 20 mm/hr.

To assess the validity of the analysis the coefficient of correlation, r, between the straight line equation predicted by the linear regression and the data points was calculated. The values of r range between 0.990 and 0.998 (Table 3). A value of $r = 1$ represents a perfect fit and $r = 0$ implies no correlation. For the whole data set the value of C_f is 1 and the value of D, 0.04 mm. Pratt and Parker (1987) obtained a run off coefficient of 0.987 and a depression storage loss of 0.32 mm for a roof sub catchment of five bungalows. The run off coefficient for this study is comparable with Pratt & Parkers (1987) value but the depression storage value is low. This may be attributable to the fact that Pratt & Parkers (1987) subcatchment included a proportion of flat roofs which are more liable to surface storage.

The values for C_f and D may be high due to the configuration of the collection area. The main collection area is a pitched roof above a two storey structure abutted by a monopitched roof above a single storey structure. The vertical surface adjacent to the monopitched roof has a rendered surface coated with masonry paint providing a relatively impermeable surface. In certain weather conditions the vertical surface could contribute to the overall collection area. Schemenauer and Cereceda (1993) have reported the potential contribution vertical surfaces can make to rainwater collection depending upon rain droplet size distribution and wind velocity.

MODELLING SYSTEM PERFORMANCE

In the field of rainwater harvesting a number of models which predict system performance have been proposed, for example Jenkins et al (1978), Latham and Schiller (1987) and Fewkes and Frampton (1993). The models proposed have not been verified or refined using data collected from an operational system.

The data collected in this study was used to assess the desirable characteristics of a rainwater sizing model. A rainwater collection simulation (rcs) model was used in conjunction with sensitivity analyses. The algorithm for the model used a yield after spillage (YAS), Latham and Schiller (1987) or spill before consumption (SbC), Hegen (1993) operating rule.

The YAS operating rule is:

$$Y_i = \text{Min}\ (D_i, Q_{i-1}) \qquad (2)$$

$$Q_i = \text{Min}\ (Q_{i-1} + R_i, S) - Y_i \qquad (3)$$

where:

Y_i	=	Yield in ith period (Litres)
D_i	=	Demand in ith period (Litres)
Q_i	=	Water in storage at end of ith period (Litres)
R_i	=	Rainfall in ith period (Litres)
S	=	Storage tank capacity (Litres)

The sensitivity of the rcs model to the time interval of the rainfall and WC time series; and the magnitude of the run off coefficient was investigated.

Time interval sensitivity

Daily times series result in a more accurate simulation of system performance than either weekly or monthly time series, Hegen (1993) and Fewkes and Frampton (1993). A further refinement is the use of hourly time series as input to the rcs model. System performance using both daily and hourly time series is illustrated in Figures 3 and 4 respectively. In both cases the rainfall loss was modelled using an initial depression storage with constant proportional loss. The difference between the daily and hourly plots is small suggesting a minimum simulation interval of a day is satisfactory for the majority of applications.

The sensitivity of the rcs model to the WC flushing time series was investigated by running the daily rcs model with the average WC flushing demand for the five month test period. Figure 5 indicates the rcs model is not sensitive to the WC flushing demand pattern. When the daily WC time series is investigated, this observation is perhaps not unexpected as demand remains at a fairly consistent level from day to day. Butler (1993) in this survey of domestic water usage also observed that the variation of WC usage on different weekdays was low. The system investigated is adequately modelled using average demand data but this observation may not be universally applicable to other systems depending upon the nature of the demand time series.

Run off coefficient sensitivity

The sensitivity of the rcs model to rainfall losses is illustrated in Figure 6. The depression storage loss was set to zero and the sensitivity of the rcs model investigated using constant proportional losses or run off coefficients ranging from 0.6 to 1.0. The selection of a run off coefficient between 0.8 to 1.0 maintains the accuracy of the rcs model. A simplified approach to the modelling of rainfall losses appears valid.

The overall run off coefficient for the trial period was estimated using the relationship:

$$C_f = \frac{V_c}{R \times A} \qquad (4)$$

where C_f, V_c, R and A are as previously defined. The value of V_c was equated to the total volume of rainwater collected and R to the total rainfall level during the trial. Data for September was excluded due to a malfunctioning of the monitoring equipment during this month. The average run off coefficient using this simplified approach is 0.96.

DISCUSSION

The performance of a rainwater collection system has been monitored over a period of five months. The flows of both rainwater and mains make-up water into and out of the collector were measured and logged at time intervals of a minute. A weather station adjacent to the test site was used to monitor rainfall, windspeed and wind direction.

Sensitivity analysis was used to identify the essential characteristics of a rainwater sizing model. A rcs model using daily data can be used to accurately predict system performance, the use of hourly data is not necessary. The daily rcs model with a YAS or SbC operating rule can therefore be used as a basis against which other models can be evaluated and calibrated. The form of the WC demand time series does not have to be defined for accurate modelling, average usage data is satisfactory. However, this observation may not be universally applicable to all applications of rainwater collection systems. Demand patterns which exhibit significant daily variance will possibly require more precise modelling.

The preliminary results of this study indicate the incorporation of rainfall losses into a rcs model is necessary but the accuracy of their prediction is not critical. The rainfall loss parameters for the roof were modelled using an initial depression storage with constant proportional loss model. A simplified model using only a constant proportional loss or run off coefficient was demonstrated to produce acceptable results.

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MONTH	WC DEMAND (LIT.)	RAIN-FALL (mm)	MAINS WATER MAKE-UP (LIT.)	OVER-FLOW (LIT.)	RAIN COLL. (LIT.)	PERC. WC WATER CONSERVED (%)
August	5650	26.8	4372	0	1806	22.6
September	4949	110.2	0	2010*	7247	100.0
October	5071	49.8	1537	673	3897	69.7
November	5134	75.4	975	2746	6404	81.0
December	5970	94.8	502	1903	8084	91.6

Table 1 Percentage of WC flushing water conserved each month

MONTH	MONTHLY WC DEMAND (LIT.)	DAILY AVERAGE WC DEMAND (LIT.)	WC USES/ DAY	WC USES/ PERSON/ DAY
August	5650	182.25	20.25	6.75
September	4949	165.00	18.33	6.11
October	5071	163.50	18.17	6.06
November	5134	171.00	19.00	6.33
December	5970	192.50	21.38	7.12

Table 2 WC demand data

DATA SET	No. IN SET	R	DEPRESSION STORAGE (D) (mm)	RUN-OFF COEFF. (Cf) (%)
Full set	54	0.998	0.04	1.00
Duration ≤ 60 min	20	0.990	0.17	1.00
Duration ≥ 60 min	34	0.998	0	1.00

Table 3 Linear Regression for rain loss parameters

* Overflow malfunction during this month

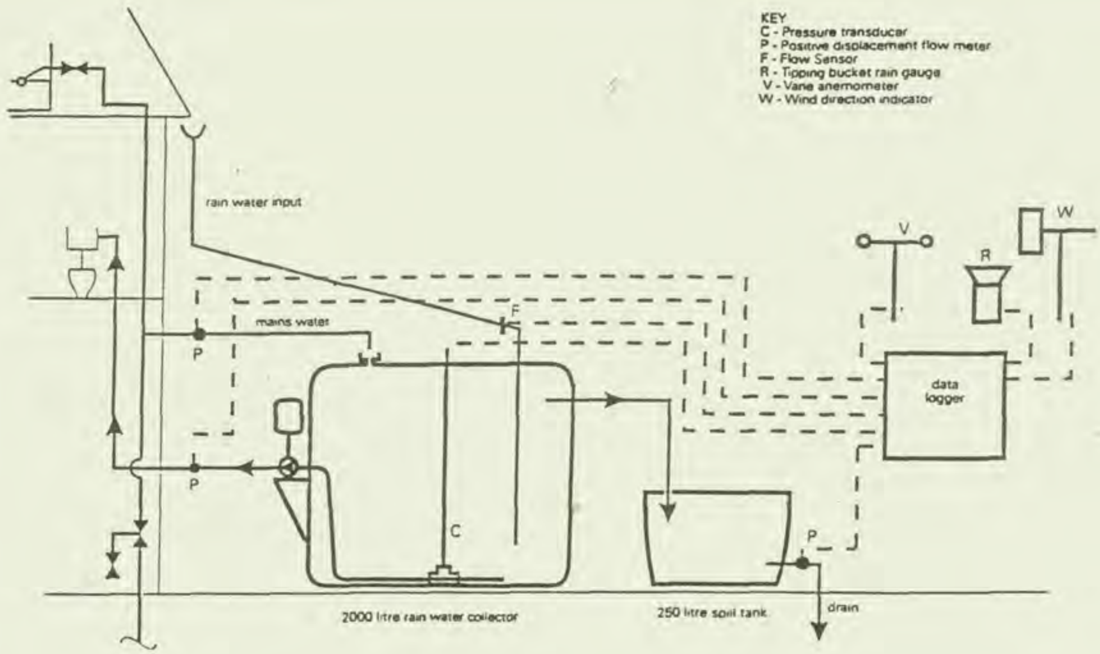

Figure 1 Rainwater collector and instrumentation

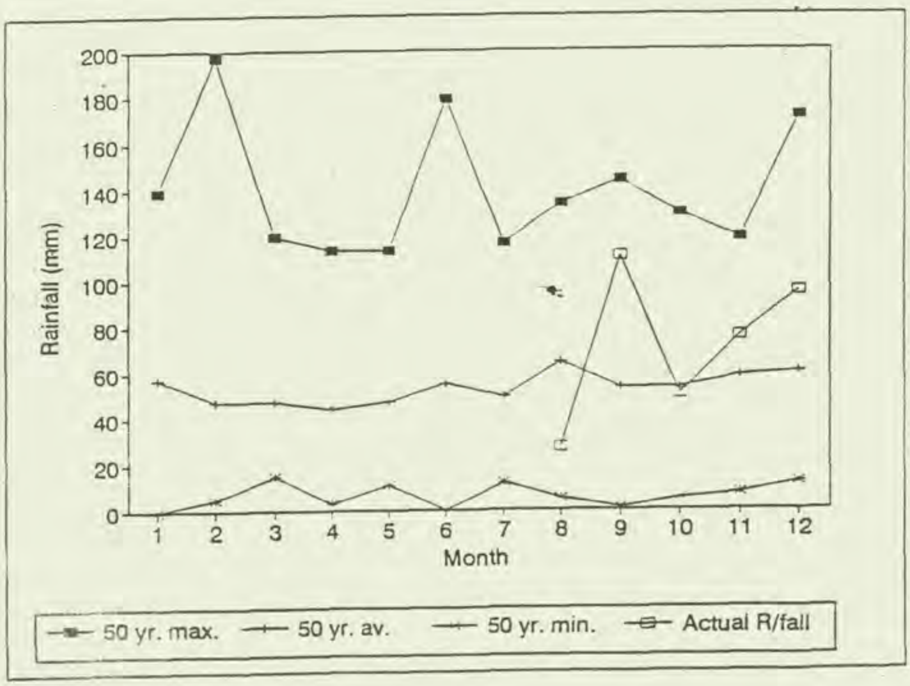

Figure 2 Monthly rainfall data for the Nottingham area

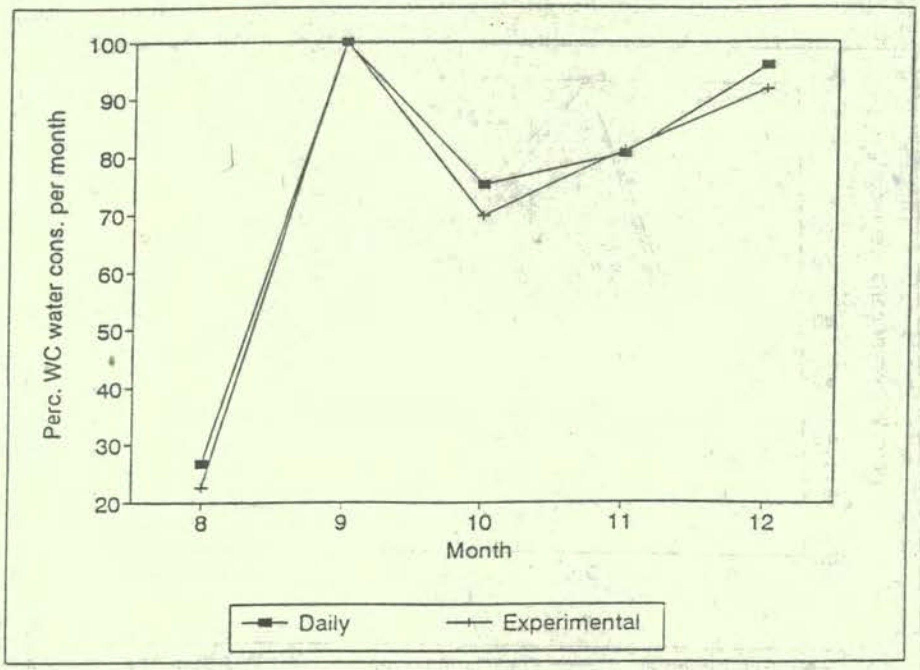

Figure 3 RCS model sensitivity to daily time series ($C_f = 1$; $D = 0.04$)

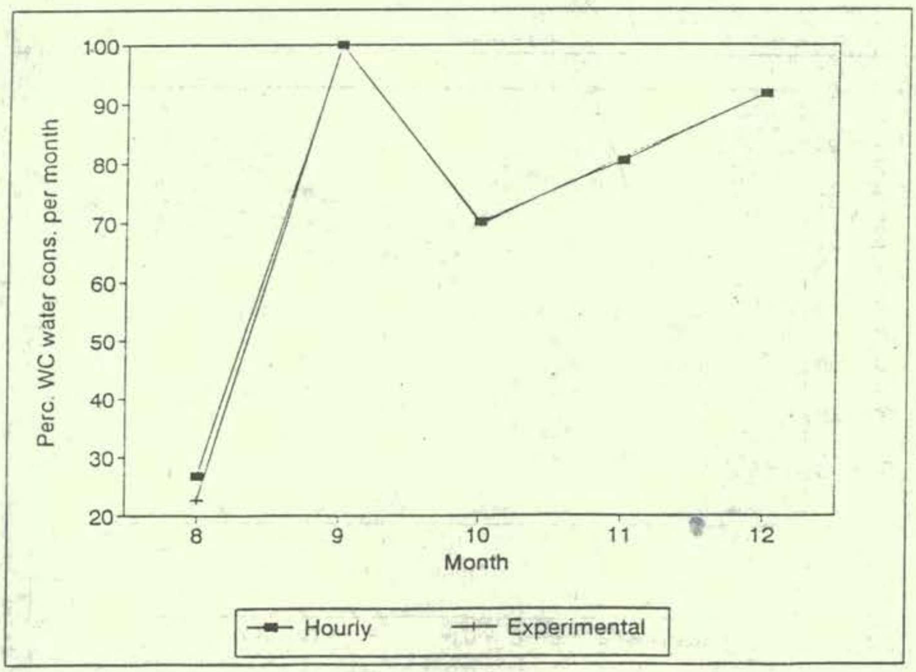

Figure 4 RCS model sensitivity to hourly time series ($C_f = 1$; $D = 0.04$)

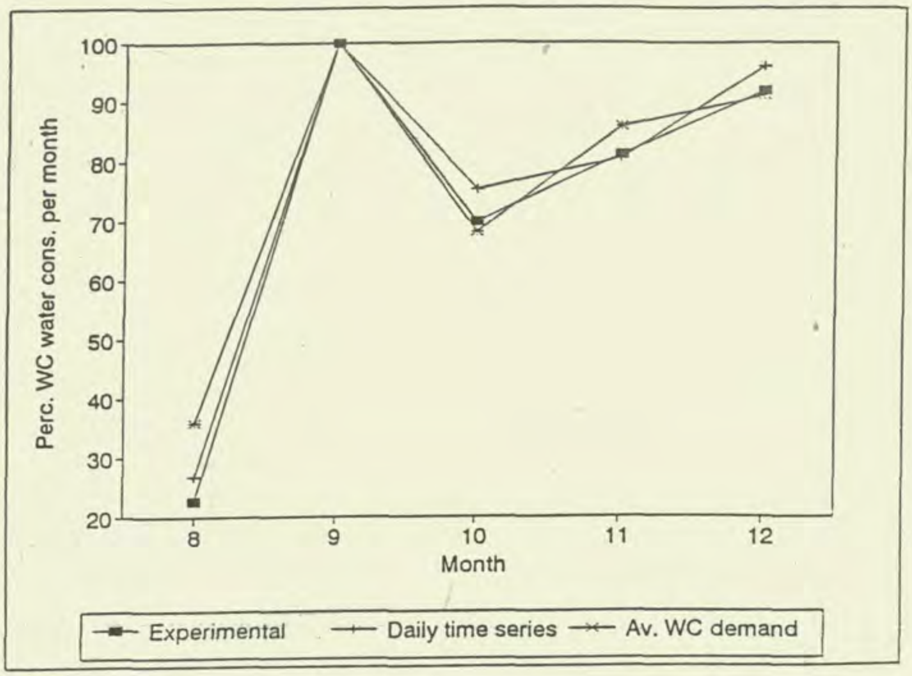

Figure 5 RCS model sensitivity to WC time series

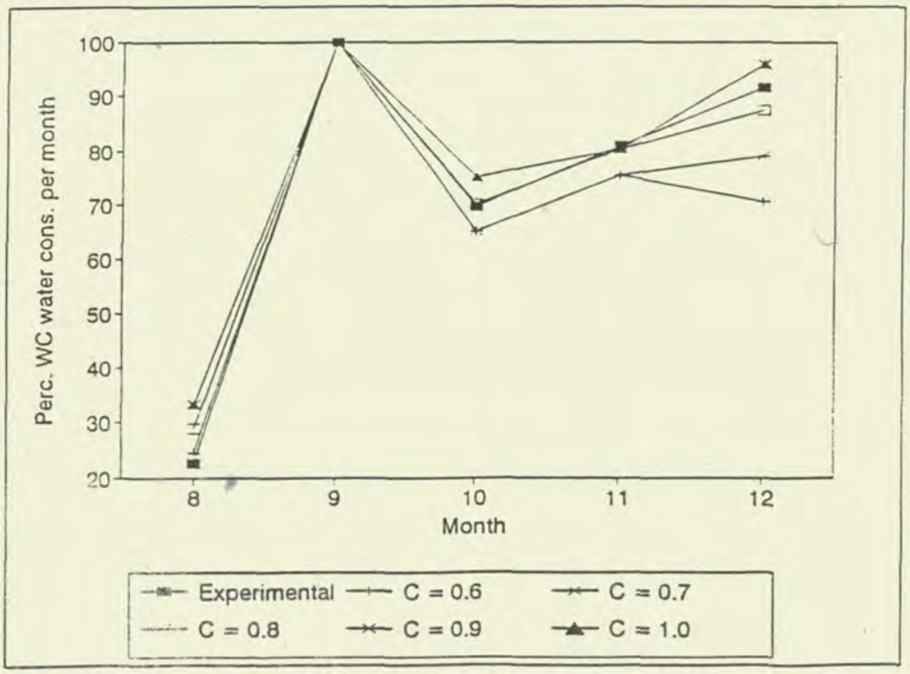

Figure 6 RCS model sensitivity to run off coefficient

Study on the Roof Water Collection Project Improvement Measurement

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Summery:Putuo district Hulu township of Zhoushan where is short of water applied roof water collection project.Drinking water resource has been solved for the inhabitants.Water quality is obviously raised through project improvement.Economic effect is significantly turned out.

key words:roof water collection sanitory measurement

Zhoushan islands is an area lack of fresh water in our country along the coast.Fresh water shortage and poor water guality are extensive existed in many islands and islets.In order to improve fresh water supply sutuation for the inhabitants,we had made a basic investigation of the roof water collection projects applied in Hulu township during 1989-1991,and projects sanitory improvement、water supply quality monitoring and economic effect evaluation as well.

1. Object and method

1.1 Object

1.1.1 Built project: There are 490 household built projects in the whole township.There are 2 forms of water collection roof.That is:gable roof and flat roof,amount to 85.5% and 14.5% respectively.There are 3 forms of water tank:underground (whole body of water tank is underground) amount to 77.4%, on the surface (whole water tank on the ground)amount to 14.0%,and semiunderground (half body of water tank is underground) amount to 8.6%. Average service time of projects is 4.1 years (from one to ten years).

1.1.2 Project improvement:20 projects,with gable roof and underground water tank,which have similar situation such as service population number and tiving standard,are selected at random.There projects are carried out sanitory improvement on construction.

1.2 On-site background

1.2.1 Hydro-geographical outline

Hulu township is located in Zhoushan islands,Hulu island called called Hulu town.ocean maritime climate,enough sunlight,great evapration, annual evaporation amount is 1199.1 ~ 1633.5mm.Annual rainfall of abundant water year can reach 1633.5mm,the annual rainfall of least water year is only 625.5mm, average amount 1100.4mm.There is a great differnce between abundant and poor rainfall year.Fresh water resource is quite short.

1.2.2 Project hygiene and the way of use

Thanks to deficient fresh water resource,inhabitants construct roof water collection project,which is constructed by grey clay tile,to collect rain acting as main drinking water source.Water tank is made of reinforced concrete or brick structure;doenward water pipe adopt reprocessed plastics square pipe, black rubber pipe, tinplate pipe and polyethylene (polypropylene) pipe.

Rain water come into water tank without any dispose,direct use.Most consumers take water with bucket,except very few consumers use minipump or hand pump.

1.3 Water quality examination parameters:

Water quality examination parameters are refered tonational drinking water sanitory standard GB5749 - 85 (except anion detergent,carbon tetrachloride,bezo (α) pyrene,666,DDT,silver) and water temperature, amonia nitrogen,nitrite nitrogen,potassium,sodium,calcium and magnesium.

1.4 Water sampling and examination method

Water sampling,transormation,preserve and examination are carried out in the light of national drinking water standard GB5750-85.

1.5 Project sanitory improvenment

The key water quality problem of roof water collection is bacteriological paraineter.Raising qualification percent of bacteriologcial parameter is hint in the study.Technical improvement measurement has set up "first block,secand seal,third disinfection". "First block" means that rough filter is added at the inlet of water tank to block sand,dust,leave and bird excreta during rain fall and run off process.Pecreasing water pollution of water tank as possible. "Second seal" means to streghen raw water resource sanitory protection at ordinary times.Cover is added at the water tank enterance.Plastic water pipe or tinplate pipe which meets with the demand of hygiene take place of original downward water pipe,minipump substituts bucket.Simple filter → water tank → minipump→ pipe → high land water tank (chlorination)→water tap to form family's supply system (see Fig.1)

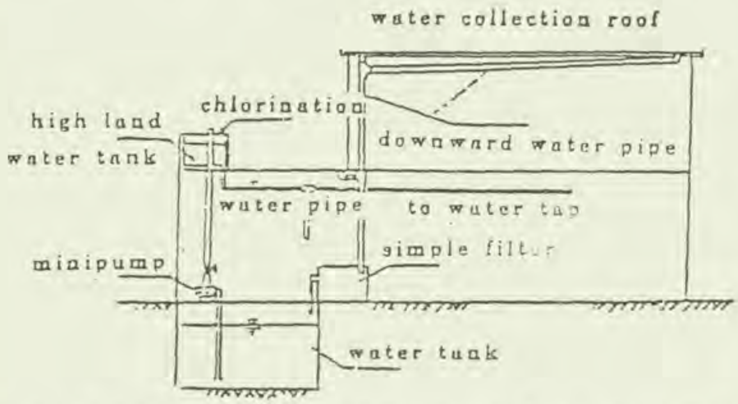

Fig 1.Diagram of roof water collection in Hulu Island

2.Results and discussion:

2.1 Water quality disinfeetion periodic depends on the chlorine residue.Chlorine residue disappearing speed is related to organic matter concentration and water temperature as well.Retention time of chlorine residue at various water temperatures is observed.If 30 minites after putting disinfectant,chlorine residue in drinking water is stable at 1.8 mg/L.Chlorine residue in water can last 48 hours at minimum effective level(0.05mg/L) when water teperature is 25-30℃degree (see Fig. 2). Chlorine residue can last 216 hours (9 days) when water teperature is 15-20℃ and 360 hours (15 days) when water temperature at 0-5℃.

The results imply,one time disinfection can insure one week safe use in spring and autumn and 2 weeks in winter,but only 2-3 days in summer.Therefore,disfection periodic should be arrarged according to various season.

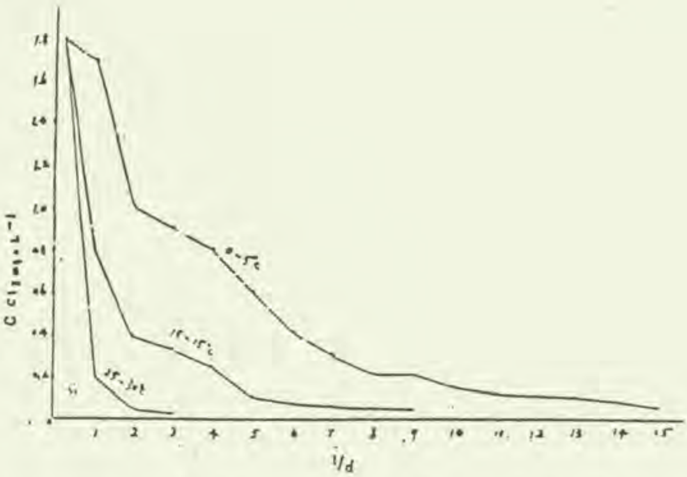

Fig 2.Retention time of chlorine residue at various water temp.

2.2 Water quality before and after project improvement

Roof water collection projects after improvement are act as research group (research group in brief).With similar situation,projects which are have not been improved act as control group.Water quality results of the two groups are shown on the following passages respectively.

2.2.1 Sense properties and general chemical parameters

Quilification percentage of colour,turbidity,semell and taste,iron, manganese,copper and zine content is 100%.There is no difference between research groups and control group.

Roof collecting water quality tends to alkline generally.95% of research group water samples PH is more than or equal to 8.5,but 80% of control group. The difference between two groups is not significant ($P>0.05$).Only 25% of control group water samples PH are more or equal to 9.0,but 84.21% of research group water samples.Large quantity of alkline material in the new built high land water tank and simple filter of research group can be solved into water,resulting in PH rising. Water tank constructures of control group have been used for a long time, the alkline extent of water quality are much lower.PH will decrease gradually as the using time increases. PH is stipulated 6.5~8.5 in national drinking water sanitory standard. However, PH range 6.5~9.5 is not hardful to health and drinking application[2].

2.2.2 Macroelements

The study has selected 4 high content elements calcium,magnesium, sodium and potasium,which are more closely related to human body.These elements are not stipulated in our national drinking water sanitory standard.In the mineral water development,these 4 elements are imperatively detected.The concentration of pottasium,sodium,calcium, magnasium is generally from several milligram to tens milligrams per litre.The roof collection water quality monitoring results have not shown too high ot too low concentration.

2.2.3 Radioactivity parameters

As the development of nuclear energy and new isotopic technology application,environmental pollution of radioactivity material may be nappened.

Rain water,especially,is directly affected by the atmosphere during falling process.The total α radioactivity is 0.019~0.056 Bq/L,total β radioactivity is 0.128~0.157 Bq/L.All samples are met with the clemand of radioactivity sanitory standard.

2.2.4 Bacteriology and some contamination parameters

Bacteriological parameters are most sensitive parameters in drinking water quality.Qualification percentage of bacteria and E.coli.of research group is 100%.Chlorine residue qualification percent is 83.33%. Bacteria qualification percent of control group is 15.0%.Total E.coli. is 40% (see Table 1).The difference between two groups is extremely significant.

Nitrite nitrogen is used to one contamination parameter.There is not stipulation in drinking water sanitory standard.Refered to national natural drinking mineral water sanitory standard GB8537-87,nitrite nitrogen (No^{2}- amount) is lower than 0.005 mg/L[1].20% samples of control group excess the limit.

Table 1. Qualification percent of water quality bacteria and some pollutant parameters

parameters	research group			control group			P
	sample number	range	qualification percent (%)	sample number	range	qualification percent (%)	
Bacteriae	19	<1-25	100	20	24-1320	15.0	<0.01
Total E.coli.	19	<3	100	20	<3-52	40.0	<0.01
Cl- (mg/L)	18	<0.05-1.5	83.3	20	未加氯	..	<0.01
NH_a-N* (mg/L)	19	<0.02-0.08	100	20	<0.02-0.04	100	
No_s-N (mg/L)	19	0.27-11.47	100	20	<0.29-4.63	100	
No_2-N* (mg/L)	19	<0.001-0.0014	100	20	<0.001-0.08	63.16	<0.01
CoD* (mg/L)	19	0.01-1.76	100	20	1.06-2.33	100	

* Consult standard:NH3-N 0.05mg/L; No3-N 0.002mg/L; CoD 3mg/L.

2.3 Project effect analysis

Project effect analysis is used to make comparison on construction investment and operation fee of several designs to judge economic effect and social effect of these projects.

2.3.1 Water supply project construction cost per ton

Family-small-size drinking water supply project in Hulu town is designed to 73 ton annual water supply.Project investment at one time is 2406.50 Renminbi (RMB). Construction cost is 32.95 RMB per ton. Centralized water supply project is built at neighbour town.Annual water supply is 73000 ton.Project investment is 1,683,900 RMB (connected with 100,000 ton water reservoir).Construction cost per ton water is 23.67 RMB (Table 2).Its construction cost is lower than family water supply project.

Table 2. Project construction cost per ton

project name	total construction cost (RMB)	annual water supply capacity (ton)	construction cost of per ton water
family water supply project of Hulu town	2,400	73	32.95
centralized water supply project of Xiashi town	1,683,900	73000	23.67

2.3.2 Annual operation fee

Annual opration fee includes manual fee of operation and maintainance of water supply project.Water quality purification and disinfectant cost and electric fee (see Table 3).Operation cost of family water supply project in Hulu is lower in the two kinds of water supply projects.

Table 3. Annual water operation cost

project name	total cost of annual operation (RMB)	practical water supply amount (ton)	cost of per ton water (RMB/T)
family water supply project of Hulu town	22.74	73	0.31
centralized water supply project of Xiashi town	195800	60000	3.26

3. Conclusion

The qualification percent of water quality paramerers E.coli and bacteria is raised up to 100% after project improvement.Chlorine residue qualification percent is raised to 83.3%.The effect is significant.One time investment is high.However annual operation cost is lower. The ratio of cost and effect is 1:2.5, all investment can be reimbursed in 4.7 years.

Reference

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2.explanation of GB5749-85. 《Drinking water sanitory standard》
3."IRC" 《Small size water supply system engineering for developing countries》

Experimental Researches on Utilizing Rainfall to Resupply Underground Water at Yanzhou county, Shandong Province

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1. Introduction

In the center of Jining municipality, Shandong province, there is an area called Wensi alluvial plain. It faces Taiyi Mountains in the east, and South Four Lake in the west. Its elevations are between 35 m to 38 m. Its total area amounts to 2848 km^2 and its annual average precipitation is 691.4 mm. Shallow underground water in this area lies hidden in the Quaternary Period. The maximum of its bottom hidden depth is approximately 50 m. The water-contained layer is of medium and big sand and cranky sub-clay. The spurting volume of water is 34.7-52.6 m^3 per meter per hour. In the end of 1960's, with the great development of irrigation through motor-pumped wells, agriculture had achieved significant progress, and this area had earned the honor of Grain Storeroom of south west Shandong. In the 1970's the establishment of motor-pumped wells developed even more rapidly, especially at Yanzhou county, located in the center of Wensi alluvial plain. In Yanzhou county, there were 6540 motor-pumped wells, and the area of effective irrigation reached up to 620 thousand Mu. But after 1975, due to the increase of agriculture consuming water and the less precipitation, the exploitation of underground water began to surpass its natural supplement gradually, which resulted in the reduce of underground level in a great scale. In 1975, the average hidden depth of underground water at the whole county was 3.07 m, but it reduced to 5.13 m in 1978, and 8.95 m in 1983. The funnel area in this county, in which the hidden depth of underground water is more than 6 meters, reached up to 460 km^2, and accounted for 72% of the county's total area. The pumping pipes had to be lowered again and again; the effectiveness of pumping equipment was reduced, the cost of agricultural practice began to rise, and the agricultural output hesitated to press forward. So Yanzhou county had not only lost its formal advantages ahead in the province, but also brought some disadvantageous ecological impacts.

2. The Local Advantageous Conditions to Utilize Rainfall to Resupply Underground Water Artificially

The general plan of utilizing rainfall to resupply underground water was firstly put forward in 1979. According to field investigation and analytic calculation, there are four local advantageous conditions in this area to implement the plan of utilizing rainfall to resupply underground water:

(1). There are good hydrological conditions and abundant potential water and shallow bearing water.

Among the water-contained sand layers between underground 3 m to 45 m, the total thickness of water-contained layer is 7 to 15 m. The majority of the water-contained layers are of medium and big sand, its actually measured permeating index in water-contained layers is K=135.8 m/24 hours. Sand layers emerge up in the northeast, which can be taken as a natural chancel to resupply underground water.

(2). In Yanzhou County, two rivers, Sihe River and Guangfuhe River, crosses its territory from north to south, the runoffs in the whole county produced by rain flow together to the two rivers. The actually measured annual runoff volume was 0.362 billion m^3, which would provide abundant water source.

(3). There are 10 tributaries and a completed canal network.

The canal network had been formed in 1970's while widely establishing field water conservancy facilities. 200 Mu land was planned as a basic unit with a full set of ditches, roads, canals and high standard green land belts with parks and woods. All those tributaries and the canal network can be used directly as water storing and resupplying project.

(4). There is a experimental field on underground water balance in Yanzhou county. Its experimental area is 6.38 km^2. Plenty of experimental results would provide scientific basis for resupplying underground water.

3. The General Distribution of Resupplying Projects of Underground Water in Yanzhou County

Firstly, a controlling water gate was built at Hejiantun on Guangfu river in 1987, and the volume of 15.14 million m^3 water was stored. In 1978, the underground water level in the area along the two sides of the river within 1 km, had risen back by 2 meters, so the primary progress had already achieved. In 1979, the primary plan and working plan of resupplying projects of underground water in Yanzhou county had been made up, the distribution of those projects was presented by Fig.1. Its planned yearly water-drawn volume was 0.135 billion m^3, the planned maximum of flowing speed was 18 m^3/second, the planned resupplying area was 480 km^2, which included 9 communes and towns or 306 villages, covered 497 thousands Mu cultivated land. In 1983, the key controlling gate of Longwang Dian had been established and begun to put into use. Up to 1986, the total length of canals was 199.2 km, and 85 bridges, culverts, water gates and reverse siphons had been built. The total investment amounted to 6.22 million Yuan. Those completion of the canal system in resupplying area was described by Table 1.

4. Various Ecological and Environmental Profits Resulted From Resupplying Projects of Underground Water

Projects of utilizing rainfall to resupply underground water commenced on experiments in 1979 and completed its full planned investment in 1986, and 300 thousands Mu cultivated land had got profits from those projects. As the rainfall in 1986 was 155.1 mm, and in 1987, it was 542.4 mm, crop drought was very serious, and the exploitation of underground water had to increase greatly. Due to the establishment and operation of those supplying projects of underground water in time, the amounts of underground water artificially resupplied took up 52.9% and 56% of the total exploitation of underground water in 1986 and 1987 respectively. See Table 2.

From their beginning in 1983 to their full completion in 1987, those projects had stored 31.187 million m^3 of water, and the yearly amount of resupplying underground water on average was 4.088 million m^3. Compared that in 1987 with that in January, 1987, the hidden depth of underground water in resupply area had risen back 1.95 meters on average, that along those main and tributary canals had usually risen back 3 meters. In these surrounding natural supplying area without artificially resupplying, as rain and water could not be fully utilized, though the rainfall was the same, the hidden depth of underground water continued to deepen because the formed runoffs disappeared quickly and underground water could not get significant supplement. Compared that in 1987 with that in January, 1987, the underground water level had fallen down 0.6 m on average. The difference between the two was 2.01 m, See Table 3.

As rain and water are used to resupply underground water, underground water level has begun to rise back steadily, which has brought a lot of good ecological and environment profits.

Table 1. The Completion of Canal System in Resupplying Area

Name of canals	Number	Planned length (Thousand Meters)	Completed Length (Thousand Meter)	Planned Flow Speed (m^3/second)
General Main canal	1	4.15	4.15	15
First main canal	1	11.05	12.55	2.5
Second main canal	1	11.4	17.8	2.5
Third Main Canal	1	19.95	22.15	9.4
Southern Main Canal	1	5.7		3
Sub-canal	14	124.55	104.25	
Tributary Canal	196	723.1	38.3	
Total	251	919.9	199.2	

Table 2. Calculation Table on Underground Water Adjustment in Resupplying Area

Year	Yearly Rainfall	Total Supplement				Consumption		Balance between Exploitation and supplement	Artificial Supplement to exploitation (%)
		Rain Permeation	Neighboring Supply	Artificial Resupply	Total	Exploitation	Vaporization		
1984	810.7	315.8	39.8	143.1	498.7	243.7	2	253.0	58.7
1985	839.2	242.2	19.2	150.3	411.7	315.0	58	38.7	47.7
1986	455.1	136.6	27.9	236.4	400.9	947.2	29.4	-75 .7	52.9
1987	542.4	131.4	25.1	255.3	411.8	456.0	28	-72.2	56
Total		826.0	112.0	785.1	1723.1	1461.9	117.4	143.8	53.7

Table 3. Statistical Table of Hidden Depth of Underground Water in Different areas, 1976-January 1st, 1987

Year	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Plain Area	2.84	3.82	4.31	3.91	4.08	3.99	5.66	6.17	6.99	4.93	3.85	5.62
Resupplying Area	2.83	4.79	4.84	4.46	4.66	4.28	6.84	6.25	7.44	3.69	3.02	4.30
Natural Supplying Area	5.17	7.14	8.65	9.78	10.09	10.10	10.74	11.27	11.78	10.83	11.08	11.87

4.1 Improving Hydro-Environment Conditions

After the implementation of resupplying underground water, the underground water level in resupplying region began to rise back gradually, whereas that in surrounding regions of natural supplying continued to fall down. In 1987, the area in resupplying region, whose hidden depth of underground water is more than 6 meters, had decreased from 72% in 1983 to 34%. After the beginning of resupplying, the proportion of the resupplyment to the exploitation of underground water has increased obviously. In 1984, its rainfall was 810.7 mm, and the proportion of artificial resupplyment to exploitation was 58.7%. It was a continuous drought year in 1987, its rainfall was 542.4 mm, artificial resupplyment took up 56% of the exploitation. From the above examples, it is clear that, no matter it is in a normal year or in a drought year, artificial resupplying underground water has obvious effects on upholding underground water level, increasing underground water storage, meeting the requirement of exploiting underground water and improving local hydro-environment conditions.

4.2 Improving Agricultural Ecological Conditions

After the operation of resupplying projects of underground water, 300 Mu cultivated land have got profits from them. As the whole county area can plant wheat on time, the initiative and flexibility for adjusting agricultural structure have been increased, and vegetable plantation area with high water-consuming is enlarging year by year. The alternate period of crop's irrigation has been shortened 3 to 5 days. and agricultural yield per unit area has been raised by 145 kg. For peasants' labor intensity has also been alleviated, they have more energy to engage.

in township enterprises and the third industry, and their living standard has been improved fatly. The water output volume per well in resupplying region usually increases by 12 m^3 per hour, Compared with that before resupplying, 172.6 thousand yuan of pumping cost was saved in the whole irrigation area in 1984, and 656.7 thousand yuan was saved in 1987. Before resupplying as the underground water level had fallen down, the area with more than 10 m hidden depth accounted for 12.7%, there were 3209 motor-pumped wells which were not able to draw water. After resupplying, from 1984 to 1987, 2812 thousand yuan of digging cost and equipment renewal cost was saved, peasants had attained great material profits, and those agricultural irrigation facilities in resupplying area had turned to good running conditions of high effectiveness and low consumption again.

4.3 Creating Conditions for Establishing New Industrial and Mineral Enterprise and Industrial Water

Before resupplying due to the continuous reduce of underground water level, 70% of local ancestral and ship enterprise could not be supplied enough water and their production was affected with different degree. After 1983. with the increase of underground water storage, and the development of agricultural water-saving projects in well-irrigation area, of agricultural water-saving projects in well-irrigation area, in addition to rational planning and utilization of Longwang Dian key projects of drawing Si river back to irrigation area, the balance of water supply and consumption has been improved greatly. When central Government considered to choose the site for building a large compound fertilizer factory and capital steel Factory tended to establish a lager steel factory and a 1000-ton penicillin factory there etc., good condition of water supply had played an important role on striving this area to be the location of those projects.

4.4 Improving the Bio-ecological Environment of Resupplying Area

Before water-storing in resupply area, as the rain fall in 1981 was only 427.9 mm, and even worse, this area confronted spring drought in the spring of 1982, some poplar planted for the purpose of separating fields with woods network, began to have the phenomena on of new leaves falling in its growth period. After resupplying, not only can't this phenomenon of new leaves falling in its growth period because of drought be found, but also trees in resupplying area grow fast. Local poplar trees after resupplying are 1--2 cm bigger in diameter than those with the same age in surrounding natural supplying area. Furthermore, the trees sprout earlier and fall leaves later, and there are few sick insects and high survival rate of sapling. the profits of woods has been uphold. As grass beside or along canals in resupplying area grow well, they have a good effect in protecting slope land. Because of resupplying, the area of water bodies has also increased respondingly, the area of fish culture water was enlarged from formerly less than 500 Mu to 1300 mu, the yearly production of fishy has increased 2100 thousand Yuan.

4.5 Forming the Concept of Underground reservoir and Reducing Reverse Profits

The implementation of resupplying underground water in Yanzhou county, is actually equal to building a large reservoir with the profitable storage capacity of more than 4.0 million m^3 and the general storage capacity of 0.1 billion m^3 by utilizing rain and water. This kind of underground reservoir has not only saved investments at large degree, but also do not have inundated loses, need not immigrate and explode mountains for stones, and establish expansive dams, sub-diversion canals and security projects. Furthermore, its vaporization is also small, and it is advantageous to maintain local people's life and production and protect soil and water.

5. The Characteristics of Planning for Utilizing Rainfall to resupply underground water

(1). Normally built irrigation facilities are requested to store the maximum volume of water, to leak no or the least, and those requirements are used to appraise the qualities of those facilities, so various anti-permeation measures are always adapted, such as using thick liquid to glue stone, concreting the bottom and faces etc., where as building resupplying underground water projects, it is required to increase permeation. Therefore canals in reapplying area not only do not need bricks and concrete, but also those regions with big permeation index should be chose to open new canals. Then the flow of permeation would be enlarged, and more ground water would be transmitted into underground water as soon as possible.

(2). In well irrigation area or well-canal irrigation area, normal water conservancy facilities draw water into canals only in irrigation seasons, while resupplying projects would draw water into canals even in non-irrigation seasons to increase permeating time and resupply more underground water.

(3). It is usually not suitable to store water in plain rivers and drainage canals at rain and flood period, but in those well irrigation areas which need resupply underground water, particularly in water shortage areas of North China, the excessive water in flood period would always be utilized and part of flood runoffs are dammed and stored at the end of flood peril, which meet and base on those area's characteristic of drought in spring and water logging in summer and re-drought in autumn.

(4). Resupplying underground water requests some specific conditions

Reapplying underground water co-exists together with the process of exploiting underground water, but this measure is not suitable to every region. Only when the exploitation of underground water surpass obviously the natural supplement or the exploitation will increase greatly and the balance between exploitation and supplement will be broken, it is the time to consider resupply underground water artificially. Furthermore, besides the real need of resupplying underground water, those areas must have suitable hydro-geological conditions required by resupplying and permeation, water source and underground storage condition.

It is also necessary to keep close observations while resupplying to ensure that the underground water level is not too high to affect the normal growth of crops.

6. The Implementation of Resupplying Projects Need Strengthen Operation Management, Emphasis Scientific Research and Have Legal Consideration.

Although the measure of artificially resupplying underground water by utilizing rain have been implemented for some years, it is still a new thing and need be improved continuously through practice. Therefore, it is necessary to establish a strong management institute and various management measures, to strengthen its technical gaudiness and carry out observations on issues like exploitation, underground water level, rainfall, surface runoff, infiltration, water-require by crops. The accuracy of original data should be carefully watched. All observation data should be calculated and analyzed on time, and should be compiled to books for storage. In order to achieve the goal of effective management, the legal system for protecting water conservancy facilities should be set up and strengthened so as to manage water by laws. Artificially resupplying underground water is a kind of water conservancy project of strategic significance, which utilizes natural rainfall scientifically, and use water resource comprehensively, and has obvious ecological profits, economic profits and social profit. This work has already begun, and is also processing healthily. With further progress of this work, it is sure that numerous water conservancy workers will accumulate more valuable experience.

Use of Porous Pavements for Water Storage

by

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ABSTRACT

The problems facing the U.K. water environment are outlined and the reasons for the need to consider local water storage and re-use are presented. Present water usage in the U.K. and the potential for reducing demand for water from the piped supply are given for a range of housing densities. The reduction of waste volumes necessitates the construction of storage to allow for water re-use in toilets or outside purposes. It is proposed that the storage be installed below driveways and footpaths; and a possible new layout for the drainage on a housing estate is given. To have widespread effect, the strategy of providing local storage and re-use needs installation costs to be limited through construction cost saving on present sewerage requirements.

INTRODUCTION

The last twenty years have seen many important developments in urban drainage in the U.K., in terms of the technologies; methods of analysis and design; and the institutional organisations of the water industry. There has been a significant shift from interest in water quantity issues, such as flood defence and water supply, towards a more balanced concern for both quantity and quality aspects within the water environment. This change has highlighted the intimate and inseparable link which must exist between water supply, use and disposal together with the environmental impacts of such actions. The supply of water, which results in the periodic disappearance of local streams and rivers because of over-abstraction of groundwater; or the disposal of wastewaters and surface waters, which leaves the householder free from health hazards and from flooding only to pollute and adversely modify receiving watercourses, should no longer be tolerated.

There are many complex, inter-related issues in the water environment in the U.K. and the problems are made no easier to solve by the involvement of many and varied organisations in the field. Some of the present concerns include that:

a) the demand for water is rising, outstripping available resources in some parts of the U.K.,

b) the available resources are not located in the areas of major demand or of expected growth in population and usage;
c) over-abstraction has resulted in unacceptably low flow regimes in several rivers;
d) despite increased capital investment in water reclamation works, there has been little improvement in receiving water quality;
e) continuing urban and highway developments have increased surface water runoff volumes and discharge rates, which have resulted in adverse changes to stream geomorphology, aquatic habitat and water quality;
f) traditional approaches to flood alleviation and channel protection, such as straightening channels and lining them with concrete and steel, have themselves created additional problems through speeding the downstream progress of floods and the downgrading of the river corridor for wildlife and human recreation.

The organisations involved in the above concerns include HM Government Departments (b, d, e and f above); the National Rivers Authority in England and Wales and the River Purification Boards in Scotland (a to f); City and County Highway and Planning Authorities (b, e and f); Water Supply and Sewerage Undertakers (a to e); Land Drainage Boards (e and f); and groups representing land owners with water abstraction and usage rights. River catchments do not define the boundaries of responsibility of many of these organisations, hence it is not unusual for two or three highway and planning authorities to be involved in decisions affecting a stretch of river. Progress towards more integrated catchment planning is slow and the effect on the individual householder of this institutional framework for managing the water environment in the U.K. is to leave him/her confused about who does care for the environment.

Householders in some parts of the U.K. have seen their price for water services double in the last four years. The private water utilities have made these price increases to allow for the required capital investments in new sewerage treatment works. To many householders little seems to have changed: sea and river water quality have not markedly improved and the environment of the rivers seems little changed. The result has been public disquiet at the increased costs for water supply and wastewater treatment. For some people, the disquiet has led them to investigate ways to reduce their water charges through more efficient use of water. In view of the relatively high water usage per person in the U.K., this move is being more widely encouraged by the National Rivers Authority, through its consideration of the various approaches to demand management, to assist in solving some of the concerns previously listed.

In many respects the future of the U.K's water environment is not in the hands of the various organisations who presently manage and regulate it, but in those of the water consumers. On the one hand, the consumer expects a secure, clean supply of water combined with efficient protection from, and disposal of, 'waste' water; and on the other hand, looks for these services to be priced reasonably and not undertaken to the detriment of the environment in general. The key agent for change can only be the water consumer, the householder, the ordinary person, who must modify his/her demand for water services, or assist with the implementation of new techniques to limit 'waste'. Some reduction in demand may be possible and the introduction of water efficient household appliances and fitments may help, but the only real target, with potential to reduce the demand for new water resources and limit the discharge of poor quality, untreated water to rivers and streams, is the reduction of 'waste'. It may then be possible for all foul and surface runoff from urban surfaces to be conveyed to some form of treatment, because volumes are less than today and within the capacities of the available reclamation plants, so protecting the water environment from further adverse impacts from untreated, unregulated discharges.

PRESENT U.K. WATER USAGE

It is estimated that each person in the U.K. draws 140 litres per day from the treated water supplies for use at home. About 5 litres of this is used for external purposes, such as watering gardens; the remainder is eventually passed to the water reclamation works for cleansing prior to discharge to rivers or the sea.

In the middle of England, away from high ground, a typical average annual rainfall runoff from roof surfaces would be 580mm. The volume of runoff depends upon roof area, which in turn varies with the style of housing, number of occupants, density of housing, etc. Table 1 shows estimates of the 'waste' water produced from households in the U.K.

TABLE 1: **An estimate of the total daily 'waste' water per household**

Houses/hectare	8	15	25	35
Persons/house	6 - 5	5 - 4	4 - 3	4 - 3
Roof Area, m^2	169	110	74	37
Stormwater runoff, litres	269	175	118	59
Domestic wastewater	810 - 675	675 - 540	540 - 405	540 - 405
Total 'waste' water	1079 - 944	850 - 715	658 - 523	599 - 464

Present concerns about the standard of treatment provided at some water reclamation works and about the rapid runoff of untreated stormwater into streams and rivers could be addressed if the present 'waste' water was better controlled. This could be achieved by locally storing the stormwater from roofs and re-using it, thus reducing the amount of treated water drawn from the supply. In the U.K. stormwater is either discharged directly to a nearby river from a separate storm sewer, in which case local damage may be caused to the water environment (concern e) previously given); or it is conveyed in a combined sewer with foul waters to the water reclamation works, which may become overloaded by the sudden increase in flow and release poorly treated effluent.

FUTURE WATER STORAGE AND RE-USE

Some part of the water drawn from the water supply may be re-used. It is estimated that some 53 litres per day is used by each person for personal and clothes washing, which could be re-used for certain purposes, such as toilet flushing for which about 43 litres per day are used per person. Table 2 illustrates the effect on water supply volumes of local storage and re-use.

TABLE 2: **An estimate of the total recoverable 'waste' water (per household per day)**

Houses/hectare	8	15	25	35
Washing water for re-use, l Stormwater, litres	318 - 265 269	265 - 212 175	212 - 159 118	212 - 159 59
Recoverable water, litres	587 - 534	440 - 387	440 - 387	271 - 218

Other wastewater must pass immediately to the water reclamation plant as at present. In due course the stored water would pass to treatment after use in toilet flushing. Combined with external uses for the re-use water, the total re-use volumes could amount to some 36% saving on demand for water from the treated supply.

TABLE 3: Summary of future demand and savings per household per day as compared with 1995

House/hectare	8	15	25	35
Present usage, litres Re-use savings, litres Savings/usage, %	840 - 700 302 - 252 36	700 - 560 252 - 201 36	540 - 420 201 - 151 36	540 - 420 201 - 151 36
Unused, recovered water entering storage daily, litres As % daily re-use	 285 - 282 94 - 112	 188 - 186 75 - 93	 129 - 126 64 - 83	 70 - 67 35 - 44

It may be seen from Table 3 that the unused, recoverable water entering storage daily could represent a very significant amount, which would provide some security of supply for re-use purposes if rainfall was lower than average. To conserve this additional volume, a suitable size of storage is required which is both economical to provide and suitable for the available space. For the U.K. situation it might be satisfactory to provide storage capacity for some 14 days' excess water, which in the cases illustrated in Table 3 could represent volumes of 4000, 2650, 1800 and 1000 litres for houses at the densities 8, 15, 25 and 35 houses/ha, respectively. For design purposes this would represent storage ratios as given in Table 4.

TABLE 4: Design storage requirements

Houses/hectare	8	15	25	35
Roof area, m^2	169	110	74	37
Persons/house	6 - 5	5 - 4	4 - 3	4 - 3
Storage volume, litres	4000	2650	1800	1000
Storage/roof area l/m^2	24	24	24	27
Storage/person, litres	667 - 800	530 - 663	450 - 600	250 - 333
Possible General Design Storage Requirements Either: 25 litres/m^2 storage per unit roof area Or: 250-800 litres storage per person. (To be adjusted according to local annual rainfall)				

STORAGE OF RE-USE WATER WITH A POROUS PAVEMENT

In the U.K. in the 1800s and early 1900s it was not uncommon for houses in urban and rural locations to have a 'soft' water cistern - a rainwater tank frequently used to supply water for washing. The construction of these cisterns below the back yard or under part of the kitchen floor ceased as more properties were connected to a reliable, piped water supply. Today, these cisterns are rarely used even when they still exist in old properties.

The provision of storage for re-use water has not been seriously considered in the U.K. in recent times and the costs are viewed as a major obstacle by house builders, anxious not to deter prospective purchasers. As mentioned previously, with the major increase in water costs, the public is showing a growing interest in re-use techniques and the capital costs are seen as less discouraging. The question which then must be addressed is where to construct the storage on new or existing property. Storage tanks are an obvious answer but they may be rather large for the available land area; require deep excavation to install below the ground, or they may be unattractive and difficult to hide if above ground; and they may require sheltering from the worst of the weather, particularly freezing conditions.

One answer is to reconstruct the footpaths and driveways in such a way that they contain the storage. Again, the storage could be a tank, but this would necessitate deep excavation. If the sub-base of the pavement is enclosed within an impermeable membrane and a suitable surface laid over the top, a storage system may be established which is easy to construct, does not need deep excavation and uses space which is open and available for a second usage.

Figure 1 illustrates a section through the construction as envisaged. The surface could be traditional paving, however it could also be permeable thus allowing stormwater from the surface to be collected to augment the roof waters. If the pavement is used for car parking the construction may need to be some 300-400mm thick to support the applied loading and providing about 100mm effective depth of water storage if crushed stone is

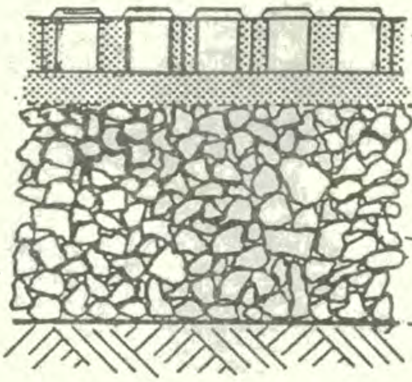

Figure 1 Cross-section of porous pavement for water storage

TABLE 5:

Houses/hectare	8	15	25	35
Roof area/plot area, %	13.5	16.5	18.5	30
Plot area, m^2	1250	665	400	125
Required storage pavement,* m^2	40	26.5	18	10
As % unbuilt-on area	4	5	5.5	11

(* Based on storage volumes given in Table 4 and 100 litres/m^2 pavement)

used, i.e. 100 litres/m^2 pavement. There are other new plastic, honeycomb materials which could be used which are 95% free volume, providing much higher effective storage per unit area.

It is unlikely that there will not be adequate areas of paths and driveways to provide the requisite storage volume. In the survey which provided the values of typical roof areas for given housing densities (Table 1), it was also found that the ground areas within which houses are constructed in the U.K. are typically 5-8 times the roof area of the house for the housing densities investigated here, the higher range occurring at the lower housing density.

Table 5 shows what impact the construction of the storage pavement has on the available ground for other purposes. The percentage of the plot area used for water storage would be quite small (4-5.5%) for all but the highest housing density; and could correspond to the area now usually allocated for car parking space(s) (12.5m^2 per car). Where driveways and parking areas are constructed today it is rare for there to be less than adequate space for standing at least a car and at the lower housing densities space is often sufficient for two or more cars. For the high density housing it has been

KEY:

Foul sewer/drain —— Foul sewer manhole Access chamber (foul)

Storm sewer/drain — — Storm sewer manhole Access chamber (storm)

Gully inlet for highway drainage

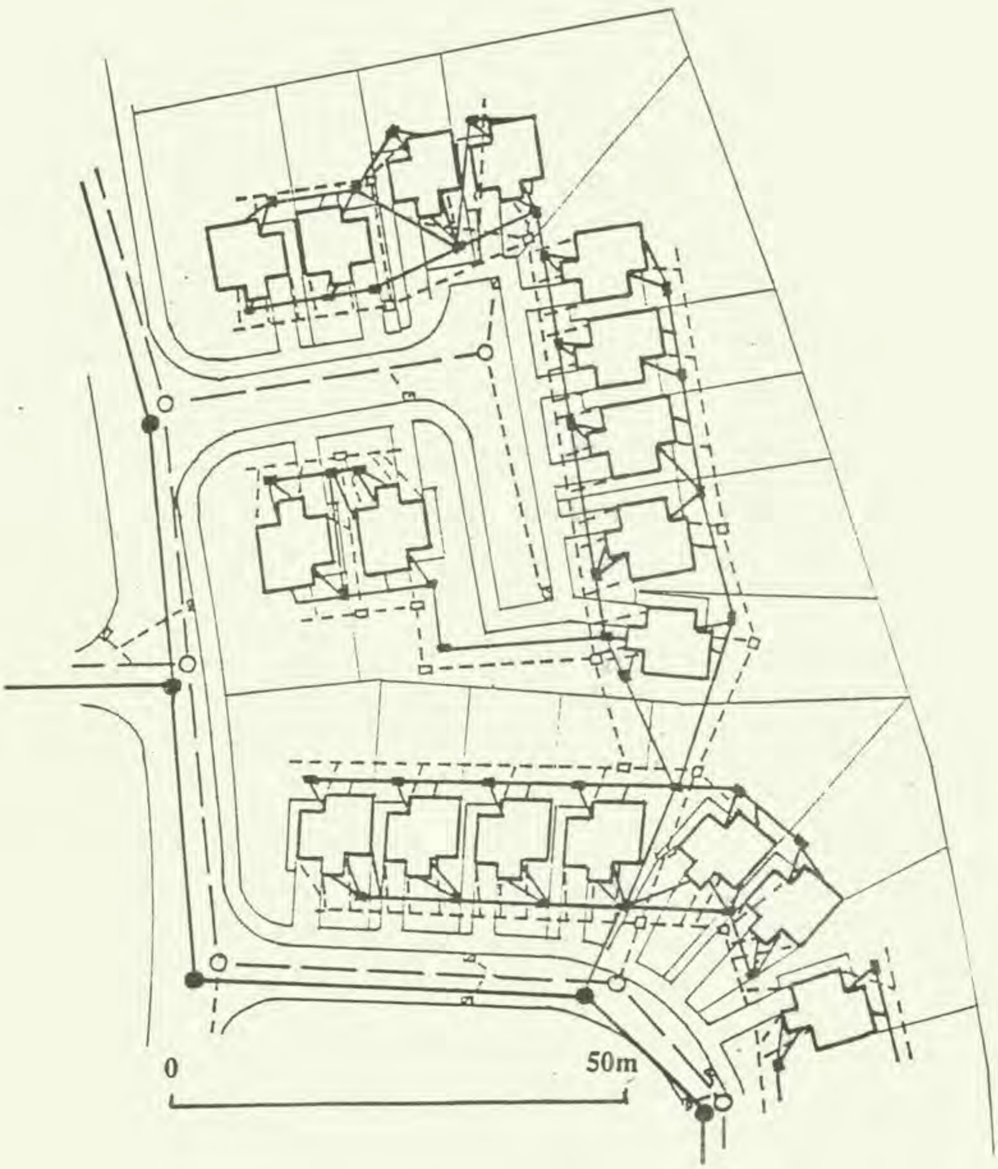

Figure 2 An existing foul and separate sewerage scheme

KEY:

Foul sewer/drain ——   Foul sewer manhole   Access chamber (foul)

Storm sewer/drain - - -   Stormwater overflow   Access chamber (storm)

Infiltration trench for stored water excess

Below-ground stormwater storage volume

Gully inlet for highway drainage

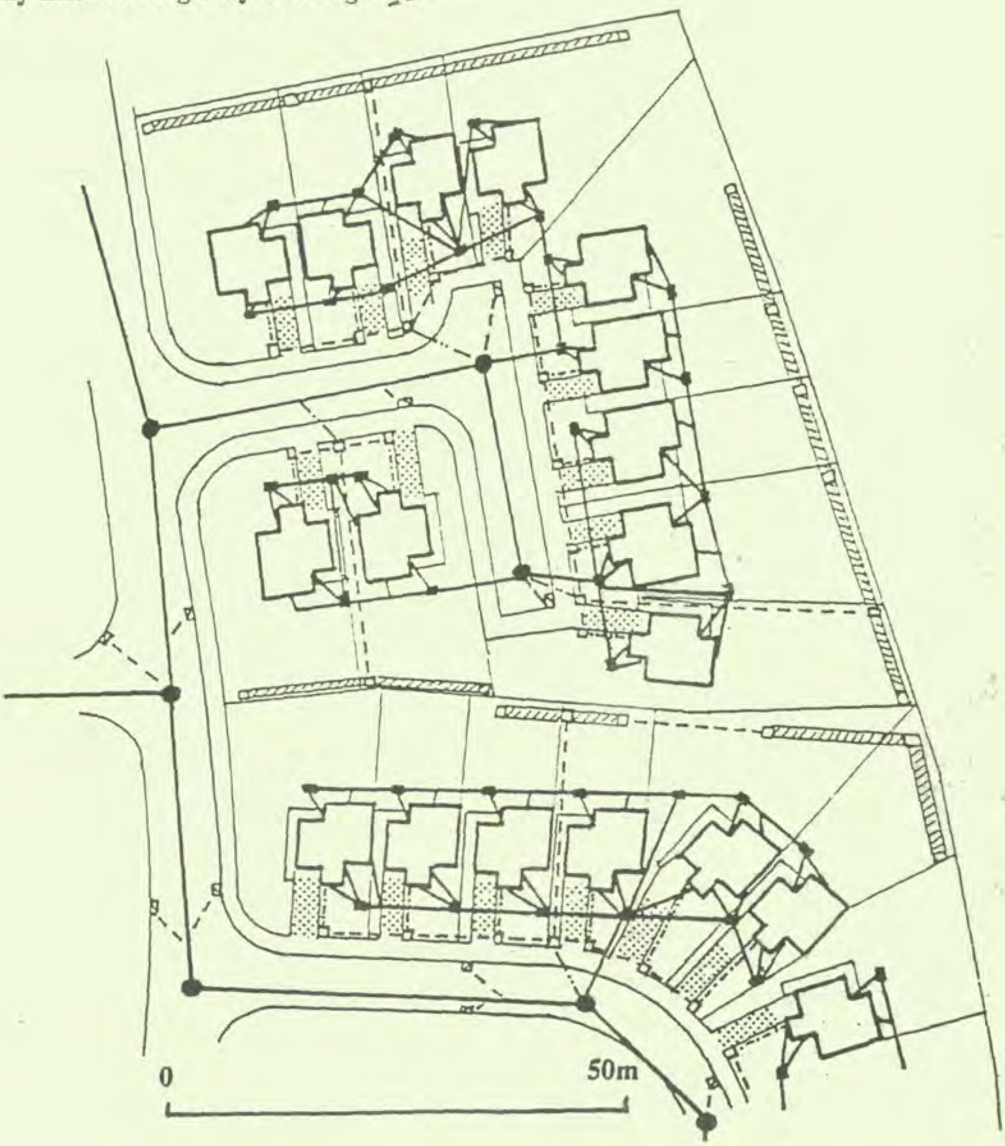

Figure 3 Possible modified drainage scheme with local storage and a combined sewer for discharge to water reclamation works

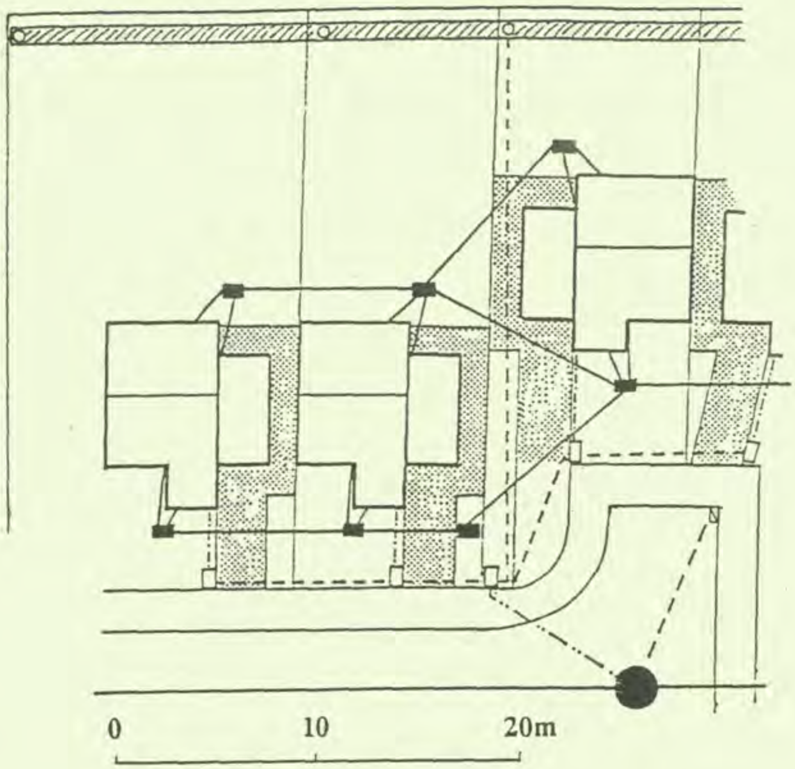

Figure 4 Detail of the possible modified drainage scheme showing local overflow controls on stored water and first disposal to an infiltration trench before overflow to the combined sewer

convenient to use communal parking areas, which would be ideal for the location of a single, communal storage pavement.

This form of water storage has a number of advantages and disadvantages. Advantages include:

- inconspicuous;
- no loss of land use if already used or planned to be paved over for footpaths and vehicle standing;
- ease of construction, hence should be reasonably cheap;
- convenient access to pumping equipment which supplies water for re-use from the storage, as the construction is shallow and the pump may be reached easily from the ground surface;
- no danger of drowning for children and animals, as storage is totally enclosed; and

- in the U.K. climate no problems with freezing below ground.

Disadvantages may be:

- durability of membrane enclosing storage; and
- difficulties of cleansing if material is washed from roof surfaces into storage, therefore, filters will be needed to avoid problem, but filters will be necessary whatever form of storage is used.

At the present time there is little encouragement from HM Government or from the Water Supply and Sewerage Undertakers for U.K. householders to install water re-use storage. Any initiatives will be at the expense of the individual and will be without guidance in line with any national standards. For the future it would be possible for the cost of such storage to be included in the price of a house purchase - without any increase in price. This could be achieved if the Sewerage Undertakers did not require Developers to construct surface water sewers. Highway runoff could be connected to the foul sewer and this combined sewer convey all waters to the water reclamation works for treatment. This would be far better for the water environment and address concerns a), d) and e) previously listed.

Figure 2 shows the installed drainage on a housing estate built in the late 1970s in the U.K., illustrating the use of separate storm and foul sewers. Figures 3 and 4 show what could be an alternative layout in the future for a similar estate with the storm sewer omitted and storage for re-use water provided below the driveways. Excess waters overflowing from storage would be passed to an infiltration trench in the first instance to recharge soil moisture. If ground water was high the outlet from the overflow pipe would automatically seal to prevent back flow from the trench to the sewer. Excess water would then pass to the combined sewer manhole.

CONCLUSIONS

The U.K. faces a number of difficult problems in the water environment in terms of both quantity and quality impacts. A strategy of local water storage and re-use could assist in the solving of some of these problems. Storage costs money to install; this cost will not be met by householders alone in sufficient numbers to meet the need; however, if in new housing developments the Sewerage Undertakers revise their requirements for separate sewers to be constructed, Developers may be able to provide the storage throughout the estate at no extra cost over that saved from the costs for a storm sewer. The debate on this approach is only just beginning, but the need for water economy is undeniable; the only question is how does the U.K. address that need. Presently, the emphasis is totally on the effect that rising prices for water services have in limiting water demand (plus a little encouragement to purchase more water efficient appliances) - this approach threatens public health and is socially divisive. An alternative has been presented here which it is hoped will be given serious consideration.

Rain Water Cistern Systems - A Regional Approach to Cistern Sizing in Nova Scotia

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ABSTRACT

Provincial guidelines for the use of rain water as a potable water supply lacks regional representation with respect to cistern sizing. In an effort to address this shortcoming a computer model, incorporating rainfall records from 21 climate stations throughout Nova Scotia, was developed. The program affords a user the choice of any of the climate station records to evaluate specific rain water cistern system design criteria. Where computer access to this software is limited, a set of 21 distinct sizing charts is available for quick reference. To facilitate the use of the program and charts, a provincial rainfall map based on 30 year normals for 77 climate stations, was produced. The significance of water conservation for this form of water supply through the use of low-flow fixtures has been evaluated.

INTRODUCTION

The use of rain water as a potable water supply in Nova Scotia has been demonstrated to be a practical alternative to unsuitable traditional groundwater or surface water sources (Waller and Inman, 1982; Scott and Waller, 1987; Waller and Scott, 1988: Waller and Scott, 1988; Waller, 1989). Existing provincial guidelines pertaining to the use of rain water for potable use, produced in 1992, offer a comprehensive review and application of the technology. Recommendations contained in the guidelines pertaining to quantative aspects of system design were based on an analysis of a single precipitation record assumed to be representative of the whole province. They therefore did not account for variations from one part of the province to another. For this reason, it was felt that a more detailed examination of the quantative issues surrounding RWCS on a regional scale was necessary.

The analyses described here improved the earlier results in several respects. It considers geographical variations in rainfall: it is based on daily, rather than monthly rainfalls; it is based on rainfall only. The use of rainfall, rather than precipitation data is assumed to improve the efficacy of model projections, due to the fact that for some areas of the province up to 30 percent of the total annual precipitation falls as unrecoverable snow. A second important feature was the utilization of rainfall records for a large number of climate stations in the province. This regional approach was intended to address any variation in spatial and temporal rainfall distribution on water supply/demand relationships throughout the province.

There were two products developed to represent the RWCS modelling work undertaken. First of these was a set of regional sizing charts with appropriate identification mapping to permit a rapid evaluation of a specific site. These charts were based on a fixed set of operating criteria felt to represent average household conditions. The second product, a Windows program, enables the user to work directly with the model, providing more flexibility in RWCS design.

METHODS AND DISCUSSION

The deterministic computer model developed for this study was based on a sizing algorithm described in Scott et. al. (1986). Daily historical rainfall data was used to simulate system operation, and to assess system performance in terms of probability of failure. The various components and products of the model are described in the following sections.

Rainfall Database

All rainfall information was obtained from Environment Canada (Atmospheric Environment Branch, Scientific Services Division). Data included 30 year rainfall normals (average annual rainfall for 30 year period) for 77 climate stations located throughout the province. In order to maximize the data record available, two overlapping climate normal periods were selected. Rainfall normals for the period 1951-80 represent 29 stations, while 48 station normals are derived from the 1961-90 period of record. Where climate normals were available for both periods, the 1961-90 values were chosen.

In addition to rainfall normals, historical daily rainfall records were obtained for 21 of the 77 climate stations. The selection of sites was determined by geographical location and the consistency and length of the data record. Individual periods of record for these particular climate stations ranged from 13 to 85 years. These data were edited to create individual climate station working files containing only those years for which a complete record of daily rainfall was available. The daily rainfall record for each of the 21 climate records identified begins with January 1 and continues either to the model's working capacity of 44 years (16,060 days) or to the end of the individual station's operational period. Occassionally, the available rainfall raw data set extended beyond the 44 year maximum. For these cases, the record of choice dates back 44 years from the most recent year of complete daily rainfall. For example, the rainfall record for Parrsboro is available from 1898 to 1993, a total of 85 years of near complete daily information. The working rainfall record identified for this station in the model was 1948 to 1993, eliminating the first 41 years of data.

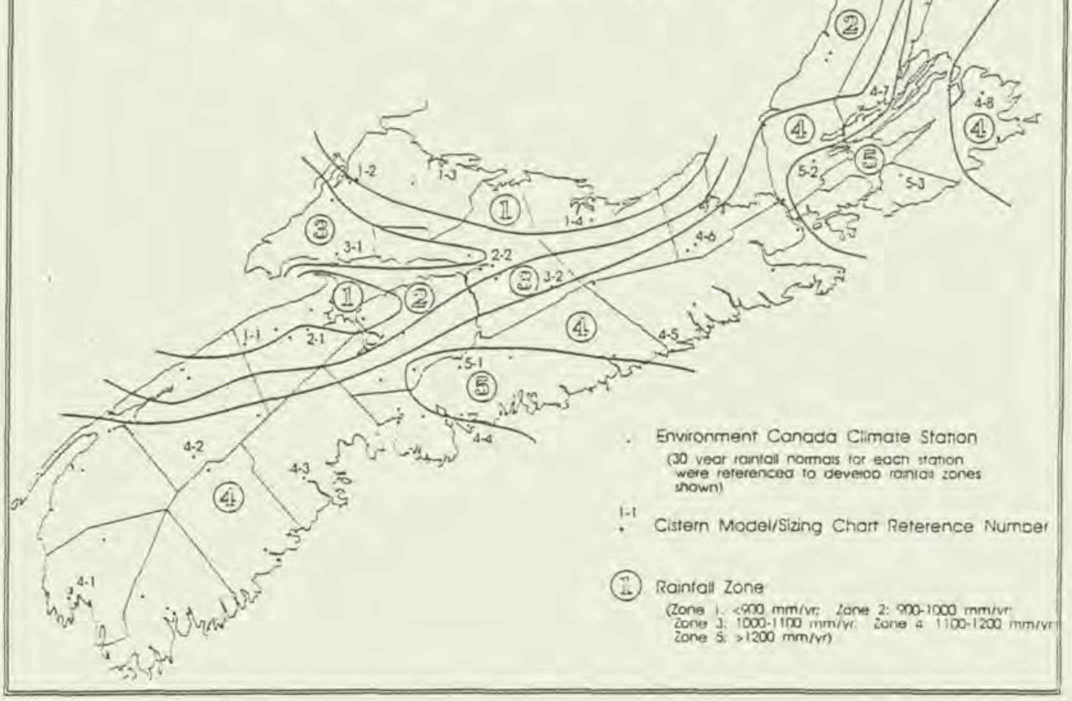
Development of Cistern Sizing Reference Map

Information presented in Figure 1 - Cistern Sizing Reference Map - was determined in the following manner. Each of the 77 climate stations were located on a map of the province to which rainfall normals were assigned. Subsequently, areas of similar rainfall amounts were identified and boundaries delineated through the use of iso-lines. Each zone was given a numeric designation to refer to a specific range of rainfall. The amount of annual rainfall represented by each of the five resultant rainfall zones are: Zone 1 - less than 900 mm/yr; Zone 2 - 900 to 1000 mm/yr; Zone 3 - 1000 to 1100 mm/yr; Zone 4 - 1100 to 1200 mm/yr; and Zone 5 - greater than 1200 mm/yr. Locations of the 21 climate stations used both in the Windows software application and to identify cistern sizing charts were identified on the reference map by means of a numeric coding.

Water Demand

An essential element in the design of any RWCS is water demand. The use of improper water use figures can result in either the system being unable to consistently meet daily water needs of the users, hence, requiring periodic purchases of trucked water, or in the case of an over-designed cistern, wasteful capital investment. In either situation, it is critical that the demand value employed in the design process be as representative as possible. For these reasons, the following section explains just how the per capita consumption figures used in this study were determined.

Figure 1. Cistern Sizing Reference Map



To simplify data presentation, information from all references has been converted (if needed) to metric and/or imperial units of measure. Metric and imperial volumes have been rounded to the nearest litre and gallon, respectively.

Most of the available information on water use applies to piped water supplies. The source for most of this data was water utility records for quarterly water use. Data on water use in private systems, however, was somewhat limited. Table 1 lists referenced residential demand figures.

From the information presented in Table 1, a per capita demand value was calculated, in turn to be incorporated into the RWCS model for the production of the individual cistern sizing charts. At a glance, it appears that the data suggests a home on a centrally piped supply would use more water per capita than its counterpart on a private well or cistern. Given the limited data on private systems, it is not possible to claim that this is a valid characterization without some uncertainity. However, based on the assumption that some reduction in water use between types of supply does exist, the estimate of per capita demand used in the charts equals the sum of the mean of private supplies (106 lpcd; 23.5 gpcd) plus a suggested 40 percent of the difference between piped (177 lpcd; 39gpcd) and private supplies. The figure of 40 percent, although somewhat arbitrary in selection, presumably adds to the security of the supply through the over-estimation of household demand for private supplies. Additional water use figures from private systems are necessary in order to validate the resulting per capita demand value of 135 lpcd (30 gpcd). This figure was used as the basis for both the cistern size estimates presented in the sizing charts and the water use figures suggested in the computer program. To be discussed later, total household water use can be reduced by as much as 50 percent (more realistically by at least 30 percent) by water conserving measures with little or no change in life style. If for any reason demand figures incorporated into the sizing charts are considered to be unsuitable, the computer software program has been written to accept any water demand value specified.

Table 1. Residential Water Consumption Values for Piped and Private Supplies.

	Demand	
Reference	lpcd	gpcd
Piped Supplies		
USEPA (Anon., 1980)	168	37
Halifax Water Commission[1]	168	37
Vickers (1993)[2]	173	38
Scott and Mooers (1994)[3]	191	42
CARP (1993)[4]	191	42
mean of piped supplies	177	39
Private Supplies: RWCS		
Scott (1987)[5]	91	20
CWRS[6]	127	28
mean of RWCS supplies	109	24
Wells		
Check (1993)[7]	104	23.0
mean of private supplies	106	23.5

[1] Internal survey of 50 to 75 residential accounts in mid-1980's: personnal commumication with staff.

[2] Vickers (1993) published water consumption values for average indoor water use (toilets, showerheads and faucets) not allowing for baths and external (landscaping, car washing etc.) uses. For a household of 2.7 persons the indoor water use was 131 lpcd (29 gpcd). The figures presented in Table 2 are estimates based on the assumption that indoor use represents 75 percent of the total household water demand.

[3] Scott and Mooers (1994) conducted a survey of 25 households in Halifax using information supplied by the Halifax Water Commission (HWC). Quarterly utility records were obtained from the HWC for the period April 1992 to May 1994 for residential properties with known number of occupants. The data set chosen was purposely designed to include a cross-section of occupant age groups and number per household. The number of occupants per household ranged from 1 to 7. The age group included homes with a single senior citizen, two senior citizens, and two parent families with up to 5 children ranging in age from infant to young adult.

[4] Clean Annapolis Rivers Project survey of 10 homes in Middleton, N.S., Of the 10 households accounts, records for 5 were deemed suitable for this study. The discarded records included homes with swimming pools and incomplete year round occupation.

[5] A single RWCS was metered for a two year period. The demand value given is a two year average.

[6] A RWCS on Shore Drive in Bedford, N.S. was the subject of research at CWRS in 1987-88. Water use during this two year period was metered and recorded.

[7] Water consumption in two rural homes was metered for up to a 4 month period during the summer and late fall (122 lpcd (27 gpcd) and 85 lpcd (18 gpcd), respectively). The value presented in the Table is a mean of the two homes and represents average daily demand for only part of the year. It is felt, however, that since the period of record covers the season when daily consumption tends to be highest, the mean figure quoted is a fair estimate of annual daily demand.

Water Conservation

Major advances in the design of low-flow fixtures have made the use of rain water as the sole source of domestic water supply more practical and economically feasible. It is estimated that incorporation of water saving devices (toilets, showerheads, faucets and appliances) can reduce the total household water demand by upwards of 50 percent when compared to a traditionally equipped home (Nova Scotia Advanced House, 1993; Saskatchewan Advanced House, 1993). Water used in the bathroom is seen to account for approximately 75 percent of the toal household demand (CMHC, 1993). Replacement of standard bathroom fixtures with low-flow toilets and showerheads in a Nova Scotian seniors complex has reduced total consumption by 33 percent (Mooers and Waller, 1992). Low-flow toilets in Saskatchewan's Advanced House contribution to the Canadian Advanced Houses Program initiated by the Canadian Center for Mineral and Energy Technology have reduced the home's total water consumption by 35 percent (Saskatchewan Advanced House, 1993). Vickers (1993) has estimated that a pre-1980's home retrofit with low-flow toilets, showerheads and aerated faucets would reduce indoor water use by 61 percent. For a home built after 1980, the savings would be 39 percent. In both cases, the per capita demand following retrofit was estimated to be 80 lpcd (18 gpcd). For the purpose of this study, it was assumed that the indoor use represents 75 percent of the total household demand. This figure is conservative in light of CMHC's suggestion that the same 75 percent of the total household demand originates from bathroom fixture use only. An underestimate of the actual indoor/total water demand ratio, however, which results in an overestimate of the total demand, will add an additional safety factor in the cistern sizing process. Thus, in terms of total household consumption, retrofit savings for indoor use (Vickers ,1993) translates into reductions of 55 percent for pre-1980's homes and 29 percent for post-1980's homes. Table 3 contains a summary of water savings resulting from water conservation measures using low-flow fixtures. For the purpose of this study, only the more recent post-1980's estimates of water use and savings were considered when developing the cistern sizing charts. It is interesting to note that based on the assumption that indoor demand is roughly equal to 75 percent of the total household demand, the estimated household per capita consumption of 174 lpcd (38 gpcd) in Table 2 is almost identical to the average per capita demand of 177 lpcd (39 gpcd) presented in Table 1.

The only water savings considered in this study were those attributable to the use of low-flow toilets. Although the use of low-flow showerheads and aerated faucets is claimed to add to further savings, they have not been factored in. The reason for the exclusion is due to the fact that homeowners of some retrofited systems have reverted back to traditional showerheads because of inadequate flows. Systems utilizing such devices, however, should realize an additional water supply safety factor. Therefore, from information contained in Table 2, low-flow toilet equipped homes (max. 6 L (1.3 gal)/flush) can realistically expect up to a 30 percent reduction in household water use when compared to a traditionally equipped home. The 30 percent reduction translates into in a lowering of the 135 lpcd (30 gpcd) demand figure adopted for this study to 95 lpcd (21 gpcd).

Table 2. Summary of Water Use Retrofit Savings With Estimated Household Savings.

	Traditional Fixtures	Low-Flow Fixtures	Reduction in Water Use
	lpcd (gpcd)	lpcd (gpcd)	percent
Vickers (1993) Pre-1980's Homes:			
Indoor use	206 (46)	80 (18)	61
Est. Total Household[1]	275 (60)	123 (27)	55
Vickers (1993) Post-1980's Homes:			
Indoor use (Vickers, 1993)	131 (29)	80 (18)	39
Est. Total Household[1]	174 (38)	123 (27)	29[2]
Saskatchewan Adv. Home			35[2]
Mooers and Waller (1992)			33[2]

[1] From figures given by Vickers (1993) the Authors have assumed indoor use to equal 75 percent of the total household demand.

[2] Used to estimate average savings for homes retrofit with low-flow toilets.

Assumptions of Cistern Sizing Model

The simulation of an operating RWCS through the use of the computer model was performed while making some basic assumptions. The following list describes assumptions associated with the software projections, either directly or as they are presented in the sizing charts (Table 3).

1. The precipitation records obtained from Environment Canada are assumed to be both an accurate representation of historical rainfall patterns and an indicator of future trends.

2. The recovery of rainfall (represented by the C value in the model) from any catchment surface is dependent on two major factors - the slope of the catchment surface and exposure to winds. Studies identified in which C values were actually measured are Ree (1976) who reported recoveries of 89 to 96 percent, and Scott (1987) who determined that the catch efficiency of a collection surface with a slope of 4:12 was 95 percent. Under the assumption a typical home in Nova Scotia has a roof surface with the 4:12 pitch, a C value of 95 percent was applied to develop the sizing charts. Although the C value for the sizing charts was fixed at 95 percent, this figure can be specified in the computer program.

3. A small amount of annual snowfall is known to accumulate on the roofs of homes during the winter season. It is also known that snowmelt contributes to roof water runoff. However, it is difficult not only to quantify the potential snowmelt contribution to a RWCS but also to determine its distribution during the winter months. For these reasons, it is assumed that snowfall does not contribute to a RWCS supply. A benefit to this omission is additional safety factor built into the design of a RWCS.

4. The maximum cistern volume for single family dwellings is set at 50 m^3. It is felt that this figure was realistic when cost/benefit relationships were examined involving collection area, cistern size and trucked water. In addition to a maximum cistern size, it is assumed that system water (cistern water plus collection surface water minus daily demand) in excess of any designated cistern volume is wasted from the system.

5. The per capita water demand for homes without low-flow toilets as a form of water conservation is 135 litres (30 gallons)/day.

6. The per capita water demand for homes equipped with low-flow toilets (maximum 6 litre (1.3 gallon) per flush units) is 95 litres (21 gallons)/day.

7. The model assumes a uniform rate of daily household water consumption throughout the year.

8. The probability that the size of cistern recommended in the sizing charts will meet the household water demand specified is 98% for the period of record of the climate station specified. For example, in the Baddeck area, the recommended size of cistern for a RWCS system equipped with low-flow toilets, 4 occupants (household daily demand of 0.380 m^3) and 155 m^2 of collection area, is 36 m^3. If this system had been in operation throughout the entire rainfall period of record used for the Baddeck area (1949-1993), approximately 12 loads of trucked water (13.5 m^3 (3000 gal.)/load) would have been required during the 44 year period. The temporal distribution of the water shortages is not restricted to any specific month or season.

9. Individuals choosing a RWCS as a domestic water supply should consider the demands of the home on the system over the long-term. A system designed for the needs of two occupants will not be adequate if the number of occupants of the household were to increase. Therefore, the minimum recommended cistern size proposed in the 1992 RWCS guidelines (N.S. Dept. of Health. 1992) of 27 m^3 (5950 gal.), rounded to 28 m^3 (6200 gal.), was adopted.

10. Model projections of cistern size relate to effective water storage. Effective water storage refers to that volume of water contained in the area of the tank between the tank overflow and a point 15 cm from the tank bottom. Withdrawal of water from the 15 cm zone located at the bottom of the tank is discouraged. Positioning of the pump intake (submersible type) or the inlet of the supply line (for homes using a piston or jet pump) in the tank at or above the 15 cm level reduces the possibility of sediment intake resulting from the resuspension of cistern sludge due to turbulence caused by either pumping activity or the filling of the tank during rain events.

Assessment of Model Projections and RWCS Performance

The ability of the model to accurately predict cistern will be reflected by how similar the design criteria used in the model are to an actual operating system. The most critical variables in the modelling equation are considered to be rainfall and household demand. The authors feel that the rainfall database available affords the best possible long-term record. Cistern sizes presented in the sizing charts are based on the demand figures estimated from information contained in Table 2.

Assessment of system performance requires a performance criteria. The cistern sizing model, from which the sizing charts were developed, evaluates system performance based on the percentage of days over the long-term the design demand is met. It would have been be futile to attempt the presentation of a number of chart groups based on varying degrees of performance. Therefore, in terms of the distribution and number of days for which the household demand was not fully met for the historical records of rainfall evaluated (Baddeck, Shearwater A and Parrsboro), it is the opinion of the authors that a 98% system performance efficiency offers the homeowner a reasonable balance between cistern cost and the cost and inconvenience associated with trucked water. If higher reliability percentages are persued, two observations are apparent. Either the cistern needed is far in excess of the 50 m^3 storage volume adopted for this study based on both economical and practical conditions, or, the suitability of RWCS technology becomes resrticted to only those households with large collection surfaces. As the reliability percentage decreases, the frequency of water shortages and the need for trucked water increases. For example, the loads of trucked water (13.6 m^3 or 3000 gallons per load) required during a 44 year period is approximately 10 and 30 at 98% and 95% efficiency, respectively. The cistern sizing charts were therefore developed using a 98% probability for system reliability and presented in a format which was felt to incorporate representative figures for collection area and household number of occupants. If necessary, the computer program affords a user the ability to adjust the design variables employed in the charts to suit specific needs.

Cistern Sizing Charts

Cistern sizing charts were developed to serve as a 'quick reference' in RWCS design for potential users without computer access. The charts were developed for each of the 21 climate stations. Table 3 presents a sample chart from Scott and Mooers (1994).

Table 3. Cistern Sizing Chart for Cistern Model/Sizing Chart Reference Number 4-4: Shearwater A. Cistern Effective Volume: Cubic Metres (Imperial Gallons x 1000)

	Homes Equipped With Low-Flow Toilets				Homes Not Equipped With Low-Flow Toilets			
	Number of Occupants				Number of Occupants			
	2	3	4	5	2	3	4	5
Household Daily Demand, m^3/d (gal/d)	0.190 (42)	0.285 (63)	0.380 (84)	0.475 (104)	0.270 (59)	0.405 (89)	0.540 (119)	0.675 (149)
Collection Area, m^2 (ft^2)								
60 (645)								
65 (700)	28 (6.2)							
70 (755)								
75 (810)								
80 (860)								
85 (915)								
90 (970)					46 (10.1)			
95(1020)		50 (11.0)			30 (6.6)			
100 (1075)		32 (7.0)			28 (6.2)			
105 (1130)		28 (6.2)						
110 (1185)								
115 (1240)								
120 (1290)								
125 (1345)								
130 (1400)								
135 (1455)			40 (8.8)					
140 (1505)			32 (7.0)			50 (11.0)		
145 (1560)			28 (6.2)			40 (8.8)		
150 (1615)						34 (7.5)		
155 (1670)						28 (6.2)		
160 (1720)								
165 (1775)								
170 (1830)				48 (10.6)				
175 (1885)				40 (8.8)				
180 (1940)				36 (7.9)				

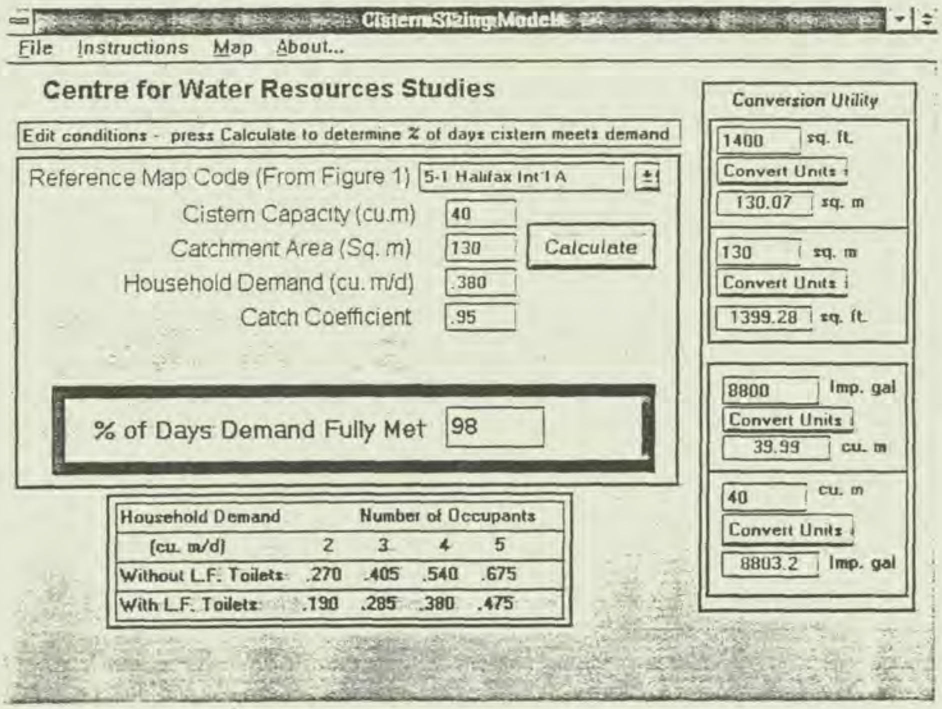
Design criteria used (collection area, number of occupants) were assumed to represent typical dwelling characteristic working ranges. Catchment area efficiency was assumed to be 95 percent. The charts are based on a 98 percent probability of system reliability. Cistern volumes have been rounded to the nearest even number.

Windows Application Software Program

The software program developed is a user friendly package enabling extreme flexibility in the selection of RWCS design variables. The program allows for the identification of a specific rainfall record, cistern capacity, collection area, catch coefficient, daily household water demand and cistern storage. The program assumes the cistern is full at the beginning of each design run. Each set of design criteria chosen is evaluated using the computer model and rated. The rating is based on the probability the design specified is able to meet the daily household water requirements.

In an effort to eliminate the need for support documentation, onscreen calculation of Imperial and Metric areas and volumetric values through the use of a Conversion Utility is possible. Also, household water demand figures for homes equipped with or without low-flow toilets are easily accessed from the screen. Information on RWCS design has been incorporated into the program, accessed by choosing "Instructions" in the menu bar. An onscreen copy of the Cistern Sizing Reference Map (Figure 1) is available using "Map". An example of the onscreen presentation is presented in Figure 2.

Figure 2. Onscreen display of Windows Program.



CONCLUSIONS

Spatial variation of annual rainfall amounts in the province of Nova Scotia ranges from less than 900 to greater than 1200 mm. RWCS design using regionally representative long-term daily rainfall data is considered to improve the efficacy of model projections. The Windows program developed incorporates historical rainfall records from 21 Environment Canada climate stations. A significant feature of the software which offers a user greater flexibilty in RWCS system design, is the ability to specify values for individual system variables. Selected variables include rainfall record, cistern capacity, catchment area, catch coefficient and water demand.

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PERFORMANCE OF AN INSTRUMENTED ROOF CATCHMENT SYSTEM IN BOTSWANA

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ABSTRACT

Botswana has a semi-arid climate with limited surface and groundwater resources and its highly variable and erratic rainfall makes water resource management predictions difficult. Many large scale groundwater and surface water projects have been completed in recent years to provide safe supplies to the urban areas of eastern Botswana. Wider use of low-cost roof catchment systems could, however, supplement individual household supplies in many parts of the country and could lead to a substantial increase in the living standards of people in remote areas. The Ministry of Agriculture has been implementing several systems for rainwater catchment, including roof catchments, in recent years.

To test one of the designs, a small instrumented roof catchment was built on grounds of the University of Botswana in July 1994. This paper describes the measurements and analysis of rainfall and roof-runoff events during part of the 1994/95 season. Using these measurements combined with stochastic modelling techniques, it seems possible to improve existing storage-demand relationships for Botswana and to make better predictions on the performance of these systems in remote semi-arid areas.

INTRODUCTION

Botswana is a land locked country straddling the tropic of Capricorn between 18°S and 27°S in Southern Africa. The climate is semi-arid with mean annual rainfall varying from less than 250 mm in the extreme southwest to almost 700 mm in the northeast (Fig. 1). The rainfall is highly erratic and normally limited to the wet season between October and April. Annual coefficients of variation range from less than 30% in the wettest areas to almost 50% in the driest. Evaporation rates are high throughout Botswana and range from 1800 mm to 2200 mm and exceeding 2000 mm/yr in many areas, Bhalotra (1987).

As a result of the harsh climate and limited good quality groundwater resources in the Kalahari sandveld which covers almost 90% of the country, most of the 1.5 million population live in a 100 km wide corridor running along the eastern border. This corridor known as the hardveld due to outcrops of the underlying ancient basement rocks, has

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somewhat better groundwater conditions and mean annual rainfall ranging from 400 mm to 550 mm in most places. The slightly wetter climate in eastern and northern Botswana supports limited rainfed arable agriculture and sedentary pastoralism although cyclical droughts make agriculture a precarious occupation.

Traditionally people in Botswana adopted a tripartite migration strategy moving between villages, cattle posts and lands areas (where crops were cultivated) at different times of the year depending on rainfall conditions. Although the practice still continues today, increasingly people are opting for more permanent settlement. This creates a major problem regarding water provision, since while dams supply urban areas and larger villages now have modern reticulated borehole supplies, most of the scattered cattle posts and lands areas have no improved modern water supplies. Even the minority that have boreholes often find that the quality and reliability of groundwater supplies are poor. In the past people only stayed at their homesteads in the lands areas during wetter periods when traditional surface water sources such as haffirs, pools and shallow wells could support them. Today in order to stay permanently or for long periods in the lands areas many households transport water considerable distances from boreholes or sand rivers by donkey cart often in 200 litre oil drums. A few more affluent households even transport water in pickup trucks. Most households, however, are very poor with around half owning no cattle. Due to the remoteness of the homesteads and the lack of easily accessible ground or surface water resources the cost of providing improved water supplies to individual households is prohibitive.

In the late 1970's the Ministry of Agriculture began experiments with a new rainwater catchment technology involving the collection of rainwater runoff from traditional threshing floor surfaces and storage in 10-20 m^3 sub-surface tanks (Fig. 2). These systems were intended to provide additional water for draught animals in order to allow people to move to the lands areas at the start of the rainy season and plough early. After initial trials and a pilot project in the early 1980's widespread implementation of several hundred of these threshing floor ground catchments throughout eastern Botswana followed through the Arable Lands Development Programme (ALDEP).

Although intended for draught animals it soon became apparent that the stored rainwater was being used mainly for household consumption including drinking. This caused concern because of the poor quality of the water and analysis confirmed high levels of bacteriological contamination (Gould, 1985), probably caused by defecation on or near the catchment apron. To try to help overcome this problem a new design was introduced in the late 1980's consisting of an elevated 40 m^2 corrugated iron roof catchment and a 7 m^3 polyethylene surface tank (Fig. 3). This was designed specifically with household water use in mind as it was recognised that rainwater collection could contribute significantly to satisfying household water demand.

In 1992 a Lands Area Water Supply (LAWS) feasibility study was undertaken following recommendations in the Botswana National Water Master Plan (BNWMP 1991) to identify appropriate technologies and implementation strategies for supplying water to people in the lands areas. The LAWS study included an extensive survey which determined that current levels of household water consumption in the lands Areas was around 10 litres per person daily. Since the mean household size is around was 5.5 the mean daily household water consumption averages about 55 litres. Among the technologies identified as having some potential to provide improved water provision to around 38,000 households (209,000 people) still unserved, were rainwater catchment systems (LAWSS, 1992).

No detailed technical analysis or modelling was conducted either as part of the LAWS study or by the Ministry of Agriculture regarding the optimum sizing of either the roof catchment area or tank storage volume. It was therefore decided to construct the experimental roof catchment system described below, measure its performance and carry out stochastic modelling to attempt to determine the most appropriate storage- demand relationship for maximising yield and reliability of such systems in Botswana.

EXPERIMENTAL ROOF CATCHMENT SYSTEM

In July 1994 a roof catchment structure consisting of a 20 m^2 corrugated iron roof with gutters and downpipe supported by treated gum poles was constructed on the campus of the University of Botswana in Gaborone (Figs 1 and 4). The downpipe was connected to a 2.5 m^3 PVC moulded plastic tank equipped with a water level recorder. An automatic syphon rain gauge was placed at the same site and rainfall and reservoir additions monitored continuously throughout the 1994/95 rainy season. Additional rainfall data was used from the Department of Meteorological Services whose main weather station is located only 700 metres from the site.

The design of the system was consistent with that used for the ALDEP roof catchment system (Fig. 3) being promoted and subsidized by the Ministry of Agriculture in remote rural areas except that the roof area was half the size and the tank only about a third of the volume.

Monitoring of rainfall and tank level measurements started on Sept. 1, 1994. However, the 1994/95 rainy season did not seem to start at all (Fig. 4). The first shower (in mid-October) fell as a tremendous hail storm with stones exceeding 5 cm in diameter. After that there were some showers in November and December, but these were all less than 10 mm. By mid-December only 32 mm rain had been recorded instead of the average 250 mm : the worst start of a rainy season in Gaborone for 60 years. On the 26th of December, however, 76 mm was recorded as a result of a 7 hour storm with an initial intensity of 80 mm/hr. The total rainfall in December was therefore equal to the long term average of about 100 mm. January 1995 was again below average with 42 mm instead of the average 100 mm.

Fig. 5 shows the reservoir level changes, clearly dominated by the 76 mm event. Despite the low rainfall the tank was nearly full by the end of January 1995. Calibration of tank volume against level yielded an average runoff coefficient of approximately 85 %.

The pattern of rainfall described here for half a year of observations is characteristic for the highly variable and erratic nature of rainfall in southern Africa, where most rain falls in high intensity showers of short duration and very wet years are followed by extremely dry years. Tyson (1986) determined an 18-year rainfall cycle in the summer rainfall region of southern Africa. This cyclicity, however, tends to disappear in the large variance of point precipitation. Using the stochastic rainfall model described below it was possible to simulate a long series of rainfall events and reservoir levels.

RAINFALL MODELLING

Rainfall in eastern Botswana was modelled recently by Gieske (1992) as a point process in continuous time (Waymire and Gupta, 1981a) and results were calibrated against the available 60 year records of daily rainfall. The model uses a time-dependent event arrival rate with one parameter and a constant depth distribution function determined by two parameters. The Poisson distribution of arrival rates is given by

$$\omega_t = \omega_0 + \omega_1 \sin^2(\frac{\pi}{T} t - \frac{\pi}{2}) \qquad (1)$$

where t is the day of the year and T=365, ω_0 is the event arrival rate in the dry season (always taken equal to 0.01) and ω_1 the arrival rate at the peak of the wet season (January). ω_1 varies with location. It was found that the mixed exponential distribution (Essenwanger, 1976) fitted the depth distribution data well

$$f(x) = 0.5a\exp(-ax) + 0.5b\exp(-bx) \qquad (2)$$

where a and b depend on location. The first parameter, a, is identified with the tail of the distribution (the large events) while parameter b models the distribution for small events. The values of the constants for Gaborone are ω_1=0.36, a=0.0680 and b=0.4716. Good agreement was reached between observed averages and standard deviations and the modelled values for numbers of events and annual rainfall.

Although the dependence of rain on season is modelled rather well, the model does not attempt to simulate climate persistence which in reality causes clustering of events over relatively short periods of time. It also generates over the 1000 year modelling period a number of extremely dry years with less than 10 rainfall events. Because the lowest recorded annual rainfall in Botswana is 85 mm (Tshane, in the southern Kalahari), a threshold of 10 events per year was set in the model. Nevertheless, the model simulates the correct decadal averages during the entire year, with the high variance observed in practice. Moreover, it is simple and fast because it uses only three parameters with two distributions. A detailed analysis of the model and a computer programme are given by Gieske (1992).

RESERVOIR MODELLING

Because in a continuous time point process, rainfall events are occurring instantaneously, reservoir storage calculations are straightforward. The depth of the event is multiplied by the average runoff coefficient and roof area to obtain the new volume in storage. If the new volume is higher than the maximum volume, then the difference is spillage and the volume is reset to the maximum value. Abstraction (draft or demand) from the tank starts immediately and is considered to be a continuous function of time. Two different demand scenarios are considered in this paper. The first is the simple constant demand regime described by many authors (e.g. Perrens, 1982a, Latham, 1983, Latham, 1984, Gould, 1985), whereas the second describes the effect of a set of rationing rules (Perrens, 1982b, Heggen, 1987) on long-term reliability of the catchment system under Botswana climatic conditions.

Constant demand

The results of the constant demand reservoir level fluctuations are illustrated in Fig. 6 for one year of the sequence where the parameters of the roof catchment at UB have been used. The model can also be used to compute the operational reliability (defined as the total time during which the reservoir is dry, divided by total time). Fig. 7 gives a plot of supply fraction against demand fraction for values between zero and one. The supply fraction is defined as the total annual demand over kAR, where k is the runoff coefficient, A the roof area and R the mean annual rainfall. The storage fraction is defined as the reservoir volume over kAR. Model simulations for a 95% reliability curve yield the solid line in Fig. 7, where the dashed line was calculated by Gould (1985) using the Ottawa model (Latham, 1983). The difference between the two curves is marginal.

As an illustration of optimal design strategy the following penalty function was chosen

$$F = 100y + 100(1-x) + 5P \qquad (3)$$

where x is supply fraction, y is storage fraction and P is the probability of failure (%). This penalty function which should be minimized, outlines the simple strategy that given a demand, tank volume and roof area should be minimized, while reliability should be maximized. The factor 5 in the formula indicates that more weight is given to the reliability of the system than to roof area and tank volume. Values of F were calculated for a grid of points in Fig. 7 and then contoured. The minimum gives the optimal design point, which in this case corresponds to $x=0.63$, $y=0.34$ and $P=3\%$.

Naturally, there are many choices for function F, incorporating various design costs, local conditions and subjective choices. Further work is being done on construction of a range of realistic penalty functions for Botswana and southern African conditions. For the experimental roof catchment at the University of Botswana the design point lies at A in Fig. 7. With a constant demand of 17 ltr/day, an average annual draft of 5908 ltr is simulated with an average spillage of 3272 ltr. The time reliability is 95 %.

Rationing

The stochastic model also produces the set of periods during which the reservoir is fallen dry. The distribution shows that there are not only very many dry periods in the range from zero to ten days but also a long tail indicating that there are some very long dry periods. It is not difficult to understand that even simple rationing rules will eliminate the number of short dry periods, but it is not immediately obvious whether the long dry periods can be effectively dealt with through a rationing strategy.

In order to determine the effect of rationing a three step rationing strategy was employed (Perrens, 1982b) where the target demand at full reservoir capacity is reduced by factors 2, 3 and 4 at respectively 75, 50 and 25 % of the tank volume. When the target demand is taken to be equal to the constant demand of 17 ltr/day for the experimental roof catchment, it is noticed that the time to drain this reservoir from 100 to 0 % is equal to about one year (the time to drain this reservoir under constant demand is 165 days). The discrete three step rationing model can be approximated by a continuous model of the form

$$V = a + b e^{-t/c} \tag{4}$$

where V is reservoir volume, t time and the constants have the following values a=-15.5, b=115.5 and c=185.8. Eqn 4 was then used to compute reservoir levels and budgets again over several one thousand year simulation periods. Failure probabilities under these conditions were found to be extremely low and on average only one dry period of 30 days is to be expected once in 500 years. The probability of a 100 day dry period is about 1 in 10000 years. Thus, with these rationing rules a practically failsafe system can be operated even under the highly variable Botswana conditions. However, the long term average yield is about 80% of the target demand, due to reduced abstraction in dry periods. Modelling further shows that under the rationing regime tank levels and spillage are consistently higher than under the constant demand regime. This suggests that tank volumes should be made larger and demand at high reservoir levels could exceed target demands to give an overall average yield which is equal to target demand without changing the high reliability. Further work is being done to evaluate such designs.

DISCUSSION

The tank volume and roof area for a given daily demand d (in ltr/day) and for a failure probability of 3% can be calculated using the minimum design point of Fig. 7, which yields

$$V = 0.2\,d \qquad and \qquad A = 1.3\,d \tag{5}$$

where V is in m^3 and A is in m^2. For the average household in the lands areas of Botswana, the average daily consumption is 55 ltr/day. This would therefore require a roof area of 72 m^2 and a storage volume of 11 m^3. If design point A from Fig. 7 is chosen with a reliability of 95% (with A=1.5d and V=0.15d) then the required roof area would be 82.5 m^2 with a tank volume of 8.25 m^3. Both sets of values are above the present size of the ALDEP roof catchment system (Fig. 3), which has a roof area of 40 m^2 and a storage volume of 7 m^3. If it is considered desirable and affordable to try to supply household demand exclusively through rainwater catchment an increase in the roof area and tank volume is to be recommended.

Further research should be carried out into economic aspects of building durable lowcost systems in conjunction with optimization schemes as illustrated in this paper. The introduction of rationing will greatly improve the reliability. However, proper rationing management will require education and training and a very simple strategy involving a one tier rationing system introduced below a single critical level may in practice be the only workable system.

Improved reliability will also require improved water quality maintenance. Study of deterioration of stored water quality on a long-term basis is essential to provide simple practical rules and technical solutions for the rural households of Botswana.

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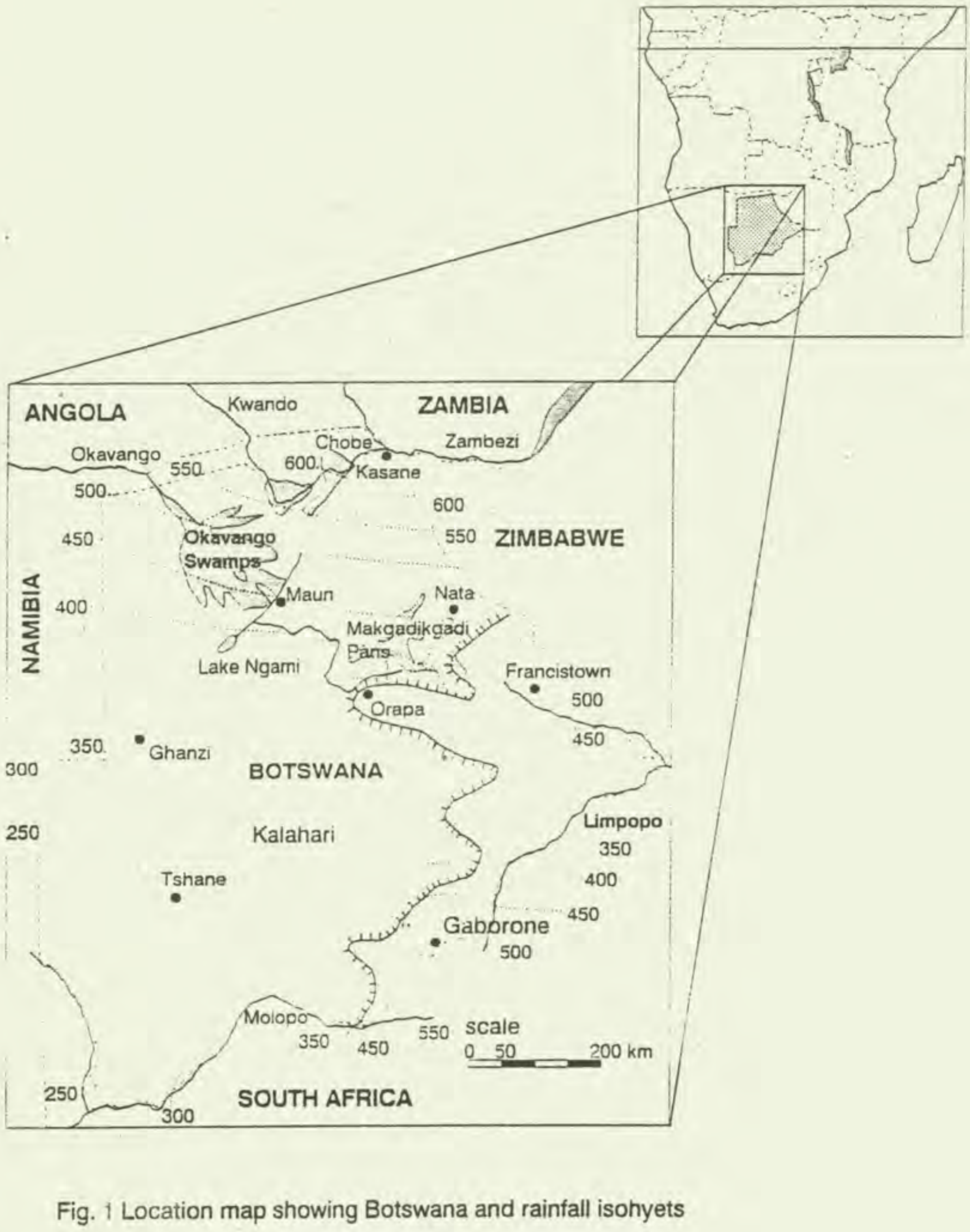

Fig. 1 Location map showing Botswana and rainfall isohyets

Fig. 2 Ground catchment system

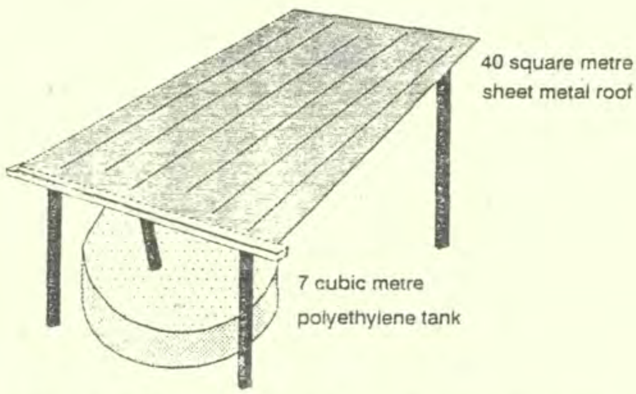

Fig. 3 Upgraded ALDEP household rainwater catchment system

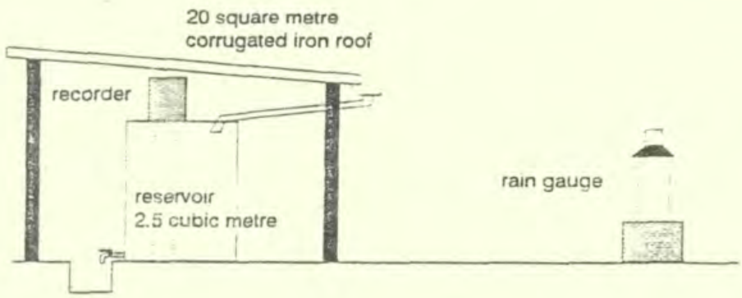

Fig. 4 Roof catchment system at the University of Botswana

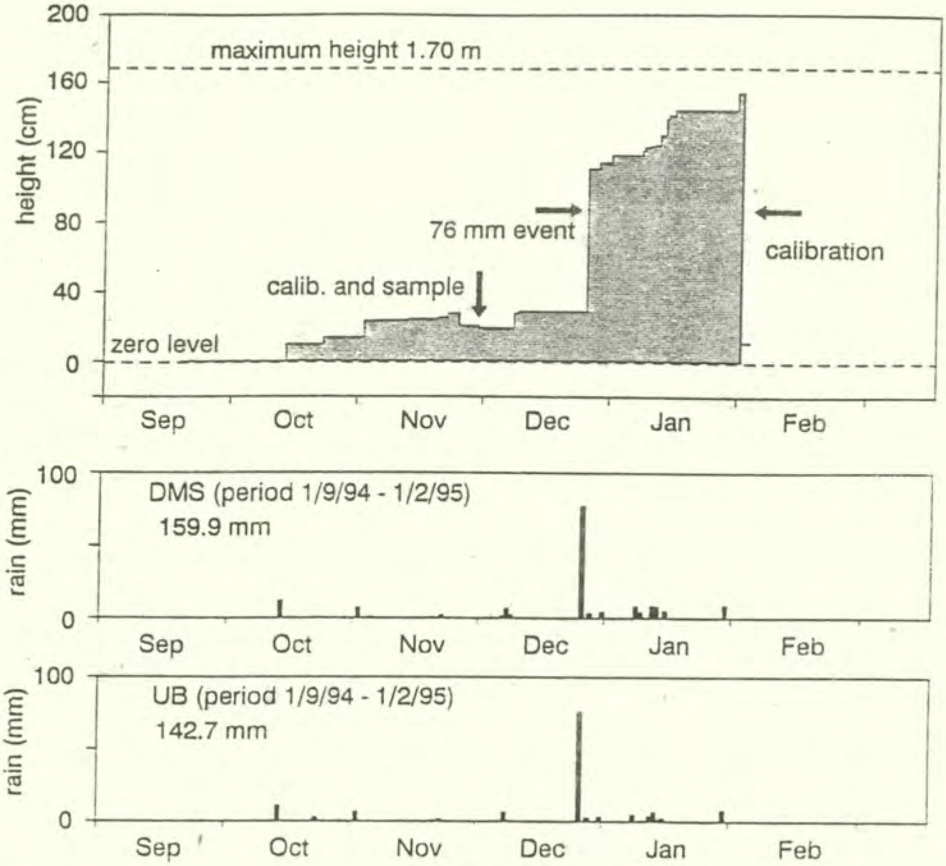

Fig. 5 Rainfall and reservoir levels in UB roof catchment system

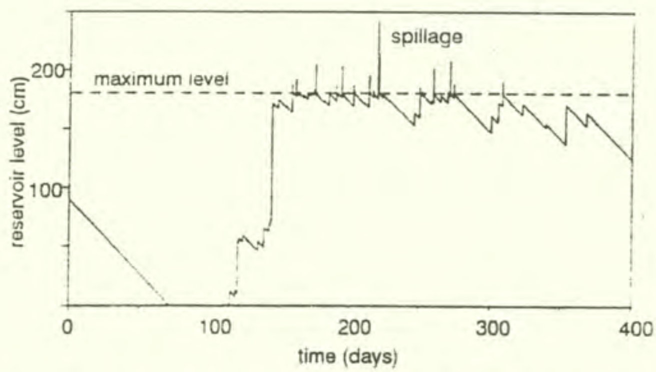

Fig. 6 One year of simulated level fluctuations for UB catchment

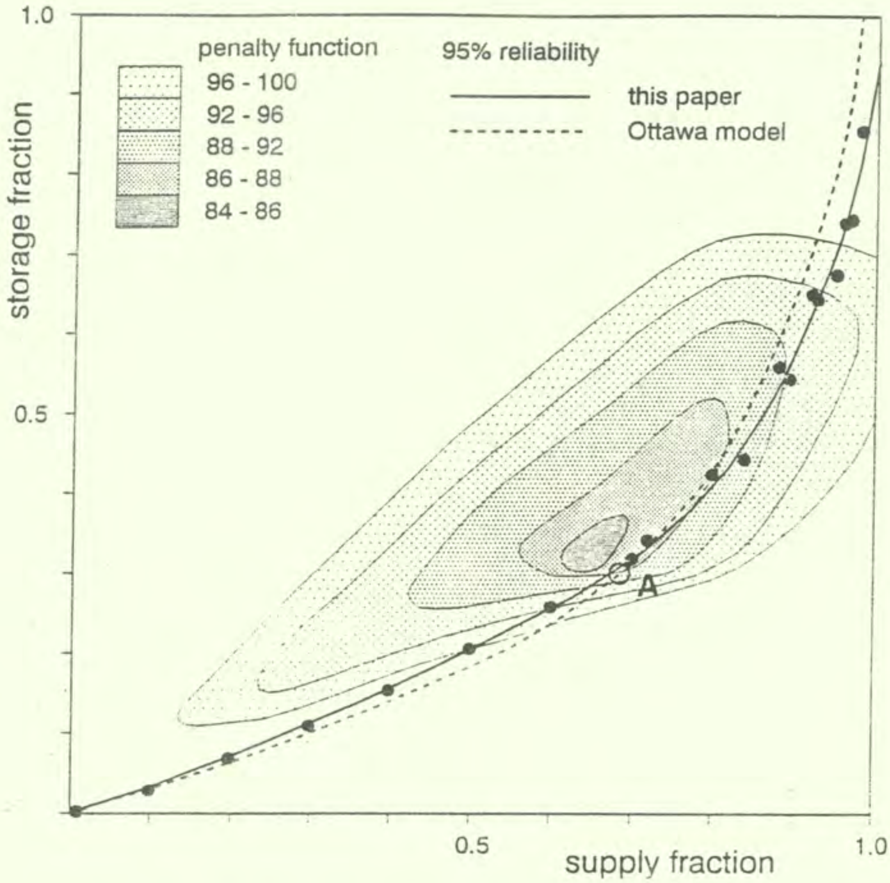

Fig. 7 Plot of supply fraction against storage fraction

SIMPLE MODEL FOR RAIN HARVESTING SYSTEMS DESIGNING

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ABSTRACT

A spreadsheet-based method for the design of rain-harvesting systems is presented. Rain-harvesting systems require collecting surfaces and reservoir storage. The designer strives to find the optimum combination of these design elements to maximize reliability at minimum cost. The spreadsheet model was applied to design a rain-harvesting system for the islands in Croatia. It was found that the method is simple to use on personal computers and that it can be easily used by persons without extensive experience in programming and modeling. With the spreadsheet program one can analyze many alternatives in a short time period and produce sets of results and graphical displays appropriate for decision making.

INTRODUCTION

Rain-harvesting systems are one of the oldest water systems still in use in many areas in the world (Fujimura,1982; Smith,1984). For many isolated areas and especially islands it is still the major source of water supply. These systems, in most cases are individual ones for single houses. In some areas like the Mediterranean it is common to have collective cistern systems for villages , small towns, manufacturing plants and agriculture purposes. Large cisterns are costly but in many areas cisterns may be the most reliable or the only source of water. Previous studies in the Mediterranean (Margeta,1987) show that rain harvesting systems could increase in the future and with new materials could be comparable with other alternatives (Maddocks,1975). A special function of the cisterns could be as a reserve system for special situations. In the Mediterranean islands, cisterns usually have two purposes: storage for rain water during the wet season and as storage for tanker imported water during the summer season.

Bigger rain harvesting system require careful analysis of both the collecting surface and reservoir volume. Depending upon water use, collecting surface can be a natural surface with some improvements or an artificially developed surface. The reservoir could be a simple plastic lined pond or cistern. The designer must concentrate their efforts on determining the optimum combination of reservoir capacity and size of the collecting surface for the specific project characteristics. There are several methods available for designing rain harvesting systems (Jankins ,1978 ; Frasier,1983; Smith, 1984). Additional information can be found in the proceedings of the First and Second and others International Conferences on Rain Water Cistern Systems (Fujimura, 1982; Smith,1984).

In this paper we present a spreadsheet based method for designing rain harvesting systems which consider design of the collecting surface and reservoir volume. It is well known that although spreadsheet programs are not as flexible as other high-level programming languages, they perfectly fit several types of problems such as those requiring simple calculations, a tabular presentation, a data base application, or a graphical presentation (Bodly 1986). Many applications of spreadsheet software to civil engineering design problems have been reported in literature. We found that a spreadsheet based method was suited for designing rain harvesting systems.

RAIN HARVESTING SYSTEM DESIGN COMPUTATIONS

The goal of designing the rain-harvesting system is to find the design that will satisfy demand with chosen level of reliability at minimum cost. Six factors control the performance of the rain harvesting system: the amount and time distribution of rainfall,the runoff coefficient at the collecting surface, the amount and time distribution of demand, the size of the collecting surface, the reservoir storage provided, and evaporation and other losses from the reservoir. For a given demand to be satisfied and a given historical rainfall data, required the designer can control the size and characteristics of the collecting surface as well as the size and characteristic of reservoir.

The Behavior of the system can be represented with mass balance equation:

$$V_{t+1} = V_t + R_t \cdot C_t \cdot S - Q_t - E_t - L_t \qquad (1)$$

Where:

- V_{t+1}, V_t - Storage of the reservoir in time t and t+1
- R_t - Rainfall during the period t
- C_t - Runoff coefficient in t
- S - Collecting surface
- Q_t - Demand in time t
- E_t - Evaporation as a function of V_t and V_{t+1}
- L_t - Other losses from system during the period t

The rainfall "Rt" was assumed deterministic in this study and constant during the time step "t". The runoff coefficient "Ct" for the given location is a function of surface characteristics and climate, and varies from time to time as a function of climatic conditions. The demand also varies in time and this variation could be prescribed in accordance with water uses. Evaporation is significant for the open reservoirs, but in the case of rain harvesting systems, the reservoir is generally covered and evaporation can be neglected. Other losses can be neglected because man made cisterns have to be waterproofed.

A time interval of one month was selected for this study as suitable for preliminary design purposes. It has been shown that results obtained using a one month interval were comparable to that obtained with a one day interval (Jenkins and Pearson 1978).

The two variables under the system designer's control, surface and volume of reservoir, are dependent. Because the size and characteristics of the collecting surface determine the inflow in reservoir and therefore the required reservoir volume.

Surface size is a constraint. The maximum size is the available area for this purpose and the minimum size is a function of the inflow, and required outflow Q(t) as calculated by:.

$$S_{min} = \frac{\sum_{t=1}^{n} Q_t + \sum_{t=1}^{n} E_t}{\sum_{t=1}^{n} R_t \cdot C_t} \qquad (2)$$

were: n - total length of time period.

Necessary surface for each time period "T" which ensure that the demand Q(t) is satisfied can be determine from equation (1), by:

$$S_T = \frac{\sum_{t=1}^{T} Q_t + \sum_{t=1}^{T} E_t - V_0 + V_T}{\sum_{t=1}^{T} R_t \cdot C_t} \tag{3}$$

$T = 1,....,n$
$t = 1,....,T$

Where: V_0 - Beginning storage
V_T - Ending storage
T - duration period

Equation (2) is valid if:

$$Rt*Ct > 0 \qquad t=1 \tag{4}$$

We can not start calculations in a month with out rain, because in that case the required surface area will be infinity large.

We are not interested in each surface but only the critical one. The critical surface for each time period analyzed is the maximum one.

$$Scri = S_T \max \tag{5}$$

The theoretical maximum necessary collecting surface are is:

$$S\max = \frac{Q_t + E_t}{R_t \cdot C_t} \tag{6}$$

At the end of the critical period. the reservoir is empty. It has been shown (Srikanthan and Mcmahon ,1984) that the reservoir calculations should begin with empty an. That procedure was adapted in this work. Therefore beginning and ending storage are:

$$V_0 = V_T = 0 \tag{7}$$

With the critical surface determined for the given input data. 100% reliability can be achieved. Reservoir volume required for this reliability now can be calculated using the mass curve procedure. Subtracting inflow from outflow. the maximum cumulative difference is the required storage for 100% reliability. For a data record of length N, given that cumulative demand equals cumulative supply (i.e., storage = 0) in the "t" month of record. for $t = 1,...,N$, then for $k < t$ the storage required at month k is:

$$V_{t,k} = \sum_{i=1}^{k} (Q_i - R_i \cdot C_i \cdot Scri + E_i) \tag{8}$$

The minimum storage required to meet the demand is:

$$V = \max_{\substack{t=1,N \\ K=1,t}} (V_{t,k}) \tag{9}$$

With this storage and critical surface area 100% reliability of supply can be achieved.

If evaporation is neglected, calculation is simplified. If calculation of evaporation is required then it can be done through an iterative procedure. This is easily implemented within the spreadsheet.

Design of a rain harvesting system for 100% reliability is not a common practice. The design is usually for a certain acceptable level of reliability. In order to find such a solution, the presented procedure can be run for each year of the "N" year rainfall record.

A frequency analysis can be made of the minimal critical surface areas and an empirical frequency curve can be obtained:

$$P(S > s)= m/(N+1) \tag{10}$$

where

P - Probability of surface to be bigger than surface s
S - Surface
s - Surface associated with order m
m - Order of surface
N - Total size of sample

A similar frequency analysis can be performed for the required minimal storage of the reservoir:

$$P(V > v) = m/(N+1) \tag{11}$$

Where:

V - Volume
v - Volume associate with order m

This analysis yields important information to the designer and decision makers because now it is possible relate reliability and system costs. For the chosen level of reliability, the critical collecting surface associated minimal storage (Vmin) can be found. If the designer wishes to improve reliability of the system by increasing storage capacity for the chosen collecting surface,it is necessary to develop a linear relationship for equivalent reduction in surface area. Adding this surface area to the original area, it is possible to estimate from the empirical frequency curve a new reliability level as result of increasing the storage capacity.

The capacity of the reservoir storage and the size of the collecting surface depend on the starting month used in the calculation. Different starting months are used in the literature on reservoir design, for example, calendar year, the water year, and financial year. There are suggestions that the separation of successive water years must be where the connection between years appears to be weakest. From a statistical point of view, starting months have to have a maximum coefficient of variation of the annual flow while the auto-correlation is minimized Svandize, 1980). From the water engineer's point of view, based on reservoir design, the annual series should be formed in such a way as to give the most severe drought conditions, and therefore, the largest storage requirement.

With rain harvesting systems the situation is different because the designer decides both the size of the collecting surface (inflow) and the size of the reservoir. The starting month defines minimal values of reservoir and collecting surface but not as a function of only rainfall. The product of rainfall and runoff coefficient defines the inflow and therefore total available water. The demand, inflow and beginning volume define the size of the collecting surface and the necessary volume. Starting with the month which gives the worst largest ratio in equation (3) and (8) will result in biggest size of collecting surface and the smallest size of reservoir. The question is what is realistic? We can expect that in the most critical year, the reservoir is empty at the end of the demand peak season, and the refilling of the reservoir will start with the wet season. Starting design with the wet season will result in the biggest size of the reservoir and smallest size of collecting surface. As we delay the starting month from the beginning of the wet season this will result in smaller sizes of reservoirs and bigger sizes of collecting surface. The question is, will this change the calculation of the reliability of supply? The answer is no because we always satisfy demand with 100% reliability for the given rainfall series. However starting month determines the critical surface and associated volume and their return period. From a reliability stand point, the best will be the combined result with volume obtained from starting the calculation with hydrology year and collecting surface obtained starting the calculation with calendar year or later. This will reduce the risk that surface will be insufficient at the beginning of the hydrologic year and that reservoir volume will be insufficient at the end of the hydrologic year.

This can be partly satisfied if calculations are started in the middle of the hydrologic year and particularly in the month with the biggest dispersion of rainfall data. With this data we can expect the biggest dispersion of results which means that we will look over a range of possible solutions. Therefore the month with biggest range of rainfall and high variance coefficient is the most suitable one. This approach seems to us the most appropriate because it gives the strongest influence of starting month on results. In general, the biggest dispersion in rain is expected in the wet season (for the northern Mediterranean region) while also gives the best starting position for trade off among surface and volume. Also in this period it is very rare to have a month without any rain. The starting month is a question of economic calculations regarding costs of collecting surface and reservoir as well as other constraints for the particular situation.

From the given storage and collecting surface cost functions of:

$$Cs = a*S^b \quad ; \quad Cv = d*V^e \qquad (12)$$

where: a,b,d,e - coefficients
Cs,Cv - surface/reservoir cost

and storage-surface linear dependence:

$$S = f*V + g \qquad (13)$$

where: f,g - coefficients

it is possible find the total cost "TC as a function of storage and collecting surface:

$$TC= a(f*V + g)^b + d*V^e \quad ; \quad TC= d(i*S + j)^e + a*S^b \qquad (14)$$

From these costs it is possible to derive the minimum total cost relationship analytically or graphically.

Knowing the minimum cost of the system for the different levels of reliability, it is possible to derive the relationship between reliability and costs of the rain harvesting system and make an appropriate decision.

SPREADSHEET COMPUTATIONS

All described steps and calculations are accomplished with the spreadsheet. The program is menu-driven and is controlled by the Macro commands such that the user requires only a minimum of spreadsheet knowledge. The calculation procedure is shown in Figure 1.

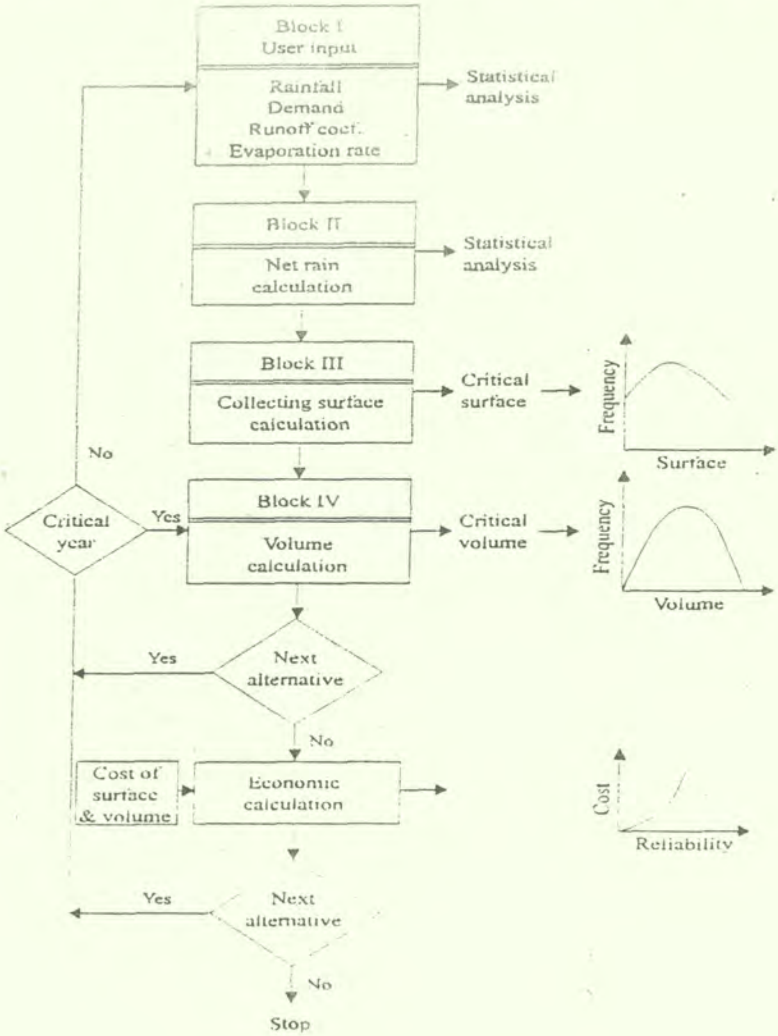

Figure 1. Calculation procedure

In this paper, as an example of the spreadsheet calculations we used data for the one island in Croatia. Thirty years of monthly rainfall records of used for the calculations. Calculation of collecting surface and reservoir volume was done for each year. As a starting month January was chosen. This month has wide variation in rainfall and no month without some rain. In this particular case, volume is not a as constrained as surface area. Evaporation is not included because in this alternative any reservoir will be covered.

The calculation where process starts with entering rainfall data, runoff coefficients , monthly water demand and evaporation monthly rates (Block I). These data are analyzed and total yearly rainfall is obtained as well as other data: average monthly rainfall, monthly standard deviation, minimum and maximum monthly rainfall , average annual rainfall and annual minimum and maximum rainfall.

Block II presents the same analysis but for net rain or effective rain. This block is obtained by multiplying the monthly rainfall and runoff coefficient. Block I and II could be associated with frequency analysis of monthly rain, total yearly rain, monthly net rain and yearly net rain with adequate graphical presentation .

Block III presents results of the minimal monthly surface area calculation, equation (3), and frequency distribution of critical yearly values (maximum yearly surface) for the period analyzed, Figure 2.

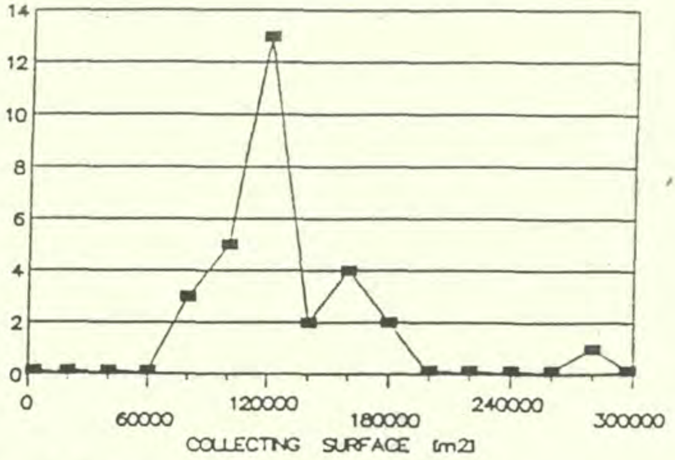

Figure 2. Collecting surface area frequency distribution.

As result of calculations in Block III we have a frequency distribution of maximum required collecting surface for the thirty year rainfall data , Figure 2. From this data we can see that the most frequent surface is 120,000 m2 (13), and that the most data are in the range from 80,000-180,000 m2 (29). Only one year give an extremely large size of collecting surface (280,000 m2) as consequences of very low rainfall in January. From this data, an empirical frequency distribution curve was obtained as a function of probability of occurrence (Figure 3.) and return periods of the particular events are estimated.

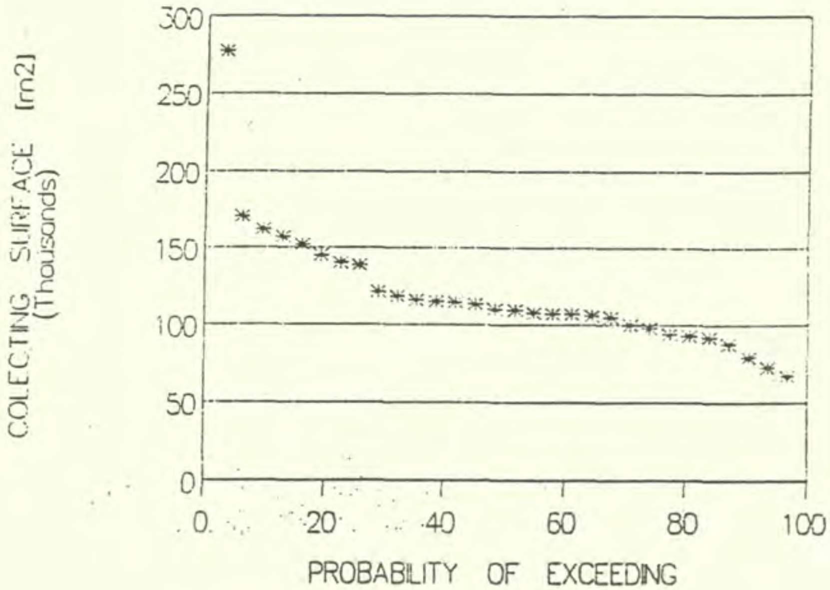

Figure 3. Empirical frequency curve for the collecting surface area.

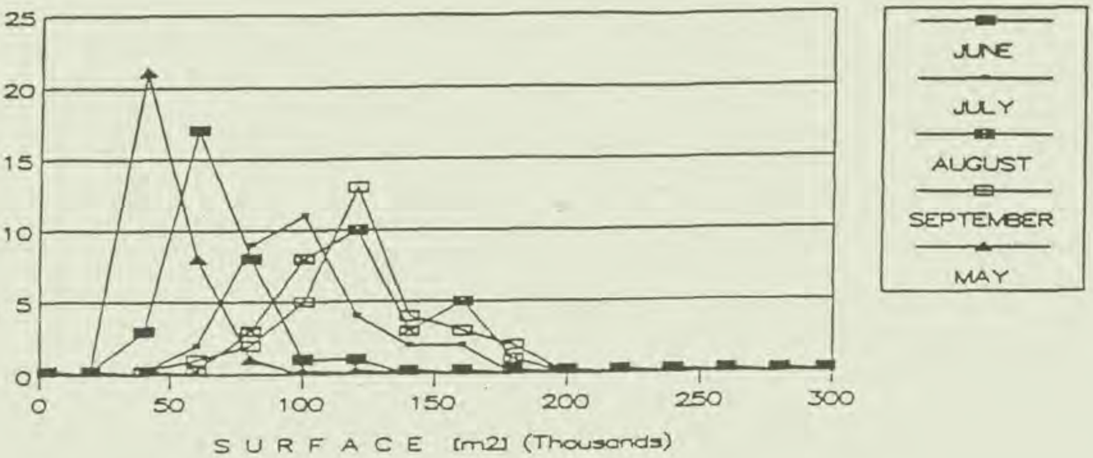

Figure 4. Frequency distribution of collecting surface area for different months

In the Block IV associated volume requirements of critical collective surface, equation (8) and (9), are calculated and their associated frequency distribution ,Figure 5.

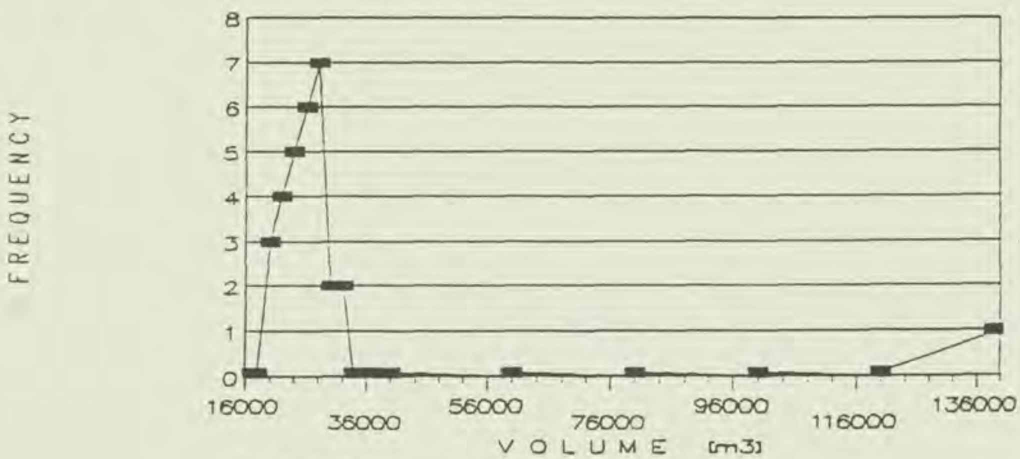

Figure 5. Reservoir volume frequency distribution.

With these four Blocks. information is obtained such that the designer and other decision makers can decide upon future calculations or solutions. By manipulating the input data block it is easy to analyze different alternatives. The calculation of surface and volume can be performed for each year or several year or over the entire record of rainfall data.

For a chosen critical year or period, it is easy to calculate necessary volume for different sizes of collecting surface area (replacing different values of the surface in the row). The results of this calculation can be graphically presented (Figure 6) and used for cost calculations. The empirical frequency curve can be easily obtained and can be used for reliability calculations of different combinations of surface and volume (Figure 3.). All this calculation can be done using the spreadsheet, step by step or automatically in accordance with program formulation.

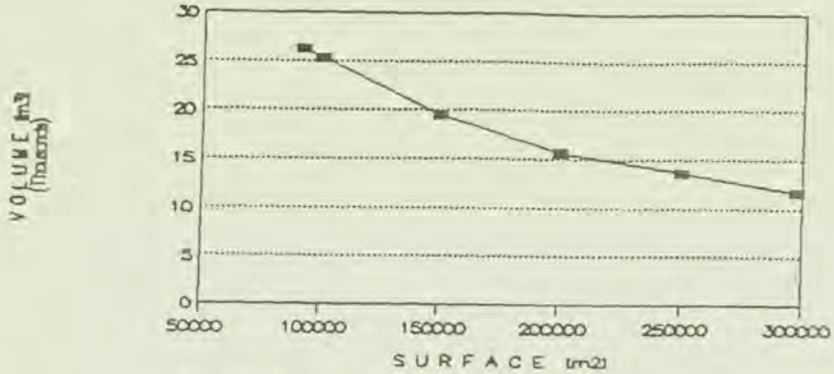

Figure 6. Volume - collecting surface area relationship.

We feel that cost calculations associated with reliability calculations are better performed step by step than automatically. This gives more flexibility to the designer to adjust results to fit local conditions.
Knowing cost functions for construction the collecting surface and reservoir we developed cost reliability curves. For the chosen period , the surface-volume relationship is known as well as the empirical frequency distribution curve. Using these two curves and cost data several different combinations: surface-volume-reliability-cost can be found and a decision about the most suitable one can be made.

CONCLUSIONS

The described method proved useful in analysis of alternative solutions for the rain harvesting system for the islands in Croatia. The model should prove equally useful for other studies. The presented method involves many simple calculation which can be easy implemented in the spreadsheet and simulated.
Spreadsheet modeling is easy and very efficient because it uses programming by example. The user is able to set up the relationship between cells on the screen that are then replicated to other rows and columns. Data structures can be seen and thus are easily understood, analyzed and recalculated if necessary. There is a built-in library of math functions, statistical functions, printing routines, and graphs, so that programming is very simple. Formulas in a spreadsheet are automatically calculated when we enter them and are recalculated each time the data involved is changed. So any input data changed will recalculate all formulas and give updated results. The other advantages of a spreadsheet is its ability to support "what if" analyses of all kinds: What if water demand pattern is different? What if the runoff coefficient is different? The automatic recalculation feature of the spreadsheet may be exploited to visualize the effect of changing parameters involve in calculations at the individual stages. With these possibilities we can analyze many alternatives in a short time period and produce a set of results and graphics appropriate for decision making.

There are other constraints to use the model for different situations than presented in this application, such as a situation with given size of collecting surface or volume of reservoirs. In such cases the situations approach to the calculation is little different but involve same calculations presented in the model.

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Design Strategies for Rainwater Collectors1/

Kwong Fai Andrew Lo*

ABSTRACT

Both large and small scale topographical wind effects determine largely the actual amount of rainwater intercepted by the collectors. The main purpose of this study is to examine the role of geographical factors on rainwater collection and to develop design strategies for optimum rainwater collection. Among the many considered, wind speed and topography were the most significant factors influencing the rainfall amount collected. It is recommended that the local wind pattern and relief ought to be included in designing the best rainwater collector.

INTRODUCTION

Even if water is a renewable resource, it is at the same time finite. Its availability is largely dictated by climate. Low precipitation in combination with a high evaporative demand by the atmosphere mean that the amount of water that remains and can be put to use is small. Moreover, it fluctuates from season to season and between years. It would be a serious mistake, however, to interpret water scarcity only in hydrological terms. Seasonal water scarities are being reported from areas that have quite high rainfall regimes.

During the last decades, much progress in the efforts to improve living conditions all over the world has been achieved through technological solutions. Total water use in the world has quadrupled during the last fifty years. At present, about forty-four percent of the world's water resources in terms of reliable runoff are being made accessible through the construction of dams, reservoirs and conveyance structures. But due to economic costs and to their social side effects, the heyday of construction of large dams and transfer systems is over. Currently, and for the future, the livelihood conditions for the burgeoning populations can only marginally be improved through such measures. Storage of water is still a must, but it is increasingly important to make sure that the considerable losses in terms of evaporation and seepage that accrue from reservoirs and conveyance systems are halted.

There are still untapped water resources and also options to make better use of scarce water resources. Various means of water harvesting provide a means to increase the amount of rainwater that can be utilized. The mounting water scarcity problem requires an increased awareness among policy makers and development planners, at all levels in society, of the significant role of water for development and in nature. New

1/ Paper to be presented at the 7th International Rainwater Catchment Systems Conference to be held on June 21-25, 1995, Beijing, China.

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approaches are needed for the proper management and use of water resources. Instead of asking how much water we need and where to get it, we should ask how much water there is and how we can best benefit from it.

Rainwater harvesting is about to come of age. Because the techniqque makes use of an untapped resource - precipitation that would otherwise be evaporated before it had a chance to play an useful role in feeding the human population - it looks like getting something for nothing. Like food, water can be harvested more efficiently. Doing so is a major priority for the twenty-first century. The main purpose of this study is to examine the role of geographical factors on rainwater collection and to develop design strategies for optimum rainwater collection.

EXPERIMENTAL SITES AND INSTRUMENTATIONS

Three experimental sites, located in the northern part of Taiwan, were selected for this study to represent a variety of local wind pattern and relief. The first observation site is located at Anpu. This site is situated approximately 832 m above mean sea level. It is resting on a saddle-like terrain between two mountain ranges, namely Tatun Mountain in the west and Chihsing Mountain in the east. The general topography is sloping slightly from north to south. The wind pattern during January and April is dominated by the upslope southerly wind, followed by the slightly less prevailing downslope northerly wind. The second site is located at Chutzehu, which is about 607 m above mean sea level. The Chihsing Mountain is situated in the eastern edge. The Yang Ming Shan National Park is in the south. The prevailing slope is from north to south. The wind pattern, according to the long-term weather records (C.W.B., 1897-1991), indicates predominately northeasterly wind throughout the observation period between January to April. The third selected site is at the National Ocean University campus in Keelung, on the roof top of the Department of River and Harbor Engineering Building. The elevation is about 20 m above mean sea level. The building is situated next to the coastline with no obvious wind barrier from all sides. The predominate wind during the observation period from December to March is the easterly wind.

A set of four recording raingages were installed at each experimental site. The receiving diameter of the raingage is about 20 cm. Custom-made slanting metal adaptors with inclination angles of 10, 20, and 40 degree were inserted into the top of three raingages. These adaptors are designed to emulate the sloping rainwater catchment collectors. The fourth raingage, without any adaptor inserted, is used to emulate the level rainwater catchment collector. All four raingages are connected to their individual drum-type recorder. The recorder drum makes one revolution a day. Recorder charts have to be changed everyday. The resolution of the tipping bucket raingage is about 0.5 mm. All raingages were placed with their adaptors facing the prevailing wind direction, which is south at Anpu, northeast at Chutzehu, and east at Keelung.

The separation of individual rainstorm is standardized using the criterion of less than 1 mm rain and separated from other rain periods by more than 6 hours (Wischmeier and Smith, 1978). Each site is also equipped with a recording anemometer and wind vane. The average wind speed and prevailing wind direction during each rainstorm can be decoded from the continuous recording charts.

RESULTS AND DISCUSSIONS

In January 1994, two sets of four recording raingages were first installed at both Anpu and Chutzehu. These raingages were set up in a square orientation. By the end of April, a total of 25 and 36 storms was cumulated at Chutzehu and Anpu, respectively. Similar set up was installed in Keelung in December 1994. Due to the building's ridge-shaped roof, the raingages were oriented in a straight line. A total of 25 storms was collected before the end of March 1995.

(A) The Influence of Wind Direction

Within the observation time period, wind direction varied slightly at both Chutzehu and Keelung sites. Direction ranges between 340 to 130 degree in Chutzehu. Since the collectors were northeast facing, they are situated in the downwind direction. Direction varies between 81 to 107 degree in Keelung. Since the collectors were east facing, they are also placed in the downwind position, However, wind direction varies a lot at Anpu, between 310 to 180 degree. The collectors were south facing. Therefore, they are at an upwind position when the wind is from the north (271 to 90 degree) and at a downwind position when the wind is from the south (91 to 270 degree). Of a total of 36 storms, 27 storms are considered upwind and 7 storms are downwind. There are 2 storms with variable wind direction. The total rainfall received by the four collectors are grouped according to the upwind and downwind position. Figure 1 shows the effect of wind direction on the amount of rainfall collected at different inclination slope angles. Apparently the same trend prevails for the upwind and downwind condition. More rainfall volume is received with the inclined slopes; whereas the level receptor harvests the least rainwater. This result indicates that the changing wind direction has no obvious effect on the rainwater collected for all four slope angles at Anpu.

(B) The Influence of Topography

Topographic variations usually exert profound effect on the actual amount of rainwater intercepted by the collectors. In this study, the inclination angle of the raingage opening was used to emulate the topographic variation of the collectors. Rainfall amount was measured at slope angles of 0, 10, 20 and 40 degree at the Chutzehu and Anpu sites. Due to the frequent malfunctioning of the 40 degree angle raingage recorder, rainfall records were obtained for the 0, 10 and 20 degree slope angles only at the Keelung site. Among all three sites, the 0 degree slope angle (level) collector received the least rainwater. The other slope angles all collected more rainwater. With respect to the level collector, rainwater increase percentages can be computed for each slope angle at each site. Table 1 lists these percentage for all three sites. At Anpu, the highest increase occurs at the 40 degree slope angle. More than 50% increase is observed when the wind is coming from the northerly (upwind) direction. This effect occurs because the raindrops are carried in an air stream that accommodates itself to the shape of the raingage. The obstruction creates a disturbance in the flow, whose main characteristic is the highly turbulent wake (A.S.C.E., 1973). Adjacent to the ground and lee of the raingage, there exists a roughly elliposidal region called a cavity in which the mean flow is toroidal, moving in the direction of the background flow in the outer portion and opposite to the background flow near the axis. That portion of the airflow and raindrops which penetrate the cavity flow region will be distorted and be easily intercepted by the rainwater collector. Changes in the collector shape and orientation to the wind affect the cavity dimension and the amount of the rainwater intercepted. For a steep inclination angle, both the turbulent wake and cavity zone are larger and more substantial flows back toward the raingage.

The highest increase also occurs at the 40 degree slope angle when the wind is coming from the southerly (downwind) direction. This effect may be partly explained by the prevailing strong wind and the airflow orientation closer to the ground surface. A strong air stream that carries raindrops along the earth surface will substantially clears a level catchment surface resulting in minimal rainwater collection.

More rainwater is collected at the 10 degree slope angle at both Chutzehu and Keelung sites. Increases exceeding 50% with respect to the 0 degree slope angle were obtained at both sites. This result differs significantly from the Anpu site. This may be associated with the wind orientation closer to the vertical and weaker wind speed at both sites. More rain may be intercepted by the less inclined raingage than the steep-angled raingage.

(C) The Influence of Wind Speed

It is obvious that wind speed will play an important role in determining the actual amount of rainwater intercepted by the collectors. To quantify this effect, average wind speed for each rainstorm was used to group data into several wind speed classes. Rainfall amount was totaled for each wind speed class. The rainfall increase percentage was computed with respect to the 0 degree slope angle. The increase percentage at the 40 degree slope angle, which is the highest increase at Anpu, is graphed in Figure 2 as a function of wind speed class. The curve shows a gradual increase in the percentage as wind speed becomes stronger. However, the percentage declines sharply when wind speed reaches above 8 m/s. This result reinforces previous discussions on the reasoning of strong upwind creating substantial airflow distortion and strong downwind enabling efficient interception on the 40 degree slope angle. Both effect point to the fact that steeper rainwater collectors are best suited for tableland topography and windy condition.

The relationship of percent rainfall increase at the 10 degree slope angle and wind speed class in Keelung is shown in Figure 3. The curve is the opposite of what is shown in Figure 2. The rainfall increase diminishes as the wind becomes stronger. This follows closely to the explaination that with weaker wind, near vertical raindrops will be readily collected by the 10 degree slope angle collector. Therefore, more gentler oriented collectors are recommended for calm, open environs.

Figure 4 displays relationship of the percent rainfall increase at the 10 degree slope angle collector and wind speed class at Chutzehu. The curve is similar to the Anpu site. Higher increase is obtained with stronger wind speed. This effect may be due in part to the close proximity of this observation site downwind from a tall mountain. The prevailing strong downslope wind, which is oriented closer to the vertical, brings more rain to the gentler-sloping collectors. As such, collectors with 10 degree slope angle are more efficient in hilly terrain with windy condition.

(D) The Influence of Storm Duration

A few storms with similar wind pattern were selected to test the effect of storm duration on rainfall collection. Again, the percentage of rainfall increase with respect to the 0 degree slope angle was used to ease comparison difficulties. Figure 5 depicts this effect based on only three storms each at Anpu and Chutzehu sites. Rainstorms from Keelung were not included because storm duration with similar wind wind pattern varied very little to provide adequate comparison. Both sites (Anpu and Chutzehu) indicate higher percent increase with longer duration. With rainstorm lasting more than 2 to 3 days, a 10 degree sloping collector may receive more than 80% of what may be collected with a level collector at Chutzehu. Similar increase may be obtained with a 40 degree sloping collector at Anpu. With the frquent occurrence of long duration rainstorms, an appropriately designed sloping rainwater collector will drastically elevate the amount of rainwater collection.

CONCLUSIONS

Rainwater harvesting is about to come of age. It has an appropriate image about it that meshes well with the gentler ideas of the late 20th century. Because the technique makes use of an untapped resource - precipitation that would otherwise be evaporated before it had a chance to play an useful role in feeding the human population - it looks like getting something for nothing. Making use of such a resource has a certain poetry to it, particularly in a field where the resource itself can never be increased or decreased; unlike food, water cannot be grown to order, even given the right soil and the right fertilizer. But, like food, water can be harvested more efficiently. Doing so is a major priority for the twenty-first century.

Both large and small scale topographical wind effects determine largely the actual amount of rainwater intercepted by the collectors. The main purpose of this study is to examine the role of geographical factors on rainwater collection and to develop design strategies for optimum rainwater collection. Among the many considered, prevailing wind direction was the least significant factor influencing the rainfall amount collected. However, wind speed and topography were the most significant factors. It is recommended that steep sloping rainwater collectors be used on tableland topography and windy condition. Gentler sloping rainwater collectors are more efficient for windy hilly terrains and calm open environs.

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Table 1. Rainfall increase percentage with respect to the level collector.

Site	Inclination angle (degree)		
	10	20	40
Anpu			
Upwind	33.9	32.0	52.7
Downwind	32.7	29.3	43.9
Chutzehu	51.4	33.6	0.3
Keelung	49.8	16.9	-

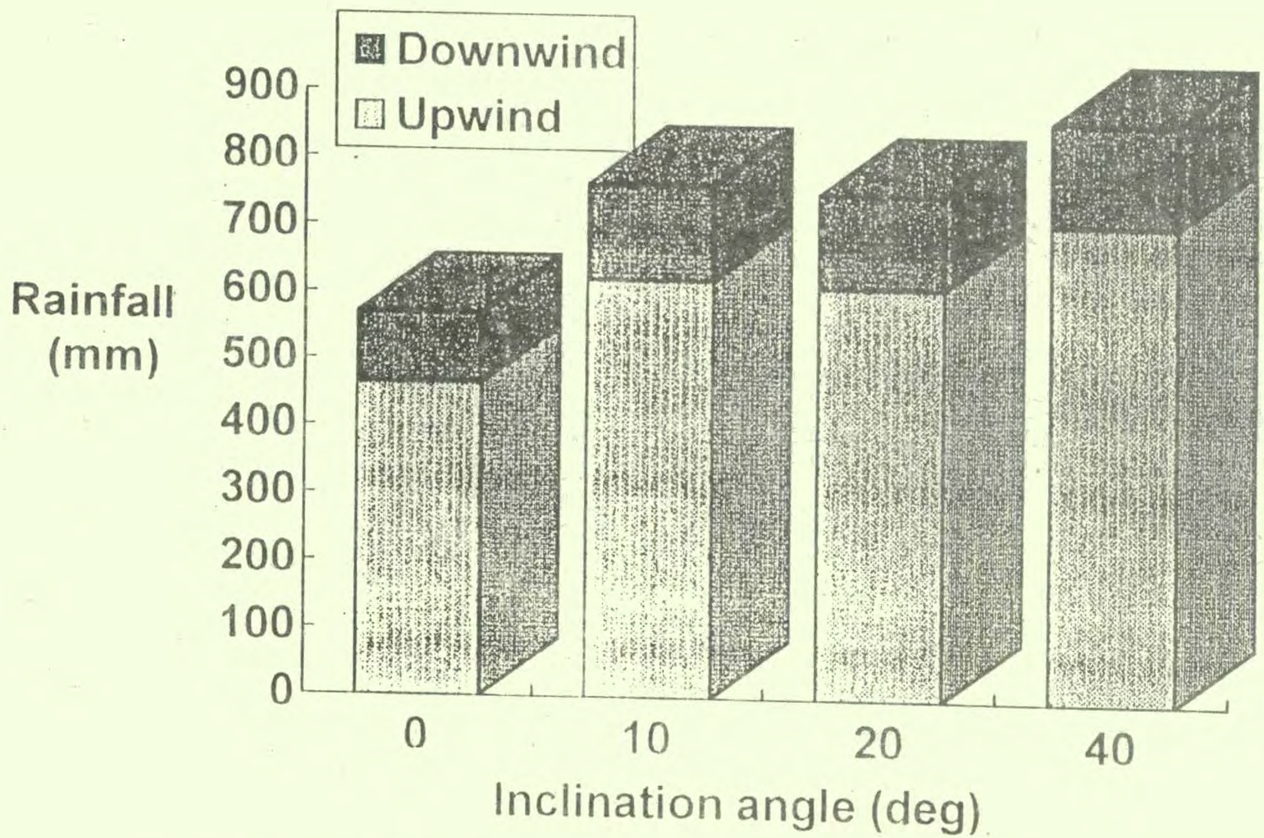

Figure 1. The effect of wind direction on rainfall received with different slope angle collectors at Anpu.

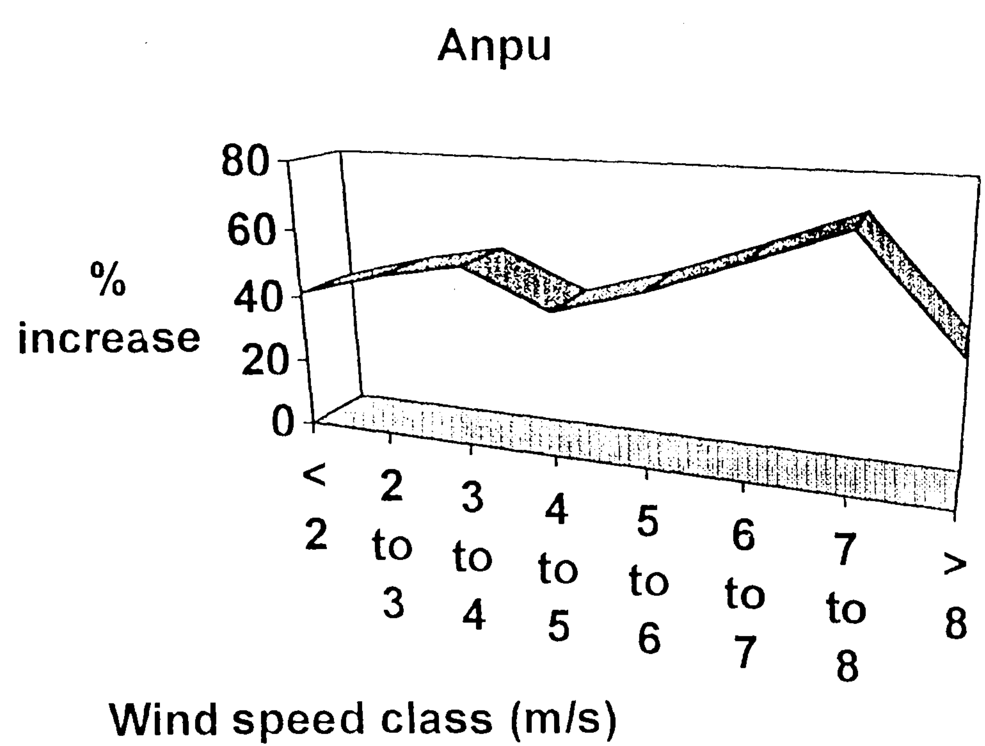

Figure 2. Relationship between the percent rainfall increase with respect to the level collector and wind speed class at Anpu.

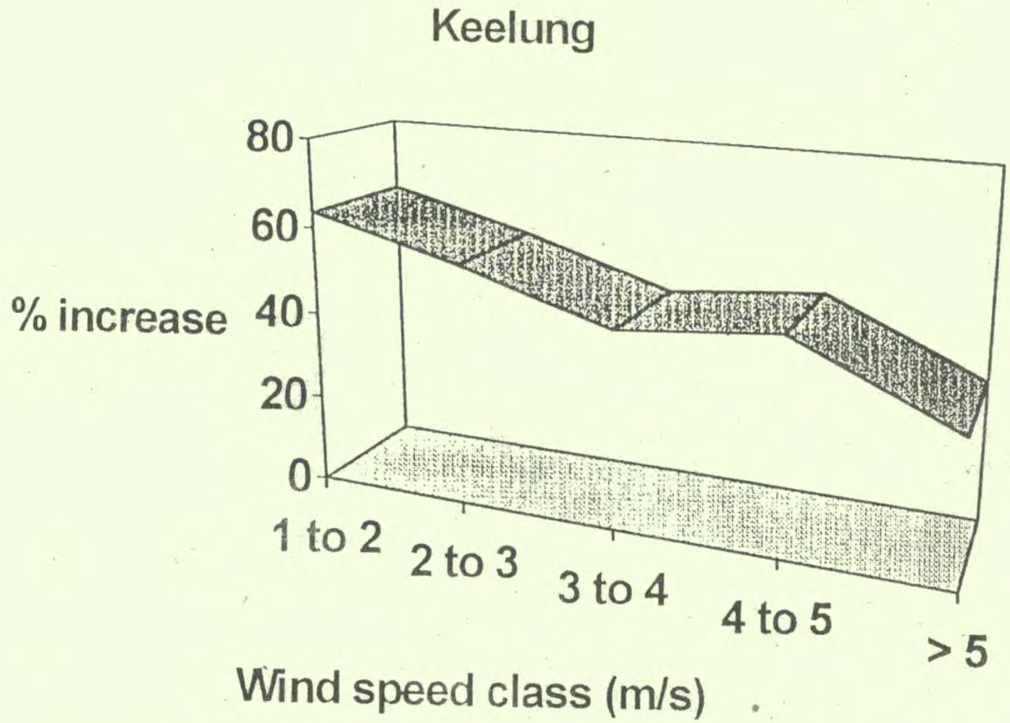

Figure 3. Relationship between the percent rainfall increase with respect to the level collector and wind speed class in Keelung.

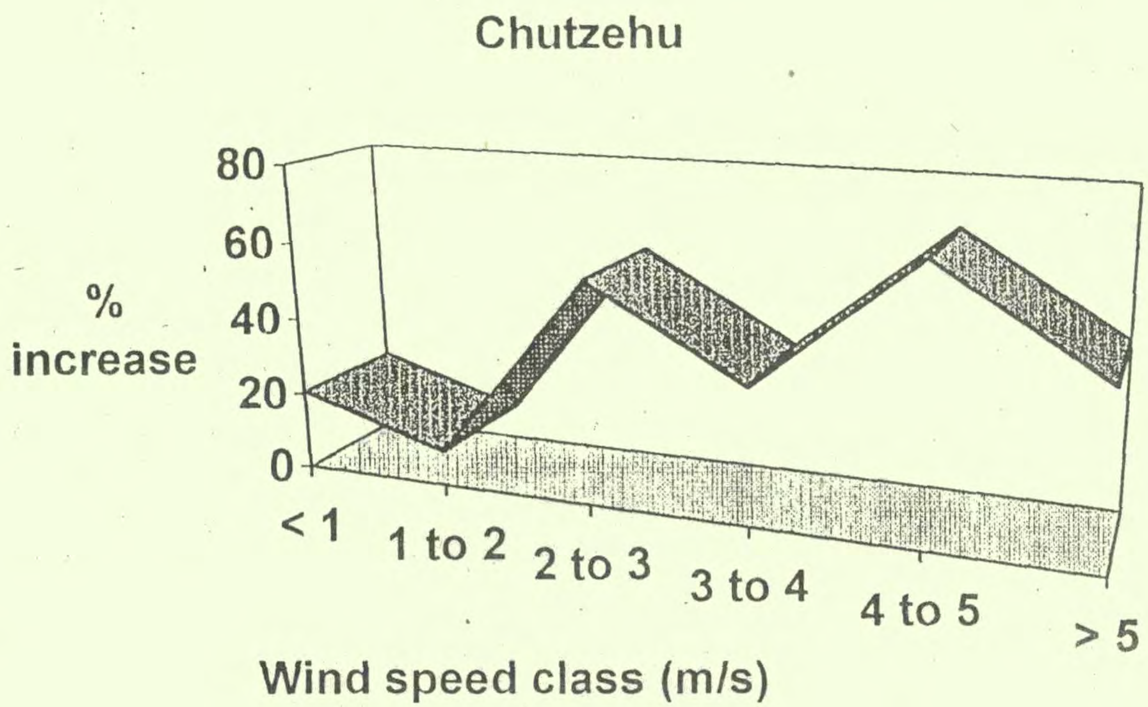

Figure 4. Relationship between the percent rainfall increase with respect to the level collector and wind speed class at Chutzehu.

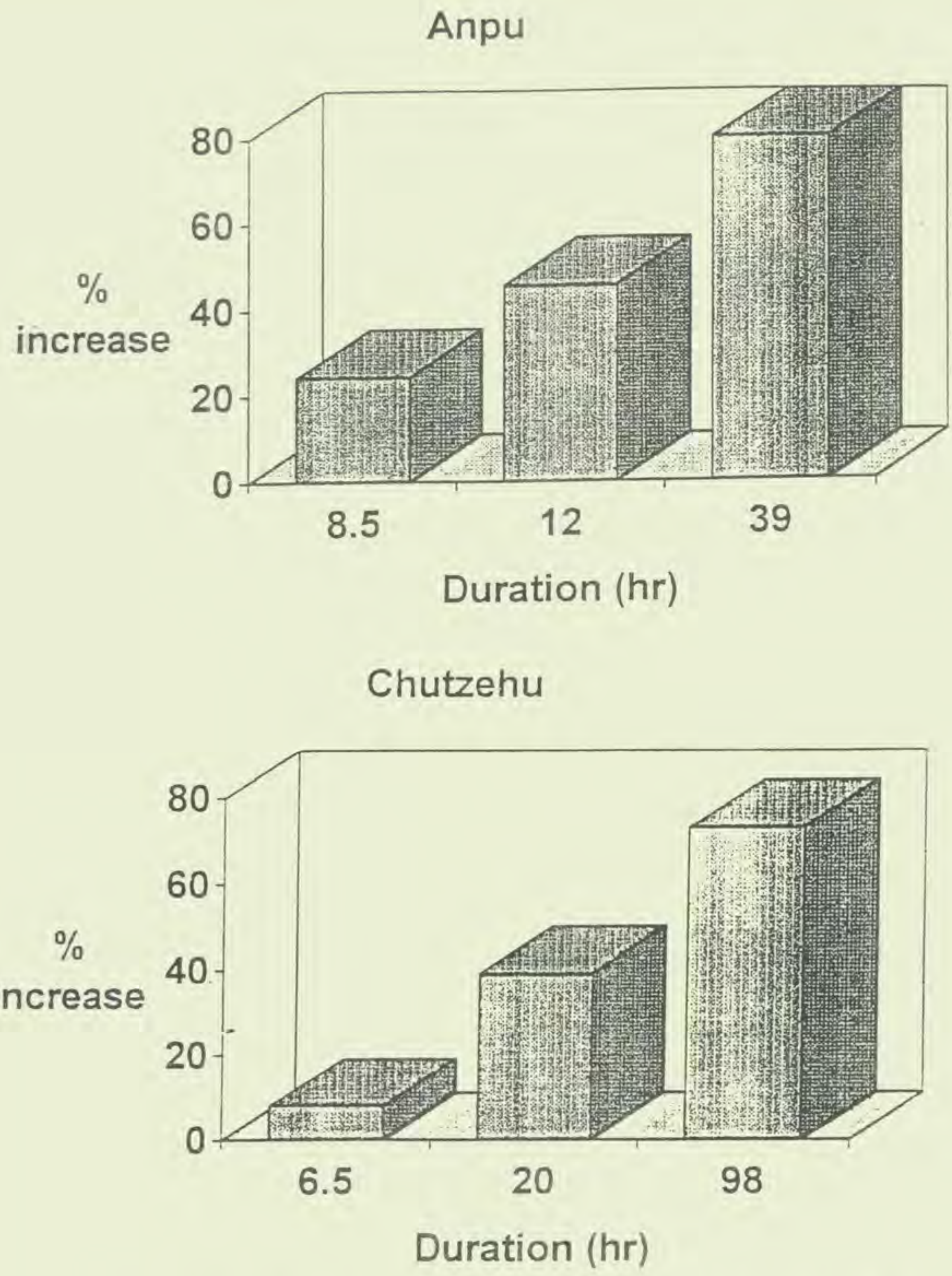

Figure 5. The effect of storm duration on the percent rainfall increase with respect to the level collector.

SAND BURIED MEMBRANE TECHNIQUE FOR RAINWATER HARVESTING IN ARID AND SEMI-ARID LANDS

By

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Abstract

The most commonly practised rainwater harvesting techniques have a wide range of costs, performance and durability which can limit the potential applicability of a treatment. An alternative technique for rainwater harvesting with potential use in arid and semi-arid lands was studied. Considering that sand is one of the most easily and cheaply available resource in the arid and semi-arid lands, it could be of great use to the inhabitants of these regions if it could be used as a component of rainwater harvesting catchment. Two configurations were tested and there effectiveness in rainwater harvesting were compared as reported in this paper.

Introduction

Domestic water supply in the arid and semi-arid lands of the world is one of the major stumbling block in the settlement of these regions. Rainwater harvesting systems are among the oldest water supply systems still in use in many of these areas. For many isolated areas and especially islands they are still the major sources of water supply. These systems are usually for single houses, although in some areas it is common to have collective storage systems for villages, small towns, manufacturing plants and agricultural purposes.

Depending upon the water use, the collecting surface can be a natural one with some improvements or an artificially developed surface. Several methods have been studied to determine the effectiveness of the collecting surfaces. Six factors control the effectiveness of the systems:

- The amount and distribution of rainfall
- The runoff coefficient of the collecting surfaces
- The amount and distribution of the demand
- The size of the collecting surface
- The reservoir storage provided
- Evaporation and other losses from the reservoir

Thus for a given demand and a given historical rainfall data, the designer can determine the size and characteristics of the collecting surfaces as well as the size and characteristics of the reservoir.

Rainwater Harvesting Techniques

Water harvesting techniques can be divided into five basic methods:

1) Vegetation management - converting woodland to grass cover

2) Natural and manmade impervious surfaces - rock outcrops, roofs, highways and roads

3) Land alterations - smoothing and soil compaction

4) Chemical treatment of the soil - making soil water repellent

5) Ground covers - soil is covered with some form of impervious membrane

These methods have a wide range of costs, performance and durability which can limit the potential applicability of a treatment. Knowledge of the advantages and disadvantages of each method of treatment is needed to select the treatment best suited to a given site.

In many parts of the world domestic water for both human and livestock use has been supplied by a method called water harvesting using structures or catchments to collect and store precipitation runoff. Properly designed water harvesting systems are potentially capable of supplying domestic water in any area where there is sufficient precipitation to grow forage. Water harvesting is less costly in many places than alternative means such as hauling or piping.

The water harvesting efficiencies of the different treatments range from as low as 7 percent on natural cover to 100 percent with butyl rubber and sheet metal treatment.

Water harvesting systems depend on precipitation which is at best a highly variable and non-uniform supply. The potential impact of any water harvesting system depends on the end product resulting from the use of the harvested water. The possible end products include livestock, crop production, wildlife watering and water for domestic purposes.

While the above rainwater harvesting techniques have depended on the capability of the structures and catchments to produce runoff, the sand buried membrane would rely on the subsurface drainage of the sand cove over the membrane to determine the water yield. This drainage characteristic of the sand would be a function of the following:

- soil moisture conditions at the time of rainfall
- soil conductivity
- rate of evaporation during and after the storm
- the infiltration characteristics of the soil and,

- the soil moisture release characteristics

The theoretical and practical considerations underlying on interflow collector of this type would therefore be more complicated than those of the overland or surface flow systems. Water yield would, however, be sensitive to rainfall and climate.

The effectiveness of the sand buried membrane system was tested using plastic sheets and this paper summarizes the preliminary results of the field trials at Kabete Campus, University of Nairobi, Kenya.

Experimental Layout

As the drainage characteristics of the sand cover would depend on its water retention characteristics, porosity, air entry pressure value and hydraulic conductivity, two types of the collector configuration were tested as shown in Figure 1. Different sand materials from Machakos, Magadi and Longonot were used to backfill the excavation over a plastic sheet lining. The drained water was collected through perforated plastic pipes and conveyed to corrugated galvanized iron tanks.

Results and Discussions

i) Sand Characteristics

The particle size distribution of Machakos, Magadi, and Longonot sands are presented as shown in Figure 2. The Machakos and Magadi sands were similar with silt and clay content (<0.063mm) ranging between 0.52 to 0.32 percent while the Longonot sand had about 2.16 percent of silt and clay.

The saturated hydraulic conductivity of the sands as determined with a standard constant head permeameter was; Machakos sand 4.6×10^{-3}, Magadi black sand 27×10^{-3}, Magadi red sand 11×10^{-3} and Longonot sand 18×10^{-3} cm/s.

ii) Moisture Release Characteristics

The behaviour of the different sands in releasing moisture is shown in Figure 3. The moisture release characteristics of the sands are very similar.

iii) Water Yield

The water obtained from the different sand catchments was collected in separate 2000 litres capacity corrugated tanks. The effectiveness of the rainwater harvesting units was then worked out on basis of the total seasonal rainfall. Generally, the trails yielded an average rainwater harvesting of efficiency of 52 and 66 percent for configurations 1 and 2 respectively.

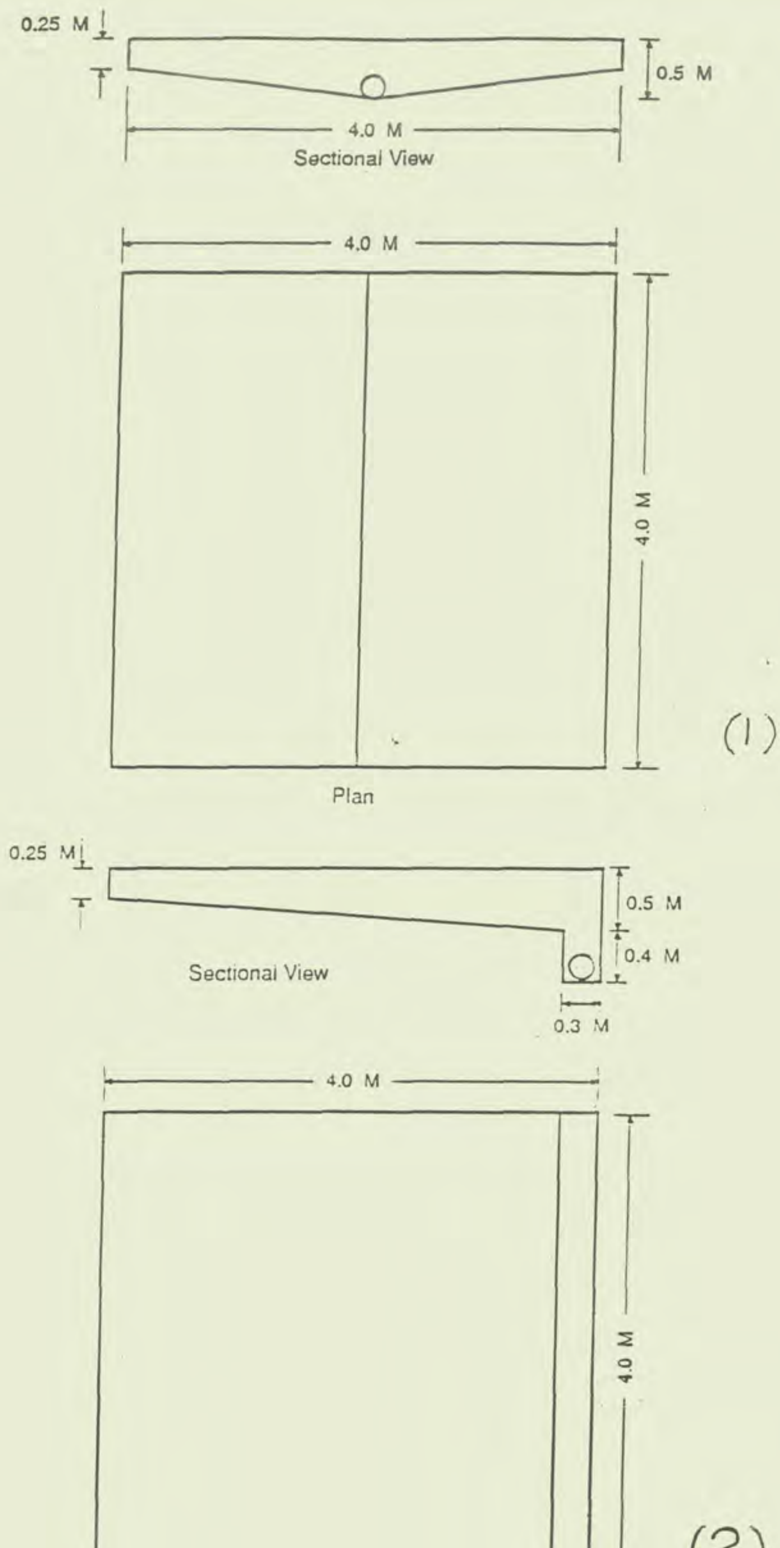

Figure 1. Test collector configurations

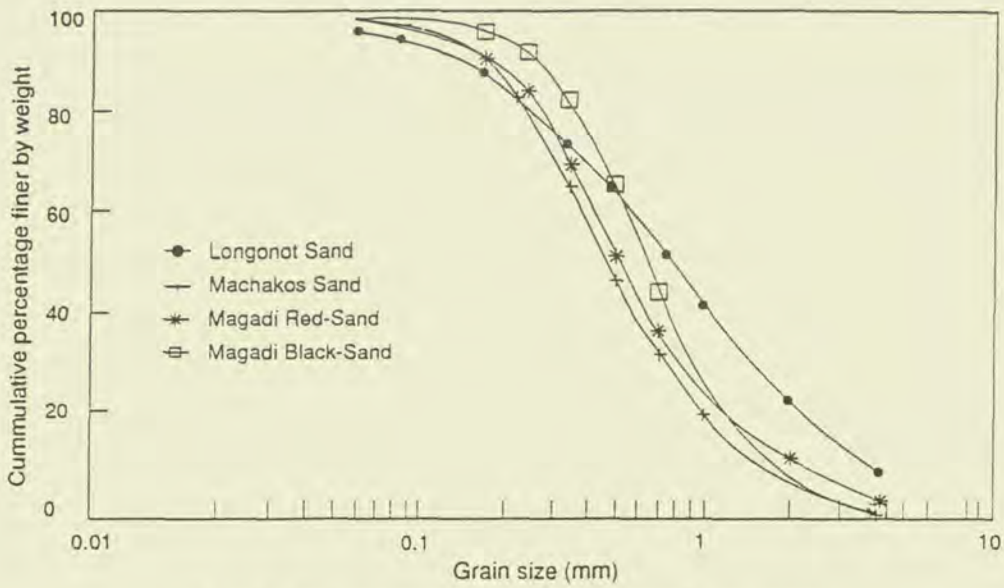

Figure 2. Particle size analysis for sands from different areas

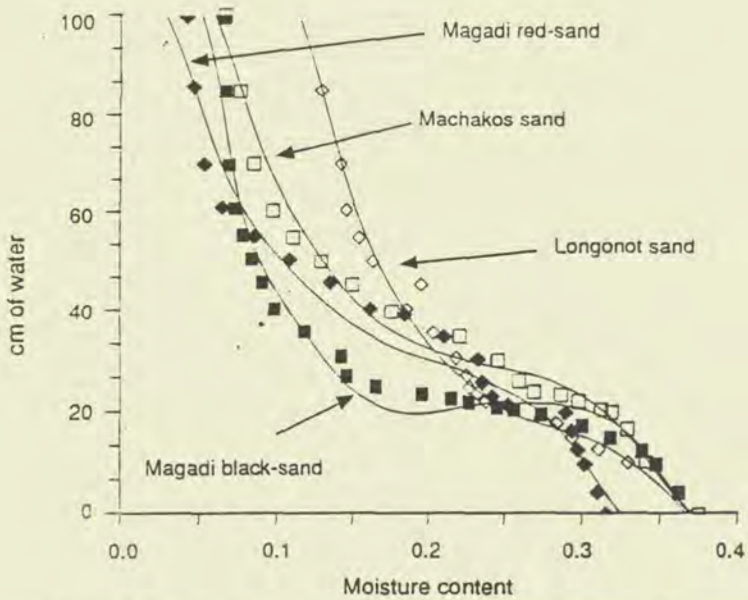

Figure 3. Moisture release characteristic curves for sands from different areas

Acknowledgements

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TRIAL RESEARCH ON MAKING USE OF HOUSE ROOF TO RECEIVE RAINWATER FOR DRINKING WATER IN COASTAL AREA

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Zhanhua County, Shandong Province is located in the coastal area to the west of the Bohai Sea and in the delta of the Huanghe River (the Yellow River). The land in the county formed from regression, and the soil is of high salt content. All shallow ground water in the area is salt water. Therefore, It is very inconvenient to get safe drinking water in the area. According to the general investigation, there are 427 villages in the county with population of 359,000. Four hundred and four of them and 316,000 people confront water shortage. The problem has been mitigated in some villages for recent 20 years, by means of dragging ponds and sinking motor-pumped wells. However, lack of drinking water is not solved at all. The problems include water loss caused by seepage from ponds, unstable water quality, high salt content in shallow well water, high fluorine and iodine in deep well water, and so on. Since 1990, with the help of Shandong Water Conservancy Bureau, Binzhou Water Conservancy Bureau and Zhanhua Water Conservancy Bureau have done experiments for rain-collecting -on-roof project to explore the effective way to solve the problems.

1 The Trial Project Design

In the project, rain-collecting roof, rainwater trough, filter tank, and water cellar are required to design.

Based on the current structure of houses, the rain-collecting roofs appear the type of '人'. The required area of a house roof is calculated by estimated precipitation, runoff coefficient and water usage quantity for one household.

The Water trough is designed as rectangle or semicircle in cross section. In view of lifetime, price, installation, and effects on health, zinc-plating iron-plate, bamboo pole and nonpoisonous glass fibre reinforced plastic are selected as trough materials.

The size of a filter tank is 80 * 80 * 95 cm^3. The bricks that pave the tank are made of No.80 cement mortar. No.100 cement mortar is used as plaster. There is a sewage drain in the bottom of each filter tank. A filter tank link a cellar with a delivery pipeline. Crushed stone and course sand fill in the filter tank.

The water cellars are designed as rectangle, square, or round. In view of collecting area, precipitation, and water usage quantity, the volumes of the cellars were 20 m^3, 12 m^3, or 9.4 m^3. The base plate, curb wall, and roof plate are seepage-preventing. There are a sedimentation basin, a water intake, and a discharge outlet in each cellar.

2 Experiment Study

2.1 On the relation between rainfall and runoff

In accordance with statistical analysis on rainfall and runoff data, we drew following conclusions:

1) The more precipitation is, the more runoff coefficient is.
2) The high intensity of rainfall is, the more runoff coefficient is.
3) The short rainfall interval is, the more runoff coefficient is.
4) According to the observational data at three households, the runoff coefficient is 0.72.

2.2 On the relations between required water-receiving area per person and optimum storage

The calculation for required water-receiving area (S) was based on annual precipitation and water quota.

$$S=Q/(P*R)$$

Water usage quantity per person (Q) is 15 kg/person*day; runoff coefficient is 0.72: P represents annual precipitation. In the experiment, the standard for firm percentage of rainfall (P) is 50%. Based on water quota and run-off data, the result of calculation showed that the optimum volume of a water cellar for a 4-person family is 12 m^3.

Table 1. Required area of rainwater-receiving for per person

Firm Percentage(%)	50	75	95	average
Annual precipitation(mm)	554.2	445.6	319.9	571.3
Area for water-receiving (m^2)	13.7	17.1	23.8	13.3

2.3 On Quality of Received Water

2.3.1 Analysis of received water quality

2.3.1.1 Observational indices

After filtering,, the observation indices by naked eyes accord with the requirement of national standards.

Table 2. The observational indices by naked eyes

Index	Maximum	Minimum	National Standard
Colour	2	0	<15
Turbidity	2	2	< 5
Smell	No	No	No strange scent
Visible objects	No	No	No

2.3.1.2 Main chemical indices

The results of the experiments showed that such chemical index as pH. degree of hardness, chloride, iodide, sulphur, iron, manganese, copper, zinc, nitrate and nitrogen were under the national hygienic standards for drinking water.

Table 3. The results of experiment for main chemical indices

Indices	Maximum	Minimum	Average	National Standard
PH	9.6	7.66	8.19	6.5 - 8.6
Degree of hardness	226			<250
Chloride (mg/L)	158.11	19.76	70.27	<250
Iron (mg/L)	0.20	unfound	0.136	<0.30
Manganese (mg/L)	<0.1			<0.15
Copper (mg/L)	0.055	<0.004		<1.00
Zinc (mg/L)	0.679	0.021	0.222	<1.00
Volatile phenol	unfound	unfound	unfound	<0.002

2.3.1.3 Toxicological Index

The results of the experiment showed that the indices, such as fluoride, cyanide, arsenic, phenol, mercury, cadmium, and Lead, were under the national standards.

Table 4. The results of experiment for the toxicological indices (mg/L)

Indices	Maximum	Minimum	Average	National standard
Fluoride	0.6	0.2	0.43	<1.0
Cyanide	unfound	unfound	unfound	<0.05
Arsenic	<0.02			<0.05
Phenol	unfound	unfound	unfound	<0.01
Mercury	unfound	unfound	unfound	<0.01
Cadmium	<0.003	unfound		<0.01
Chromium	<0.005	unfound		<0.05
Lead	<0.01	unfound		<0.05

2.3.2 The factors that affect the quality of received water

2.3.2.1 Filtering effect

Before filtering, the received water is turbid, and whether the indices of colour or of turbidity is higher than the national standards. After filtering, it turns clear.

Table 5. Comparison of observational indices before filtering and after filtering

Indices	Before filtering		After filtering	National standards
	5 minutes after rainfall	20 minutes after rainfall		
Colour	25	25	2	<15
Turbidity	>80	31	2	< 5
Smell	No	No	No	No
Visible substance by naked-eyes	Suspended substance	No	No	No

2.3.2.2 Disinfection

According to the results of the experiment for water quality, the content of bacterial and colon bacillus is much more than the national standards.

Table 6. Comparison between before disinfecting and after disinfecting

Indices		Maximum	Minimum	Average	International standards
Bacteria coefficient	Before disinfecting	2000	560	1100	< 100
	After disinfecting	30	1	11	
Conol bacillus	Before disinfecting	>230	>230	>230	< 3
	After disinfecting	< 3	< 3	< 3	

3 Benefit Analysis

3.1 Economic Benefit Analysis

3.1.1 Economic Benefit

There are 36 households covered by the rainwater-receiving project. The total storage capacity is 360 m^3, and total recycled water storage is 900 m^3/year. According to the price of desalination by electrodialysis (5 yuan/m^3), the benefit is 4500 yuan per year.

If it take one hour daily to carry water for one person in each household. 45.6 labor*day/household per year is saved. For 36 households, the sum is 1641.6 labor*day. According to 15 yuan/day for one labor, the benefit is 24624 yuan.

If added sideline income is 200 yuan/household. total 7200 yuan is saved. As the result, the total economic benefits is 36324 yuan per year.

3.1.2 Cost of the project

The average investment per household is 1200 yuan, the total investment for 36 households is 43200 yuan. If the life time of the project is 20 years, the depreciation charge is 2160 yuan (43200*0.05). The annual maintenance cost is 864 yuan (2% of the total investment).

3.1.3 Returns period

The returns period = 43200/(36324-2160-864)=1.3(year)

3.2 Social benefits and ecological benefits

The achievement of the project improved the hygienic condition. It provides the people, who used to drink salt water and dirty water ever before, with hygienic water. Diseases occurrence reduces, and the health condition is improved.

The project promotes courtyard cultivation. So It results in improvement of the ecological environment.

IMPROVING A KIND OF WATER HARVESTING SYSTEM IN NORTH - EAST IRAN

Ali Akbar Abbassi*

Abstract

An old practice of storing the rainwater in North East of Iran such as Jajarm plain is using Abanbar. In this paper a kind of Abanbar that is using in Jajarm plain is described. This system is studied and some problems such as sediment siltation and possibility of polluting are found. A modified type of Abanbar is recommended which has not abovementioned problems.

Introduction

Rainwater harvesting identified as one of the low cost option for rural water supply is still widely practiced in the world today.

The concept of collection and storage of rain water as old as have been recorded for many years ago. Rainwater harvesting is practiced in arid and semi - arid regions. Harvested water at the end of a rainy season sould be stored to use during the dry season. Harvested water is often used to supply human consumption or livestock weaering in remote areas where travel between there and springs or other available water sources is inconvenient.

The system should be occasionally maintained to obtain the maximum benefit and to prevent the further problems. Protection of harvested water from contamination is too important.

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Location ofthe study region

Jajarm plain is an arid region situated approximately between latitudes 55° 30′ and 56° 45′ North and longituds 36° 30′ and 37° 47′ East. This region situated in North - East of Iran as a part of khorasan province. Mean annual rainfall is about 132 milimeters and mean annual evaporation is about 3500 milimeters. Mean elevation from mean sea level (M.S.L) is 950 meters. The storms occure from March to May and November to December while dry season is from June to October. The storms often occure in high intensity.

Descripation of water harvesting system

In this region distance of villages is about 60 kilometers. There are some Qanat and spring in village that use for domestic water agricultural water. Between villages there are rangelands that use for stock raising. Since ranglands far from Qanat and spring. A kind of Abanbar use for water harvesting which show in fig.1. This system is normally built by masonary or local materils and bricks that coated with mortar of cement. The capaceity of the system is normally 60.000 literes.

A part of floodwater divertes from streams to Abanbar with a small ditch in this system.

Harvested water use during dry season for drinking and human consumption.

Advantages and Disadventages of the system

a. Advantages

1- Storage of considerable volume of rainwater for dry season in arid area that there are not spring, Qanat or other water sources.

2- Materials are in site, hence constraction costs is low.

3- Constraction procedure is simple

4- Water is cool in summer and water loss through evaporation is low.

5- Reducing of peak flood

b. Disadvantages

1- Sometimes flow depth in stream is not adequate to divert floodwater into conveyance ditch, hence the harvested water is not enough.

2- The eroded soils are delivered into the conveyance and Abanbar and cause sedimentation problems which will reduce their capacity.

3- There is the possibility to pollution the harvested water.

4- The materials that accumulate on the bottom of Abanbar can have siginficant impact on capacity of Abanbar and water quality.

Recommendation for improving system

The important componets that should be consider in preparing a rainwater harvesting system are catchment areas (size, soil, cover and slopes), collection and conveyance, sediment setteling basin, filteration and storage tank (Bocek, Yoo and Duncan 1991). Each component sould be carefully designed, constracted, operated and maintained for the maximum benefit. Quality of the harvested water from a catchment area should be considered when the water is used for human consumption.

a. Construction and operation

Because of diverted floodwater from stream depend on flow depth in stream and variation of bed profile stream, sometimes diverted floodwater is not adequate for human consumption, hence recommend that the Abanbar construct at the end of subcatchmen. To determine location of Abanbar an emprical formula are used for the determination of floods and flows into the Abanbar. In many cases, the follwing rational formula has been applied (chow, maidment and mays 1988)

$$Q = \frac{1}{3.6} C.\ I.\ A$$

where: Q= dishcarg m^3/s C= runoff coefficient. I= rainfall intensity mm/hr. A= catchment area in km^2.

For prevention of sediment into the system. should be prevented of soil erosion from catchment area. especially from the concentration flow area and constructing a sediment setteling basin before the inlet of Abanbar.

For using of storage water recommend that isntead of direct touch with water. should be used valve. The component of recommended system is shown in fig. 2.

b. Maintenance

The system should be occasionally maintained to obtain the maximum benefit and to prevent further problems. Maintenance should include cleaning sediment in the conveyance and Abanbar. It is recommended that the conveyance and Abanbar should be clean once time every years because Waller and Scott found that materials accumulate as sludge on the bottom of cisterns can have significant impact on cistern water quality (Scott and Waller 1991). and maintenance include repairing Abanbar, conveyance and intake.

Conclusion

Abanbar is a simple and suitable water harvesting system in arid area for human consumption. The ancient system have some problems such as sedimentation in conveyance and storage system and procedur of using water.

Some recommendation is proposed for improving system that if used for constraction and maintenance of system, efficiency of system is improved.

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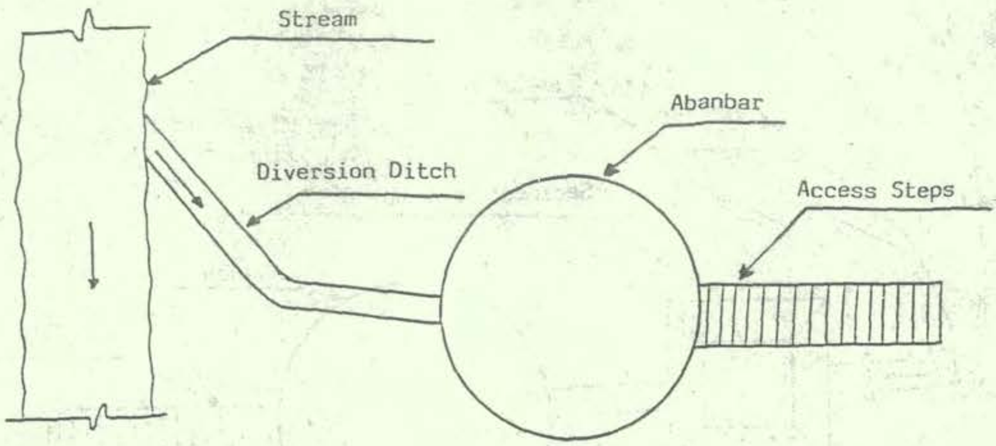

Fig.1-a-Typical Plan of Ancient Abanbar

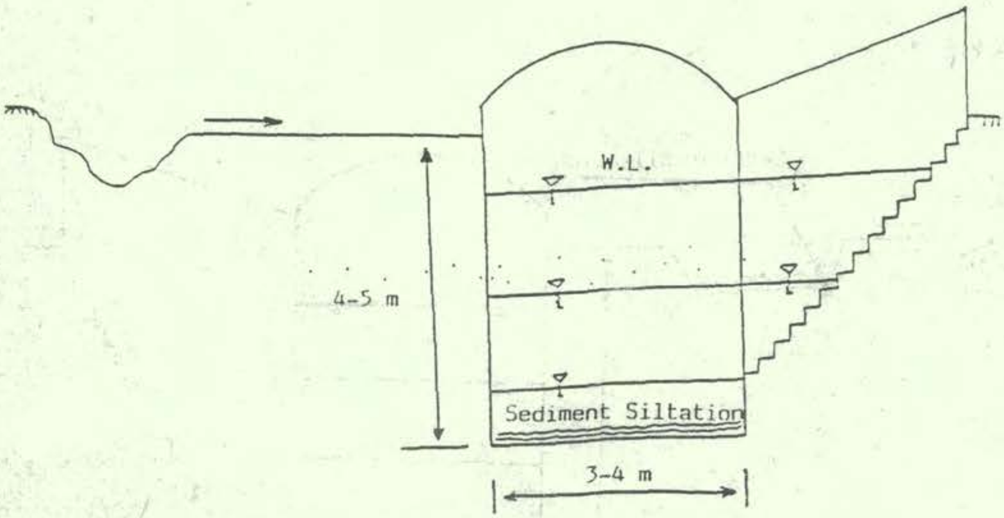

Fig.1-b-Typical Cross Section of Ancient Abanbar

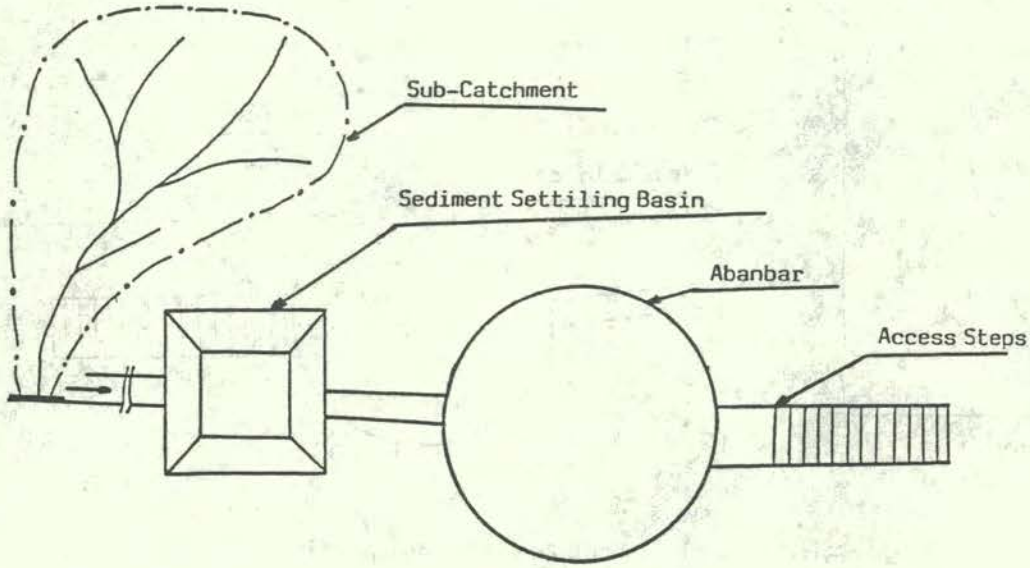

Fig.2-a-Typical Plan of Modified Abanbar

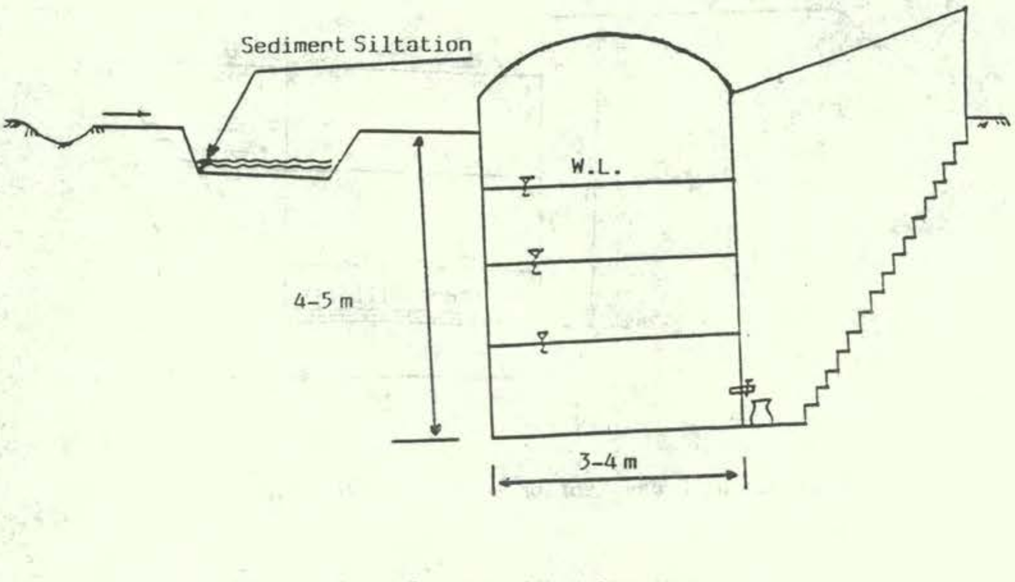

Fig.2-b-Typical Cross Section of Modified Abanbar

GUTTERING: BARRIER TO THE EFFECTIVENESS OF RAINWATER CATCHMENT SYSTEMS IN DEVELOPING COUNTRIES.

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INTRODUCTION.

Water harvesting can be applied in many locations in the world but is of particular importance in countries with Arid and Semi-Arid lands, where it may often provide the only feasible solution for an improved water supply. Its potential very much depends on climate hydrology, landscape, and vegetation.

In African Arid and Simi-Arid regions today, as much as 80% of the total rural population relies on unimproved traditional water points. These include shallow water holes, depressions among rock outcrops, ponds or lakes permanent or seasonal rivers, springs and shallow groundwater accessed by hand-dug wells.

Considerable potential exists to improve existing sources and better use the resource potential of an area. Yet these improvements often are not carried out due to lack oftechnical expertise and financial resources or because users are not organised to implement such improvements.

Rooftop and tank systems provide an on-site source of water supply next to homes or public buildings such as schools or health centres. They can be constructed wherever there are permanent settlements experiencing difficult water supply conditions. Usually they require roof areas of more than 30m² but even small areas can provide a partial supply to relieve some of the burden of fetching water. Roof top harvesting systems are comprised of the foof top as the catchment area, connected by gutters and pipes to astorage container. The most suitable rooftop surfaces are corrugated iron sheet, although tiles and asbestos sheet roofs can also be used. Thatched roofs pose problems as the run off is lower and generally of low quality. It is also more difficult to fix gutters to thatched roofs. The water collected from thatch is usually coloured, unattractive and more often contaminated.

Commercial gutters are usually expensive, while home made gutters of wood or bamboo are usually inefficient. Recently in Uganda, North Kigezi Diocese Water Programme pioneered construction of simple, improved low-cost gutters and hangers from iron sheet and wire. Local production of gutters need to be explored further as it may contribute significantly to the effectiveness of programmes and offer suitable source for generating income. Guttering systems made from bamboo have also been tried widely in some rural areas and has been proved to be effective.

However in general, very little concern has been shown for gutters internationally. Their purpose and installation are usually not part of the project and they are usually left to the owner to supply and install. The result is that gutters are poor, leaking or inadequate and valuable water is wasted. In low rainfall areas, collecting all the rain available is crucial to delivering all the benefits of the system. In high intensity rainfall areas, considerable attention should be put on ensuring that the gutters are large enough to handle intense showers.

The gutter frequently inhibits the performance of rain-water catchment system. Rainfall intercepted by the roof is lost in transmission to the cistern. If the gutter is blocked by debris, the problem is one of maintenance. If the gutter is improperly installed, the problem is one of construction. If the gutter is fundamentally undersited, too flat or too logn, the problem is of design.

TECHNICAL FEASIBILITY.

Even in the arid regions of Africa, there is often sufficient water available to supply drinking and agricultural needs through the dry season if only rainfall and run off are captured and stored for later use.

The technical feasibility of the various water harvesting systems largely depends on the skills of the Community, the availability of local materials and labour, and for large systems on availability of equipment . In assessing the technical feasibility of a particular systern, it is very important to take into account the experience already acquired to avoid repeating mistakes previously made by others.

The quantities and types of materials required for the various options usually do not pose sericus problems, perhaps with the exception of roofing materials, cement and chicken wire. Checking of a detailed materials inventory against the local contract suppliers or natural resourse surveys will point to any shortfall.

Commercial gutters are usually expensive, while home made gutters of wood or bamboo are usually inefficient. While the manufactured metal gutters are expensive but are more efficient. Therefore a balance must be reached.

Many designs of water harvesting systems are simple, labour intensive and require a limited amounts of tools. Still checks should be made to see whether even these simple tools are available. Wherever possible labour intensive inputs should be optimised and simple tools and instruments should be used.

Most water harvesting systems, except for individual roof catchments are communal systems and require organisation of the community to manage and maintain the system and avoid the risk of contamination. If no history of community based management exists, this may prove to be difficult and it may even be better not to install the system until community management systems have been proven in a piyot area.

Identifying potential technologies

Insight into local conditions will provide opportunity to identify the most suitable technologies which could be applied. If experience exists with traditional harvesting techniques, dialogue with users will give an indication of their appropriateness and acceptance. Often different technologies may be technically feasible, but not all may be equally appropriate.

The overall assessment of the project area can only provide a general indication of the technologies which can be applied. The ultimate technology selection will largely depend on the skills, capacities, needs and preferences of the individual communities. It is essential, in order to assure system sustainability, that communities are provided with information concerning maintenance requirements and financial implications for each of the technology options considered. Preferably a range of technologies and options should be identified from which the community can choose the most feasible and affordable option closest to their needs.

Technical considerations

A careful designed and constructed gutter system is essential for any roof catchment system to operate effectively. A properly fitted and maintained gutter- down pipe system is capable of diverting more than 90% of all raiwater run off into the storage tank, the remaining being lost through evaporation, leakage, rain-splash and overflow. In design calculations, it is usually better to assume a runoff coefficient of 0.8 for roof catchments, lower values(0.2-0.6) apply for ground catchments. All too often both individuals and projects overlook the importance of guttering . This frequently results in only the runoff part of the roof being utilised. In other instances gutters have not slopped in the direction of the tank and down pipe or have rusted through and not been repaired.

Even where roofs have well constructed and maintained gutters, if they are too small, considrable quantities of runoff may be lost due to overflow during torrential storms. In many tropical climates intense convectional rainfall accounts for a large proportion of total annual rainfall. A useful general rule is that 1cm2 of guttering is required for every m^2 of roof area. A $100m^2$ roof area would require a gutter cross-sectional area of $100cm^2$. In other words, a 10cm x 10cm gutter would suffice.

A greater problem than gutter size is probably hanging gutters securely so that they do not sag or fall during heavy rainfall, and keeping them positioned so that they catch both gushing flow and dripping flow from the edges of the roof. Ensuring adequate slope for the entire system so that water does not stand and damage gutters or attract mosquitoes, is usually important.

CONSTRUCTION GUIDELINES FOR PLACING GUTTERS

Size and shape

The gutter must be large enough to channel water from heavy rains without overflowing. The shape is also important. If it is too shallow it may overflow. If it is too narrow the water from the roof may shoot over the gutter and be lost. For most roof catchments a gutter with a cross-sectional area of $70-80cm^2$ is sufficient for the range of slopes recommended here. The minimum recommended width for a square and semicircular gutters is 8cm. For a triangular shaped gutter the width should be at least 10cm. The minimum recommended depth is 7.0cm for any gutter.

Slope

The gutter should be placed at a uniform slope to prevent water from pooling and overflowing the gutter. For most roof catchments the slope should be in range of 0.8cm/meter to 1.0cm/meter.

Location

The gutter must collect all the water running off the roof during light and heavy rainstorms. To achieve this the gutter should be located so that the roof overhangs the gutter by 1cm or 2cm and the gutter extends beyond the edge of the roof by at least 7cm.

Supports

The gutter must be well supported. The number of supports depend upon the type of guttering material but it is recommended that most gutters be supported at least every 50-60cm. The simplest means of support is by tying wire round the gutter and fastening it to the roof. The guttor can also be nailed to the roof or be provided with wooden supports underneath.

Joints

All joints should be leak proof. Joints can be sealed using tar, pitch or a similar material. Strips of plastic can also be laid in the gutter to prevent leakage. The joining material should be one which does not contaminate the water.

GUTTERING MATERIALS

The gutter material selected should be light in weight, water resistant and easily joined. To reduce the number of joints and thus the likelihood of leakages, a material which is available in long straight sections is preffered.

Gutters and downpipes can be made of a variety of materials, wood, metal, plastic and bamboo being examples. Those made from organic materials will require more frequent replacements.

Manufactured metal Gutters

Aluminium or galvanised sheet metal guttering is the technology of choice in most areas in developing Countries. The gutter section are joined with special brackets and hung with metal straps or long spikes with sleeves which are driven through the upper part of the gutter's width and into wood backing.

In the open market, galvanised sheet is slightly less expensive but tends to corrode more quickly unless coated with high quality rust-resistant paint. Hardware for joining and hanging the system also is an additional cost.

Thus higher costs or un availability are likely to eliminate manufactured metal gutters as possibilities in most rural areas of developing Countries.

Bamboo as a local guttering material

Of all the locally available materials like split palm and wood boards, bamboo if available offers the best choice. The bamboo to be used should be thick(15-20cm) and strong. It can be simply split lengthwise with a machete and the diaphram removed with a machete or knife. Bamboo can be cut in the lengths needed and overlapped at supports and tied firmly.

The gutters can be supported by simple poles with a V notch at the top and burried about 30cm in the ground to make them stable. The gutters are tied on the tripods using wire or locally available heavy string. Each pole or set of three poles(making up a tripod) in a row is cut shorter than the last in order to ensure a slope into the filter and storage vessel.

FOUL FLUSH AND FILTER SYSTEMS

Although not absolutely essential for the provision of portable water in most circumstances, when effectively operated and maintained, foul flush and filter systems can significantly improve the quality of roof run-off. If poorly operated and maintained however, such systems may result in the loss of rainwater runoff through unnecessary diversion or overflow and even contamination of the supply. In very poor communities where the provision of even a basic roof tank represents a substantial up grading of the water supply, the addition of an elaborate foul flush mechanism to the catchment system would add unnecessary expense and complication to the system and could even risk jeopardizing its effective use.

However in some locations where roof surfaces are subjected to a significant amount of blown dirt, and dust or where particularly good quality water is required, a foul flush system can be very effective. Numerous devices have been developed, but they can be generally be grouped into two categories: manually operated and automatic systems.

Manual system

Usually lower cost and easier to devise, these will be the obvious choice in most poor areas. An attractive and simple approach is to attach the down pipe so that it can be propped in the "waste position", then propped in the tank inlet after the roof is clean. Open trough downpipes like split bamboo can be suspended beneath the outflow of the gutter with wire or local fibre; closed down pipes with a flexible joint can be moved in the same manner.

The task of moving the downpipe can be performed consistently by any one including children. People in developing Countries tend to be conscious of the precise moment it begins to rain because drying laundry must be brought in.

Another simple technique for tanks with small covers is to leave the cover on, blocking the flow of water into the tank, until the roof is clean. A similar approach(for very small containers like jars) is to move the container in position under the down pipe only after an appropriate interval. Both these routines may be objectionable from a public health point of view; they cause mud and pools of standing water at the tank. Nevertheless, they may be the method of choice where a more complex down pipe and foul flush arrangement is impracticable.

Automatic systems

Automatic roof cleaning devices are available commercially only in a few areas, but they may be fabricated from local materials in some situations. One simple automatic device is a container or receptacle for dirty water called a "roof washer". After the roof washer receptacle screen is usually attached between the downpipe and the foul flush container, to keep out leaves and other large pieces of debris that would float on the water in the receptacle and clog the overflow pipe to the tank.

O.1 or full tins, used for harbouring water in many areas, might be converted to roofwashers. Midwest plan service(1979) recommends about 10 liters of roof washer receptacle capacity for every $30m^2$ of roof area. Other sources(eg. Dooley, 1978) say a roof washer should be big enough to hold the first 20 minutes of run off.

A problem with such a simple device is that when the beginning of a rainstorm is torrential, water will pour vigorously into the roof washer from the down pipe, stirring dirt and bird dropping so that they are carried through the overflow pipe into the tank instead of settling at the bottom of the receptacle. To inhibit this stirring action, a baffle can be mounted crossways, instead the roof washer and/or a vertical screen can be installed dividing the down pipe side from the tank inlet side. Roof washers must have a drain and a removable cover so that they can be cleaned after each rain.

More complicated "automatic" foul flush devices tend to require more attention and stronger structures with more hardware mounting in the downpipe.

CONCLUSIONS AND RECOMMENDATIONS

Design and construction specification and drawings should be easily available to the people. Fabricated items like gutters, downpipes,diversion systems as well as roof washers should be available readily. All items must be of good workmanship with-out costing too much money.

Successful implementation of rainwater techniques will depend a great deal on how well the people are conditioned to receive these new ideas. Conducting regular training programmes for the common people in a particular area will greatily benefit them.

If the gutter design is to be improved, technical impetus must come from a higher level. Regional or national authorities must take initiative in determining and publishing appropriate standards in understandable form.

Design is but one portion of the engeneering problem. Socio and economic considerations of gutter systems must be taken into account. Gutter technology must be appropriate to those who employ rainwater catchment. Proper design must combine sound hydranlic theory with achievable implementation.

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EXPERIMENT STUDY OF STORMEWATER DRAINAGE PIPES OF INFILTRATION TYPE*

Wang Wenyuan[1]　　Ji guixia[2]

ABSTRACT

Trying to use a new kind of permeable stormwater drainage system,which let rain water permeate into soil layers to replenish groundwater and reduce flow rate in drainage pipes,will bring about significant economical and environmental benefit. In this paper the behave experiments of perforated drainage pipes,as a part of the system,were made and the relationship between free,steady flow rate of infiltration water and its influential elements was studied. Equations of free,steady flow rate of infiltration water of unit length under different perforating conditions were deduced. This report provide reference for design or study of permeable stormwater drainage system.

KEYWORDS

Rain water utilization; drainage system; experiment study; infiltration.

INTRODUCTION

Accompanied by urbanization,the pavement or impermeable area is getting larger and larger,the infiltration volume of rain water reduces and the groundwater receives less water to replenish itself. On the other hand the runoff increases,the construction cost and flooding risk of stormwater drainage system increases.In the recent thirty years many developed countries have practised some stormwater retention or infiltration works and some legislation,which have bring about significant economical and environmental benefit(Li,1992;Xue,1989).At present many cities in our country are expending and innovating their large number of old drainage system.'Direct drainage',the traditional model,still dominates the design of stormwater drainage systems. So there is the need to start a study of stormwater infiltration and drainage system(SWIDS) that includes permeable pavement,permeable stormwater inlet and special infiltration well,permeable stormwater drainage pipe etc. SWIDS lets rain water infiltrate to replenish groundwater while rain water is draining to the water bodies,where the water table is lower and the permeability of upper soil is higher.

There is a series of problems which should be resolved for designing a SWIDS,e.g.hydrologic analysis,hydraulic design,water quality control,environmental evaluation etc. In this paper infiltration experiments of perforated stormwater drainage pipes are conducted to study the relationships among the infiltration flow rate and its influential elements.

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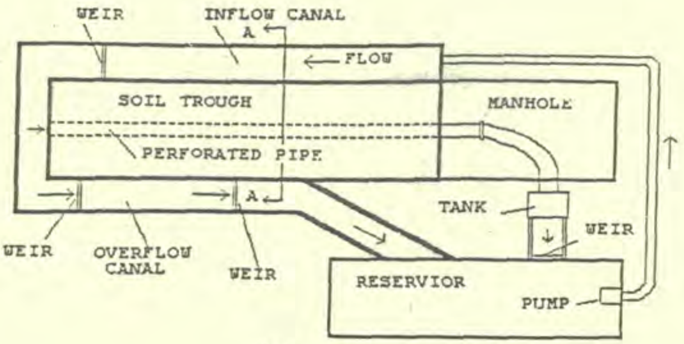
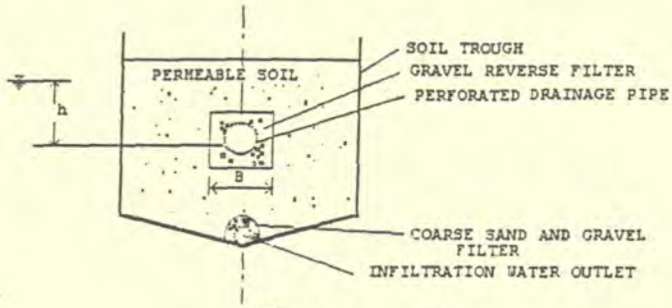


(A) Plan view



(B) Section AA

Fig.1 Experiment system

EXPERIMENTAL SYSTEM

The experimental system, as shown in Fig. 1, includes four parts: water supply system, water transportation system, soil trough and perforated pipe with infiltration installation, and measurement equipment.
In the system the perforated drainage pipe is a plastic pipe, 4 m in length, 10 cm in diameter (and surrounded with gravel reverse filter). The permeability coefficient of the soil is $5.6 \cdot 10^{-2}$ cm/s.

RESULTS

1. For perforated stormwater drainage pipe with insufficient openings

1.1 Steady infiltration flow rate of unit length pipe increases along with the hydraulic head on the openings logarithmic-linearly , as shown in Fig.2.

1.2 Steady infiltration flow rate of unit length pipe increases along with opening area logarithmic-linearly when the opening area is less than a certain amount, while the flow rate keeps a certain constant when the opening area is larger than the certain amount. We may define the certain amount of the opening area as critical opening area F_{cr}. The F_{cr} decrease while the hydraulic heads increase. This is shown in Fig.3, Fig.4 and Fig.5.

1.3 According to the data collected when the total area of openings is less than the critical opening area F_{cr} the relation among steady infiltration flow rate, hydraulic head on the openings and total area of openings in the unit length pipe can be expressed as a bivariate lineal regression equation(Li,1989)

$$\log q = -0.270 + 0.385 \log h + 0.898 \log F \qquad (1)$$

where q is the steady infiltration flow rate of unit length pipe($m^3/s \cdot m$),h,shown in Fig.1(B), is hydraulic head on the openings(m) and F is the area of openings of unit length pipe(m^2/m).The whole interrelation coefficient of the equation with the measured data is 1.0003.
Equation(1) can be rewrited as

$$q = 0.537\ h^{0.385}\ F^{0.898} \qquad (F<F_{cr} \text{ or } F=F_{cr}) \qquad (2)$$

and in general

$$q = c\ h^{0.385}\ F^{0.898} \qquad (F<F_{cr} \text{ or } F=F_{cr}) \qquad (3)$$

where c is a comprehensive resistance coefficient related with the total area and shape of perforated openings, character of reverse filter and permeability of the surrounding soil(in this experiment c=0.537).The others are the same as before.
The critical area of openings F_{cr} is varied with h and can be determined from Fig.3,4,5. The range of the ratio of critical area of openings to the surfacearea of the drainage pipe,named as critical opening rate,is about 0.1~ 0.13 %.
2.For perforated drainage pipe with sufficient area of openings

Under the condition that the area of openings is larger than the critical one,the steady infiltration flow rates increase along with the hydraulic head

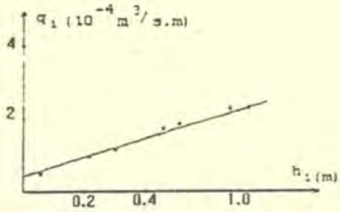


Fig.2 Relation between infiltration flow rate and hydraulic head

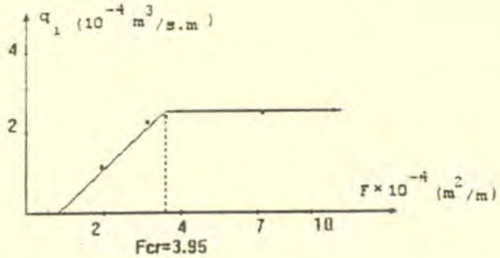


Fig.3 Relation between infiltration flow rate and total area of openings under hydraulic head 0.23m

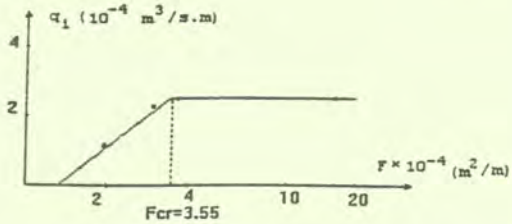


Fig.4 Relation between infiltration flow rate and total area of openings under hydraulic head 0.3m

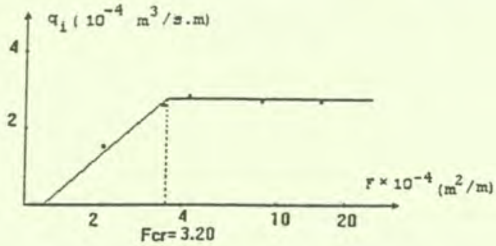


Fig.5 Relation between infiltration flow rate and total area of openings under hydraulic head 0.5m

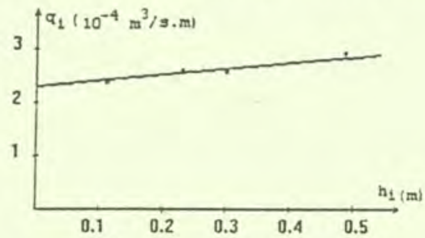


Fig.6 Relation between infiltraation flow rate and hydraulic head

on the openings linearly while other conditions remain unchanged,as shown as Fig.6.

The relation between infiltration flow rate and hydraulic head can be expressed as a lineal regression equation

$$q = 2.308 \cdot 10^{-4} + 1.430 \cdot 10^{-4}\ h \qquad (4)$$

where q and h are the same as ones in equation(1). The interrelated coefficient is 0.998.Considering the other influential elements in this experiment ,i.e. permeability of the surrounding soil $K=5.6 \cdot 10^{-4}$ m/s and the dimension of the perforated drainage pipe with its reverse filter surrounded B=0.3,shown as in Fig.1(B),the equation(4) can be rewrite as

$$q = K(1.373\ B + 0.255\ h) \qquad (5)$$

and in general

$$q = K(\ m\ B + n\ h)$$

or

$$q = m\ K(\ B + p\ h) \qquad (6)$$

where m,n,and c are coefficient,in this experiment m=1.373,n=0.255 and p=0.186. The others are the same as before.

CONCLUSIONS

Depending on the critical area of openings F_{cr},the rain water infiltration through perforated drainage pipe can be divided as two types,the infiltration of insufficient openings and the infiltration of sufficient openings. Because the F_{cr} is generally small most of infiltration through perforated pipes belong to the latter type and can be expressed as equation(6). In fact there is difference between the experiments and practical projects.Some adjustment of the coefficient in the equation(6) are needed when designing a infiltrated stormwater drainage system.This report only provides a foundation, so more study works should be done in the come days.

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Rainwater Utilization in Izumo Dome and some Reformations for Automatic Rainwater Catchment System

Kouichi TAKEYAMA * , Isao MINAMI **

ABSTRACT

This paper dealt with abnormal precipitation in summer in 1993, 1994 and some rainwater utilizations in Izumo Dome in Shimane Prefecture in Japan. Izumo Dome is a hybrid structure composed of laminated wooden beam arches and it is the biggest wooden construction in Japan. And it is used for multi- purpose events in rainy district, and the rainwater and groundwater are used for many objects , and these system has saved much money and worked for making the active community in the district.

Nextly , this paper studied on the development and reformation for the automatic rainwater catchment and distribution system. At first, some effects of syphon and filter were examined for improving the water quality in the tank, and secondly the automatic water distribution by the photovoltaic cell by solar energy, pump and timer were added. And the appropriate system of automatic rainwater utilization system were examined for the water use as in green house or drinking .

I INTRODUCTION

In the summer season of 1993, we had many rainy days in many places in Japan but in 1994 very severe lack of rain water. And many big cities as well as rural districts had to restrict the municipal water supply, and farmers did for the irrigation water, too. And one of the most severe cities is Matsuyama City , Fukuoka City and Takamatsu City. And the utilization of rainwater gathered much attention as Tokyo International Rainwater Utilization Conference that was held in Sumida-Ku in Tokyo August 1994. Sumida-Ku has the Kokugikan that is the center hall of Japanese Sumou Wrestling, that has rainwater utilization system, and many Rojisons. Rojison is a small scale rainwater utilization system that gather rainwater by roof of house and make storage in tanks in underground and pump up by manpower. And with this water, alley even blind alley may become a small park.

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This district has very severe experience that it had a very big earthquake as Kanto Earthquake that happened Sept. 1st 1923, then about 142 thousands people died with big fire. This time big earthquake caused suspension of water supply, and this made more disastrous fire. So people of this district are so eager to storage water close to them and make alley, park and refugee.

And the Symposium of Japan International Rainwater Catchment Systems Association was held in Takamatsu City in October 1994 with much attention of many people. Because in Takamatsu City, the average annual precipitation is about 1200mm, and this data shows the typical case of the light precipitation, and there are so many Tameikes (irrigation ponds) near the city, and this city has very famous park that is called as "Ritsurin Kouen Park", and many trees and flowers in the park were blighted in last summer .

Here we investigated, at first, the possibility of the utilization of rainwater and the suitable volume of the tank by the precipitation data of last summer season at Takamatsu city and Matsue City, and secondly , the rainwater utilization in Izumo Dome in Izumo City in Shimane Prefecture in Japan , and it's contribution to the regional development, and thirdly, the some reformations for the improvement of the quality of the water from the rainwater catchment tank with the the automatic rainwater catchment and distribution by the photovoltaic cell with solar energy that has pump and timer.

II . Some abnormal precipitation cases of summer in 1994

About the precipitaion in summer season in Japan, we had very extreme data. In 1993 we had abnormally much precipitation and abnormally light precipitation in 1994.

Japanese Ministry of Agriculture and Fishry announced that the damage of agricultural products was more than 77 billions yen and the damage of rice production was about 25 billions yen in the summer of 1994 .

One of the most severe lack of rainfall and restriction of water supply was happened in Matsuyama City in Ehime prefecture. Here the restriction of water supply began the July 26th and ended November 26th, and in the most severe conditions, water was supplied only 5 hours in a day (from August 22th untill October 22th). And similar severe conditions happened in Fukuoka City, Takamatsu City, Kurashiki City and others.

Fig.1 shows the location of these cities with average value of annual precipitation. And Matsuyama City, Kurashiki City and Takamatsu City are located around the Seto Inland Sea. And Matsuyama city locates 120 km west-south west direction from Takamatsu City in Shikoku District.

In the case of Matsue City, and near this city, many rice fields were blighted as photo 1 by the lack of water. The population Matsue City is about 140 thousand but the damage of the tree and flowers in the street was broadcasted as 940 thousand US dollars in Newspaper.

Now we had some data as monthly rainfall data in Matsue and Takamatsu Cities in Summer Cases in 1993, 1994 and average value in Table 1

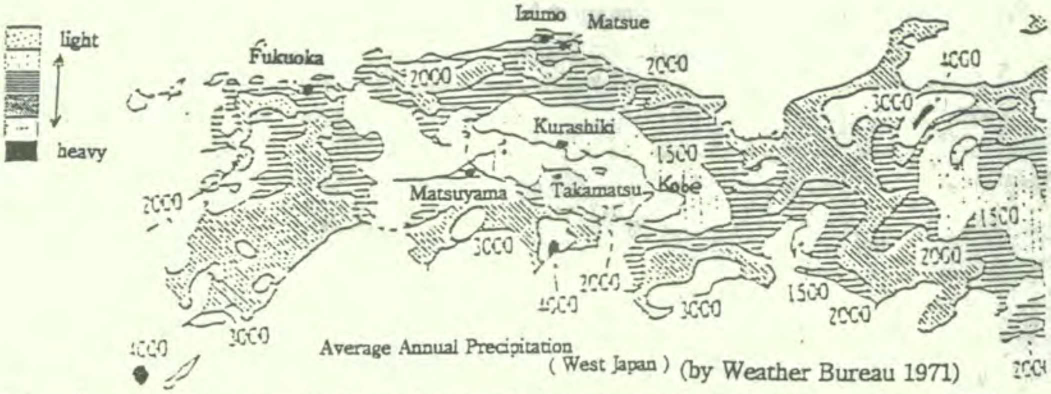
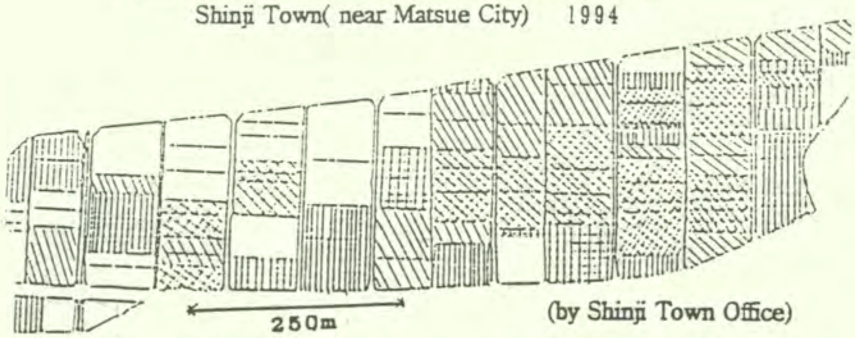


Fig. 1 Locations of many cities that had severe lack of water with average of annual precipitation.

Photo 1 Blighted rice field August 19th at Ogida in
Shinji Town(near Matsue City) 1994



Blighted ratio	Area	Blighted ratio	Area
100%	591a (26%)	30～50	218a (10%)
70～100	500a (22%)	0～30	579a (25%)
50～70	392a (17%)	Total	2280a

Fig.2 Blighted ratio in Ogida rice field August 19th 1994

Table 1 some data as monthly precipitation in Matsue and Takamatsu Cities
in Summer Cases in 1993, 1994 and average value mm/month

	Matsue City			Takamatsu City		
	average	1993	1994	average	1993	1994
June	196.0	344.0	139.5	164.4	317.5	88.5
July	268.3	423.0	8.0	129.8	320.5	58.5
August	145.4	284.0	95.0	93.5	190.0	26.0

In Japan, June and the first half of July are usually included in rainy season. And the annual precipitation of Matsue City is near the average one of Japan as 1,800mm. Here it may be proposed that if we prepare the rainwater catchment system by a roof of a house with the area of 100 m^2, this may gather as 180m^3 of rainwater in a year, so in June at Matsue City we can gather 14m^3 last June. And in Japan a person uses about 250 L(0.25m^3) of water supply and a family of 4 members uses about 220 L of water in watercloset, and with bath about 400 L is used. " Why we use the drinkable clean water purified with high cost into the watercloset or garden or small farm ?!!"

III Outline of and the Rainwater Utilization there

3-1 Outline of Izumo Dome

Izumo Dome is a multi-use dome of a hybrid structure, composed of laminated wooden beam arches, teflon membrane, and steel tension members. The laminated arches were producted by Bohemia Inc. in the United States. And it is the biggest wooden construction with semi-open perimeter with operable windows.

Table 2 Dimensions of Izumo Dome (by Izumo Dome Office)

Land Area	Dome Site	31,487 m^2
	Park	61,342 m^2
	Total	92.829 m^2
Diameter at Column		140.7 m
Height	Dome Height	48.9 m
	Maximun Height	53.9m
Arena		
Dirt Ground		11,140m^2
Turf Track		2,269m^2
Observation Stand		2,297m^2
	Capacity	5,000 person

Usually we have many rainy days in this district especially spring, fall and winter, and many events were cancelled by the rain. But after the opening of this Dome in March 1992 , multi- purpose events were held with high frequency against rainy days. And the average event-opening time is 9.9 hours in a day in 1993. And rainwater and groundwater are used for closets, ground and Japanese garden. And this system has saved much money and Izumo Dome works for making the active community in the district.

And Izumo Dome's dimension is shown as Table 2 .

Photo 2 Izumo Dome and it's Japanese garden (by Izumo Dome Office)

3−2 Rainwater and groundwater utilization in Izumo Dome

In Izumo Dome, rainwater is gathered by it's big roof into big tank of 200m ^{3} and after filter 70m3 of water is storaged in the another tank and used for miscellaneous uses as water for ground, Japanese garden and closet without drinking. And water for drinking and washing hands is supplied by municipal goverment. July 1994 Izumo Dome could not gather rainwater but plentiful ground water was pumped up. Data of the utilization of rainwater and groundwater is as Table3 , and about 2 million yen has saved for water cost in a year.

Tabel 3 The utilization of rainwater and groundwater in Izumo Dome in Shimane
(from March 1993 to Februaly 1994) (by Izumo Dome Office)

Utilization of rainwater and groundwater 12,955m ^{3} (1,080 m ^{3} /month)

Water cost by municipal goverment

first 10m ^{3}	x ¥115	= ¥ 1,150
next 10m ^{3}	x ¥119	= ¥ 1,190
〃 30m ^{3}	x ¥129	= ¥ 3,870
〃 50m ^{3}	x ¥140	= ¥ 7,000
〃 980m ^{3}	x ¥129	= ¥47,980
discount with exchange rates	Δ ¥1,890	
	total	¥152,300

annual saved cost of water by municipal goverment

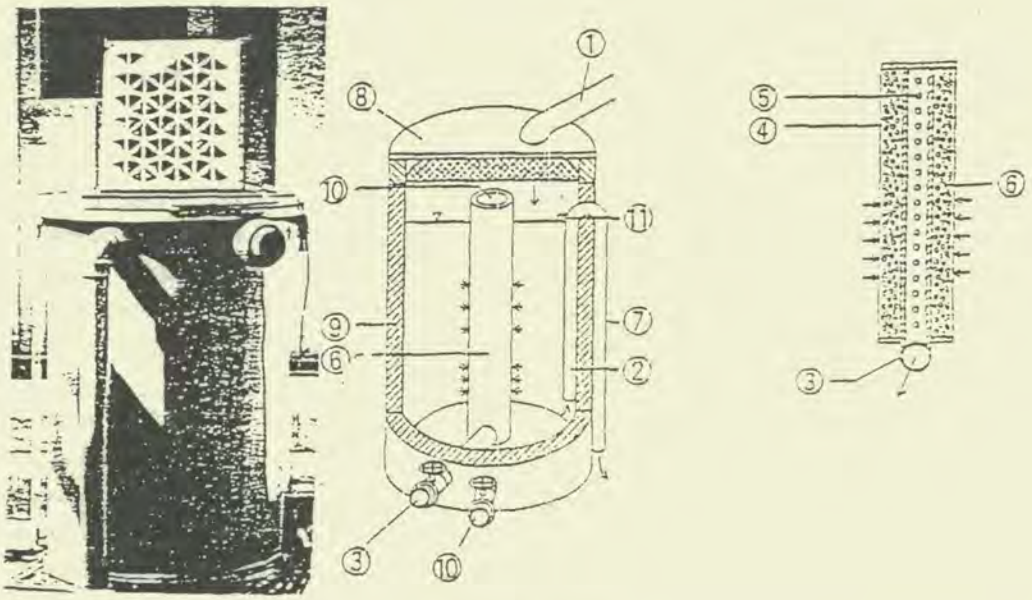
152,300 x 12months= ¥1,827,600

Ⅳ **Automatic rainwater utilization System**

Photo. 3 and Fig.3 is the automatic rainwater utilization sytem that is set near the green house or water use facilities. At first rainwater is gathered by the roof and storaged in the covered tank that prevent sunshine and insect. Nextly solar power by the photovoltaic cell by solar energy that has pump and timer was added to supply the water up to water use facilities.

We have developed some facilites as the " Selective drainage of dirty water near bottom by syphon automatically " and "Drainage hole" of surface water with oil and air and some dust by filters. Because many places as in Iejima island in Okinawa Islands gather rainwater by roads and airstrips , so many dust and oil were mixed with rainwater, then these facilities
drainage the dust in bottom water and oil in surface water simultaneously, and automatically.

Nextly tight cover that prevent sunshine and insect was set, because planktons , algae and mosquito should not generate and multiply.



① Inlet pipe if rainwater
② Selective bottom water drainage syphon
③ Outlet pipe
④ Outside plate wih many holes
⑤ Inside plate with many holes
⑥ Filter
⑦ Automatic syphon
⑧ Cover that prevent sunshine and insect
⑨ Tank
⑩ Drainage pipe
⑪ Drainage hole of surface water with oil and air

Photo 3 and Fig. 4 Automatic rainwater utilization sytem and structure of storage tank and filter

Thirdly rainwater is improved by a filer of charcoal or limestone or carbonized chaff and net , and some effect of these materials were compared against acid rainwater .

And this time the solar array (cells) , battery ,motor, pump and timer was added . Then rainwater was storaged, purified and irrigated to flower garden and paddy field automatically .

In this case about 30 liters of water is sprinkled up to flower garden in a day. Then the quantity of water is controled by the set of time of operation of pump and motor. And now the effectsof the materials of filter as mesh size of microfilter and boiling effect for the sterilization of colon bacillus etc. are under investigation , bacause we want to get some bottle of drinking water from the rainwater.

Here only a little part of the storage tank is made into drinking water, and not the much part of the tank, so we could design the appropriate area of solar array and battery size from the test and investigations. In this system rainwater was gathered from the drainage trough of the experimental room, then the total cost was about ¥300,000 and with bigger tank , wider area of solar cell, stronger battery and expensive filter, it becomes more higher cost.

Table 4 Dimensions of automatic rainwater utilization System

1	Tank	volume 180 L, plastics
2	Solar cell	12V , max current 0.61 mA
3	Pump	1.5L/min (2500rpm) 3.5Kg/cm ^{2}
4	Motor	12V , 40 W
5	Timer	OMRON
6	Battery	12V 4AH(bike battery),or 12V 28AH(car battery)
7	Filter	limestone, active carbon ,zeolite and micro filter
8	Boiling pot	12V ,13A 600cc about 20−30 min for boiling

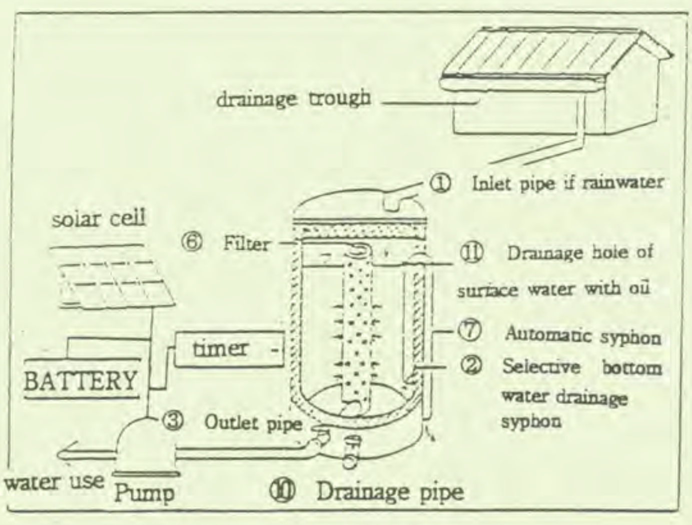


Fig.5 Scheme of automatic rainwater utilization system

V Result and discussion

Automatic rainwater utilization system as this proved very high function as to storage clean water by excluding the dirty water at upper and down part of the tank simultanesously and sprinkle up to the water use facilities automatically by solar energy when the energy are very powerful one. Even very hot and no rainy summer as 1994, water for green house or small farm and park could be supplied in one or two months by setting bigger tank and roof. And against acid rain, too, the reformation of the water quality could be done by using appropriate filter as limestone, zeolite and active carbon. And these materials should be chosen with the aim of water use. Moreover to reform water quality drinkable ,it's need to get rid of bacilluium, as colon bacillus with the microfilter of 0.45 μ m with ϕ 47mm. But to adopt such method to get some water by such method,we need big pressure or sink power by solar energy. Then to get drinkable water, boiling the water in a small pot by solar energy and battery was effective.

Aknowlegement

January 17th 1995 Kobe City and many cities near Kobe in Hanshin district had disastrous big earthquakes and this caused big fire, and with the destruction of the "life line" as water supply, gas , electric power supply and trafic means, about 5,000 people died. In Japan to find a suitable site to construct new dam to gain new water resource became difficult, and the dam site became far from water consumers. And these long and complicated "life lines " become so weak against earthquake and other disasters. Here the popularization of the automatic rainwater catchment and it's utilization system with solar energy with appropriate filter and to get clear quality of water near our living place, and not to construct big dam in remote place should be promoted for the environmental conservation. And such system should be surely world wide hopeful technique.

At ending this paper, sincerely express much thanks to Mr. Hara the chief of section at Izumo Dome Project Office and Mr. Yoshioka the chief of section of Industry of Shinji Town Office ,they presented us many valuable data.

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ANALYSIS OF PLANNING, DESIGNING AND CONSTRUCTION OF RAIN WATER UTILIZATION PATTERN AND EFFECT IN HULA MOUNTAIN GRASSLAND OF XINJIANG

Han Xiankun*

1. General Conditions of Hula Mountains, Necessity and Forms of Rain Water Utilization

Hula Mountain grassland is situated in the southern piedmont of Tianshan in Xinjiang, about 30km north of the Korla city with elevations of 2000 to 3400m. The available grassland covers an area of 968 sq. km where the natural grass is of high quality. Annual average precipitation in mountain area is about 241mm, and summer rainfall amounts to 186mm, accounting for 69.7% of the year's total. Summer rainfall interval is 7 to 10 days.

The existing problems in Hula Mountain grassland utilization are mainly found as uneven distribution in water and grass. In places where water is available grass is inadequate and vice versa. In some places it would take 2 to 3 days or even more days to go there and back for obtaining drinking water for man and animals. This has seriously affected grazing and grassland utilization.

In order to cope with this issue, the author, based on local people's experience, puts forward schemes for improving impoundment construction in mountain areas for providing drinking water for man and animals as well as proposals for their implementation. In addition, local labours were also organized by the author himself to build more than a dozen reservoirs in the mountain areas. Facts proved that impoundment reservoir construction is a proper engineering measure in solving drinking water issue in mountain areas because they are simple to be operated, cost-saving and high-benefitted in providing drinking water for man and animals in addition to the improvement of grassland utilization rate. Hence it is quite worthy to be popularized. Pertinent technical issues in reservoir construction are stated in the following text.

2. Highlights of Reservoir Types and Planning for Providing Drinking Water for Local People and Animals

2.1 Types of reservoirs used as drinking water source for man and animals

Three types of the above-mentioned reservoirs are identified. Type one involves damming in gullies on mountains which is

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similar to a dammed reservoir, being also referred to as damming impoundment. Type two involves in artificial excavation of reservoirs on open ground where runoff flows through, also called excavating impoundment. Type three refers to rock pits which are explosed on rocks by using natural terrain, or to rock pit reservoirs which are built by damming in outlet of a dustpan-shaped rock to form a pit. The first two types are that with permeable layer on bottom of the impoundment whereas the latter one with inpermeable layer.

2.2 Characteristics of mountain impoundment reservoirs used as drinking water source for man and animals

(1) Drinking-water-dominated for man and animals;
(2) Locally built with local available materials and for local use and not for diverting water to other places;
(3) Designing and construction adaptable to difficult conditions of labour inadequancy, poor transport facilities and uneven distribution of building materials in mountain areas.

2.3 Major planning arrangements of impoundment reservoirs used as drinking water source for man and animals

(1) Reservoirs should be located in proper places of grassland and along grazing route where water source is deficient;
(2) Collecting area of considerable extent or water source (e.g., spring water) should be guaranteed. Since there are plentiful of rainfall in mountain areas and capacity of reservoir is by no means large, this particular condition can be satisfied generally.
(3) Raw materials can be taken locally. Major building materials in particular should be available nearby. This is quite essential. The issue can be coped with in site selection and improvement of structure.
(4) Make full use of natural landform to reduce work load.

No strict geological conditions are required since reservoir capacity is small and dam is low.

3. Design and Construction of Impoundment Reservoirs Used as Drinking Water Source in Mountain Areas

3.1 Determination of reservoir capacity

Capacity determination is mainly done according to topographic conditions, grassland quality and distribution, number of livestocks coming and going as well as incoming water amount. The capacity of reservoirs built by us ranges from several cubic meters to several hundred cubic meters.

3.2 Main points for impoundment structure selection

(1) This is depended upon objective conditions like construction conditions, raw materials, topography and geology.
(2) Try not to use cement, sand and water for the first two are

hard to be transported and the latter, deficient in mountain areas.

(3) The anti-seepage issue for the first two types of impoundment can be solved through treatment by using plastic membranes. Dry laying can be practiced at batter to prevent animal trampling and wash-off at outlet.

3.3 Main points for design and construction of anti-seepage impoundment with plastic membranes

Anti-seepage impoundments with plastic membranes are the top priorities in providing drinking water for man and animals in mountain areas. Essentials for design and construction are described below.

(1) Bottom of impoundment: First, the bottom of impoundment below designed water level is covered with plastic membrane, the unwelded joints are treated by means of joints lapping, and the width of overlapping is 10cm for anti-seepage. Then, a layer of earth about 30cm thick is spread over it, above which is another layer of 20-cm-thick dry-laid bricks. The function of it is to prevent animal trampling, damaging plastic membranes and disturbing water when the water is used.

(2) Dam body: Roller compaction earthen dams are adopted. Plastic membranes are used as core of dam which are overlapped with bottom plastics to prevent dam-body seepage, to lower infiltration line and diminish dam-body cross section.

As dam height is relatively low, primary batter is adopted as earthen dam batter, upstream batter is taken as 1:2.0 and downstream one, 1:1.5. To prevent animal trampling, linings with dry-laid bricks are preferred. Linings are also done at downstreams for individual small dams, and dam batter is very steep.

(3) In order to offer solutions to excess water discharge, outlets can be added or overflow dam can be built as damming, and the linings are both dry-laid bricks. If the discharged flow is high, the dry-laid bricks should be thickened or wire cage contained bricks can be used along with gobi or plastic membranes as cushion. If grass linings are adopted, level laying should be taken to replace vertical laying for the sake of increasing thickness and anti-wash capability.

(4) In order to keep reservoir water clean and easy to fetch water, water discharge and lifting facilities such as hand-operated pump and hanger should be provided, thus man and animals can fetch or drink water outside of the impoundment.

4. Cost-Benefit Analysis of Impoundment as Drinking Water Source for Man and Animals in Mountain Areas

Analysis and calculation is done based on the five impoundments completed in 1979. Total capacity of these impoundments is 1364 cubic meters, the maximum is 600 cubic meters, and the minimum, 84 cubic meters. The arrangement is types one and two. Four of them use plastic membranes as means for anti-seepage, and trhe other one, grout laying and dry laying.

Cost analysis: About 118kg of plastic membranes, 1500kg of cement, 30kg of dynamites and 606 person/day were used to build the five impoundments. Unit consumption (i.e., per cubic meter capacity consumption) were 0.09kg of plastic membranes, 1.1kg of cement, 0.02 kg of dynamites, and 0.44 person/day.

Benefit analysis: Intervals of slight rains in mountain areas are 7 to 10 days (calculated based on 8.5 days), impoundment utilization coefficient is 0.7, and per unit sheep drinks 2kg of water, hence they can satisfy requirement of 56,164 unit sheep for drinking water.

5. Conclusion

Facts proved that the construction of impoundments can satisfy drinking water requirements for man and animals and improve rain water utilization rate in mountain areas. Advantages are identified as following:

(1) They are adaptable to mountain conditions, easy to be opearted and maintained, and simple in design and construction. The incomplicated technique is easy to be handled by local farmers and herdsmen who can build impoundments themselves. Compared with other manners in obtaining water sources such as turbine pump, water ram and well drilling, this option involves in low cost, low expenditures for maintanence and management in addition to wide scope in application and being free from limitations of surface and ground water regimes.
(2) They gain benefit the same year and are reliable to be used. Once a project is completed, it would be effective and gain benefit.
(3) Both labour and materials are saved as raw materials are available locally. The low cost yielded high benefit.
(4) They are small in size and scatteredly in distribution, so an independent unit can gain benefit separately.

In summary, the author holds that rain water utilization and impoundment construction offer an effective way to the improvement of grassland utilization rate and to the solution to drinking water issue for man and animals. It is quite worthy to be extended.

Section 11

METHODOLOGY AND MODELING

Rainfall Intensity and Rainwater Catchment

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Abstract

This paper illustrates the influence of rainfall intensity on rainwater catchment performance. Attention to the peak intensities, a small analytic cost, leads to catchment efficiency, a potentially significant benefit. An example illustrates the approach. A rule-of-thumb is suggested for estimating spill from the gutter.

Introduction

A structural beam does not fail because of its average loading. One would not design a bridge based on the average count of cars and trucks over a year. The bridge is analyzed for its heaviest loading, one that might occur only when a string of trucks parks upon it, a rare, but entirely possible occurrence.

Consumers do not drink water at some constant "average" rate. Rain does not fall over a month or season at some uniform pace. Rainfall within a storm does not occur at some steady intensity. Assumptions of averages cause design and analysis, be it for a bridge or a rainwater catchment system (RWCS), to be unrealistically simplistic and potentially inadequate.

A RWCS gutter may overflow between the catchment area and the cistern during the heavy portion of a storm. Such spill is a wasted resource, a resource that might be harvested were the gutter better sized. The dynamic system calls for improved numeric analysis of the unsteady state.

Kinematic Wave Routing

Kinematic wave routing describes unsteady spatially-varied flow down a catchment and along a gutter without attenuation. Kinematic wave routing method is based on conservation of mass,

$$\frac{\delta A}{\delta t} + \frac{\delta Q}{\delta x} = q \qquad (1)$$

where Q is discharge, x is distance, q is lateral inflow per unit length, and t is time. Reformulating Eq. 1,

$$\frac{\delta Q}{\delta t} + c_k \frac{\delta Q}{\delta x} = q \qquad (2)$$

$$c_k = \frac{\delta Q}{\delta A} \tag{3}$$

where A is cross-sectional area and c_k is kinematic wave velocity, often approximated by an exponential form. Eq. 2 may be solved by any number of numerical methods, a common approach being a linear second-order scheme using central differences.

The US Army Corps of Engineers rainfall-runoff computer program HEC-1 has kinematic wave options for both overland and channalized flow. HEC-1 can model a RWCS, treating the catchment area as an impervious watershed, the gutter as a channel and the cistern as a reservoir. Unfortunately, while HEC-1 computes with standard FORTRAN precision, the output is formatted for watershed scale, not rooftops. Printed discharge may truncate to a printed hydrograph array of 0.00 m^3/s. The problem is resolved by storing values with more decimal digits in a user-formatted file to be retrieved later.

A RWCS Example Problem

A planar school roof, 20 m by 10 m is pitched 1:12. The gutter is a trapezoid, 5 cm base with 0.5:1 sideslopes, 6 cm deep and sloped at 0.005. The gutter hydraulic capacity is 0.001 m^3/s Fig. 1 is the hyetograph of a 7-mm 30-min storm.

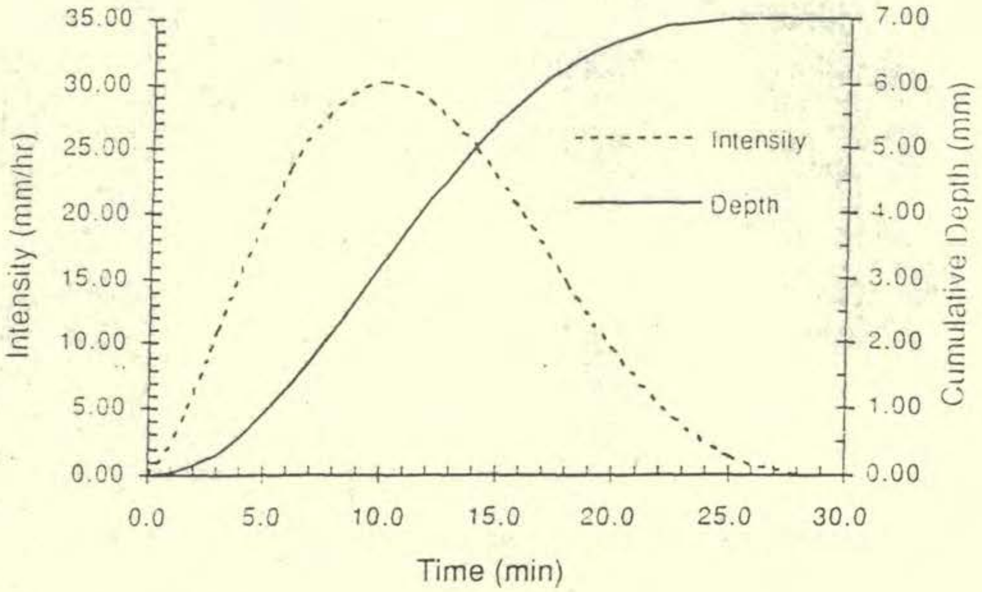

Figure 1. Hyetograph

Fig. 2 illustrates the HEC-1 runoff hydrograph routed as a kinematic wave. Discharge spills in excess of the horizontal "Gutter Capacity" line. The total area under the discharge curve is 1.4 m^3, the product of the rainfall depth and catchment area. The area above the capacity line is the intercepted rainfall that spills before delivery to the cistern. The area below the line is the RWCS yield. In Fig. 1, 22.1 percent of the intercepted rainfall spills and 77.9 percent is delivered.

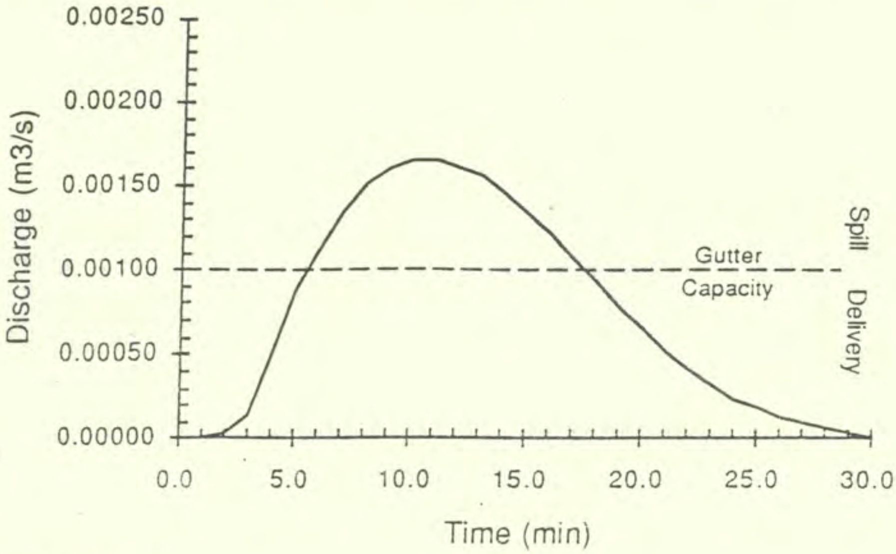

Figure 2. Runoff

Fig. 3 indicates 11 rainfall distributions for a 30-minute storm of any depth. Rainfall intensity is the slope of the curve. A "0" is perfectly uniform rainfall. Fig. 1 has a "5" rainfall distribution. A "10" starts slowly, peaks at a high intensity and then diminishes. Frontal storms tend to have more-uniform rates; convective storms tend to have intense peaks.

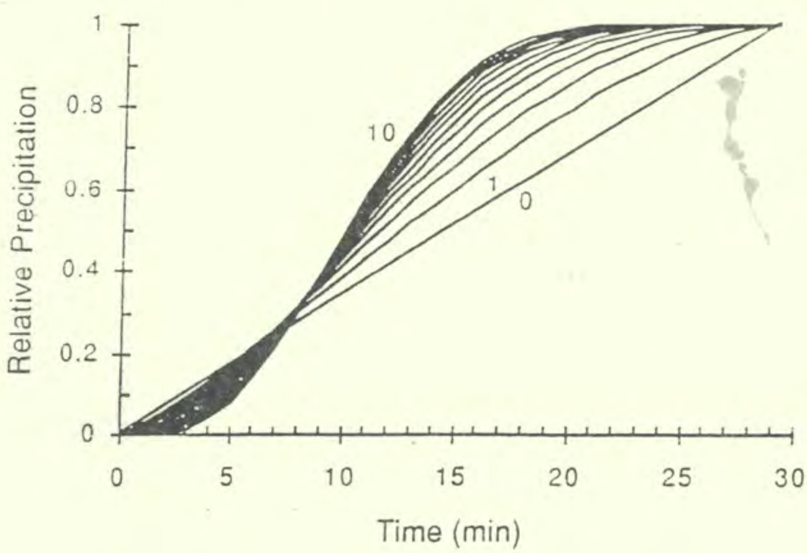

Figure 3. Rainfall Distributions

Computation of Fig. 3 is not crucial for this illustration. For those interested, the ratio of rainfall intensity at t compared to the peak intensity at time t_p is,

$$\text{Relative Intensity} = \left[\left(\frac{t}{t_p}\right)^{\frac{t_p}{d}} \left(\frac{d-t}{d-t_p}\right)^{1-\frac{t_p}{d}} \right]^K \quad (4)$$

where d is the storm duration and K is the rainfall distribution.

Fig. 2 summarizes the HEC-1 simulated RWCS yields in percent of total interception for the 11 rainfall distributions. For reference, the sixth point is the 77.9 percent of Fig. 2. The polynomial regression fits rainfall distributions 1-10.

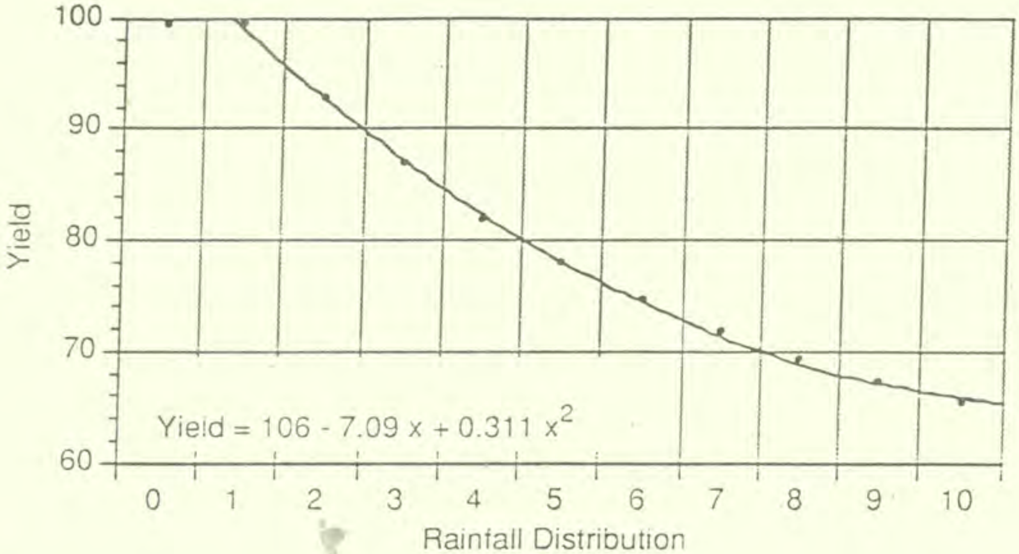

Figure 2. Yield vs. Rainfall Distribution

For the same catchment area, same trapezoidal gutter and same depth of rainfall. the RWCS harvests all the rainfall if the storm occurs uniformly (rainfall distributions 0 or 1), but only two-thirds of the rainfall if the storm has an intense peak (rainfall distribution 10). If water is a scarce commodity, spilling one-third is a significant loss.

The example illustrates a RWCS adequately sized to capture the mean storm intensity, but potentially inefficient if the rainfall intensity significantly varies.

Discussion

If a RWCS is to efficiently harvest storms of high peak intensity, the gutter may need to be enlarged. Design may need a higher degree of engineering analysis. Kinematic wave routing is an appropriate hydraulic approach. HEC-1 is a useful platform for such analysis.

It is, of course, not suggested that most RWCS design include a rigorous study of intensities, routing and hydraulic capacities. The pragmatic analyst should simply be aware of the relationships of rainfall intensity to RWCS efficiency and appropriately anticipate spill when intensities are high. If spill is unacceptable, improve the gutter.

In lieu of hydraulic simulation, a simple rule-of-thumb is proposed. Qualitatively assess the storm behavior on the 0-10 distribution scale. Decrease the RWCS efficiency approximately 4 percent for each unit of rainfall distribution. Lacking any knowledge of the distribution, assume approximately a 15 percent spill of the intercepted rainfall.

A Model For System Making Use Of Rain In Arid Area

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We have proposed a system making use of rain in arid and semi-arid area which is consist of making use of concentrate rain of agriculture, field's irrigation, regional balance, urban-village's concentrate rain or circulation for hydro-control and protected environment through cooperation with The Institute of Arid Metearological Research in Gansu, Irrigational Station in Jiuquan, Arid Agriculture Centrein Dingxi et al., from 1985 to 1994. This paper has been putforwarded simple model through observations and experiment and research as follows:

Model making use of concentrate rain of arid agriculture: Experiment of concentrate rain was proceeded from 1987 to 1989, on the semi- arid field in Dingxi. It has been considered semi- arid field as a system consisting of soil, plant, air and also founded a model resisting drought and increacing crop that can received and stored rain fully and decreased inefficient evapotranspiration and decreased loss of water, soil, fertilizer in arid or semi- arid field. Experiment has been adopted agricultural technological measure that the arid or semi-arid field ridged and fiuted, then all of ridge was covered plastic film and gully was planted. Main parameters of the model are rain $\sum R_t$, evapotranspiration $\sum E_t$, concenrtrate rain $\sum W_c$ and soil moisture W_s. It's eqiation of gully planted is as follows:

$$\sum R_t + \sum W_c + W_s - \sum E_t = 0 \quad \text{---------------} (1)$$

$$\sum W_c = [(2h/l) F_m \sum R_t] \quad \text{---------------} (2)$$

$$W_s = 0.1DH(W_O - W_m) \quad \text{---------------} (3)$$

$$\sum R_t + [(2h/l) F_m \sum R_t] + 0.1DH(W_O - W_m) - \sum E_t [1 - (2h/lC_E)] = 0 \quad \text{---------------} (4)$$

Where C_E is coefficient of containning ineffective evapotranspiration, F_m is coefficient of receipt moisture on slop covered plastic film, about 0.7-0.9, h is high of ridge, L is width of gully, W_O, W_m effective moisture of soil and maximal molecular moisture of soil respectively, D is Volume weight, H=1000, slope angle of ridge is 45°, ratio of gully and ridge width is about one.

We had planted spring wheat and corn on the field. When rain falled on the ridge covered plastic film, it will be flowed into the gully quickly to increase the amount of concertrate rain $\sum W_c$. Because of covered plastic film on ridge, ineffective evapotraspiration and flow-off was contained and $\sum E_t$ was decreased.

Experimental conclusion is that gully soil was increased mean moisture 22-33% and wheat was increased mean crop 25-30% than contrast field. (Chen et al. 1993)

Model making use of field's irrrigation: Experiment had been researched model making use of field's irrigation for oasis with Cooperation Irrigational Station in Jiuquan, from 1985 to 1987. It has been considered oasis field as a hydro-control model of system consisting of soil, plant and air. It's main parameters are irrigation $I_t=W_b - W_e$ (soil moisture of beginning and end) evapotranspiration E_t、rain R、flow-off F、seepage d、soil moisture S、plant P. It's equation is asfollows:

$$I_t=\int_{to}^{t} f\ (E_t\ R\ F\ d\ S\ P)\ dt \qquad \text{---------------} (5)$$

$$W_b - W_e + R - E_t - F - d = 0 \qquad \text{---------------} (6)$$

In consideration of the more conditions which are plain field, less rain and flow-off and planted irrigational depth for oasis, we can gain the follwing equation:

$$W_b - W_e - E_t = 0 \qquad \text{---------------} (7)$$

$$E_{ty}= 17.12\ (1.045^{T+U} + 1.045^{T-U})\ cm \qquad \text{---------------} (8)$$

$$E_{tm}= 4.47\ (1.045^{t})\ cm \qquad \text{---------------} (9)$$

$$E_{td}= 0.745\ (1.045^{t1} + 1.045^{t2})\ mm \qquad \text{---------------} (10)$$

$$W_v= DH\ ((r - d)/rd - 0.75W_d)\ m \qquad \text{---------------} (11)$$

Where E_{ty}, E_{tm}, E_{td} is evapotranspiration of year, month, day, respectively, t is year average temperature ℃, u= 0.366A, A is yeartemperature difference, t is month average temperture, t_1, t_2, is month average temperture near two months respectively, W_v supplied water capacity, D is volume weight, r is specific gravity, W_d is wiltting pointcoefficient about 0.16-0.20.

We cite an example useing of Xincheng Team-1 in oasis of Jiuquan for explaining the estimate program, value and interval of irrigation. The parameters about △W, E_t are in table 1 as follows:

Table 1 The parameters about estimating W, E_t

item / station	D	r	n	Wo	Wd	mean temperature						
						3	4	5	6	7	8	year
Xincheng Team-1	1.47	2.58	0.43	0.24	0.16 0.20	1.8	9.4	15.6	20.1	21.8	20.7	7.3

The parameters about estimating irrigational times and interval N are shown in table 2.

Table 2 Paramenters about irrigation times and N

station	planting stage		seeding		third-leaf		jointing		heading		blooming		milky		gold		ripe stage		growing days
			b	e	b	e	b	e	b	e	b	e	b	e	b	e	b	e	
Xincheng	day /mon	16 /3	6 /4	12 /4	27 /4	15 /5	23 /5	28 /5	3 /6	10 /6	15 /6	18 /6	25 /6	26 /6	18 /7	21 /7	18 /7	31 /7	138
team-1	order day/mon				1 (5/5)		2 (25/5)		3 (10/6)		4 (21/6)								
	No=45			Na=25				Nb=15				Nc=10				Nd=30			

According to above parameter and equation, we have designed simple program and estimated irrigational amount of spring wheat 364-398m^3/mu in Irrigational Station of Jiuquan 343-406 m^3/mu. It can save on water 200-300 m^3/mu than the contrast field and decrease loss of soil, fertilizer and improve structure of soil. (Chen et al. 1990. 1993)

Model making use of regional balance: We had researched the model making use of regional balance in title of monitoring of the hydro-control system of oasis and oasis exploitation from 1985 to 1991. It was discussed model of regional balance by example of Dunhuang Oasis. It is a relative balance model controlling regional applied water through researching regional supplies $\sum I_i$, requirements $\sum R_i$, store $\sum S_i$, output $\sum O_i$. It's equation is as follows:

$$\sum I_i=\sum R_i + \sum S_i + \sum O_i \quad \text{----------------} (12)$$

If use of example in Jiuquan Oasis, regional supplies are water resources of surface $W_m=6.73*10^8$ m^3, flow of ground water $G_0=0.42*10^8$ m^3, seepage of rain condensation $P=0.504*10^8 M^3$, then:

$$\sum I_i=W_m+G_0+P=7.654*10^8$$
$$\sum R_i=6.67*10^8\ m^3,$$
$$\sum S_i=0.146*10^8\ m^3,$$
$$\sum O_i = 0.838*10^8\ m^3.$$

If use of example in Dunhuang Oasis, regional supplies are $\sum I_i=2.824*10^8\ m^3$, $\sum R_i=1.462*10^8\ m^3$, $\sum O_i=1.287*10^8 m^3$ (output of canal seepage only), $\sum S_i=0.75*10^7\ m^3$. (Chen 1987. 1990)

Model making use of urban-village's concentrate rain or circulation: We had researched design and use of mult-functional plastic warm- tent and concentrate rain plastic warm-tent from 1990 to 1994. It includes courtyard, storing reservior and circulative, clear applied water for population, factory-mine, office and has been developed in recent years.

According to supplies $\sum IC_i$, requirements $\sum RC_i$, output $\sum OC_i$, it's equation is as follows:

$$\sum IC_i = \sum RC_i - a\sum OC_i \quad \text{-------------- (13)}$$

$$\text{order } \sum OC_i = b\sum RC_i$$

Where a is clear ratio, b is output-requirments ratio. (Holl et al., 1987)

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SPATIALLY VARIED FLOW OVER A SIDE WEIR IN A RECTANGULAR CHANNEL

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ABSTRACT

Steady spatially varied flow has a non-uniform discharge in an open channel resulting from the addition or diminution of water along the course of the flow. The longitudinal water surface profile is normally found by expressing the appropriate general equation in finite difference form and solving using a trial and error step-by-step procedure. In this paper a simple alternative method is presented using a Runge-Kutta second and fourth order numerical technique. The method is applied to a channel side weir where the discharge in the main channel is decreasing in the direction of flow. Both the length of weir to extract a given discharge and the water profile are computed and compared for the different techniques.

INTRODUCTION

Steady spatially varied flow is defined as flow in which the discharge varies gradually due to the addition or diminution of water along the direction of flow. Typical examples of flow with decreasing discharge are channel side weirs, widely used for diverting excess water from drainage or irrigation systems and also for controlling water levels in canals and in flood relief schemes on rivers. This particular type of structure is usually a long rectangular notch installed along the side of the channel for the purpose of diverting or spilling excess flow. Alternatively, structures that cause the discharge to increase along the course of the flow are side channel spillways which divert excess water into collector channels and storm overflow structures in water treatment plants.

The salient principles governing spatially varied flow with decreasing discharge are different from that of a similar flow with increasing discharge. Both types are fully discussed in Chow (1959) and Chadwick and Morfett (1993), but in cases where the flow rate is decreasing there is no appreciable energy loss, and the equation for the longitudinal water surface profile can be derived from the energy principle and is given by:

$$\frac{dy}{dx} = \frac{S_o - S_f - \dfrac{Q}{gA^2}\dfrac{dQ}{dx}}{1 - \dfrac{Q^2B}{gA^3}} \qquad (1)$$

where at any distance x measured along the channel bed:

S_0 is the slope of the channel bed
S_f is the slope of the energy gradient line
A is the cross sectional area of flow
B is the water surface width
y is the depth of flow
Q is the flow rate

dQ/dx is the discharge subtracted per unit length of the channel and is a negative quantity for a decreasing flow rate.

In channels where the flow rate is increasing due to added water there is a significant energy loss caused by the turbulent mixing of the water entering the channel and the water flowing in the channel. Since the energy loss cannot be quantified the momentum principle is employed to derive the slope of water surface profile and is given by:

$$\frac{dy}{dx} = \frac{S_o - S_f - \dfrac{2Q}{gA^2}\dfrac{dQ}{dx}}{1 - \dfrac{Q^2B}{gA^3}} \qquad (2)$$

where in this case dQ/dx is the discharge added per unit length of the channel and is a positive quantity for an increasing flow rate.

NUMERICAL SOLUTION METHODS

The differential equations 1 and 2 can be expressed in finite difference form by replacing the differential terms, that is, dy/dx and dQ/dx by $\Delta y/\Delta x$ and $\Delta Q/\Delta x$ respectively. The resulting equations can then be solved numerically using either a trial and error iterative procedure or the proposed Runge-Kutta technique.

Trial and Error Procedure

In this approach the channel is divided into a number of finite steps of length Δx such that the depth of water changes by Δy over each step. The change in Δy over the known step length Δx is initially assumed to enable the variables on the right hand side of Eqs. 1 or 2 to be computed at the mid point of the increment. Thus S_f, Q, A (and B, if a variable) would be the values at the mid point of the interval. The unknown value of Δy can then be computed and compared with the guessed value, with the process repeated for each step length Δx until the guessed and computed values agree to within a specified tolerance.

Runge-Kutta (R-K) Technique [Robertson et al 1987, France 1993]

As in the above procedure the channel is divided into a number of finite steps of length Δx and the water surface depth y at each step along the channel can be found using either the second order R-K technique or for greater accuracy the classical fourth order technique. The second order solution is given by:

$$y_{i+1} = y_i + (k_1 + k_2)\Delta x / 2 \qquad (3)$$

where y_{i+1} is the depth of water at the end of the step length Δx.

y_i is the depth of water at the beginning of the step length Δx.

k_1 is the value of the right hand side of either Eqs. 1 or 2 computed at $x = x_i$ and $y = y_i$.

that is $k_1 = f(x_i, y_i)$

likewise $k_2 = f(x_i + \Delta x, y_i + k_1 \Delta x)$

where f refers to function of and k_1, k_2 are the R-K coefficients.

Alternatively the fourth order R-K techniques is given by:

$$y_{i+1} = y_i + (k_1 + 2k_2 + 2k_3 + k_4)\Delta x / 6 \qquad (4)$$

where again k_1 is the value of the right hand side of either Eqs. 1 or 2 computed at $x = x_i$ and $y = y_i$

that is $k_1 = f(x_i, y_i)$

and $k_2 = f(x_i + \Delta x/2, y_i + \Delta x/2\ k_1)$

$k_3 = f(x_i + \Delta x/2, y_i + \Delta x/2\ k_2)$

$k_4 = f(x_i + \Delta x/2, y_i + \Delta x/2\ k_3)$

Thus providing the depth y is known at $x = 0$ that is the initial conditions Eqs. 3 and 4 can be computed for each value of depth y_{i+1}, and hence the water surface profile in the channel.

EXAMPLE (Chadwick and Morfett p.440, 1993)

Figure 1 shows a rectangular channel of width 2.5m wide incorporating a side weir to divert excess water from the channel. The channel bed slope is 0.002 and Manning's roughness coefficient $n = 0.015$.. The design discharge in the channel upstream of the side weir is $5.96 m^3/s$ and the weir is to draw off $0.5 m^3/s$ from the channel. The sill height is 0.84m (measured above the channel bed) and the weir discharge coefficient is 0.7. If the maximum depth of flow at the downstream end of the weir is 0.7m. Estimate the required length of the weir.

Trial and Error Solution

Downstream of the weir the discharge is $5.96-0.5=5.46m^3/s$ and the flow in the channel at this section is assumed to be uniform. The normal depth corresponding to $5.46m^3/s$ is calculated to be $1.06m$ (i.e. $x=0, y_i=1.06m$) so it is easiest to start the computation here and 'march' upstream. A step length Δx is selected (initially $0.5m$ then $0.05m$) and the value of y_{i+1} at the upstream end of the step has to be guessed (say $1.05m$) that is assume $\Delta y=0.01m$. At the mean value of depth for the step (i.e. $\bar{y}$) the corresponding area A is computed, and the incremental discharge ΔQ over the step length Δx is found from the weir formula.

$$\Delta Q = (2/3) C_d \sqrt{2g}\, \Delta x \left(\bar{y} - z\right)^{3/2} \qquad (5)$$

Q_{i+1} may now be calculated $(=Q_i+\Delta Q)$ and hence the mean discharge for the step. This enables the average friction slope to be found from Manning's equation. Substituting the mean values of Q, A and S_f together with $dQ/dx=\Delta Q/\Delta x$ into Eq. 1 yields a calculated value for Δy. This is compared with the original (guessed) value and the iterative procedure continued until the values converge to a satisfactory degree of accuracy. The process is then repeated for the next step, and so forth, until the total draw off is $0.5m^3/s$.

Runge-Kutta Solutions

Commencing with $y_i=1.06m$ the R-K coefficients are computed to enable the depth y_{i+1}, to be found at the upstream end of the first step using the second and fourth order R-K techniques. The incremental discharge ΔQ is calculated from Eq. 5, hence the discharge Q_{i+1}, at the end of the first step. The computed value of y_{i+1} is then taken as the value of y_i for the next step and the process repeated until the required draw off is obtained.

RESULTS

Table 1 shows a comparison between the trial and error solution and the R-K results with the depth and discharge printed out every 0.5m from the downstream end of the weir. A weir length of nearly 3.5m was computed using the trial and error approach and a length of just over 3.5m using both the second and fourth order R-K methods. From the table it can also be observed that the R-K solutions gave similar water surface profiles to that predicted by the trial and error method. The problem was then repeated for a step length $\Delta x = 0.05\text{m}$ and the computed weir length was found to be 3.3m using the trial and error approach and 3.35m from both R-K solutions, with the water surface profiles almost identical. Note the depth of flow increases along the weir section. This is correct according to Frazer (1957) as the depth is greater than the critical depth at the upstream end of the weir with subcritical flow in the weir section.

DeMarchi (1934) derived the following equation for length of side weir:

$$L = \frac{3}{2}\frac{B}{C_d}(\phi_1 - \phi_2)$$

where B is the width of the channel and ϕ_1 and ϕ_2 are given by:

$$\phi_1 = \frac{2E_1 - 3z}{E_1 - z}\sqrt{\frac{E_1 - y_1}{y_1 - z}} - 3\sin^{-1}\sqrt{\frac{E_1 - y_1}{E_1 - z}}$$

$$\phi_2 = \frac{2E_2 - 3z}{E_2 - z}\sqrt{\frac{E_2 - y_2}{y_2 - z}} - 3\sin^{-1}\sqrt{\frac{E_2 - y_2}{E_2 - z}}$$

in which z = height of the weir; E = the specific energy head; y = depth of flow; and suffixes 1 and 2 refer to the upstream and downstream ends of the weir respectively. Substituting into Eq. 5 the relevant data, with values of y_i and Q_i taken as 0.97m and $5.96\text{m}^3/\text{s}$ respectively, (the value of $y_i = 0.97\text{m}$ was computed for $\Delta x = 0.05\text{m}$) the weir length L was found to be 3.16m which differs by about 6% from the result for L computed in this study. DeMarchi's formula however assumes there are no energy losses across the length of the side weir and the channel bed is horizontal.

CONCLUSIONS

The results for both water surface profile and weir length in a rectangular channel using the Runge-Kutta approach compare favourably with the traditional trial and error procedure; however the former method is easier to program and is significantly quicker. The approach can be readily extended to include flow over a side weir in any shape of channel.

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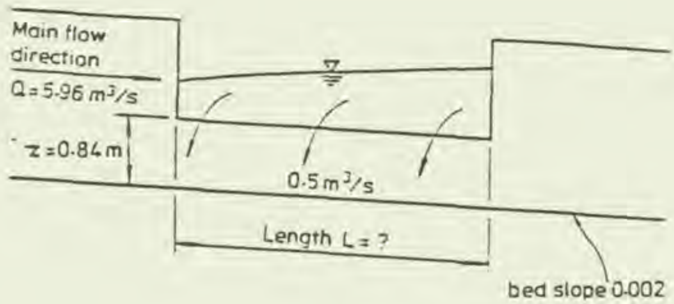

Fig. 1 Flow Over a Side Weir

TABLE 1

Total distance from d / s end (m)	Trial and Error Solution			2nd Order R-K Solution			4th Order R-K Solution		
	depth y (m)	ΔQ (m^3/s)	Q (m^3/s)	depth y (m)	ΔQ (m^3/s)	Q (m^3/s)	depth y (m)	ΔQ (m^3/s)	Q (m^3/s)
0.0	1.060		5.460	1.060		5.460	1.060		5.460
		0.100			0.096			0.097	
0.5	1.046		5.560	1.046		5.556	1.046		5.557
		0.090			0.087			0.087	
1.0	1.032		5.649	1.032		5.643	1.032		5.644
		0.080			0.078			0.078	
1.5	1.018		5.729	1.019		5.721	1.019		5.722
		0.071			0.069			0.069	
2.0	1.095		5.801	1.005		5.790	1.005		5.791
		0.063			0.061			0.061	
2.5	0.992		5.864	0.992		5.852	0.992		5.853
		0.055			0.054			0.054	
3.0	0.979		5.919	0.998		5.905	0.980		5.907
		0.048			0.047			0.047	
3.5	0.967		5.967	0.968		5.952	0.968		5.954
					0.041			0.041	
4.0				0.956		5.993	0.956		5.995
	Weir discharge = 5.967 - 5.460 = 0.507 m^3/s ∴ weir length L ≈ 3.5m			Weir discharge = 5.952 - 5.460 = 0.492 m^3/s ∴ weir length L ≈ 3.5m			Weir discharge = 5.954 - 5.460 = 0.494 m^3/s ∴ weir length L ≈ 3.5m^3/s		

Characteristics and Design Criteria of Gutter Snipe

**Luo, Ching-Ruey*

ABSTRACT

In order to keep leaves, bugs, dead birds, and other debris out of the drinking water, the gutter snipe was designed with experimental data by Prof H.E.Finch. Water travels down the roof and along the gutter to the downspout where the gutter snipe is installed. The water goes through the slots in the screen, to be stored, while the solid matter, such as debris, is removed before it becomes immersed in the water system and decomposes.

To study the characteristics and design criteria for the gutter snipe system, the analytical method with the discharge, Q, diameter of pipe, D, and the friction factor, f, are used for both laminar and turbulent flow situations. The optimum design capacity is finally determined.

I. Introduction

Gutter snipe, which is suggested by prof. H.E. Finch, is used to collect rainwater with flushing out leaves and other debries from this rainwater. The water goes through the slots of the screens(in *FIG.1*). How much of the rainwater will be stored ? What is the need of the diameter of pipe for laminer or turbulent inflow ? What is the optimum design situation ? All of these objectives, of course, have to be studied in this paper.

II. Theoretical Considerations

Three steps of the necessary considerations for the design criteria of this gutter snipe will be <A> free-body diagram of fluid acting forces system ; <B> free-body dagram of fluid and objectives acting forces system ; and <C> effective discharge and velocity after screens.

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Three factors, such as diameter of pipe, D, the friction factor, f, and the inclined angle of the screen, θ, will be used to decide the discharge, Q_o, and acting force, F_x.

<A>Freebody Diagram of Fluid Acting Forces System

In FIG. I , the discharges of Q_0,Q_1 and Q_2, and the velocities of $\overline{V}_o$, $\overline{V}_1$, $\overline{V}_2$ and the acting forces of F_x and F_y must be decided first with the given diamenterk, D, screen inclined slope, θ, and the friction factor, f. The basic consideration of the theories are

(a) Continuity Equation

$$Q_0=Q_1+Q_2=\frac{\pi}{4}D^2\,\overline{V}_0 \qquad \text{———— (1)}$$

(b) Equation of Motion

1. In X—Direction

$$Fx=\rho\, Q_0\,\overline{V}_0\cos\theta-\rho\, Q_1\,\overline{V}_1 \qquad \text{———— (2)}$$

where $\emptyset=\frac{\pi}{2}-\theta$

2. In Y—Direction

$$Fy=\rho\, Q_0\,\overline{V}_0\sin\theta-\rho\, Q_2\,\overline{V}_2$$

that is :

$$\rho\, Q_2\,\overline{V}_2=\rho\, Q_0\,\overline{V}_0\sin\theta \qquad \text{———— (3)}$$

(c) Equation of Energy Conservation

Considering the energy system on the surface of screen, where $P_0=P_1=P_2=Patm$ and $Z_0=Z_1=Z_2$, from equation of energy conservation without energy-loss, we have :

$$\overline{V}_0=\overline{V}_1=\overline{V}_2 \qquad \text{———— (4)}$$

By combining Eqs.(1),(2),(3) and (4), the results are :

$$Q_2=Q_0\sin\theta \qquad \text{———— (5)}$$

$$Q_1=Q_0\,(1-\sin\theta) \qquad \text{———— (6)}$$

$$Fx=\rho\, Q_0\overline{V}0\,(\sin\theta+\cos\theta-1) \qquad \text{———— (7)}$$

and $Q_0=\frac{\pi}{4}D^2\overline{V}_0=\frac{\pi}{4}\nu^2 R_e^2\,\overline{V}_0^{-1}$ ———————— (8)

where : $Re=\frac{\overline{V}_0 D}{\nu}$ = Reynolds Number ;

ν = Fluid Kinematic Viscosity

$=2\times10^{-5}\ m^2/s$ at 20°C ;

That is ,

$Q_0=g_1(Re)$ and

$Re=g_2(f)$

where, f = friction factor in Moody Diagram ;

From Eq.(5), Q_2 will be as large as possible for the purpose of collecting rainwater ; meanwhile, the discharge Q_1 in Eg.(6) is only just enough for flushing out the solid matter, or say, as small as possible.

<B>Freebody Diagram of Fluid and Objectives Acting Forces System

In FIG. 3, the force for the hinge to hold on the screen can be obtained by :

$$Fx+W\sin\emptyset - F - \mu_{N.}\,W\cos\emptyset=\frac{W}{g}a_x \qquad (9)$$

Assuming $a_x=0$, the Fx = F when it is :

$$\mu_{N.}\cos\emptyset=\sin\emptyset \qquad (10)$$

and $\emptyset=26.57^\circ$ with $\mu_N=0.50$:

This $\emptyset$-value will be the critical-angle for the body equilibrium itself without any other acting force. By given any small force with water flushing, the solid matter can be moved away easily.

<C>Effective Discharge and Velocity after Screem

The energy-loss (in FIG.4) after screen will be solved in order to calculate the effective velocity and discharge. The formula used to have the solution is :

$$\Delta h = \beta(\sin\theta)\left(\frac{b-t}{b}\right)^{4/3}\left(\frac{\overline{V}_0^2}{2g}\right) \qquad (11)$$

where : $\beta = 1.67$ and(b-t) = the length of the slots ; and

b = the total lengthe of screen.

III. Results of Analysis

The results will be obtained by the following steps :

$$f \rightarrow Re \rightarrow \overline{V}_0, D \rightarrow Q_0 \text{ and} \qquad (12)$$

$$\rho, Q_0, \overline{V}_0, \theta \rightarrow Fx \qquad (13)$$

where : $f = \frac{64}{Re}$ for Laminar Smooth Pipe Flow —— (14)

and $f = \frac{0.3164}{Re^{1/4}}$ for Turbulent Smooth Pipe Flow

when $Re \leqq 10^5$ —— (15)

and $Q_2 = Q_0 \cdot \sin\theta$ —— (5)

The results for laminar and turbulent flow for a given set of data of D, f, and θ, are from Table 1. to Table 10.

IV. Discussion and Conclusions

After the solutions from Table 1 to Table 10, some phenomena can be listed as follows :

(1) The situation of turbulent flow with f=0.02 and any value of θ for any value can be neglected due to the consideration of material strength and economic views.

(2) The ratio of discharge and force between laminar and turbulent flow for f=0.10 will be :

$$\frac{Q_{0L}}{Q_{0T}} = 6.4 \ ; \ \frac{F_{XL}}{F_{XT}} \fallingdotseq 40 \qquad (16)$$

where "L" means "laminar" and "T" means "turbulent".

(3) The ratio of discharge and force between laminar and turbulent flow for f=0.05 will be :

$$\frac{Q_{0L}}{Q_{0T}} = 0.80 \ ; \ \frac{F_{XL}}{F_{XT}} \fallingdotseq 0.63 \qquad \text{——— (17)}$$

(4) Generally speaking, the flow situation is always turbulent flow, the criteria for the design of gutter snipe with Eq.(10) and Eq.(17) is :

"f=0.05 and θ =63.43° of Turbulent Flow"

(5) The effective discharge and effective velocity for f=0.05 and θ =63.43° of turbulent flow is :

D \ t/b	0.5		0.6		0.7	
D	Q_2'	V_2'	Q_2'	V_2'	Q_2'	V_2'
D=50.8mm	9.8×10^{-4}	0.482	1.03×10^{-3}	0.507	1.07×10^{-3}	0.529
D=101.6	1.96×10^{-3}	0.241	2.06×10^{-3}	0.254	2.14×10^{-3}	0.265
D=152.4	2.94×10^{-3}	0.161	3.09×10^{-3}	0.169	3.21×10^{-3}	0.176
D=304.8	5.88×10^{-3}	0.082	6.18×10^{-3}	0.085	6.42×10^{-3}	0.088

where : $\frac{(\overline{V}_2')^2}{2g} = (\overline{V}_2)^2/2g - \Delta h = $ Eg.(11) ; $\overline{V}_2 = \overline{V}_0$;

Finally, the ratio between the effective discharge, Q'_{2T} and the inflow discharge, Q_{0T}, is ;

Q'2T/Q0T = 0.85~0.93

Table 1 Laminar Flow for $\theta = 15°$

$\theta = 15°$									
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8mm	5.10×10^{-4}	1.32×10^{-4}	2.89×10^{-2}	1.02×10^{-3}	2.64×10^{-4}	1.16×10^{-1}	2.55×10^{-3}	6.60×10^{-4}	7.22×10^{-1}
D=101.6	1.02×10^{-3}	2.64×10^{-4}	2.89×10^{-2}	2.04×10^{-3}	5.28×10^{-4}	1.16×10^{-1}	5.10×10^{-3}	1.32×10^{-3}	7.22×10^{-1}
D=152.4	1.53×10^{-3}	3.96×10^{-4}	2.89×10^{-2}	3.06×10^{-3}	7.92×10^{-4}	1.16×10^{-1}	7.65×10^{-3}	1.98×10^{-3}	7.22×10^{-1}
D=304.8	3.03×10^{-3}	7.84×10^{-4}	2.89×10^{-2}	6.12×10^{-3}	1.58×10^{-3}	1.16×10^{-1}	1.53×10^{-2}	3.96×10^{-3}	7.22×10^{-1}

Table 2 Laminar Flow for $\theta = 30°$

$\theta = 30°$									
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8mm	5.10×10^{-4}	2.55×10^{-4}	4.70×10^{-2}	1.02×10^{-3}	5.10×10^{-4}	1.88×10^{-1}	2.55×10^{-3}	1.28×10^{-3}	1.176
D=101.6	1.02×10^{-3}	5.10×10^{-4}	4.70×10^{-2}	2.04×10^{-3}	1.02×10^{-3}	1.88×10^{-1}	5.10×10^{-3}	2.55×10^{-3}	1.176
D=152.4	1.53×10^{-3}	7.65×10^{-4}	4.70×10^{-2}	3.06×10^{-3}	1.53×10^{-3}	1.88×10^{-1}	7.65×10^{-3}	3.83×10^{-3}	1.176
D=304.8	3.03×10^{-3}	1.52×10^{-3}	4.70×10^{-2}	6.12×10^{-3}	3.06×10^{-3}	1.88×10^{-1}	1.53×10^{-2}	7.65×10^{-3}	1.176

Table 3 Laminar Flow for $\theta = 45°$

θ=45°									
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8^{mm}	5.10×10^{-4}	3.61×10^{-4}	5.32×10^{-2}	1.02×10^{-3}	7.21×10^{-4}	2.13×10^{-1}	2.55×10^{-3}	1.80×10^{-3}	1.330
D=101.6	1.02×10^{-3}	7.21×10^{-4}	5.32×10^{-2}	2.04×10^{-3}	1.44×10^{-3}	2.13×10^{-1}	5.10×10^{-3}	3.61×10^{-3}	1.330
D=152.4	1.53×10^{-3}	1.08×10^{-3}	5.32×10^{-2}	3.06×10^{-3}	2.16×10^{-3}	2.13×10^{-1}	7.65×10^{-3}	5.41×10^{-3}	1.330
D=304.8	3.04×10^{-3}	2.15×10^{-3}	5.32×10^{-2}	6.12×10^{-3}	4.33×10^{-3}	2.13×10^{-1}	1.53×10^{-2}	1.08×10^{-2}	1.330

Table 4 Laminar Flow for $\theta = 60°$

θ=60°									
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8^{mm}	5.10×10^{-4}	4.42×10^{-4}	4.70×10^{-2}	1.02×10^{-3}	8.83×10^{-4}	1.88×10^{-1}	2.55×10^{-3}	2.21×10^{-3}	1.176
D=101.6	1.02×10^{-3}	8.83×10^{-4}	4.70×10^{-2}	2.04×10^{-3}	1.77×10^{-3}	1.88×10^{-1}	5.10×10^{-3}	4.42×10^{-3}	1.176
D=152.4	1.53×10^{-3}	1.33×10^{-4}	4.70×10^{-2}	3.06×10^{-3}	2.65×10^{-3}	1.88×10^{-1}	7.65×10^{-3}	6.63×10^{-3}	1.176
D=304.8	3.04×10^{-3}	2.63×10^{-3}	4.70×10^{-2}	6.12×10^{-3}	5.30×10^{-3}	1.88×10^{-1}	1.53×10^{-2}	1.33×10^{-2}	1.176

Table 5 Laminar Flow for $\theta = 75°$

$\theta = 75°$									
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8mm	5.10×10^{-4}	4.93×10^{-4}	2.89×10^{-2}	1.02×10^{-3}	9.85×10^{-4}	1.16×10^{-1}	2.55×10^{-3}	2.46×10^{-3}	7.22×10^{-1}
D=101.6	1.02×10^{-3}	9.85×10^{-4}	2.89×10^{-2}	2.04×10^{-3}	1.97×10^{-3}	1.16×10^{-1}	5.10×10^{-3}	4.93×10^{-3}	7.22×10^{-1}
D=152.4	1.53×10^{-3}	1.48×10^{-3}	2.89×10^{-2}	3.06×10^{-3}	2.96×10^{-3}	1.16×10^{-1}	7.65×10^{-3}	7.39×10^{-3}	7.22×10^{-1}
D=304.8	3.03×10^{-3}	2.93×10^{-3}	2.89×10^{-2}	6.12×10^{-3}	5.91×10^{-3}	1.16×10^{-1}	1.53×10^{-2}	1.48×10^{-2}	7.22×10^{-1}

Table 6 Turbulent Flow for $\theta = 15°$

$\theta = 15°$									
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8mm	8.00×10^{-5}	2.07×10^{-5}	7.19×10^{-4}	1.30×10^{-3}	3.36×10^{-4}	1.84×10^{-1}	5.00×10^{-2}	1.29×10^{-2}	277.00
D=101.6	1.60×10^{-4}	4.14×10^{-5}	7.19×10^{-4}	2.60×10^{-3}	6.73×10^{-4}	1.84×10^{-1}	1.00×10^{-1}	2.59×10^{-2}	277.00
D=152.4	2.40×10^{-4}	6.21×10^{-5}	7.19×10^{-4}	3.80×10^{-3}	9.84×10^{-4}	1.84×10^{-1}	1.50×10^{-1}	3.88×10^{-2}	277.00
D=304.8	4.8×10^{-4}	1.24×10^{-4}	7.19×10^{-4}	7.70×10^{-3}	1.99×10^{-3}	1.84×10^{-1}	3.00×10^{-1}	7.76×10^{-2}	277.00

Table 7 Turbulent Flow for $\theta = 30°$

θ=30°									
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8mm	8.00×10^{-5}	4.00×10^{-5}	1.17×10^{-3}	1.30×10^{-3}	6.50×10^{-4}	3.0×10^{-1}	5.00×10^{-2}	2.50×10^{-2}	451.00
D=101.6	1.60×10^{-4}	8.00×10^{-5}	1.17×10^{-3}	2.60×10^{-3}	1.30×10^{-3}	3.0×10^{-1}	1.00×10^{-1}	5.00×10^{-2}	451.00
D=152.4	2.40×10^{-4}	1.20×10^{-4}	1.17×10^{-3}	3.80×10^{-3}	1.90×10^{-3}	3.0×10^{-1}	1.50×10^{-1}	7.50×10^{-2}	451.00
D=304.8	4.80×10^{-4}	2.40×10^{-4}	1.17×10^{-3}	7.70×10^{-3}	3.85×10^{-3}	3.0×10^{-1}	3.00×10^{-1}	1.50×10^{-1}	451.00

Table 8 Turbulent Flow for $\theta = 45°$

θ=45°									
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8mm	8.00×10^{-5}	5.66×10^{-5}	1.32×10^{-3}	1.30×10^{-3}	9.19×10^{-4}	3.40×10^{-1}	5.00×10^{-2}	3.54×10^{-2}	510.00
D=101.6	1.60×10^{-4}	1.13×10^{-4}	1.32×10^{-3}	2.60×10^{-3}	1.84×10^{-3}	3.40×10^{-1}	1.00×10^{-1}	7.07×10^{-2}	510.00
D=152.4	2.40×10^{-4}	1.70×10^{-4}	1.32×10^{-3}	3.80×10^{-3}	2.69×10^{-3}	3.40×10^{-1}	1.50×10^{-1}	1.06×10^{-1}	510.00
D=304.8	4.80×10^{-4}	3.39×10^{-4}	1.32×10^{-3}	7.70×10^{-3}	5.44×10^{-3}	3.40×10^{-1}	3.00×10^{-1}	2.12×10^{-1}	510.00

Table 9 Turbulent Flow for $\theta = 60°$

	θ=60°								
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8mm	8.00×10^{-5}	6.93×10^{-5}	1.17×10^{-3}	1.30×10^{-3}	1.13×10^{-3}	3.00×10^{-1}	5.00×10^{-2}	4.33×10^{-2}	451.00
D=101.6	1.00×10^{-4}	1.39×10^{-4}	1.17×10^{-3}	2.60×10^{-3}	2.25×10^{-3}	3.00×10^{-1}	1.00×10^{-1}	8.66×10^{-2}	451.00
D=152.4	2.40×10^{-4}	2.08×10^{-4}	1.17×10^{-3}	3.80×10^{-3}	3.29×10^{-3}	3.00×10^{-1}	1.50×10^{-1}	1.30×10^{-1}	451.00
D=304.8	4.80×10^{-4}	4.16×10^{-4}	1.17×10^{-3}	7.70×10^{-3}	6.67×10^{-3}	3.00×10^{-1}	3.00×10^{-1}	2.60×10^{-1}	451.00

Table 10 Turbulent Flow for $\theta = 75°$

	θ=75°								
Factor / Diameter	f=0.10			f=0.05			f=0.02		
	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)	Q_0(cms)	Q_2(cms)	Fx(kg)
D=50.8mm	8.00×10^{-5}	7.73×10^{-5}	7.19×10^{-4}	1.30×10^{-3}	1.26×10^{-3}	1.84×10^{-1}	5.00×10^{-2}	4.83×10^{-2}	277.00
D=101.6	1.60×10^{-4}	1.55×10^{-4}	7.19×10^{-4}	2.60×10^{-3}	2.51×10^{-3}	1.84×10^{-1}	1.00×10^{-1}	9.66×10^{-2}	277.00
D=152.4	2.40×10^{-4}	2.32×10^{-4}	7.19×10^{-4}	3.80×10^{-3}	3.67×10^{-3}	1.84×10^{-1}	1.50×10^{-1}	1.45×10^{-1}	277.00
D=304.8	4.80×10^{-4}	4.64×10^{-4}	7.19×10^{-4}	7.70×10^{-3}	7.44×10^{-3}	1.84×10^{-1}	3.00×10^{-1}	2.90×10^{-1}	277.00

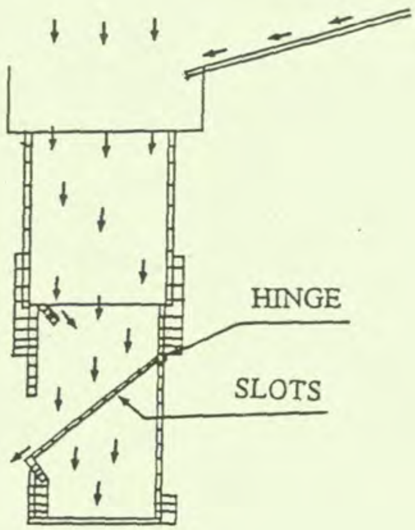

FIG.1 Gutter Snipe

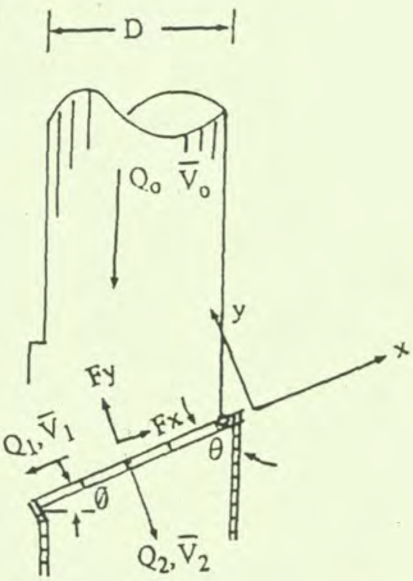

FIG.2. Freebody Diagram of Fluid

Acting Forces System

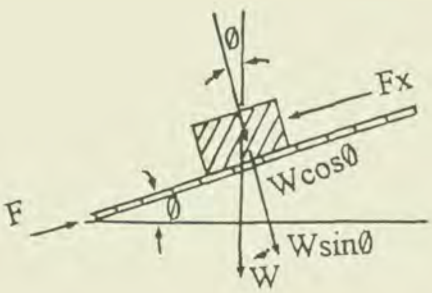

FIG.3. Freebody Diagram of Fluid and Objectives Acting Forces System

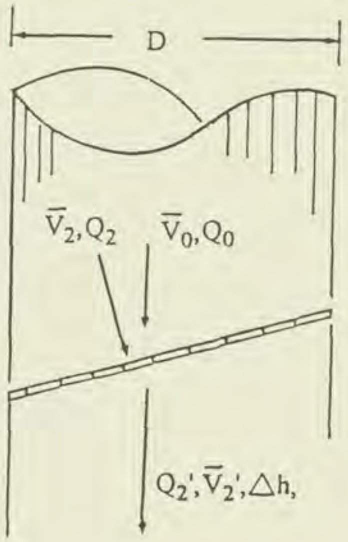

FIG.4. Effective Discharge and Velocity after Screens

ANALYSIS OF RAINFALL AS A DESIGN PARAMETER FOR RWCS

BY

NGIGI, S.N.[1]

ABSTRACT

In the arid and semi-arid lands (ASAL), rainfall occurs as concentrated storms which last for a short period leaving the rest of the year dry. Therefore, the need to develop optimal design procedure for rainwater catchment systems (RWCS) to ensure adequate and reliable water supply is a pre-requisite. The meagre annual rainfall interspersed with years of intense, destructively high precipitation requires RWCS which could efficiently regulate the water availability.

So far, there have been no defined design procedures for the existing RWCS. The critical design parameters and the stochastic nature of rainfall are rarely considered. Due to inappropriate designs, women and/or children walk long distances to fetch water which may be of inferior quality.

In this paper, the analysis of rainfall in terms of probability of occurrence, distribution, amount, reliability, and the length of critical wet and dry spells is carried out in the view of optimizing the design of RWCS. A procedure for generation of synthetic rainfall data, to obtain a long and more reliable rainfall record, which is paramount in RWCS design, is also briefly outlined.

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INTRODUCTION

In the ASAL, which covers more than 75% of Kenya, the surface water is scarce and the exploitation of groundwater is not economically feasible for the rural poor people. Therefore, rainwater remains predominantly the only viable source of water for domestic water supply.

In the rural areas, large number of households do not have access to safe drinking water or are far from water points. According to UNICEF (undated) quoted by Mathenge (1992), only 31 percent of the rural Kenyans have access to safe drinking water. In the dry, low potential areas this is as low as 20%. Thus 69-80% of the rural population in Kenya have no access to safe drinking water.

In most ASAL, women and/or children spend about 85% of their time drawing, carrying, managing and using water (Gitau, 1992). In majority of the cases, the water is not safe for drinking and is not even adequate. Hence provision of adequate designs of RWCS would save time and energy which may be used in other productive activities such as farming, health care, commercial activities etc. and subsequently improving the standards of living for the rural people. Due to the stochastic nature and variation of rainfall which is the main design parameter in the design of RWCS, a number of authors have devised design methods considering these factors. In design of RWCS, rainfall is the only parameter that the designer has least control. Thus, the design of the optimal rainfall value is of paramount importance as it determines the size of both the storage facility and catchment areas. This in turn determines the cost and reliability of the system. In design of RWCS, different design rainfall intervals and values are in use. The most common interval are month, season and annual and the values include average rainfall, mean rainfall, minimum rainfall, different probability levels of rainfall, and annual maximum daily rainfall among others. Simple and advanced computer models have also been developed.

Design of RWCS requires both hydrological and economical considerations as the major design criteria. Hydrological design is the process for assessing the impact of hydrologic event on a water resource system and choosing values for the key variables of the system so that it will perform adequately. The hydrologic design scale is the range of magnitude of the design variables, such as rainfall within which a value must be selected to determine the inflow to the system. The most important factors in selecting the design value are adequacy, cost and safety. In RWCS, the optimal design parameters are the ones that balances the conflicting considerations of adequacy and cost. There are three approaches commonly used to determine a hydrologic design value, namely, empirical approach, risk analysis and hydroeconomic analysis (Chow et al., 1988).

In design of RWCS, it is necessary to anticipate the possibility of drought more severe than has ever occurred and therefore, the solution is at the limit of possibilities giving only a certain reliability level. If rainwater harvesting is to meet the criterion of sustainability, which is the integration of economic, environmental and social objectives, it should provide a service with minimum failure, especially where there is no easy alternatives available.

METHODOLOGY

Rainfall Series Analysis

Rainfall analysis based on the existing historical or simulated rainfall records is a time series analysis. This involves the prediction of future events based on historical records. Therefore, the determination of the trend and any periodicity in the rainfall series is necessary. To accomplish this, the consistency of the available rainfall records is evaluated either by statistical or graphical methods. The one sample run test (Siegel, 1956 and Ogallo, 1978) was used for testing the homogeneity of the data. The double mass curve method was further used to confirm the results. The trend analysis was carried out using Spearman's rank coefficient method and the periodicity in the trend was tested by serial correlation and spectral analyses (Haan, 1977). Low filter moving average approach, using the binomial coefficient method (WMO, 1966), were used to smoothen the annual rainfall series and to show any general trend.

Design rainfall amount

The monthly rainfall values for the wet months were considered in the desisn of RWCS for domestic purposes.

The seasonal rainfall values were considered adequate for RWCS for agriculture. The Weibull plotting position and rainsum criterion were used to determine the rainfall values at different probability levels. The rainsum criterion is based on the rain falling during a wet period lasting for several days, designated as wet spell. The total rain over the successive wet days is referred to as rainsum and the rainfall lasting over successive days as the rainrun (Sharma, 1993b). In the design of RWCS, we are interested in the longest rainrun which may produce the maximum rainsum. The rainsum were modelled using Weibull model of probability (Sharma, 1993b) with its parameter derived from the daily rainfalls for each wet month. The probability distribution functions (pdf) for the rainsum is given by:

$$P(S \leq D) = 1 - \exp\left[-\left(\frac{D}{\beta}\right)^{\alpha}\right] \qquad \ldots(1)$$

where: $P(S \leq D)$ = probability of rainsum less than or equal to a particular value, D mm;
α and β = parameters of Weibull distribution.

In the study of maximum rainsum, one is interested in the largest value of S denoted by S_m. The determination of probabilities of S_m's requires the involvement of order statistics. The simplification of these analysis is provided in (Sharma, 1993b and 1994) and the resulting form of equation is

$$P(S_m \leq D) = \exp[-np\,(1 - pp)\ .\ (P(S > D))] \quad for\ 0 < D < \infty \qquad \ldots(2)$$

where: p = probability of any day being wet;
pp = probability of a wet day given that the previous day is wet;
n = number of days.

The values of parameters of Weibull distribution, α and β are obtained from the following relationships:-

$$r_1 = Sin\pi(pp - 0.5) \qquad \ldots(3)$$

$$\overline{X}_w = \frac{\overline{X}_d}{p} \qquad \ldots(4)$$

$$S_w = \frac{pS_d + (1-p)\,\overline{X}_d^2}{p^2} \qquad \ldots(5)$$

$$\overline{S}_m = \frac{\overline{X}_w}{(1 - pp)} \qquad \ldots(6)$$

$$S_v^2 = S_w\left[i + 2r_1\ \frac{i(1-r_1) - (1-r_1^i)}{(1-r_1)^2}\right] \qquad \ldots(7)$$

$$Where\ i = \frac{1}{(1-pp)}$$

$$\overline{S}_m = \beta\,\Gamma\left(1 + \frac{1}{\alpha}\right) \qquad \ldots(8)$$

$$S_v^2 = \beta^2\,\Gamma\left(1+\frac{2}{\alpha}\right) - \Gamma^2\left(1 + \frac{1}{\alpha}\right) \qquad \ldots(9)$$

Where: r_1 = serial correlation between daily rainfall at lag one;
X_d = mean of daily rainfall, mm;
X_w = mean of daily rainfall over wet days, mm;
S_w = variance of daily rainfall over wet days, mm²;
S_d = variance of daily rainfall, mm²;
S_m = estimate of mean of rain-sum, mm;

S_v = estimate of variance of rainsum, mm²;
Γ = notation of gamma function.
α, ß, p and pp are as earlier defined.

The parameter α and ß are then obtained by iterative solutions of equations (8) and (9). Then from the anticipated reliability levels, the value of the rainsum, D is obtained.

Design critical length of wet and dry spells

The persistent behaviour of monthly dry and wet spells were fitted to the Markov model. The critical dry and wet spells from the historical data were compared to those obtained by the Markov model and their cumulative distribution functions (cdf) plotted for each rainy month. From the serial correlation analysis of the daily rainfall records, the statistical significance at each lag was tested and a correlogram up to lag 7 (1 week) was developed showing the 5% and 95% confidence limits.

The pdf for the length of wet and dry spells can be given by the Markov model as:-

$$P(L_w \leq j) = 1 - pp^{j-1} \text{ or } P(L_w > j) = pp^{j-1} \quad \ldots (10)$$

and

$$P(L_d \leq j) = 1 - qq^{j-1} \quad \text{or} \quad P(L_d > j) = qq^{j-1} \quad \ldots (11)$$

where: L_w and L_d = length of wet and dry spell respectively;
pp = P(W/W);
qq = P(D/D);
j = length of the spell.

The critical length of wet (L_{wm}) and dry (L_{dm}) spells is given by the following pdf:

$$P(L_{wn} \leq j) = \exp\,[-np\,(1-pp).P(L_w > j)] \quad \ldots (12)$$

and

$$P(L_{dm} \leq j) = \exp\,[-nq\,(1 - qq).P(L_d > j)] \quad \ldots (13)$$

The analysis requires estimates of p, q, pp, qq and r_k . In the present analysis probabilities p, q, pp and qq were approximated by estimates of relative frequencies for the data set for each month. These values were ranked and the mean and median values used in the analysis.

For the design of RWCS, the critical spells are obtained from the values at the required reliability levels. A graph of cdf of the critical spells was also plotted where the required values could be are obtained easily.

Length of historical rainfall records

The length of the sample of the rainfall data is supposed to be long enough to be able to represent the parent population adequately. The WMO (1966) recommended that the length of any rainfall record to be used for climatological analysis should be at least 30 years. In most cases especially in the remote ASAL, the length of the rainfall records is normally inadequate and sometimes not reliable. Thus the need to extend the records to eliminate any shortcomings related to inadequate rainfall data.

A number of rainfall stochastic simulation methods are in use today. In the present study, a simple synthetic rainfall data generation procedure is proposed. A combination of Markov chain and Gamma distribution function has been recognized as a simple and effective approach in generating daily rainfall data for many environments (Geng et al., 1986). The Markov chain model is used to describe the occurrence of daily rainfall while the Gamma distribution function is applied to fit the amount of rainfall for each rainy day.

The two-part model for rainfall simulation consists of a two-state, first order Markov model and a two parameter Gamma distribution function. The Markov chain model includes parameters of two transitional probabilities, P(W/W) and P(W/D). Once the estimates of these probabilities are obtained, the simulation of the occurrence of rainfall can be accomplished by comparing the computer generated random uniform deviates with these transitional probabilities. That is, a uniform random deviate, u, on the interval [0, 1] is generated and if u is less than or equal to P(W/W) or P(W/D), which ever is approximate then such a day is classified as a dry day, otherwise it is a wet day.

The amount of rainfall on a wet day can be generated by inserting the two parameters of the gamma distribution function for a wet day. Thus, a synthetic rainfall simulation program can be easily written as long as the required parameters for a given environment are known. The simulated data distribution function is then tested by the appropriate statistical test such as the Kolmogorov-Smirnov and Chi-square tests (Siegel, 1956) among others. The simulated data statistical parameters are also compared with those of the existing records. The simulation methods are specific for each interval of rainfall data required but in any of those methods, the determination of the pdf of the data is the cornerstone for successive simulation.

RESULTS AND DISCUSSION

Description of the study area

The study area is situated along the Mombasa-Nairobi railway line in Makueni district, Eastern province of Kenya. The rainfall pattern in the Kibwezi region is bimodal, with the long rains between March-May and the short rains between Nov.-Dec. The rainy seasons are interspersed by wet and dry spells. The annual rainfall ranges from 240 mm to 1240 mm with a mean of 620 mm and inter quertile range of 310mm. It is characterised by low annual totals, strong seasonal concentration and high temporal and spatial variation. The long term mean monthly rainfall distribution is presented in fig. 1.

The study area falls under the ASAL where rainfall is the main climatic element that influences the socio-economic activities. The area suffers from scarcity of water and hence there is need to embark on rainwater harvesting to reduce the over dependence on relief food supply and to supply good quality water for domestic use.

Rainfall series analysis

The result from one sample run test shows that the historical record is consistency as the calculated statistics Z' equal to 0.46 is less than the 95% confidence level i.e. $Z' < 1.96$ obtained from the normal distribution tables. The record's homogeneity was further confirmed from the double mass curve analysis. This means that the historical data could be used for design of RWCS comfortably without errors due to inhomogeneity in the data. The Spearman's rank test gave a correlation coefficient of -0.082 which is not statistically significant. Therefore, there is no statistical evidence that the rainfall may tend to increase or decrease in the long run. Other statistical test such as Mann-Kendall rank test and Von Neumann ratio test etc. could also be applied. Sometimes a trend in climatological series may arise from heterogeneity in the data (Ogallo, 1978).

In the periodicity analysis, the correlogram, fig. 2, showed a cycle of about 10-11 years for the annual rainfall series while the spectrum, fig. 3, showed even shorter cycle of 3-4 years and 5-6 years. The smoothened annual rainfall series, fig. 4, shows that the trend is generally oscillatory with increasing amplitudes along the time series with the peaks recurring at intervals of about 10-11 years and 16-20 years. Such long cycles have limited predictive value for the design of RWCS which normally have a return period of 10 years. The time series analysis gives a rough idea of the expected future changes in the rainfall pattern of an area, hence the expected performance of the RWCS based on such data.

Rainfall reliability

The probability of exceedance of a certain amount of rainfall in a given period of time used in the design of RWCS, gives its risk of failure. The higher the probability, the lower the risk of failure but the higher the cost of the system. The choice is a compromise depending on the cost of an alternative source of water and the economic standards of the individual. The probability of exceedance, obtained by the Weibull plotting position for the wettest month, seasons, calendar and agricultural years are presented in table 1.

The calendar year is taken from Jan.-Dec. while the agricultural year is taken from Oct.-Sep. which depend on the cropping pattern of the study area. From the result in table 1, it is possible to select a design rainfall amount at different reliability levels for various purpose of RWCS. The monthly and the seasonal values are applicable in RWCS for domestic and agricultural use respectively. Designs using the wettest month will also be adequate for other months for RWCS for domestic use. Similarily, for agriculture, the design values are obtained from the wetter season depending on the planting dates.

Table 1: The rainfall amounts (mm) for November and seasons at different probability levels.

Probability %	November	Long rains	Short rains	Calendar year	Agric. year
10	309	430	567	988	923
20	260	340	450	888	827
30	206	304	410	727	759
40	178	252	364	671	699
50	148	213	325	620	608
60	136	188	278	576	567
70	118	148	248	547	536
80	91	98	215	445	468
90	60	67	189	378	408
95	45	44	172	360	320

Rainsum analysis

The first requirement for the analysis of the rainsum is to identify the nature of dependence in the occurrence of wet spells, i.e. whether they are dependent or random (Sharma, 1993b). This was accomplished by the serial correlation analysis of the daily rainfall. The correlogram, fig. 5, from such analysis shows that the occurrence of wet days follow Markov order one persistence. Thus proving the adequacy of Markov model applied to the occurrence of the rainrun and consequently the rainsum. The rainsum analysis was carried out following equations (1) through to (9) for each month. The result for the Weibull distribution parameters for the wet months are presented in table 2.

Table 2: The Weibull distribution parameters.

Parameter	Jan.	Feb.	Mar.	Apr.	May	Oct.	Nov.	Dec.
p	0.13	0.10	0.18	0.27	0.13	0.11	0.41	0.36
q	0.87	0.90	0.82	0.73	0.88	0.89	0.59	0.64
pp	0.46	0.40	0.47	0.45	0.35	0.44	0.61	0.57
α	0.93	0.93	0.86	0.89	0.90	0.67	0.87	0.92
β	9.34	10.98	19.67	21.90	6.96	4.88	31.35	26.26

The graph of $P(S_m \geq D)$ and D was plotted for each month and season from which the design rainfall value at various reliability levels can be obtained. A sample of such graphs is shown in fig. 6. The rainsum values for the rainy months and seasons are tabulated below.

Table 3: Rainsum values for the rainy months and seasons at various probability levels.

Probability (%)	March	April	Nov.	Dec.	Long rains	Short rains
10	80	95	145	113	200	283
20	60	75	115	90	154	221
30	47	68	95	75	130	182
40	37	58	80	63	107	151
50	30	44	63	55	84	123
60	22	36	55	45	65	103
70	17	30	45	37	52	84
80	10	22	35	30	35	66
90	4	15	22	18	20	40
95	0	8	13	10	8	23

Note: The median values have been used in the computations.

The design of RWCS derived from the rainsum criterion will be adequate since the design rainfall is lower than that obtained from the frequency analysis. Therefore these values should be used cautiously as they tend to yield bigger catchment areas which may be expensive. But for ASAL, these values could be more desirable as they would provide a more reliable RWCS. The seasonal or annual values can be obtained from the summation of the relevant monthly values and used appropriately. The median gives a slightly higher values than the mean, and hence they are more reliable especially in the ASAL.

Critical length of spells

The critical length of spells in the RWCS design is the dry spell which determines the required storage capacity. For domestic purposes, monthly dry spells are critical while the seasonal dry spell is critical for agriculture. In the ASAL, the critical dry spell is dictated by the months without adequate rainfall to supply the demand. The critical wet spells are important mainly for in-situ RWCS for agriculture where successive storms may cause excessive runoff due to limited storage capacity of the soil. The critical length of spells are perfectly fitted to the Markov model and therefore the application of this model reduces the time required for analysis substantially. The required critical length of spells could be obtained from the cumulative distribution function derived from the Markov model at various confidence levels, notably 95% level (Sharma, 1993a).

CONCLUSIONS

The success or failure of any RWCS, in terms of adequacy and reliability, largely depend on the appropriate analysis of rainfall as a key design parameter. It is worth noting that rainfall is one of the major parameter that the designer has least control over and hence it should be handled delicately during the design of RWCS. The size of the collecting surface depends on the expected rainfall and the anticipated demand. The storage capacity is determined by the predicted runoff and the critical length of shortage. Therefore, adequate analysis of rainfall is a prerequisite for reliable design of RWCS in a specific locality. Otherwise, wrong or inadequate analysis could lead to inappropriate designs. Optimal designs of RWCS, especially for domestic water supply would save the rural women a lot of time and energy spent in search of water from long distances. Adequate water supply would also improve the health of the family by reducing the incidence of water related diseases. This would give the women more time to attend to other family duties as less time would be wasted on fetching water and taking the children to the hospitals.

In case of RWCS for agriculture, excessive designs would lead to waterlogging, soil erosion, failure of storage facilities such as farm ponds among other environment catastrophy. Whilst on the other hand under designs would lead to water stress. Thus inadequate designs would reduce crop yields drastically. Sustainability in RWCS largely depend on the adequacy of design which is based on selection of optimal design parameters. Design is only one phase of any project and hence other project phases should be well incooperated for an environmentally friendly outcome. Let's strive to reduce the burden of women by promoting rainwater utilization by optimization of RWCS designs as this would achieve our national and global goal of improving standards of living of the world's people while at the same time preserving our environment for the future generations.

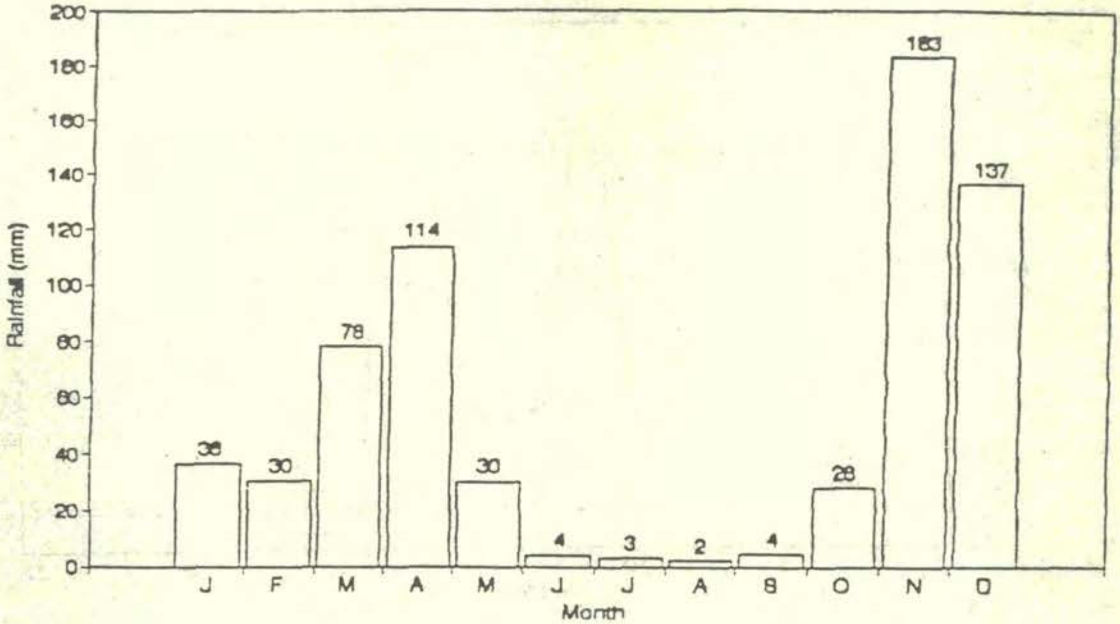

Figure 1. The long term mean monthly rainfall distribution.

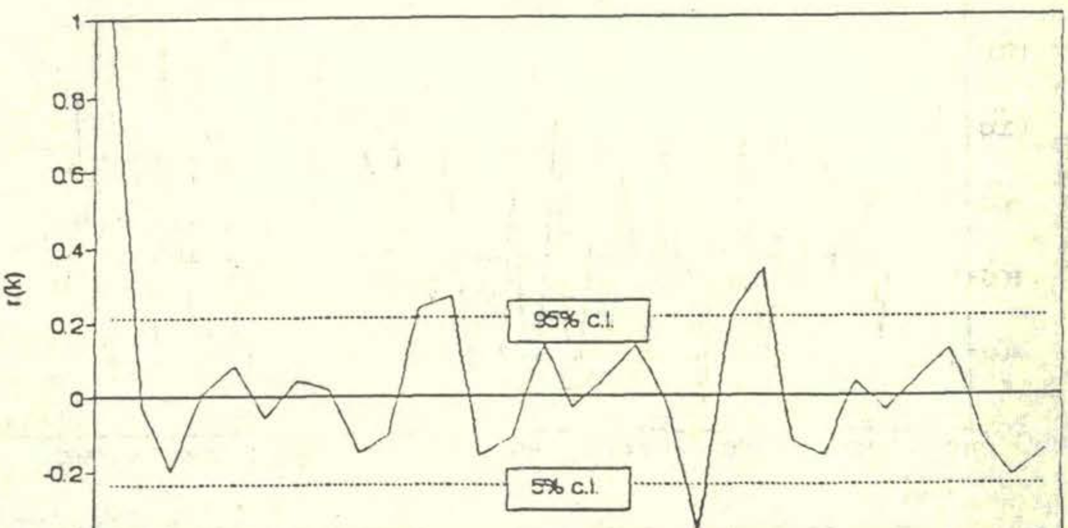

Figure 2. The correlogram of the annual rainfall series

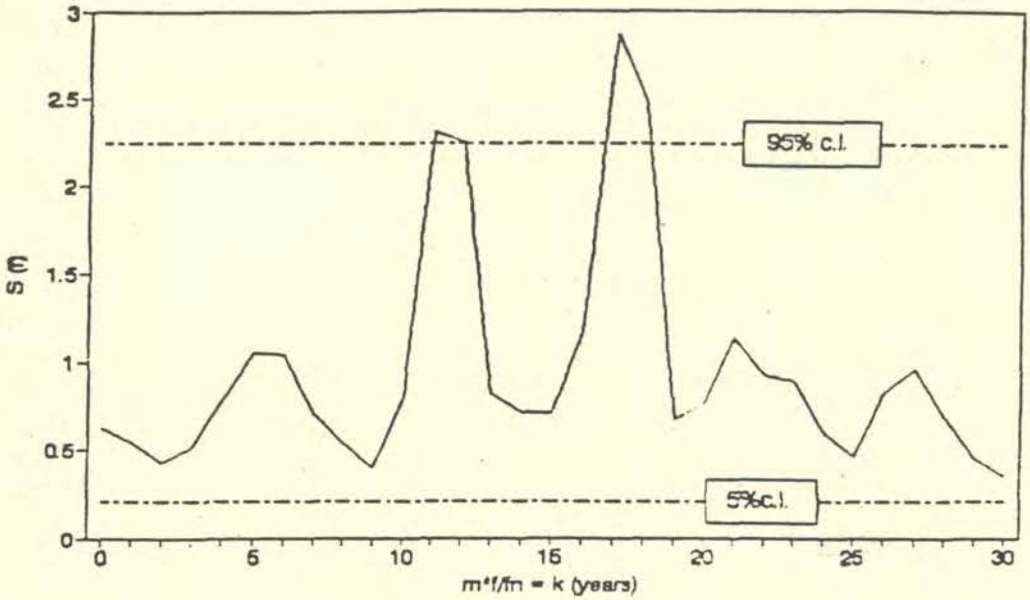

Figure 3. The spectrum of the annual rainfall series

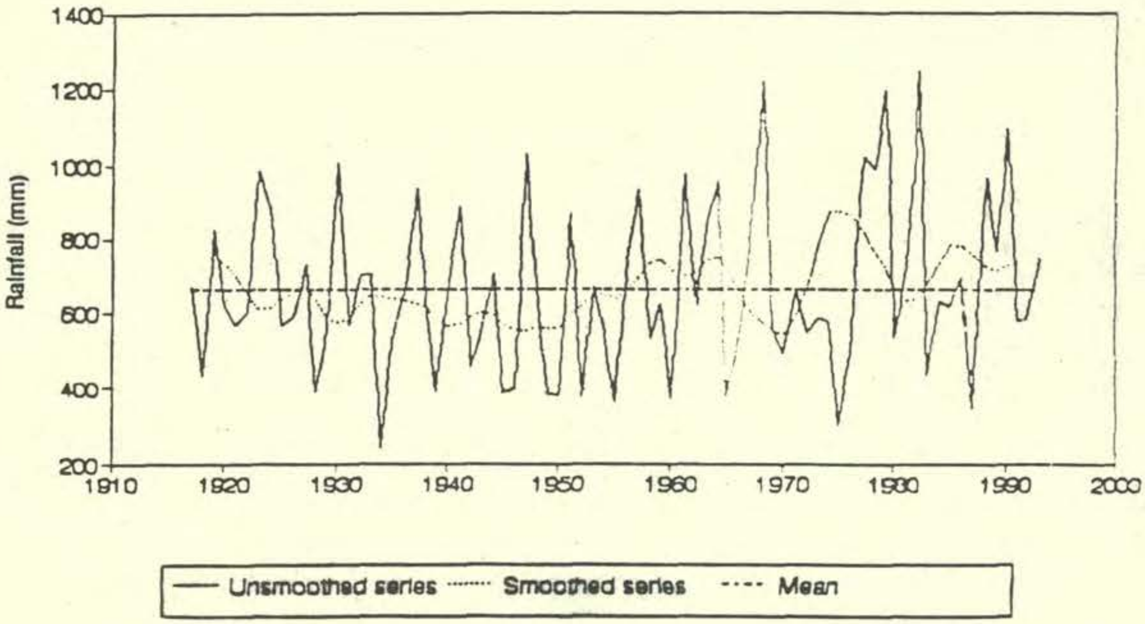

Figure 4. The unsmoothened and smoothened annual rainfall series

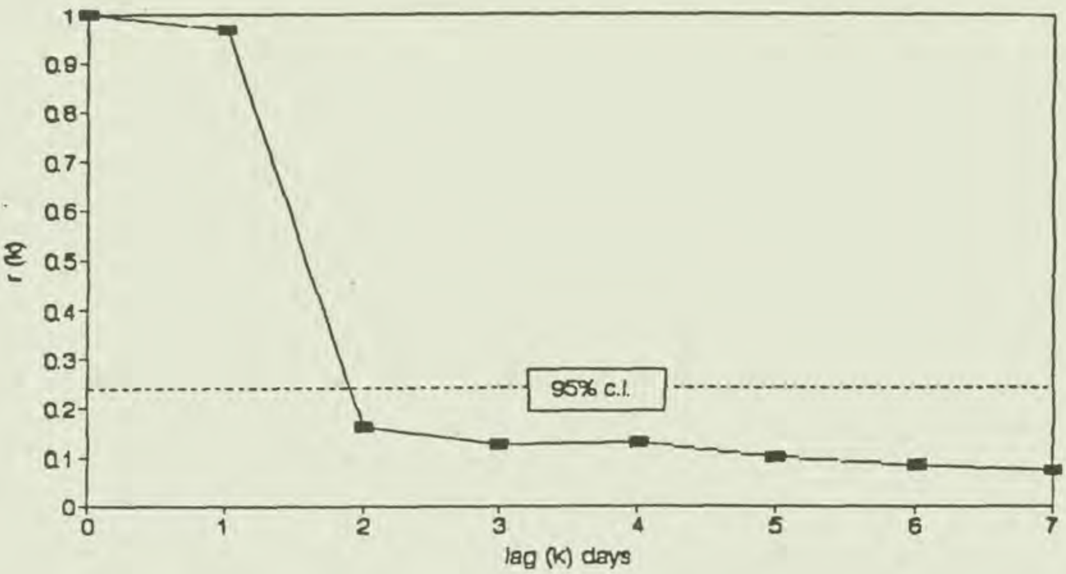

Figure 5. The correlogram of the daily rainfall data

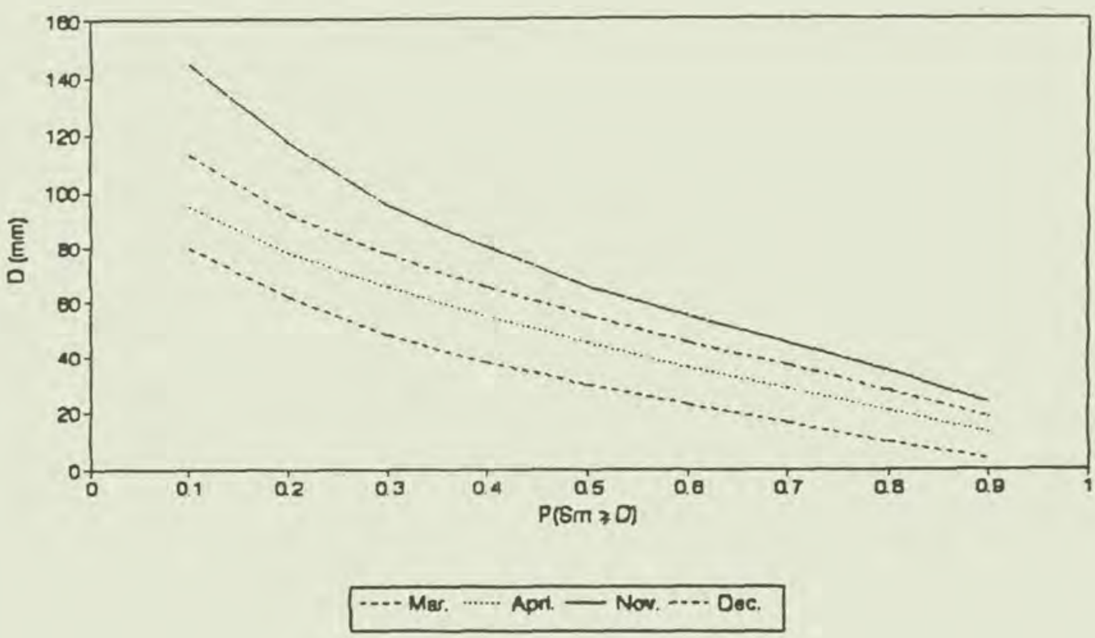

Figure 6. The cdf of the rainsum for the wetter months.

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EFFECTIVE RAINFALL MODEL FOR UPLAND CROP IRRIGATION

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ABSTRACT

Factors influence Effective Rainfall (ER) for irrigation are crops, soil texture, rainfall pattern, topography, etc. It is different in paddy rice and up land field irrigation, but it can be used more rainy water in paddy rice field than which in up land, it can be saved irrigation water, and saved operation cost in irrigation system. Effective rainfall can not be predetermined before planning and design of irrigation projects, but it can be saved the water recourses which are stored in reservoirs or ponds or in under ground.

Consider the factors of soil texture, soil moisture, depth of root zone etc. to work out a effective rainfall model of upland crop irrigation in this paper. It can be used to the area of Chia-Nan Irrigation system.

INTRODUCTION

The meaning of effective rainfall (ER) for irrigation is the rain water to supply crop during irrigation, it can be used the irrigation water economically both in quantity and management on labor. If we going to supply irrigation water 100 mm from turn out, assume conveyance loss 20% in ditches from the gate to the irrigation field, say 20 mm, and application efficiency of surface irrigation in the field is 50%, the net water used by crop is about 40 mm, it means that if supply water by rainfall to the field directly, it can be saved the water 60 mm at the turn out. In another words, it can be saved 1.5 times of irrigation water to compare the quantity in turn out. It also can be saved labor for irrigation practices.

We have to consider what is the purpose to save irrigation water? what conditions are available for saving water? Take water source as an example, if the water source is taking from river, the most case is that if the rain is falling in irrigation service area, it must be raining in whole watershed, so that a lot of water is running in to the river, even the irrigation water can be saved in the service field at the down stream of the river, it also can not be saved the water during that time, but if the effective rainfall is used in the service area where the water source comes from reservoir or pumping from ground water, it can be stored the quantity of water both in reservoir or under ground, it also can be saved the operation cost for water management.

Another problem we have to consider that can effective rainfall be used for planning and design in irrigation project? I say no, because the value of ER can not be predetermined before planning and design. So, it can not be considered the factor of ER for planning and design irrigation projects.

FACTORS AFFECTING EFFECTIVE RAINFALL (ER)

Many factors affecting effective rainfall, such as crop , soil texture, rainfall pattern, irrigation, topography, cropping pattern etc. the detail is stated as below:

1. Crop: Kinds of crop and crop's growing season are influenced ER very much, Evapotranspiration and root depth of the crops are different in growing season, even in the some crop .General speaking, the maximum evaptranspiration and the deepest root zone are occurred at the flower stage of the crop, so that, the largest ER are occurred at this period. If the crop is planted at rainy season, there is the largest ER of the crop. If talking with the rate of ER, it is the smallest in rainy season and the largest in drought reasn.

2.Soil texture: Soil texture is very important fector to influence ER, it includes physical and chemical characteristics of soil, such as water holding capacity, infiltration, salt content etc. In order to figure out ER in some irrigation area, it has to investigate soil texture first. The items include below:

(1) Soil available moisture: It is the difference between field capacity to wilting point, caly soil has a lager soil available mixture than which in sandy soil. It means that it has a larger ER in clay soil.

(2) Soil infiltration: Sandy soil has the larger infiltration, if it is a short period rain shower, it may be satisfied the ER in the root zone, no more run

off flows on soil surface, but it is easy to occur run off and less ER in soil root zone.

3. Intensity of rainfall: Intensity of rainfall is related to ER very much, if a general rain is falling, it will be got the larger ER; A short period strong shower, may occurred run off on soil surface, the quantity of rain may not be effective. The large size of rain drop is also influenced infiltration after the large diameter of rain droped to the soil surface, the soil fine parftical will fill to the soil space by the drop force, it will be became less infiltration.

4. Irrigation: If irrigation quantity and interval can be adjest automacly, it can be got the higher rate of ER, take irrigation souce come from reservoir, pond or under ground as an example, it can be supplied irrigation water on time, the rate of ER is high. Time of rainfall is also influenced ER. If the rain is just falling after irrigation, the rain is no more effective.

5.Topography: If cultivated land has a large slope, the rain water will flow on land surface quickly, less iffiltration to the root zone is happened, it becomes lower ER. If the cultivated land is very rough, the rain water will stay in the land surface longer, it may become more ER.

6. Cropping pattern: If control cropping pattern can be got higher ER., for instance, a farm cultivates larger evapotranspiration crops in rainy season and the lower consumptive use of crop in drought season, it can be got higher ER. Talking about cultivation method, if use the methods of contour cultivating, crops inter-cropping, rotation-cropping, mulching the land surface, etc., they can be increased the utilization of ER.

except the factors above, the water level under ground, the location of hard pan or impervious layer, drainage facilities, fertilizer application etc. are influenced ER. but the factors of crop evapotranspiration, soil texture are the most important to influence ER. The maximum irrigation depth is the up limit effective rainfall on the some crop, it will be discussed later in this paper.

COMPARE THE EFFECTIVE RUNFALL ON PADDY RICE TO UPLAND CROP FIELD

The factors influenced ER which mentioned in the previous article are the general case, the ER on paddy rice field and upland crops are much different. In order to compare the differences. the detail is stated as below:

1.For paddy rice irrigation:

A. In most time during growing season, the water is ponded on the ground surface of paddy rice field, so that more water can be received from rainfall, especially at the time when no water is standing on the ground surface.

B. The quantity of ER is proportion to the degree of maintenance of the levees which are surround the paddy field.

C. The quantity of ER is proportion to the height of levees which are surrounded along the paddy field.

D. The quantity of ER is inverse proportion to the deep percolation in the root zone.

E. The quantity of ER is larger in the middle of growing season and less at the beginning and the end of the growing season.

2. For upland crop irrigation:

A. Up limit soil moisture content in root zone is field capacity, so that ER is also limited in this level.

B. If the soil moisture in root zone at the low limit near wilting point, it may store more ER before irrigation.

C. Deep roots can be store more ER in the root zone.

D. If a hard pan or impervious layer beneath root zone, there will be stored more water after rainfall. Contrary, Sandy soil has more deep percolation water infiltrated to become ground water.

The characteristics of ER both in paddy rice and up land crop fields are described as above, the reader may know how to control the ER during irrigation. In order to utilize the rainfall water properly in both fields of paddy and upland crop, the estimated methods are described in the section below.

LATERAL REVIEW OF ESTIMATING EFFECTIVE RAINFALL

1.Estimation of ER for up land crop irrigation

(1) The method of Walter: This method is adopted one month period for estimation ER. Using average daily rainfall times rainy days equal to ER in the month. it can be used where the rainfall is evenly distributed and have many rainy days in the month.

(2) Method of U.S. Federal Soil Conservation Service: This method is applied to Agricultural Research Service, Agricultural Reclamation Bureau in the United States of American. This method does not consider the factors of crop and the distribution of raifall pattern. It only consider the factor of monthly rainfall. So that , it is a rough method for estimating ER.

(3)Antecedent rainfall index method: This method was established by Fisher and Leuke, the equation is below:

$$E_n = R_n + K \times r_{n-1} + K^{n-2} r_2 + K^{n-1} r \quad or$$

$$E_n = R_n + K \times E_{n-1} \text{ .... } (1)$$

where R_n is rainfall in the day; K is constant depend on the soil texture and weather conditions, here use 0.95; K E_{n-1} is a residual of ER, generally, the value of n is less than 60, this equation does not consider the factors of crop, run off and the distribution of rainfall, therefore, only use the case which the storm intensity is not so large.

(4) The method is used in the north side of Cho-Shui-Hsi basin in Taiwan, it is established by Water Resources Planning Cimmission, Ministry of Economic Affairs in Taiwan, the method is count from daily rainfall, the first day from 20 to 60 mm is said ER. If the continuous rainfall for many days, divide it into sets, one set equal to three days, the first rainfall is from 20 to 60 mm it is effect. If the rainfall is less than 30 mm in first set, no more count the rainfall and start again as the first set.

(5) Budgeting method: It is calculated by daily rainfall and consumptive use of crop then compute the residual effective soil moisture in the root zone, even the rainfall very small, it also can be counted as ER. This method is the most accurate than the methods above.

(6) The method from Water Conservancy Bureau in Taiwan.

A. When the soil moisture is more than field capacity after rainfall:

ER (mm) = [field capacity(%) - soil moisture(%) before rainfall] * Depth of root zone (mm) + daily consumptive use of crop * (rainy days + 1)

B. When the soil moisture is less than field capacity after rainfall:

ER (mm) = [Soil moisture after rainfall(%) - soil moisture(%) before rainfall] * Depth of root zone (mm) + daily consumptive use of crop *rainy days.

2.*Estimation ER for paddy rice irrigation.*

(1) Agriculture and Forest Department in Japan: Up limit of daily ER is about 50--80 mm and low limit is 5 mm. Total rainfall within 5 days times 70%--80% then divide the rainy days (5) is equal to daily ER. If rainfall is continuous, the maximum daily ER is calculated by the equation below:

Daily max. ER = Utilized rainfall - [ER in the day's before - daily consumptive use in that day]

If daily rainfall is less than the calculated max. ER, the value is effective; if daily rainfall is larger than the calculated value, the rainfall is max. ER.

(2) Hand Book of Agriculture Civil Engineering in Taiwan: Daily ER is about 3--30 mm, the total ER is about 70% --90% of total rainfall in growing season.

(3) Irrigation department in India:

A. In the period of transplanting (June to August) daily rainfall is from 1/4 to 3 in, the rainfall is effective, but the total rainfall within 10 days is limited to 5 in.

B. Growing stage: daily rainfall from 1 to 2 in, it is effective, but the total rainfall within 10 days is limited to 3 in.

(4) Cho-Shui-Hsi Basin, Estimated by Water Resources Planning Commission, Ministry of Economic Affairs in Taiwan:

A. If the growing period in rainy season, the effective rainfall is about 60% of monthly rainfall.

B. If the monthly rainfall is less than 100 mm, it is effective during September to April next year.

(5) ER in Tou-Yung Irrigation Association in Taiwan:

A. If daily rainfall is between 5 to 36 mm, it regards effective.

B. If the basic continuous rainfall 30 mm and plus the sum of depletion water depth (daily deplete water depth 6 mm in paddy field), the total rainfall is effective.

(6) ER in Chia-Nan Irrigation Association in Taiwan:

A. If daily rainfall is under 30 mm, there are effective.

B. The sum of daily average ER in a month divided by the days in that month is equal to daily average rainfall.

C. Daily rainfall more than 30 mm, the irrigation practice will be adjusted as the Table below:

Rainfall (mm)	Subtract The % Of Water In Turn Out	Days	Remark
40	20	2–3	depend on soil texture
50	50	2–3	
more than 60	stop	more than 3	

EFFECTIVE RAINFALL MODEL ON UPLAND CROP IRRIGATION IN CHIA-NAN AREA IN TAIWAN

1. Back ground of Chia-Nan Irrigation Association: CHia-Nan Irrigation Association is located in the south-western part of Taiwan, a large agricultural area in Chia-Nan irrigation system, it includes the districts of Yun-Lin, Chia-I and Tainan, the agriculture area is about 264,000ha , 48% of total cultivation area in Taiwan. It is the largest irrigation association in Taiwan. The climate is sub-tropical with average temperature 21--24°C, annul average rainfall is about 1600 mm, but 80% is falling in May to August, very shortage water source in this area, so that the three year rotation cropping pattern was adopted, it means that the crops paddy rice, upland crops and sugure cane were rotated whih in three year, so that , in order to supply the enough water by nature rainfall is very impotant.

2. Basic data collection project: In order to develop upland crop cultivation under shortage water source condition in this area, use the nature rain water is very important, so that, a basic data investigation projects were carried out since 1991, The basic data include soil texture, water holding capacity in root zone, apparent specific gravity, infiltration, under ground water level etc.. The data are distributed in 25 working stations in the service area, it is about 1000--2000 ha in each station. The project was done before June 1994.

3. Effective Rainfall (ER) Model: A model was worked out based on the data which investigated during 4 years (1991--1994). The calculation is followed the equation below:

$$d = (Fc - wp) \times 0.75 \times A_s \times D$$

Where d depth of water to be refilled in root zone; F.C. field capacity of the soil; W.P. wilting point of the soil; A_s apparent specific gravity; D depth of root zone; 0.75 is the readly available soil moisture. It may injure the crops, if we irrigation until the soil moisture at wilting point, so that we are going to refill the water at 0.75 available soil mixture.

The root zone depth of crop, general used 40cm in depth in Taiwan, because the crops in Taiwan are shallow root system, the crop growing period about less than 4 months, but sugar cane is a longer growing period, the calculations are used 60 cm depth of root zone. All the calculations are listed in the Table below:

Effective Rainfall Model on Irrigation in Chia-Nan Area in Taiwan.

District	Station	Soil Texture	As	Area (Ha)	ER In Depth Of Root Zone (mm)	
					40 Cm	60 Cm
Nan-Hsin	Kuei-Jen	SIL	1.54	1033	61	96
		SIC	1.48		71	108
		L			53	79
	Hsi-Shih	SIL	1.54	868	50	82
		S			40	60
		C			53	78
	An-Nan	LS	1.43	1014	22	24
		L	1.57		50	80
		SIL	1.58		71	113
		SICL	1.6		77	113
	Hsin-Hwa	SL	1.6	849	50	54
		LS			35	53
		L	1.52		33	51
		SIL			41	61
		SICL			48	7
	Hsin-shih	L	1.49	1050	49	77
		SL			40	59
		SIL	1.47		44	73
		C			54	81
		SICL			54	81
	Feng-Hwa	SIL	1.55	1025	56	82
		SIC			50	75
		SICL	1.52		46	72
	Shan-Hwa	L	1.46	2212	53	78
		SICL			52	78
		SIC	1.46		55	83
		SIC			51	75
	An-Ting	SL	1.46		38	51
	Kang-Kou	SIL	1.51	1003	67	104
		SL	1.61		49	74
	Kung-Uen	SIL	1.44	1021	57	76
		SL	1.5		42	66

As: apparent specific gravity

Chia-Li	Hsue-Chia	LS	1.58	1758	23	32
		L	1.66		52	78
		SIL	1.57		54	78
		CL			57	85
		C			51	74
		SICL			55	82
Chia-Li	Hsi-Kang	SIL	1.59	1209	63	105
		SIC			50	76
		L			46	68
	Urn-Ney	SIL	1.53	1679	70	108
		SICL			51	76
		SIC			51	77
	Chia-Li	SIL	1.48	940	54	88
		CL			68	102
		SIC	1.48		64	98
		L	1.41		31	47
	Ow-uang	SIL	1.55	1748	56	85
		SL			47	71
		L	1.54		38	73
		LS			50	67
	Tzu-Lung	SIL	1.57	1286	68	94
	Chi-Ku	SL	1.4	1346	39	58
		L	1.47		38	56
		SIL	1.45		36	43
	Shnh-Wa	SIC			51	75
Ma-Tou	Mo-Tou	SIL	1.63	1166	57	89
	Chung-Ying		1.75	968	59	88
	Hsia-Ying	C	1.63	1808	66	102
		SIL	1.69		65	96
		L	1.73		58	83
	Liu-Chia	SIL	1.69	1866	57	86
		SIC	1.71		74	102
		L	1.62		58	88
	Lung-Tien	SIL	1.6	1700	62	91

Hsing-Ying	Chung-Chi	L	1.68	1736	58	83
		SICL	1.61		65	93
		SIC	1.68		74	102
	An-Chi	L	1.81	1218	56	80
		SICL	1.69		69	97
	Shyh-An	L	1.7	1295	63	87
		SIL	1.8		72	100
	Hou-Pi	L	1.72	1791	53	81
		SIL	1.63		76	108
		SL	1.79		46	59
		SIC	1.5		49	72
	Hsin-Ying	SL	1.78	1142	36	55
		L	1.74		65	86
		SL	1.78		36	55
		SIL	1.67		73	114
	Liu-Ying	SICL	1.74	1610	86	89
		L	1.87		55	83
	Yen-Shui	L	1.8	1330	68	98
		SIL	1.73		78	91
	Huan-Ya	SIL	1.7	1077	57	95
		L	1.65		66	67
		SICL	1.86		51	76
Paihp Reservoir	Pai-Ho	SIL	1.64	2309	76	103
		L	1.63		70	116
	Tung-Shan	SIL	1.78	1.24	67	106
		SL	1.7		61	89
Chia-Yi	Chung-Ying		1.75	968	59	88
	Hsia-Ying	C	1.63	1808	66	102
		SIL	1.69		65	96
		L	1.73		58	83
	Liu-Chia	SIL	1.69	1866	57	86
		SIC	1.71		74	102
		L	1.62		58	88
	Lung-Tien	SIL	1.6	1700	62	91
	Chung-Chi	L	1.68	1736	58	83
		SICL	1.61		65	93
		SIC	1.68		74	102

Pot-Zu	Chu-Tsun	L	1.53	1390	39	66
		SICL	1.76		46	95
	Sung-Mei	SIL	1.73	1259	57	88
		SIL	1.63		50	84
	Shu-Lin	L	1.75	1668	34	48
		SIL	1.74		49	77
	Pot-Zu	SIL	1.56	1663	50	75
		SICL	1.6		55	91
	Lu-Tsao	SIC	1.67	2181	59	86
		SICL	1.65		68	100
	Mei-Pu	SICL	1.67	917	64	98
	Chung-Shih	SIL	1.7	667	91	85
		SL	1.71		38	49
	Kuang-Yung	SIL	1.66	1021	67	101
		SIC	1.67		50	73
		L	1.72		25	72
	I-Chu	SIL	1.62	1148	63	90
	Suan-Tou	SIL	1.59	1569	51	77
	Liu-Chiao	SIL	1.61	1513	61	92
		SL	1.66		15	27
	Hsia-Jyi	SL	1.61	1039	33	44
	Ping-Chi	SIL	1.73	1081	54	91
	Hsia-Tan	SICL	1.51	919	62	94
		SIL	1.63		67	97
		L	1.58		43	61

4. Application of this model: The figures shown on the larst two columns of the list are maximum effective rainfall when the soil moisture at 0.75 available soil moisture in the depth 40 cm or 60 cm of the root zone. If you like to know how much rainfall is effect, you have to know soil moisture in the root zone before received the rain water, therefore measure the soil moisture of the root zone periodical is necessary, it may know how much water is used. If a small rain is received, you may know how much irrigation water is needed to supply again. If there is a lot of rain water is received by the soil root zone, you may know how much water is become surface run off, how much water is deep procoleted into the ground. Both the surplus water data can be used for drainage design and estimated under ground water resources.

CONCLUSION

Definition of Effective Rainfall for irrigation is to supply water for crop use. It is influenced by the factors of crop, soil texture, rainfall pattern, topography, etc., More rain water can be used for paddy rice irrigation. ER is less used for up land crop irrigation, it is proportion to depth of root zone, depletion of soil moisture, presence of hard pan depth beneath of root zone, etc.

Utilization of ER can be saved water in water storage bodys or under ground water system, but can not be saved the water which intakes from rivers. It also can be saved operation and labor cost during irrigation.

There are six methods for estimation ER of upland crop irrigation which mentioned in this paper, the budgeting method and the model mention in this paper are the most accurate in up land crop irrigation, but it has to measure the soil moisture periodically in the field. Six methods are mentioned in this paper in different conditions in paddy rice field.

A new model is developed in this paper, the maximum effective rainfall is calculated based on the basic data of soil texture, soil moisture constants of the soil, depth of root zone etc.. It can be estimated ER of up land crop irrigation, If the rain water less than irrigation depth, the supply irrigation depth can be calculated. If the rain water much more than the irrigation water, the data can be used for drainage design and estimated under ground water resources.

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A Preliminary Research on Alfalfa Water Consumption and Rainfall Utilization

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Abstract

Purple flower alfalfa (Medicago Satival) is one of the fine quality perennial herbages. Its distinguishing features are droughht and salt endurance, high output and good quanlity. Alfalfa has a high capacity in utilization of rainfall, then it can depend on precipitation for its growth. So extending the alfalfa planting area in Heilonggang Region in Hebei Province is an important way for developing animal husbandary in this region. And the rainfall utilization can also be increased.

Supported by National Natural Science Foundation of China, a project was conducted from 1994 to study the water consumption pattern and rainfall utilization of alfalfa. The field experiments were carried out at the Nanpi Eco- agricultural Experimental Station, CAS. By measuring the soil water changing, the water consumption and water use efficiency of alfalfa in this area. Begins in the middle of March and ends at the beginning of October with a total 218 days. During its growth period, four mowing were conducted with total yield of 12712.5kg/ha, total water used at 616.5mm. Water use efficiency at 20.55kg/ha · mm. For the total water consumed, it was nearly the same with winter wheat, but the alfalfa hadn's given any irrigation, mainly depend on rain fall. In 1994 the precipitation was 669.3mm, which alfalfa used was about 568.0mm, which was 92.1% of its total water used, and rainfall utilization rate by the alfalfa reached 84.9%.

Key words: Alfalfa water consumption, Rainfall utilization

1. The site

The test plot has a area of 0.3ha, which is located at the grass experimental field of Nanpi Eco-agricultural Experimental Station, CAS. The testing alfalfa has grown for 8 years. The soil is a kind of Chao soil, and is sandy loamy with salt content at 0.08%, nutrient contents for 0 to 20cm soil layer at 0.81% for organic matter, 0.061ppm for total N, 4.25ppm for available P and 127.5ppm for available K.

It is semi arid moonsoon climate, dry and cold in winter, little rainfall and windy in spring, and hot and rainy in summer. Annual average temperature at 12.3℃, lowest at −15℃ to −20℃, highest at 38 to 40℃. Annual average precipitation is 541.7mm, for normal flow year, precipitation at 515.3mm, for low flow year at 452.3mm and high flow year at 565.3mm. Rainfall mainly falls during June to August, which takes up 70% of the annual precipitation. In Heilonggang water shortage is a serious problem. For every mu farmland, only 80 to 100 m^3 water available. Irrigation water comes from the shallow fresh water and slight salt water. Groundwater table below surface is at 7 to 9 meters.

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2. Methods

The soil water contents at the experimental site were measured at about 4-days intervals by using netron probe. The access tube was installed to 3 meters. soil moisture measured at 20 cm intervals would be shortenned. Rainfall information was collected from a nearby meteorological station. Yield of alfalfa was measured by mowing many small area of $1x_1\ m^2$, after dried, the dry output of the alfalfa was got. The growth stages were recorded included the seedling stage, flowering stgae and mowing stage.

3. Results and Analysis

3. 1 Growth period and yield of alfalfa

The stage of turning green for the alfalfa in this region begins in the middle of Marth. the last mowing usually falls at the beginning of October, total growth period 218 days. There were four mowings in a year with a total yield about 12712. 5kg/ha. Table 1 gives the yield of every mowing and the growth stage.

Tab. 1 Growth stage and yield of the alfalfa

Se. mowing	Growth stage	Growth duration	Yield (kg/ha)
1	12/3~14/5	64	5086. 5
2	15/5~19/7	66	3676. 5
3	20/7~27/8	39	2529. 0
4	28/8~5/10	49	1420. 5
Total	12/3~5/10	218	12712. 5

3. 2 Alfalfa water consumption

The water used by alfalfa can be calculted based on the equation:

$$E_p = W_o + P - R - W_1 \quad (1)$$

$$W_o = H_r(\theta_1 - \theta_2)/10 \quad (2)$$

$$P = \sum_{i=1}^{n} P_i \quad (3)$$

Where

E_p: Total water consumed by alfalfa

W_o: Soil water used by alfalfa

P: Effective rainfall during the growth period of alfalfa

R: Runoff from the alfalfa field

W_1: Soil water percolation outside the root soil layer

H: The depth used for calculation soil water changing r: Soil bulk density (0~60cm at 1.35g/cm^3, 60~100 at 1.4 and 100~300 at 1.45)

δ_1 and δ_2: soil water content at the beginning and ending

Based on calculation using the above equation, alfalfa water consumption for each mowing are listed in table 2.

Tab. 2 Alfalfa water consumption

Se. mowing	Effective Rainfall (mm)	Soil water used (mm)	Total (mm)
1	52.9	128.4	181.3
2	316.1	−82.0	243.1
3	181.7	−51.7	130.0
4	17.3	53.8	71.1
Total	568.0	48.5	616.5

3.3 Water used at different growth stage of Alfalfa

The first three mowings ocuurred during 12 March to 27 August, the duration was 169 days, during this time water consumption was 545.4mm, daily average at 3.2mm. Since the weather conditions and growth period are different for each mowing, the water consumption were also changing. Tab. 3 gives the water used at different stage of the alfalfa for each mowing.

Tab. 3 Water consumption of alfalfa at different growth stage for each mowing

Se. mowing	Item	Turning green to start of noding	Start of noding to flowering	Flowering to mowing	Total
1	water consumed	111.9	46.4	23.0	181.3
	stage duration	37	13	9	64
	daily water used	3.0	2.2	3.2	2.8
2	water consumed	18.3	31.9	183.9	234.1
	stage duration	24	22	20	66
	daily water used	0.3	1.5	9.2	6.5
3	water consumed	42.9	53.4	33.7	130
	stage duration	17	14	8	39
	daily water used	2.5	3.8	4.2	3.3

Generally after alfalfa flowering, water consumption reaches the highest, average daily consumption was 5.5mm, at its early stage, the water consumption is at the lowest with average at 2.1mm/day.

3.4 Alfalfa water use effeciency

The four mowings around a year for the alfalfa, the total water used was 616.4mm, total output at 12712.5kg/ha, avarage water use efficiency at 20.55kg/ha • mm. The first mowed alfalfa had the highest water use efficiency, which was at 27.9kg/ha • mm, and the lowest was the second mowed alfalfa, at 16.35kg/ha • mm (see tab. 4). Compared with winter wheat and maize, it was higher at 24.5% over the water use efficiency of winter wheat-summer corn, separately higher than winter wheat at 71% and corn at 14%, respectively.

Tab. 4 Water use efficiency (WUE) by alfalfa

Se. mowing	Yield (kg/ha)	Water used (mm)	WUE (kg/ha • mm)
1	5086.5	181.3	27.9
2	3676.5	234.1	16.35
3	2529.0	130.0	19.5
4	1420.5	71.1	19.95
Total	12712.5	616.5	20.84

3.5 Soil water changing pattern of alfalfa

Based on the 11 times measuring of the soil water contents and calculation results, 0~200cm soil water stored fluctuated between 376.8 to 548.9mm, and soil moisture varied between 13% to 18.3%, which were changed with rainfall. From spring to July, soil water content gradually decreased, after July along with the rainy season, the soil water content greatly increased.

Water stored at 0 to 60cm soil layer was about 85 to 152mm, from spring to the end of June, it gradually decreased, then till the beginning of August, it increased quickly. It decreased again from then on. For the water stored at 60 to 120cm soil layer, it fluctuated between 122 to 175mm, and its changing with season was the same as the 0 to 60cm soil layer, only the stored water was higher. For the deeper layer of soil water stored, at 120 to 180cm soil layer, it varied at 112mm to 176mm, the same trend with the other two layers, but the time when its water content begun to increase was a little later. Water stored in 180 to 200cm soil layer was relatively stable. The results showed that the alfalfa mainly extracted water from 0 to 180cm soil layer.

For the quantity of water stored at different layer of soil, taking the time between 17 April to 27 August, total water stored from 0 to 200cm soil layer was 434mm, which from 0 to 60cm took up 27.6% at 119.8mm, 60 to 120cm taking up 33.2% at 144.1mm, 120 to 180cm taking up 29.3% at 127.1mm.

For soil water content along the soil profile, the water content at 0 to 60cm soil layer was greatly affected by rainfall and the evapotranspiration of alfalfa, for 60 to 160cm soil layer, its water content didn't chang much with the changing of 160 to 200cm soil layer was relatively stable and kept at higher level.

4. Conclusions

In Heilonggang region, the alfalfa was generally mowed three or four times a year, total yield at 11427 kg/ha to 12712.5kg/ha, in which the first mowing had the highest yield, which took up 40% of the total output.

Water consumption of alfalfa was about 545.4mm to 616.5mm, water use efficiency at about 20.83 to 20.95kg/ha • mm. For the total water used, it was nearly the same with the water used by winter wheat-summer corn. Though planting alfalfa was not water-saving, alfalfa can use rainfall effectively at about 84.9%, and it can also give high yield and use water efficiently. So developing alfalfa planting in water shortage area is an important way in effectively utilization of rainfall.

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