MEDITERRANEAN ACTION PLAN
PRIORITY ACTIONS PROGRAMME

UNITED NATIONS ENVIRONMENT PROGRAMME

WASTEWATER REUSE FOR IRRIGATION IN THE MEDITERRANEAN REGION

REUTILISATION AGRICOLE DES EAUX USEES DANS LA REGION MEDITERRANEENNE

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This volume is the forty first issue of the Mediterranean Action Plan Technical Report Series.

This Series will collect and disseminate selected scientific reports obtained through the implementation of the various MAP components: Pollution Monitoring and Research Programme (MED POL), Blue Plan, Priority Actions Programme, Specially Protected Areas and Regional Oil Combating Centre:

Ce volume constitue le quarante premier numéro de la série des Rapports techniques du Plan d'action pour la Mediterranée.

Cette série permettra de rassembler et de diffuser certains des rapports scientifiques établis dans le cadre de la mise en oeuvre des diverses composantes du PAM: Programme de surveillance continue et de recherche en matière de pollution (MED POL), Plan Bleu, Programme d'actions prioritaires, Aires spécialement protégées et Centre régional de lutte contre la pollution par les hydrocarbures.

PREFACE

The United Nations Environment Programme (UNEP) convened an intergovernmental Meeting on the protection of the Mediterranean (Barcelona, 28 January - 4 February 1975), which was attended by the representatives of 16 Mediterranean coastal states. The meeting discussed the various measures necessary for the prevention and control of pollution of the Mediterranean Sea, and concluded by adopting an Action Plan consisting of three main components:

- integrated planning of the development and management of the resources of the Mediterranean Basin (management component);
- a co-ordination programme for research, monitoring and exchange of information and assessment of the state of pollution and of protection measures (assessment component);
- a framework convention and related protocols with their technical annecces for the protection of the Mediterranean environment (legislative component).

All components of the Action Plan are interdependent and provide a framework for comprehensive action to promote both the protection and the continued development of the Mediterranean eco-region. No component is an end in itself. The Action Plan is intended to assist the Mediterranean Governments in formulating their national policies related to the continuous development and protection of the Mediterranean Region and to improve their ability to identify options for alternative patterns of development and to make appropriate allocations of resources.

The Priority Actions Programme (PAP), a component of the integrated programme of the Mediterranean Action Plan (MAP) promotes the exchange of experience in the fields of integrated planning and management of resources in the Mediterranean Region.

The starting point of the PAP activities is the awareness that the protection and sound management of the environment can only be implemented by means of a rational development which implies optimum exploitation of natural resources.

Within the framework of the definition of the PAP activities, the representatives of the Mediterranean governments, the Contracting Parties of the Barcelona Convention, have established the following priorities for the PAP:

- human settlements
- water resources management
- soil protection against erosion
- tourism
- aquaculture
- renewable sources of energy.

In the above-mentioned areas, the following activities are being completed:

- directories of Mediterranean institutions and experts
- water resources management
- integrated planning and management of Mediterranean coast zones
- protection and rehabilitation of historic settlements
- land-use planning in earthquake zones
- soil protection against erosion
- solid and liquid waste management, collection and disposal
- development of tourism harmonized with the environment
- aquaculture
- renewable sources of energy
- environmental impact assessment
- balance between the hinterland and the coastal zones.

The United Nations agencies, many international organizations and almost all Mediterranean countries play an active part in all these activities.

This volume, which is the forty first in the Mediterranean Action Plan Technical Reports Series, contains selected documents concerning the Priority Action entitled "Water Resources Development in Mediterranean Islands and Coastal Areas", prepared within the Phase III of the action, implemented in the period 1986-1987, dealing with treatment and use of sewage effluent for irrigation in the Mediterranean region.

PREFACE

Le Programme des Nations Unies pour l'environnement (PNUE) a convoqué une réunion intergouvernementale sur la protection de la Méditerranée (Barcelone, 28 janvier - 4 février 1975) à laquelle ont pris part des représentants de 16 Etats riverains de la mer Méditerranée. La réunion a examiné les diverses mesures nécessaires à la prévention et à la lutte antipollution en mer Méditerranée, et elle s'est conclue sur l'adoption d'un Plan d'action comportant trois éléments fondamentaux:

- Planification intégrée du développement et de la gestion des ressources du bassin méditerranéen (élément "gestion");
- Programme coordonné de surveillance continue, de recherche, d'échange de renseignements et d'évaluation de l'état de la pollution et des mesures de protection (élément "évaluation");
- Convention cadre et protocoles y relatifs avec leurs annexes techniques pour la protection du milieu méditerranéen (élément juridique).

Tous les éléments du Plan d'action étaient interdépendants et fournissaient le cadre d'une action d'ensemble en vue de promouvoir tant la protection que le développement continu de l'écorégion méditerranéenne. Aucun élément ne constituait une fin à lui seul. Le Plan d'action était destiné à aider les gouvernements méditerranéens à formuler leurs politiques nationales en matière de développement continu et de protection de zone de la Méditerranée et à accroître leur faculté d'identifier les diverses options s'offrant pour les schémas de développement, d'arrêter leurs choix et d'y affecter les ressources appropriées.

Le Programme d'Actions Prioritaires (PAP), partie du plan intégré du Plan d'Action pour la Méditerranée (PAM), a pour but de promouvoir des échanges d'expériences dans les domaines de la planification intégrée et de la gestion des ressources des zones côtières méditerranéennes.

Le point de départ des activités du PAP est la connaissance que la protection et la promotion de l'environnement ne peuvent être réalisées que grâce à un développement raisonné qui se traduit par une exploitation optimale des ressources naturelles. La notion même de l'environnement, conçue dans un sens plus large, et tout particulièrement dans des conditions méditerranéennes, constitue en même temps la plus précieuse ressource de la Région.

Dans la phase de la définition des activités du PAP, les représentants des Gouvernements Méditerranéens, Parties Contractantes de la Convention de Barcelone, ont précisé les domaines prioritaires du PAP, notamment:

- établissements humains;
- gestation des ressources en eau;
- protection des sols contre l'érosion;
- tourisme;
- aquaculture;
- sources d'énergie renouvelables.

Dans les limites des domaines précités, les actions suivantes sont en voie d'achèvement:

- répertoires des institutions et experts méditerranéens;
- gestion des ressources en eau;
- planification intégrée et gestion des zones côtières méditerranéennes;
- protection et réhabilitation des sites historiques;
- aménagement du territoire dans les zones sismiques;
- protection des sols contre l'érosion;
- gestion, collecte et élimination des déchets solides et liquides;
- développement du tourisme en harmonie avec l'environnement;
- aquaculture;
- sources d'énergie renouvelables;
- évaluation des impacts sur l'environnement;
- interrelation côte - arrière-pays.

A toutes les actions prennent part les organismes des N.U. et de nombreuses organisations internationales, y compris la participation active de presque la totalité des pays méditerranéens.

Le présent volume, le quarante premier de la Série des rapports techniques du PAM, englobe un choix de documents relatifs à l'action prioritaire intitulée "Développement des ressources en eau des îles et zones côtières méditerranéennes", préparés à l'intérieur de la Phase III de l'action, mis en oeuvre dáns la période 1986-1987, et concernant l'épuration et la réutilisation agricole des eaux usées dans la région méditerranéenne.

EDITORIAL

The subject of this technical paper is "Wastewater treatment and re-use for irrigation in the Mediterranean Region". It is based on documents presented in the workshop on "Treatment and Use of Sewage Effluents for Irrigation in the Mediterranean Region" (Split, November 1987), within the activities of the Priority Actions Programme (PAP) of the Mediterranean Action Plan (MAP).

This project "Wastewater treatment and re-use for irrigation in the Mediterranean Region", within the priority action "Water Resources Development in Mediterranean Islands and Coastal Areas" has been implemented with WHO/EURO and FAO. The documents of the above-mentioned workshop are presented in three parts:

Part I - Introduction (presents results of the workshop),
Part II - Some general and specific aspects of wastewater treatment and re-use for irrigation,
Part III - Country reports and case studies.

The documents prepared in the course of this action will not be presented chronologically or in their original form, but in such a way as to describe clearly and concisely the basic subject, without superfluous details which are unsuitable for this kind of paper. Therefore, some documents will be presented partially and some in their entirety.

The principal aim of this paper is to describe the techniques and methods used, and to review briefly the situations in this field.

The purpose of this volume is to produce papers useful to local water authorities, as well as to decision-makers and technicians in the field of water resources development in the Region, in order to give information on the situation in other areas, and to present experience and possibilities for resolving the problems of wastewater treatment and re-use for irrigation in the Mediterranean Region.

Prof. Jure Margeta
Co-ordinator of the Priority Action
on Water Resources Development

EDITORIAL

Cette communication technique a pour thème "l'épuration et la réutilisation agricole des eaux usées dans la région méditerranéenne". Elle repose sur les documents présentés lors de l'Atelier sur l'épuration et la réutilisation agricole des eaux usées dans la région méditerranéenne, organisé à Split en novembre 1987 au sein du Programme d'actions prioritaires (PAP) du Plan d'action pour la Méditerranée (PAM).

Le projet "Epuration et réutilisation agricole des eaux usées dans la région méditerranéenne", faisant partie de l'action prioritaire "Développement des ressources en eau dans les îles et les zones côtières méditerranéennes", est réalisé conjointement avec l'OMS/EURO et la FAO. Les documents de l'atelier précité sont groupés en trois parties:

lère partie - Introduction (présentation des résultats de l'atelier),
IIe partie - Certains aspets généraux et spécifiques de l'épuration et de la réutilisation agricole des eaux usées,
IIIe partie - Rapports nationaux et études de cas.

Les documents rédigés au cours de cette action ne seront pas présentés selon leur ordre chronologique ou dans leur forme originale, mais de manière à exposer avec clarté et concision leur sujet fondamental, sans les élourdir de détails superflus qui ne conviennent guère à ce type de communication. Il s'ensuit donc que certains d'entre eux sont présentés de manière partielle et que d'autres le sont intégralement.

La présente communication vise avant tout à exposer les techniques et méthodes utilisées ainsi qu'à examiner brièvement la situation dans le domaine.

L'objectif de ce volume est de produire un document utile pour les autorités locales, de même que pour les décideurs et techniciens en matière de développement des ressources en eau dans la Région, leur permettant ainsi d'appréhender la situation dans d'autres zones et d'acquérir des enseignements et des moyens de trouver des solutions aux problèmes posés par l'épuration et la réutilisation agricole des eaux usées dans la région méditerranéenne.

Prof. Jure Margeta
Coordonnateur de l'action prioritaire
sur le développement des ressources en eau

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PART I

INTRODUCTION

WASTEWATER RE-USE IN THE MEDITERRANEAN REGION

CONCLUSIONS AND RECOMMENDATIONS

From Workshop on Treatment and use
of Sewage Effluent for Irrigation, Split, November 25-27, 1987

The conventional water resources available over a large part of the Mediterranean Region, and particularly in the islands and arid coastal zones, are already being exploited. The availability of necessary water quantities will be in future a limiting factor of development, especially in the eastern and southern zones. The expected demographic growth, the development of towns, industries and tourism, as well as the increase in the production of energy and food, will all require a sensible management of the conventional water resources and the development of new resources. Apart from that, the increasing water consumption will provoke a greater sea and coast pollution.

At present, 16,000,000 ha of land are irrigated in the Mediterranean Region, with an annual increase of 200,0000 ha. It is expected that by the year 2025, the surface to be irrigated will increase by the additional 4,000,000 ha in the northern part, requiring 40,000,000,000 m^3 of water for irrigation per year, and by 7,000,000 ha, requiring 70,000,000,000 m^3 of water for irrigation per year in the eastern and southern parts of the Mediterranean Region.

Those facts, among others, underline the need to implement thoroughly and expeditiously, new unconventional water resources, such as wastewater, along with the implementation of necessary measures for its re-use, sanitary protection and control.

Departing from such orientation, and after the presentation of the prepared documents followed by a thorough discussion, the workshop defined the following:

General conclusions

1. Wastewater re-use, as a form of water supply, has been used in the Region for some time now, the degree varying from one area to another.

2. Specific features of particular areas, regarding the wastewater quality, as well as the demand for water and habits of the population, require specific approach and solutions which must be gradually adapted to the actual situations and technology development in the Region.

3. Wastewater re-use can have various applications, such as: irrigation (industrial crops, fodder and pasture, high and marshland crops, urban green areas and forests), recharge of aquifers, aquaculture and industrial re-use.

4. Since a significant part of the Mediterranean Region is arid, wastewater re-use is of major interest since it represents a complementary resource, fully mastered and independent of climate (aridness).

5. Agriculture uses not only the effluent water, but also its other constituents, such as organic matter and nutrients (Nitrogen and Phosphorus), which are thus converted from an environmental nuisance to an asset.

6. The mandatory purification of the wastewater before re-use contributes directly to the environmental protection. Besides the general positive environmental effect, wastewater re-use has a particular importance for ecologically sensitive areas: in marine environment (more or less protected bays, flora and fauna of the continental shelf); inland environment (littoral flora and fauna, forests, etc.).

7. Wastewater re-use can contribute greatly to the protection of aquifers, especially in karstic areas, which, due to the specific hydro-geological characteristics, are exposed to all forms of pollution from the surface.

8. Inappropriate wastewater re-use can have negative effects, like too high concentrations of Nitrogen, Phosphorus, trace elements, build-up of pathogens or trace organisms, in soil and/or ground water, consequently threatening the health of humans, animals and plants.

9. Problems related to the re-use of adequately-treated wastewater are of an inter-disciplinary nature, requiring a simultaneous intervention of purification, irrigation system, quantitative and qualitative yield of crops, environmental protection, control, and particularly the socio-economic and sanitary aspects.

10. One of the by-products of wastewater treatment is sludge. Attention to an adequate disposal or use of sludge should not be overlooked. It represents a potential of fertilizing mineral and organic matter that can be useful in agriculture. The trace elements content and hygienic quality must, however, be considered in order to avoid risk for the health of humans, animals and plants, as well as soil pollution.

Specific conclusions and recommendations

1. Effluent quality standards have to regard simultaneously the physical, chemical and biological characteristics. Many existing health standards are considered to be too restrictive. A more flexible guideline has been recently proposed. It is important that the wastewater re-use standards be, at the same time, strict enough to avoid all sanitary risks, and not so strict as to rule out completely irrigation with treated wastewater.

2. The three necessary measures for avoiding and controlling the effects of re-use which could generate environmental and sanitary problems are:

   - restrictions of crop types in accordance with the quality of applied effluents;
   - selection of irrigation techniques which minimize direct contact between the effluent on one hand, and crops and/or farmers on the other; and,
   - application of adequate wastewater treatment methods.

3. Waste stabilization ponds have been found to be simple and cost-effective in treating urban effluents for agricultural use. It can produce effluents of good quality that can be used for irrigation, and in some situations, even for unrestricted irrigation. However, the method requires relatively more land and can create odour problems.

4. Considering the favourable climatic conditions prevailing in the Mediterranean region, innovative, low-cost treatment methods are preferable wherever land availability is not a limiting factor, and if they do not compromise the effluent quality. Such methods, based on natural purification processes, are simple and easy to operate, as well as cost-effective. Some examples of such processes already in use in the Region, are: maturity ponds; DRT (Deep Reservoir Treatment); and SAT (Soil Aquifer Treatment). These methods can produce good quality effluent, in some cases adequate for unrestricted irrigation.

5. New wastewater treatment technologies are at advanced stages of development and might be applicable in the future for agricultural re-use. These include aquatic vegetation, overland flow, creation of wetlands and anaerobic treatment of domestic effluent in USAB (Upflow Anaerobic Sludge Blanket) reactors.

6. Inter-seasonal storage is an essential element of efficient effluent use, aimed at compensating between the constant wastewater supply and variable effluent demand for agriculture. Storage installations, either surface or underground, act also as treatment units: they can serve as complementary treatment units, or even for principal effluent treatment.

7. Trace elements represent a potential hazard associated with the use of effluents and sludge in agriculture. It is advisable to monitor trace elements accumulation in soils, plants and animals consuming the fodder irrigated by wastewater. Appropriate measures have to be taken in order to avoid agricultural, environmental and health problems.

8. Where treated effluent is used for irrigation, there is a potential danger of high levels of salinity. Therefore, adequate agricultural practice and management must be applied to prevent excessive accumulation of salinity in soils.

9. Wastewater could represent a significant resource for agricultural irrigation in some countries of the Region. Generally, it can be said that re-use of effluents in agriculture could be a solution to water scarcity under most conditions provided that adequate precautions are taken in the design, operation and maintenance of the systems in order to protect individual and collective health.

10. Treated wastewater can constitute a supplementary resource to be taken into consideration in the processes of water resources planning, in order to overcome the conflict between the urban and agricultural demands.

11. In the process of re-use application planning on a national level, it is advisable to take into consideration the economic possibilities and other relevant factors, and with regard to them decide whether to build immediately one or more complete plants or to start more facilities with a lower level of treatment.

12. When selecting the technology (purification, irrigation, etc.), technical and economic conditions, as well as the limiting factors of the site should be taken into account.

13. Urban storm water should be treated in order to secure a better protection of water resources against pollution. At the same time, the effluent water would be rendered safer for irrigation purposes.

14. In order to improve the chemical quality of the wastewater to be re-used it is necessary to avoid mixing domestic wastewater with industrial or similar chemically contaminated effluents.

15. Even if freshwater reserves are still sufficient for agricultural uses, re-use for forest irrigation (which is less restrictive), could be advisable, for both timber and fire-wood production and creation of fire-breaks.

16. In the Mediterranean countries suffering from water scarcity, either at national or local levels, wastewater should be considered as an unconventional water resource, and the re-use should be integrated in the water management system, including clear definition of re-use priorities and strategies, as well as coherent laws and regulations.

17. Both restricted and unrestricted re-use should be considered as viable solutions for the Mediterranean Region. Supervision of effluent use is possible, and restricted irrigation can be practised using low treatment level and irrigating fodder, fibre or seed crop. When strict supervision of effluent use is difficult, a high level of treatment is necessary, so that the effluent meets the requirements for unrestricted re-use.

18. The economic feasibility of re-use projects depends on efficient use of the effluent. Thus, seasonal storage installations should be incorporated in re-use schemes and efficient irrigation methods should be applied.

19. Raising of public awareness, health promotion and education components may have to be introduced into the re-use projects.

20. Management of wastewater re-use for agriculture has to be preceded by an action on designing a sanitation network, implementing of devices and choosing of treatment techniques. All concerned sectors (sanitation, agriculture, health, tourism, environment,...), at the levels of managing bodies, municipalities and users, have to harmonize their activities on adopting and orientation scheme of sanitation, financing of investments and taking over the responsibility for functioning of installations. This harmonization requires the establishment of an inter-sectoral institution. Responsibilities must be assigned and capacity created for operation and maintenance of treatment systems and for monitoring of effluent quality and respect of crop policies.

21. The economic feasibility of re-use projects depends on the selection of appropriate treatment method and the efficient use of the effluent. It requires inter-sectoral collaboration, among local government, agriculture and health sectors in the planning and implementation of re-use projects, with particular reference to apportionment of cost among the beneficiaries.

22. Re-use of effluent in agriculture is a new technology and its successful implementation depends, among others, on public acceptance of the produce of farms using treated effluents, support of the public health officials and availability of trained manpower to manage treatment facilities and use effluents efficiently and safely at the farm level. Appropriate education and training are required for the above-mentioned target groups.

Recommendations for follow-up

1. Wastewater re-use represents an important issue for a large number of Mediterranean countries. It is, therefore, necessary to secure a continuous following of the development of technology, as well as the regular exchange of experience in its application.

2. It is recommended that cooperation in this field between FAO, WHO and MAP, through PAP/RAC, as well as with other interested relevant organizations, be continued and intensified.

3. It is necessary to apply an integrated approach to the problem, due to its complex nature. A check list for such an approach is given in this report.

4. As a possible follow-up in this field, the following has been recommended:

   - to check the possibilities of joint preparation of a code of practice;
   - to prepare, as demonstration documents, environmental impact, and health impact assessments for selected specific cases;
   - to organize a joint workshop to present and discuss the above documents and new achievements in the field.

PART II

SOME GENERAL AND SPECIFIC ASPECTS OF WASTEWATER RE-USE FOR IRRIGATION

RE-USE OF SEWAGE EFFLUENTS IN AGRICULTURE SOME NEW DIMENSIONS

By

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1. INTRODUCTION

In many arid and semi-arid countries of the world which are faced with acute water shortages, the re-use of sewage effluents in agriculture is considered an important strategy in conserving water resources. In humid and temperate countries on the other hand, agricultural use of effluents offers a safe method of disposal of municipal effluents, thereby reducing water pollution problems associated with other disposal methods. In addition, the use of effluents in agriculture has been proved to be beneficial from the point of view of the nutritive value of these effluents and their ability to improve soil fertility.

A major overriding issue, in the agricultural use of effluents is, however, the possible adverse health impact on those consuming agricultural produce derived from 'sewage farms', the farm population and those residing near sewage-irrigated fields. Further, cultural and social barriers in some countries may not permit the use of sewage in agriculture.

Recent developments in the agricultural use of sewage effluents have shown beyond doubt the technical and economic feasibilities of this venture, and means of achieving acceptable levels of health protection. The practice requires a high level of management, monitoring of the quality of sewage effluents and farm produce, and strict adherence to certain environmental health practices. This paper discusses some new dimensions that have emerged recently in relation to quality criteria, appropriate treatment methods, farm management practices and environmental management measures, with particular reference to the current and potential use of sewage effluents in the Mediterranean countries.

2. CHARACTERISTICS OF MUNICIPAL WASTEWATER

Municipal wastewater is defined as the spent water of a community consisting of water-carried wastes from residences, commercial buildings and industrial plants and surface and groundwaters that enter the sewerage system (WHO, 1973). It consists mainly of a mixture of water and wastes which generally include dissolved and suspended solids made up of human and animal wastes, oils and greases, vegetable and animal residues, household chemicals, soil, bacteria and viruses. Table I illustrates the composition and characteristics of a typical municipal sewage effluent, DTCD (1985). The medium strength wastewater is typical of the type of wastewater in countries where water supply is not limiting, whereas the strong effluent is mostly the case in countries where water is sparingly used owing to limited availability or cost. Weak wastewater is found when the sewerage is mixed with storm and groundwater. A key consideration in the successful re-use of municipal wastewater in agriculture is the removal or reduction of the level of those substances which are detrimental to crop production, human health and environment, through practical and economically feasible means of treatment.

Table I

Physical and chemical characteristics of domestic wastewaters

Major Constituents	Concentration (in mg/l) Strong	Medium	Weak
Total solids	1 200	700	350
Dissolved solids	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chlorides a/	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50
BOD b/	300	200	100

a/ This amount should be increased by the concentration of these constituents in the carriage water. The table shows major constituents only.

b/ BOD is the five-day biological oxygen demand measured at 20° C. It is a measure of the biodegradable organic content of wastewater.

3. WASTEWATER RE-USE IN THE MEDITERRANEAN COUNTRIES

A clear overall picture of the re-use of sewage effluents in agriculture in the Mediterranean countries has still not been developed but more and more information has emerged in recent years. Wastewater re-use is widely accepted in many Mediterranean countries and most countries operate their own national sewage effluent collection, treatment and re-use systems based on national requirements. Shuval et al. (1986) presented examples of current wastewater re-use practice in agriculture around the world including Mediterranean countries such as Israel, Egypt, Tunisia and Cyprus. FAO (1987) analysed the status of marginal quality water use for plant production in Europe which included the use of not only municipal effluents but also industrial effluents and other types of low quality water. Table II presents a summary of the status of effluent re-use in agriculture for selected Mediterranean countries.

There is no doubt that treated wastewater is becoming an increasingly important source of water for agriculture in many Mediterranean countries. As public health considerations and environmental protection measures have become well established, the primary and secondary treatments of effluents have become mandatory processes. This has meant that treated wastewater has become a fairly good quality water for crop production. Through choice of crops, adoption of good irrigation management practices, in cooperation with environmental management measures and disinfection of agricultural products at the household level, treated wastewater can be used safely in many Mediterranean countries for crop production.

Taole II

Status of Effluent Re-use in Some Selected Mediterranean Countries

Country and Source of information	Brief description of status
Cyprus (Krentos, 1985)	Nicosia Central Prisons Sewage Treatment Plant: Operational since 1955. Treatment is by conventional trickling filter type. Effluent is used to irrigate alfalfa and forage crops. Akrotiri Sewage Treatment Plant: Operational since 1962. Treatment is by percolating filter. After disinfection by chlorine, a portion of the effluent is used to irrigate 12 ha lawn by sprinklers. The balance is mixed with dam water to irrigate citrus (minisprinklers) and grapes (furrow). Zenon-Kemares II Sewage Treatment Plant: Completed in 1984, operational but not at its full capacity. The effluent after chlorination is used to irrigate lawns of a football stadium. Nicosia Sewerage System: Stage I was completed, stage II under construction. Treatment is by aerated and facultative lagoons. The effluent after chlorination is used to irrigate fodder, cotton and jojobas.
Egypt (Abdel Ghaffer *et al.*, 1985)	El-Gabal El-Asfar Farm: Since 1911, the effluent from Cairo city is used in the farm to grow citrus. The area of the farm is 1250 ha. Alexandria Sewage Effluent: Studies are under progress to irrigate the Western Delta region using effluent from Alexandria. The potential is recognized as to an area of 30,00 ha from an expected discharge of 1.2 million cubic metre per day.
Israel (Shuval *et al.*, 1986)	In 1983 it was estimated that about 24 per cent of treated effluent (50 million cubic metres per year) is used in agriculture. In 1982, the total area under sewage irrigation was estimated at 10,000 ha of which 87% was for cotton, 7% was for citrus and the balance for other crops. Sprinkler irrigation is the main method of irrigation. Vegetables eaten raw are prohibited for sewage irrigation. Predominant treatment process is oxidation pond method.
Tunisia (Mara and Cairncross 1987)	Currently there are 12 re-use schemes with three more planned for implementation. Wastewater from the capital city Tunis is re-used to irrigate citrus since 1964. Current area under sewage irrigation is around 600 ha and the plan is to extend this to 40,000 ha. Treatment processes used are activated sludge, waste stabilization ponds and oxidation ditches.

4. QUALITY CRITERIA IN EFFLUENT RE-USE

Quality criteria refer to limiting values of certain physical, chemical and biological parameters of water or effluent established for an intended use. The criteria form the basis to judge whether a given source of water or effluent is suitable or not suitable for the intended use, for example irrigation, aquaculture, landscaping and so on. FAO (1985) has established quality criteria for conventional sources of water for irrigation (Table III). The major quality concerns considered were salinity, sodicity and toxicity. WHO (1973) recommended health and treatment criteria for the re-use of effluents for irrigation, recreation and municipal re-use (Table IV). A combination of physical, chemical and biological criteria was proposed by Kandiah (1987) for agricultural use of sewage effluents.

The WHO health criteria (1973) were evaluated recently and were found to be excessively restrictive. It was argued that the WHO standards were based on an evaluation of potential health risks associated with pathogen survival in wastewater, soil and crops and on technical feasibility. In an expert consultation of WHO, World Bank, UNDP and IRCW held in Engelberg, IRCWD (1985), it was resolved that the WHO health criteria required fundamental revision. Based on an evaluation of actual epidemiological evidence and recognizing significant progress made in the design and use of waste stabilization ponds during the past two decades, the Engelberg Consultation, IRCWD (1985) proposed more relaxed biological criteria for effluent re-use in agriculture (Table V).

It should be emphasized that the Engelberg criteria place a great deal of value on waste stabilization ponds for the treatment of wastewater. However, extensive land requirement, odour-related problems and decrease in aesthetic value of land may limit the use of waste stabilization ponds in some Mediterranean countries. On the other hand, they appear to be well-suited to the arid and semi-arid countries of the region where plenty of land is available and the ponds can be conveniently isolated from heavily populated areas. The Engelberg standard is still considered tentative, as it is looked upon by some as being too relaxed and has the potential to create health hazards if not strictly followed.

In terms of chemical constituents, particularly dissolved salts, municipal effluent is normally considered of high quality (TDS ranges 1 200 mg/l in strong effluents to 350 mg/l in weak effluents). Nitrogen and chlorides could be present in amounts greater than the recommended values but they can be easily dealt with. The health hazard that may arise from the presence of metals in domestic effluents cannot be overlooked. Table VI presents typical concentrations of metals in domestic wastewater in developed countries (FAO 1987). An account of the health and environmental impacts of these metals as related to agricultural re-use of effluents is presented later in this paper.

Table III

Guidelines for Interpretations of Water Quality for Irrigation[1]

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Salinity (affects crop water availability)[2]				
EC_w	dS/m	< 0.7	0.7 - 3.0	> 3.0
(or)				
TDS	mg/l	< 450	450 - 2000	> 2000
Infiltration (affects infiltration rate of water into the soil. Evaluation using EC_w and SAR together)[3]				
SAR = 0 - 3 and EC_w =		> 0.7	0.7 - 0.2	< 0.2
= 3 - 6 =		> 1.2	1.2 - 0.3	< 0.3
= 6 - 12 =		> 1.9	1.9 - 0.5	< 0.5
= 12 - 20 =		> 2.9	2.9 - 1.3	< 1.3
= 20 - 40 =		> 5.0	5.0 - 2.9	< 2.9
Specific Ion Toxicity (affects sensitive Crops)				
Sodium (Na)[4]				
surface irrigation	SAR	< 3	3 - 9	< 9
sprinkler irrigation	me/l	< 3	< 3	
Chloride (Cl)[4]				
surface irrigation	me/l	< 4	4 - 10	> 10
sprinkler irrigation	me/l	< 3	<3	
Boron (B)	mg/l	< 0.7	0.7 - 3.0	> 3.0
Trace Elements (see Table 3)				
Miscellaneous Effects (affects susceptible crops)				
Nitrogen (NO_3 - N)[5]	mg/l	< 5	5 - 30	> 30
Bicarbonate (HCO_3) (overhead sprinkling only)	me/l	< 1.5	1.5 - 8.5	> 8.5
pH			Normal Range 6.5-8.4	

1 Adapted from FAO Irrigation and Drainage Paper No. 29 Rev. 1, 1985.

2 EC_w means electrical conductivity, a measure of the water salinity, reported in deciSiemens per metre at 25°C (dS/m) or in units millimhos per centimetre (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l).

3 SAR means sodium adsorption ration. SAR is sometimes reported by the symbol RNa. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by EC_w.

4 For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive. With overhead sprinkler irrigation and low humidity (< 30 per cent), sodium and chloride may be absorbed through the leaves of sensitive crops.

5 NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen (NH_4- and Organic-N should be included when wastewater is being tested).

Table IV
Suggested Treatment Processes to Meet the Given Health Criteria for Wastewater Re-use

	Irrigation			Recreation		Industrial reuse	Municipal reuse	
	Crops not for direct human consumption	Crops eaten cooked; fish culture	Crops eaten raw	No contact	Contact		Non potable	Potable
Health criteria (see below for explanation of symbols)	A + F	B + F or D + F	D + F	B	D + G	C or D	C	E
Primary treatment	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●
Secondary treatment		●●●	●●●	●●●	●●●	●●●	●●●	●●●
Sand filtration or equivalent polishing methods		●	●		●●●	●	●●●	●●
Nitrification						●		●●●
Denitrification								●●
Chemical clarification						●		●●
Carbon adsorption								●●
Ion exchange or other means of removing ions						●		●●
Disinfection		●	●●●	●	●●●	●	●●●	●●●[a]

Health criteria:
A Freedom from gross solids; significant removal of parasite eggs
B As A, *plus significant removal of bacteria.*
C As A, plus more effective removal of bacteria, plus some removal of viruses.
D Not more than 100 coliform organisms per 100 ml in 80% of samples.
E No faecal coliform organisms in 100 ml, plus no virus particles in 1000 ml, *plus no toxic effects on man, and other drinking-water criteria.*
F No chemicals that lead to undesirable residues in crops or fish.
G No chemicals that lead to irritation of mucous membranes and skin

In order to meet the given health criteria, processes marked ●●● *will be essential. In addition, one or more* processes marked ●● will also be essential, and further processes marked ● may sometimes be required.
[a] Free chlorine after 1 hour.

Table V

Tentative Microbiological Quality Guidelines for Wastewater Use in Agriculture

Reuse process	Intestinal nematodes (2) (arithmetic mean no. of viable eggs per litre)	Faecal coliforms (geometric mean no per 100 ml)
Restricted irrigation (3)		
Irrigation of trees, industrial crops, fodder crops, fruit trees (4) and pasture (5)	≤ 1	not applicable (3)
Unrestricted irrigation		
Irrigation of edible crops, sports fields and public parks (6)	≤ 1	≤ 1000 (7)

(1) In specific cases, local epidemiological, socio-cultural, and hydrogeological factors should be taken into account, and these guidelines modified accordingly.
(2) *Ascaris, Trichuris* and hookworms
(3) A minimum degree of treatment equivalent to at least a 1-day anaerobic pond followed by a 5-day facultative pond or its equivalent is required in all cases.
(4) Irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground.
(5) Irrigation should cease two weeks before animals are allowed to graze.
(6) Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist areas
(7) When edible crops are always consumed well-cooked, this recommendation may be less stringent.

Table VI

Typical Concentration of Metals
in Domestic Wastewater in Developed Countries

Components	Typical Concentrations in ppm
Aluminium	400 - 1000
Arsenic	2 - 5
Cadmium	2 - 5
Chromium	15 - 40
Cobalt	1 - 2
Copper	40 - 100
Iron	600 - 1500
Lead	40 - 100
Manganese	60 - 150
Mercury	1 - 3
Nickel	15 - 40
Silver	4 - 10
Zinc	130 - 300

5. WASTEWATER TREATMENT

The selection of a wastewater treatment process or a combination of processes depends upon:

(a) the characteristics of the wastewater;

(b) the required effluent quality, and

(c) the cost and availability of land.

Let us consider a medium strength effluent for our discussion. Table VII presents an analysis of the treatment requirements of this medium strength municipal effluent to meet quality criteria stipulated in Tables III, IV and V. It emerges that treatment is required only with respect to (1) reduction in suspended solids and grease (2) lowering the nitrogen content and (3) reduction in BOD.

Table VII

Treatment Requirements of a Typical Medium-Strength Municipal Effluent

Characteristics of the Wastewater	mg/l	Agriculture and health standard required	Appropriate Treatment methods.
Dissolved Solids	500	No restriction for irrigation in relation to salinity. 450 mg/l TDS refers to good quality water.	No treatment.
Suspended Solids	200	Can create problems in irrigation systems. Level should be reduced to 50 mg/l for use in drip and micro irrigation.	Primary and secondary treatment or waste stabilization ponds.
Nitrogen	40	Should be reduced to about 25 to 30 mg/l for most crops. For sensitive crops the recommended level is 5 mg/l.	During normal primary and secondary treatment or waste stabilization ponds the level on N is reduced to 10-20 mg/l. Vegetative beds or activated sludge methods can be used if nitrate is to be reduced to very low levels.
Phosphorus	10	No agriculture related problem is expected at this level.	No treatment.
Chloride	50	No chloride toxicity is expected at this level	No treatment.
Alkalinity	100	No major problem is expected in normal irrigation systems. In drip irrigation systems the drippers may get clogged. This problem can be solved by acid treatment.	No treatment.
Grease	100	This should be removed, as it can cause problems in irrigation pipes, oil deposited on soil and reduce quality of crops when sprinkler method of irrigation is used.	Removed by primary treatment processes or in waste stabilization ponds.
BOD	200	This must be reduced to 50 mg/l for restricted irrigation and 15 to 20 mg/l for unrestricted irrigation.	Primary and secondary treatment with chlorination or waste stabilization on ponds with retention time of 20 to 40 days.

6. CONVENTIONAL TREATMENT PROCESSES

The conventional wastewater treatment processes are designed to lower the BOD and suspended solids to enable the effluent to be discharged into natural water courses. Primary and secondary treatments have been adapted as standard methods in treating municipal effluents because, in many cases, the resulting effluent will have a suspended solids content of about 20 mg/l and an 85 to 90 per cent reduction in BOD resulting in an effluent that is suitable for discharge into many rivers.

Raw wastewaters contain 10^7-10^9 fecal coliforms per 100 ml. Conventional wastewater treatment processes, supplied with disinfection, produce an effluent that complies with bacterial quality required for agricultural use of effluents. From the public health viewpoint, primary and secondary treatments supplemented with disinfection will produce an effluent that is acceptable for uncontrolled irrigation. However, the adoption of these conventional treatment processes needs to be analysed in terms of cost and availability of trained manpower and institutional facilities.

7. WASTE STABILIZATION PONDS

In the context of agricultural re-use of effluents, a low-energy low- maintenance and low-cost system of treatment is preferable to a system that demands requirements of skilled manpower and is costly. The waste stabilization pond systems not only meet the quality requirements but also the operational and economic criteria in the context of agricultural use of effluents. Their major disadvantage is the large area requirement, but in many developing countries, sufficient land is normally available at relatively low cost.

Waste stabilization ponds are normally designed in a series of aerobic, facultative and maturation ponds with a total of 10 to 40 days of retention time. Detention time depends on the quality of the incoming wastewater, the quality required of the treated effluent, design of the pond and temperature and other operating conditions.

The performance of a set of five waste stabilization ponds in Northeastern Brazil as reported by Mara et al. (1983) is presented in Table VIII.

Table VIII

Performance of a series of five Waste Stabilization Ponds in Northeast Brazil (mean pond temperature: 26°C)

Sample	Retention time (days)	BOD_5 (mg/l)	Suspended solids (mg/l)	Fecal coliforms (/100ml)	Intestinal nematode eggs (/litre)
Raw wastewater	-	240	305	4.6×10^7	804
Effluent from:					
Anaerobic pond	6.8	63	56	2.9×10^6	29
Facultative pond	5.5	45	74	3.2×10^5	1
Maturation pond 1	5.5	25	61	2.4×10^4	0
Maturation pond 2	5.5	19	43	450	0
Maturation pond 3	5.8	17	45	30	0

While the appropriateness and applicability of waste stabilization ponds in the hot climates of developing countries are well recognized, their suitability in developed countries and under cold climatic conditions is still debatable.

8. VEGETATIVE BEDS

Another low-energy and maintenance type of treatment is the wetland system in partially treated or untreated wastewater which is detained in reservoirs with natural or aquatic vegetation. The ability of aquatic plants in natural wetlands to reduce BOD, pathogens, nitrogen and organic compounds in wastewater has led to the use of wetland systems for treatment of wastewater.

Carefully designed man-made aquatic systems have been experimented with and found to be successful. The major function of green plants in aquatic systems is to create an environment that promotes filtration, bacterial action, aerobic and anaerobic conversions and aeration by means of releasing oxygen in the root zone. Green plants also metabolize toxic organic compounds, produce toxic secretions that kill pathogenic organisms and stabilize pH. Water hyacinth systems have been researched extensively in the United States of America, (Wolverton et al., 1983). Lately, experiments have been conducted to evaluate the suitability of other aquatic plants such as broadleaf cattail (Typha latifolia), common reed (Phragmites australia) and duck potato (Sagittaria latifolia) in reducing pollutants in municipal wastewater.

Salut (1987) reported that when raw sewage was applied to test basins planted with common reed and duck potato, 90% of the total suspended solids and 80% of the BOD were removed. Based on these research data, a pilot vegetative filter beds system was established in Emmitsburg to treat wastewater that previously has passed through a primary clarifier and a trickling filter. The results have been very encouraging.

9. FARM MANAGEMENT PRACTICES

Wastewater can be used in crop production through proper treatment and adopting appropriate farm management practices such as crop selection, suitable irrigation practices and minimizing contact between farm workers and pathogens during irrigation water application.

10. CROP SELECTION

Based on human utilization, crops can be classified into three categories, namely:

(a) crops not destined for direct human consumption
(b) crops eaten cooked or processed, and
(c) crops eaten raw.

Depending on the effluent quality, appropriate selection of crops should be made from the above three categories.

When treatment is partial or minimum (for example the sewage has only undergone primary treatment) during which gross solids and parasitic eggs are removed, then irrigation should be limited to industrial crops such as cotton, flax, jute, sugar beet, sugar cane, fodder crops and pastures.

If the wastewater is treated by primary and secondary treatment processes or has undergone a fair treatment in waste stabilization ponds (and has resulted in an effluent having less than one viable egg of intestinal nematode egg per litre and less than 1000 fecal coliform per 100 ml), then crops eaten cooked or processed can be grown using these effluents.

To grow crops that are eaten raw such as salads and fruits, the wastewater should undergo disinfection in addition to primary and secondary treatment or full treatment in waste stabilization ponds. It is desirable, if the coliform count is less than 100 fecal coliform per 100 ml, as compared to 1000 fecal coliforms per 100 ml in the case of crops eaten cooked.

11. IRRIGATION PRACTICES

Irrigation water can be applied to crops in many ways, but the major methods are:

(a) flood irrigation - (by border or basin) wetting almost all the land surface
(b) furrow irrigation - wetting only part of the ground surface
(c) sprinklers - crop, soil and surfaces are wetted by overhead application, the same way as rain
(d) drip irrigation - (localized irrigation) slow application of water in continuing drops very close to individual plants.

The selection of an appropriate method depends on the quality of the effluent, the crop to be grown, the potential risk to health workers and the technical skill of the farmer.

The levels of suspended solids, biological matter and inert material, often related to the level of treatment of the effluent, will determine whether low pressure sprinkler or drip systems are appropriate or not because of the high potential of clogging associated with them. Tables IXa and IXb present the clogging hazards of trickle irrigation system related to physical, chemical and biological properties of effluents.

Table IXa

Physical, Chemical and Biological Contributors to Clogging of Localized (Drip) Irrigation systems as Related to Irrigation Water Quality

PHYSICAL (Suspended Solids)	CHEMICAL (Precipitation)	BIOLOGICAL (Bacteria and algae)
1. Sand	1. Calcium or magnesium carbonate	1. Filaments
2. Silt	2. Calcium sulphate	2. Slimes
3. Clay	3. Heavy metal hydroxides, oxides Carbonates, silicates and sulphides	3. Microbial depositions: (a) Iron (b) Sulphur (c) Manganese
4. Organic matter	4. Fertilizers (a) Phosphate (b) Aqueous ammonia (c) Iron, zinc, copper, manganese	4. Bacteria
		5. Small aquatic organisms: (a) Snail eggs (b) Larva

Table IXb

Influence of Water Quality on the Potential for Clogging Problems in Localized (Drip) Irrigation Systems[1]

Potential Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Physical				
Suspended Solids	mg/l	< 50	50 - 100	> 100
Chemical				
pH		< 7.0	7.0 - 8.0	> 8.0
Dissolved Solids	mg/l	< 500	500 - 2000	> 2000
Manganese[2]	mg/l	< 0.1	0.1 - 1.5	> 1.5
Iron[3]	mg/l	< 0.1	0.1 - 1.5	> 1.5
Hydrogen Sulphide	mg/l	< 0.5	0.5 - 2.0	> 2.0
Biological				
Bacterial populations	maximum number/ml	<10 000	10 000 - 50 000	> 50 000

If the wastewater meets the agricultural and health criteria discussed in this paper, then the choice of irrigation method will be based on cost, water availability and ground slopes. If the wastewater does not meet these quality guidelines, then:

(a) spray irrigation is limited to only fodder, fibre and seed crops;

(b) sprinkler irrigation is not recommended under windy conditions as there is a potential for the pathogens to be carried away in the spray mist with the wind drift and to cause health hazard to the farm population;

(c) furrow, surface or localized irrigation are used only for vegetables consumed after cooking;

(d) surface and drip irrigation are normally used if TDS is high as overhead irrigation can cause low-quality produce and yield reduction through foliar absorption of salts and also produces leaf burn. In the case of furrow irrigation, planting on the shoulders of the furrows are preferred over planting on the centre of the ridge;

(e) blending of sewage water with normal water is recommended. If normal irrigation water is available but not fully adequate in quantity, a blend of treated sewage water with the normal water will produce a mixed water that can be used with minimum adverse effects on crop production and health.

Mara (1987) presented an analysis of the advantages and disadvantages of different methods of irrigation in relation to disease transmission, water use efficiency and cost (Table X).

Table X

Advantages and Disadvantages of Different Methods of Wastewater Application to Land in Relation to Disease Transmission Risks, Water Use Efficiency and Cost

Method of application	Advantages	Disadvantages
Border and furrow irrigation	Low cost	High potential health risks to fieldworkers, crop handlers and consumers; low water use efficiency
Sprinkler irrigation	High cost, medium water use efficiency	High potential health risks to fieldworkers, crop handlers and consumers, especially if irrigated crops consumed raw
Subsurface and localised irrigation	Low health risks, high water use efficiency	High cost

12. METAL CONTAMINATION IN RELATION TO USE OF SEWAGE

The metals that may be present in sewage can be broadly divided into two categories, namely: those that can pose significant health hazards and those that do not. Generally five metals such as cadmium, copper, molybdium, nickel and zinc (all except molybdium are also known as heavy metals) could cause serious health risk to humans. They are normally present in small amounts, generally less than 10 mg/l in municipal effluents, but the presence in larger amounts cannot be overruled. Rarely do these metals exhibit toxicity to plants, but in most cases they are accumulated in the plants themselves and when the latter are consumed by humans or domestic animals, a health hazard develops. Another important consideration is their cumulative loading. At present in many developed countries there are maximum permissible cumulative loadings of metals on agricultural lands. Biswas (1987) reported permissible heavy metal loadings in five European countries (Table XI).

Table XI

Maximum Permissible Cumulative Loading of Metals in KG/HA for Agricultural Land

Country	Cd	Cu	Cr	Pb	Hg	Ni	Zn
France	5.4	210	360	210	2.7	60	750
Germany, FR	8.4	210	210	210	5.7	60	750
Netherlands	2.0	120	100	100	2.0	20	400
Sweden *	0.075	15	5	1.5	0.04	2.5	50
UK	5.0	280	1000	1000	2.0	70	560

* 5-year loading, but can be repeated.

Cadmium is one of the dangerous heavy metals. It can accumulate in human and animal livers and causes serious health hazards.

FAO (1987) summarized the effects of metals in relation to sewage effluent re-use as follows:

(a) While copper is necessary for both humans and plants, at higher concentrations it can be toxic to plants and thus reduce yields. At even higher concentrations, it causes animal toxicity, especially in sheep. Nickel, on the other hand, can be phytotoxic to plants at around 50 mk/kg of plant tissues, but is relatively non-toxic to humans and animals. Molybdenum is generally not a problem to humans and plants, but can be toxic to farm animals, especially cattle. Zinc is relatively non-toxic to humans and animals, but like cadmium, its uptake by plants is greater when the pH is below 6.5.

(b) Other metals that may be present in water are aluminium, antimony, arsenic, chromium, iron, lead, manganese, mercury and selenium. Some of these metals, like aluminium, iron and manganese may be present in appreciable quantities in natural soils, and other metals like arsenic, mercury and selenium are present in such minute quantities in treated wastewater that no documented case exists where they have posed a health problem.

(c) Aluminium, beryllium, copper, manganese and nickel may cause problems in acidic soils and can especially retard the optimal growth of vegetables. Excessive iron concentrations may lead to clogging and also contribute to corrosion of irrigation equipment.

Recommended maximum concentrations of metals in irrigation water and their potential impacts in crop production are presented in Table XII (FAO 1985).

Table XII

Impact of Metals in Irrigation Water on Soil and Biota

Metal	Recommended Maximum Concentration	Impact on Soils and Biota
Aluminium (Al)	5.0	Can cause non-productivity in acid soils(PH 5.5), but more alkaline soils at pH 7.0 will precipitate the ion and eliminate any toxicity.
Beryllium (Be)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cadmium (Cd)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentration that may be harmful to humans.
Cobalt (Co)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Chromium (Cr)	0.20	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Copper (Cu)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
Iron (Fe)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Lithium (Li)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (0.075 mg/l). Acts similarly to boron.
Manganese (Mn)	0.20	Toxic to a number of crops at a few- tenths to a few mg/l, but usually only in acid soils.
Molybdenum (Mo)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Nickel (Ni)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Lead (Pb)	5.0	Can inhibit plant cell growth at very high concentrations.
Selenium (Se)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Vanadium (V)	0.10	Toxic to many plants at relatively low concentrations.
Zinc (Zn)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH 6.0 and in fine textured or organic soils.

13. CONCLUSIONS

1. In view of the limited water resources of some countries in the Mediterranean region, augmenting the conventional irrigation water resource by treated effluents has become an important consideration. In addition, agricultural re-use of effluents is gaining support in the humid countries of the region as an alternative means of wastewater disposal. The present technology has made it possible to treat municipal wastewater to a quality level that can be used for unrestricted irrigation with minimum environmental and health hazards.

2. Effluent quality standards have been established in terms of physical, chemical and biological characteristics. The WHO health standard is considered to be too restrictive and based on potential health hazards rather than on actual epidemiological evidence. A more relaxed guideline has been recently recommended which is compatible with waste stabilization pond treatment of the municipal effluent. It is important that wastewater re-use standards should be strict enough to permit irrigation use without undue health risk but not so strict that they would virtually rule out irrigation with sewage effluent.

3. Conventional primary and secondary treatments of wastewater together with disinfection produce an effluent that is acceptable for unrestricted irrigation in relation to health criteria. However, these methods appear to be costly and require skilled manpower and greater operation and maintenance facilities.

4. Waste stabilization ponds have been found to be simple and cost-effective in treating municipal effluents for agricultural use. They can produce effluents of good quality that can be used for unrestricted irrigation. However, the method requires relatively more land, can create odour problems and may not be effective in some heavily-populated and humid temperate countries.

5. The use of vegetation to purify municipal wastes has gained popularity in recent times. Work is under progress in the use of vegetative beds for treating municipal effluents and some encouraging results have already been obtained.

6. A combination of crop selection, adoption of appropriate irrigation methods and on-farm management practices and adherence to environmental health practices enables the use of sewage effluents without serious agricultural, environmental and health problems.

7. There is a potential danger of heavy metal hazard associated with the use of effluents in agriculture. There is a need to monitor heavy metal accumulation in soils and plants and take appropriate preventive measures to avoid hazard to human health.

8. In quantitative terms, the value of wastewater for re-use by irrigated agriculture may not be very significant compared with the overall volume of water used for irrigation. Yet re-use of wastewater appears to be a viable solution to water shortages in many countries in the Mediterranean region. In the final analysis it can be said that re-use of effluents in agriculture is a practical solution to water scarcity under most conditions, provided that adequate precautions are taken in the design and operation of the systems to protect the health of the individual and of the community.

14. REFERENCES

1. Abdel-Ghaffar, A.S., El-Attar, H.A. and El-Sokkary, I.H., (1985), Egyptian experience in the treatment and use of sewage water and sludge in agriculture. Paper presented at the FAO Regional Seminar on the Treatment and use of Sewage Effluents in Irrigation. Nicosia, Cyprus.

2. Biswas, A.K. (1987). Role of wastewater re-use in water planning and management in "Treatment and Re-use of Sewage Effluents for Irrigation". Edited by Biswas A.K. and Arar A. Buttersworth Scientific, Guildford, U.K.

3. DTCD (1985). The use of non-conventional water resources in developing countries. Natural/Water Resources Series No. 14, Department of Technical Cooperation for Development, United Nations. New York, U.S.A.

4. FAO (1985). Water Quality for Agriculture. FAO Irrigation and Drainage Paper No. 29, Rev. 1. Food and Agriculture Organization. Rome, Italy.

5. FAO (1987). Aspects of marginal quality water for plant production in Europe. Paper presented at the European Commission on Agriculture, 25th session. Chania, Greece.

6. IRCWD (1985). Health aspects of wastewater and excreta use in agriculture and aquaculture: The Engelberg Report, IRCWD News No. 23. Duebendorf, Switzerland.

7. Krentos, V.D. (1985). Treatment and use of sewage effluent for agriculture in Cyprus. Paper presented at the FAO Regional Seminar on Treatment and Use of Sewage Effluent for Irrigation. Nicosia, Cyprus.

8. Mara, D.D., Pearson, H.W. and Silva, S.A. (1983). Brazilian stabilization pond research suggests low-cost urban application. World Water Vol. 6, No. 7.

9. Mara, D.M., and Cairncross (1987). Wastewater and excreta use in agriculture and aquaculture in developing countries. UNEP/WHO working document. WHO, Geneva, Switzerland.

10. Salut Inc. (1987). Municipal wastewater purification in a vegetative filter bed. A research status report. New York, U.S.A.

11. Shuval, H.I., Avner, A., Badri, F., Eliyahu, R. and Perez, Y. (1986). Wastewater irrigation in developing countries. World Bank Technical Paper No. 51. World Bank. Washington, D.C., U.S.A.

12. WHO (1973). Re-use of effluents: Methods of wastewater treatment and health safeguards. A report of WHO Meeting of Experts. Report No. 517. WHO, Geneva, Switzerland.

13. Wolverton, B.C., McDonald R.C. and Duffer, W.R. (1983). Micro-organisms and higher plants for wastewater treatment. J. Environmental Quality, Vol. 1

INTEGRATED PLANNING AND PLANNING AND ON-FARM ECONOMICS OF RECLAIMED WASTEWATER IRRIGATION

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1. ABSTRACT

Re-use of wastewater in agriculture may serve both as a waste disposal method and as a supplementary unconventional water source for irrigation in areas which suffer from water scarcity. An overview of various re-use aspects is presented, including effluent quality for irrigation, wastewater treatment methods, irrigation methods and integrated planning of wastewater re-use schemes. Special emphasis is placed on economic aspects of wastewater re-use and assessment of project feasibility. A detailed economic analysis of a specific wastewater re-use project in Israel is presented. Existing and potential wastewater re-use schemes in the Island of Mallorca, Spain are discussed as a case study for conditions in Mediterranean islands and coastal areas.

2. INTRODUCTION

The use of domestic wastewater for irrigation of agricultural crops is one of the most attractive and popular re-use options in many regions of the world, for the following reasons·

- irrigation is usually needed in areas where water tends to be scarce and wastewater re-use is necessary for supplementing available fresh water sources. It is also a safe water source, independent of climatic conditions.

- agriculture requires large amounts of water, which are used once only since irrigation is a consumptive use. Thus, there is no danger of gradual accumulation in the water of undesirable substances by continuous recycling.

- agriculture can use not only the water, but also additional resources found in wastewater, such as organic matter or nutrients (nitrogen and phosphorus), which are thus converted from an environmental nuisance to an asset.

- irrigation is relatively flexible with respect to water quality requirements. Some crops can be irrigated with low quality water, and some water quality problems can be overcome by suitable agricultural practices.

- use of wastewater for irrigation prevents its discharge to receiving water bodies and resulting pollution of water resources.

The Mediterranean coasts and islands suffer from limited water resources and present a case in which municipal wastewater should be regarded as an unconventional water supply source that can be developed and integrated within existing regional water supply schemes. Utilization of treated wastewater for irrigation will decrease the demand for fresh water from groundwater sources and thus result in a reduction of the salinity of the water extracted from aquifers. In addition, wastewater re-use will prevent the pollution of the Mediterranean coastal water and encourage tourism which is an important source of income in the Mediterranean zone.

3. FACTORS RELATED TO IRRIGATION WITH EFFLUENTS

When considering irrigation with treated wastewater, several related factors and terms should be recognized. Some of these are presented below.

- **Restricted and unrestricted irrigation:** "Restricted irrigation" refers to the use of low quality effluent in specific areas, where only certain crops should be cultivated. The restrictions imposed usually refer to the types of crops to be cultivated, the irrigation methods, the harvesting method, fertilizer application rates, the distance of irrigated fields from houses and the distance between non-drinkable and drinkable water supply mains. "Unrestricted Irrigation" refers to the use of high quality effluents for irrigation of all crops on any soil type, without any adverse environmental effect on the soil, crops, animals, persons involved in the production process or persons consuming agricultural products.

- **Effluent quality:** The effluent quality is the main factor that dictates the type of re-use (i.e. restricted or unrestricted irrigation), types of crops and irrigation methods. The effluent quality should be considered in respect of two aspects: public health and agronomics. Most existing standards for wastewater re-use deal only with public health aspects and prescribe the treatment processes or quality parameters that the effluent must meet before it can be used to irrigate a certain category of crops. These include mostly bacteria, viruses and other pathogens and sometimes also organic matter (BOD, COD, S.S.), dissolved oxygen, pH and residual chlorine. However, agronomic aspects related to crops and soils must also be taken into account. These include salinity, sodium absorption ratio of the water, nitrogen, phosphorus, chloride, bicarbonate, heavy metals, boron and other trace elements, pH and synthetic organics (including pesticides). Considering the agronomic aspect of effluent quality, water quality standards established for crop irrigation with fresh water are, at present, also the best available criteria for effluent re-use. However, there are additional constituents in wastewater, usually absent from or unimportant in fresh water. For such constituents, specific re-use standards will have to be developed in the future. At present, only preliminary guidelines can be established based on available knowledge. Additional information concerning effluent quality for irrigation can be found in Pettygrove and Asano (1).

- **Irrigation methods:** The effluent quality has an effect on the irrigation method to be used. Surface irrigation methods can utilize low quality effluents, whereas sprinkler and mainly drip irrigation require higher quality effluents, because of the danger of clogging orifices of the irrigation equipment by suspended solids. This problem can be overcome by utilizing filters at the head of the irrigation system.

- **Seasonal Storage:** While municipal wastewater is available at a relatively constant flow, irrigation water is required mainly during the dry season. In order to compensate between the constant supply and variable demand, seasonal storage is required. There are two possibilities for storage: surface storage and groundwater storage. In both cases, storage acts as a supplementary treatment stage.

- **Treatment in relation to project size**· The project size has implications for treatment levels and treatment methods. In small-scale projects the number of effluent consumers is small, supervision of effluent use is possible and restricted irrigation can be practised, utilizing low treatment levels. In large-scale projects the effluent must be distributed among many consumers and strict supervision of effluent use is difficult, thus a high level of treatment is required, so that the effluent meets the public health, agronomic and aesthetic requirements for unrestricted use (no adverse effects on crops, soil, humans and animals).

- **Economic aspects**· From the point of view of overall economic evaluation, the wastewater treatment system and the effluent re-use system are regarded as an integrated system for which a combined cost/benefit analysis should be carried out in order to assess the feasibility of the project. Similar to other irrigation projects, the economy of a re-use project depends on many factors, most of which are specific to each project and include soil type, climatic conditions and irrigation methods. In addition, the feasibility of re-use projects depends on the distance of the re-use area from the source of wastewater and on the deduction of alternative disposal costs from the project costs.

4. EFFECT ON PUBLIC HEALTH AND IMPLICATIONS REGARDING WASTEWATER TREATMENT AND CLASSIFICATION OF IRRIGATED CROPS

Public health effects are of the greatest importance when considering wastewater re-use for irrigation. Pathogenic organisms (bacteria, viruses and parasites) are the significant parameters when considering health effects.

Recent publications (2, 3, 4, 5) conclude that previous public health orthodoxy which held that every excreted pathogen that can persist in the environment, in soil or on crops irrigated with wastewater is a potential cause of serious disease in humans, is basically overly conservative because human infection is not dependent only on the presence of pathogens on soils and crops. It depends also on the minimum dose of a pathogen necessary to cause infection (which varies greatly for different types of organisms), on the persistence time of the pathogens in the environment and on the level of immunity to endemic diseases.

A combination of the above factors leads to the conclusion that the amount of excess infection and diseases, caused by various classes of pathogens when irrigating with untreated wastewater is in the following order of descending magnitude·

- intestinal nematode infections (Ascaris, Trichuris and the hookworms)
- excreted bacterial infection (bacterial diarrhoeas and typhoid)
- excreted viral infections (rotavirus diarrhoea and hepatitis A).

According to Shuval in World Bank Technical Paper No. 51 (2), the first quality criterion for wastewater use in agriculture is the complete, or almost complete, removal of the eggs of intestinal nematodes (to a geometric mean of less than 1 viable nematode egg per litre). In addition, a major reduction (to a geometric mean of less than 1,000 fecal califorms per 100 ml) in the concentration of excreted bacteria is recommended for unrestricted use of wastewater in agriculture. If these standards are met, other pathogens such as nematode eggs and protozoal cysts are also reduced to undetectable levels.

The priority criteria for effective wastewater treatment for the specific purpose of pretreatment for agricultural irrigation, as based on the recent publications (2, 3, 4, 5) are in the order:

- maximum removal of helminths and protozoa
- effective reduction in bacterial and viral pathogens
- freedom from odour and objectionable appearance (i.e. effective reduction of BOD).

These specific design criteria and their order of priority differ from those for reducing surface water pollution from BOD and COD, and thus result in different optimal treatment strategies.

Remedial measures based on conventional wastewater treatment practices developed in industrial countries were not designed for, nor are they particularly effective in, removing pathogens.

Based on the recent findings, a series of practical alternative remedial measures for controlling negative health effects may be considered as follows:

- restrictions on types of crops irrigated so as to prevent consumers from being exposed directly to infection through contaminated vegetables or salad crops eaten raw

- selection of irrigation techniques and procedures so as to minimize direct contact between wastewater and crops

- wastewater treatment and/or storage practice, aimed at effectively reducing first the concentrations of priority pathogens to low levels, and, in subsequent stages, to levels below which the incidence of excess infection is essentially controlled.

In addition, improved occupational health and hygiene conditions are necessary.

The re-use systems for irrigation may be classified in three categories (A, B and C) according to the crop type, the restrictions imposed on the irrigation system and the risk to public health. These categories depend on the effluent quality (2,6).

Categories A and B correspond to restricted irrigation while category C corresponds to unrestricted irrigation for all types of crops including those consumed raw (Table I).

As a consequence of the limitations, irrigation of categories A and B is generally applicable in limited, well-controlled zones, while irrigation of category C is adequate for large-scale projects which may include crops that demand water of high quality.

5. WASTEWATER TREATMENT SCHEMES FOR RE-USE

The development of planned effluent re-use schemes, which took place in the last two decades came, in most cases, after wastewater treatment plants designed for discharge purposes were already in operation. The conventional approach to wastewater re-use starts with a municipal effluent, which is usually available after conventional primary-secondary treatment carried out for the purpose of discharge to a water body (Fig. 1). Such effluent is normally suitable only for restricted irrigation and limited industrial use.

Table I

Categories of Crops Irrigated with Treated Effluents

Category of Crop	Category "A"	Category "B"	Category "C"
Definition of crop and restrictions	1. Crops not for human consumption (for example cotton). 2. Crops normally processed by heat or drying before human consumption (grains, oil seeds, sugar beets). 3. Vegetables and fruit grown exclusively for canning or other processing that effectively destroys pathogens. 4. Fodder crops and other animal feed crops sun-dried and harvested before consumption by animals. 5. Landscape irrigation in fenced areas without public access (nurseries, forests, green belts).	1. Pasture lands, green fodder crops. 2. Crops for human consumption that do not come into direct contact with wastewater on condition that no windfall be marketed (orchards, stalked vine and hung crops-tomatoes, cucumbers, etc. and vineyards irrigated by surface and drip irrigation). 3. Crops for human consumption normally eaten only after cooking (potatoes, eggplant, beet roots). 4. Crops for human consumption, uncooked whose peel is not eaten (melon, citrus bananas, nuts, groundnuts).	1. Any crops for human consumption normally consumed uncooked, and grown in direct contact with waste-water effluent (fresh garden vegetables such as tomatoes, carrots, fruits, etc.). 2. Landscape irrigation in areas with free public access immediately after irrigation on condition that during spray irrigation, areas are fenced so that there is no public access within 15 metres of wetted irrigation zones.
Required effluent quality	Low	Intermediate	High

Source: TAHAL - Re-use of the wastewater of Lima, Peru (6).

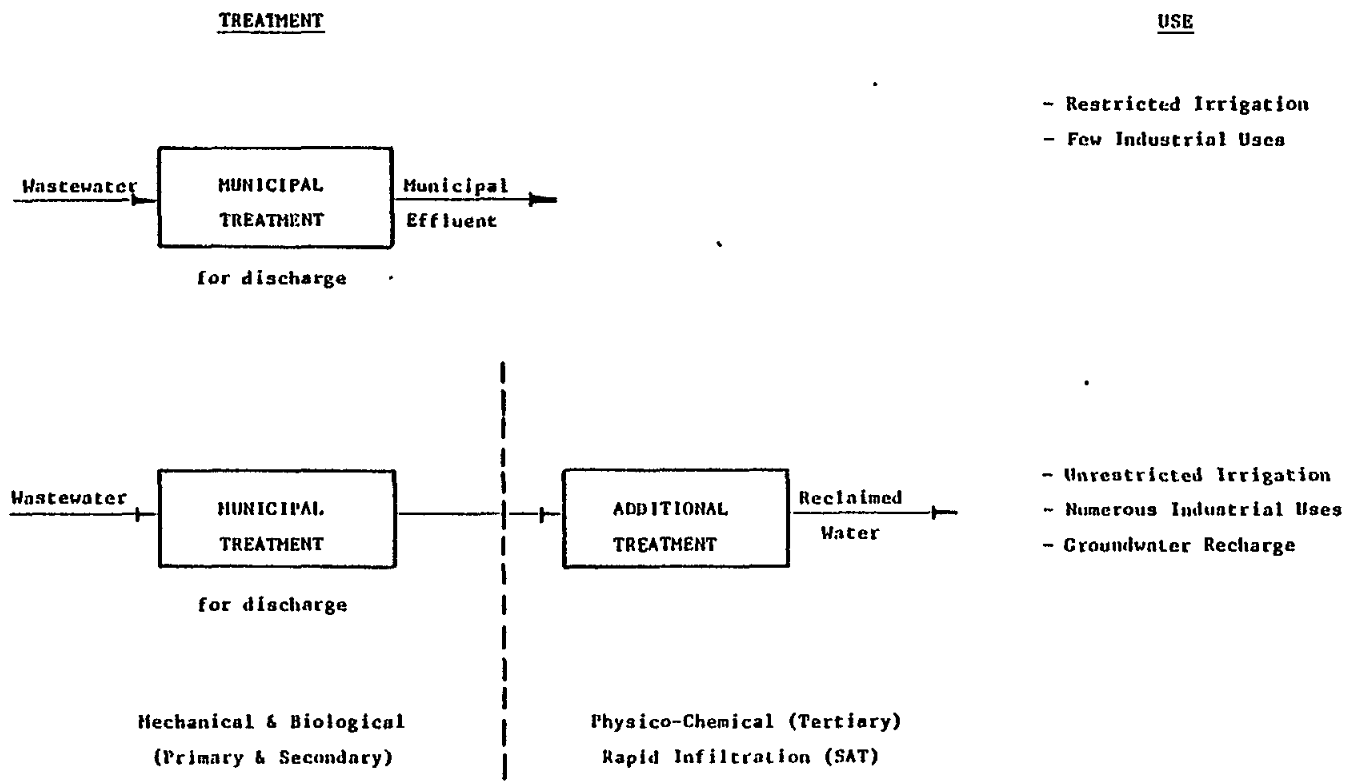

Fig.1 Traditional Approach to Wastewater Treatment for Re-use

In order to produce a higher quality effluent, which is suitable for unrestricted agricultural re-use, for numerous industrial uses and for potable aquifer replenishment, additional treatment has to be provided. Tertiary treatment by physico-chemical processes, in addition to primary-secondary treatment by mechanical and biological processes, is usually included in re-use schemes where a higher water quality is required.

Conventional treatment processes generally used for wastewater treatment for restricted irrigation include biological treatment of any type, sometimes followed by chlorination. Some conventional treatment schemes for restricted irrigation are presented in Fig.2. These include primary treatment, oxidation ponds of various types, aerated lagoons, trickling filters, activated sludge and oxidation ditch.

During recent years, some additional low-cost, innovative treatment methods have been developed.. These can be used as treatment processes for restricted irrigation and sometimes as additional treatment processes after conventional biological treatment, to produce effluents for unrestricted irrigation. These processes include:

- overland flow with collection of the effluent by surface drains
- aquaculture by means of water hyacinth, duckweed or other plants of similar properties
- aquaculture by wetlands, using plants, trees, fish, birds and biological purification chains in general.

An attractive process which was developed in Israel and is in widespread use in this country is the Deep Reservoir Treatment (DRT), which will be presented later. An interesting process which is in a preliminary stage of development is the anaerobic treatment of domestic wastes in USAB (Upflow Anaerobic Sludge Blanket) or fluidized bed reactors.

Conventional additional treatment in the production of effluent for unrestricted irrigation usually consists of coagulation-sedimentation with alum and polyelectrolytes, followed by filtration and chlorination. This process is standard practice in the treatment of turbid surface waters. A newer development related to tertiary wastewater treatment, which is also "borrowed" from the surface water treatment industry, is the "direct" or "contact" filtration process. Another tertiary process is the high lime treatment process followed by polishing ponds for recarbonation and ammonia stripping. The above additional schemes for unrestricted irrigation are presented in Fig. 3.

Also in the case of additional treatment processes, for high quality effluent production, some alternative innovative low-cost treatment methods have been developed. Some of these have been mentioned previously (aquacultures, overland flow and Deep Reservoir Treatment). Others are land application methods (in addition to overland flow which is also a land application method). These include:

- slow-rate infiltration
- rapid infiltration by spreading basins to a low depth and collection of the percolated water by underdrains
- rapid infiltration by spreading basins to the groundwater and pumping of the effluent by wells.

The last process is also known as the Soil Aquifer Treatment process (SAT). This process is practised in Israel and will be discussed in continuation. The combination of primary-secondary and tertiary treatments is, in some cases, so expensive that the production of effluent for irrigation becomes prohibitive from an economic point of view. The use of

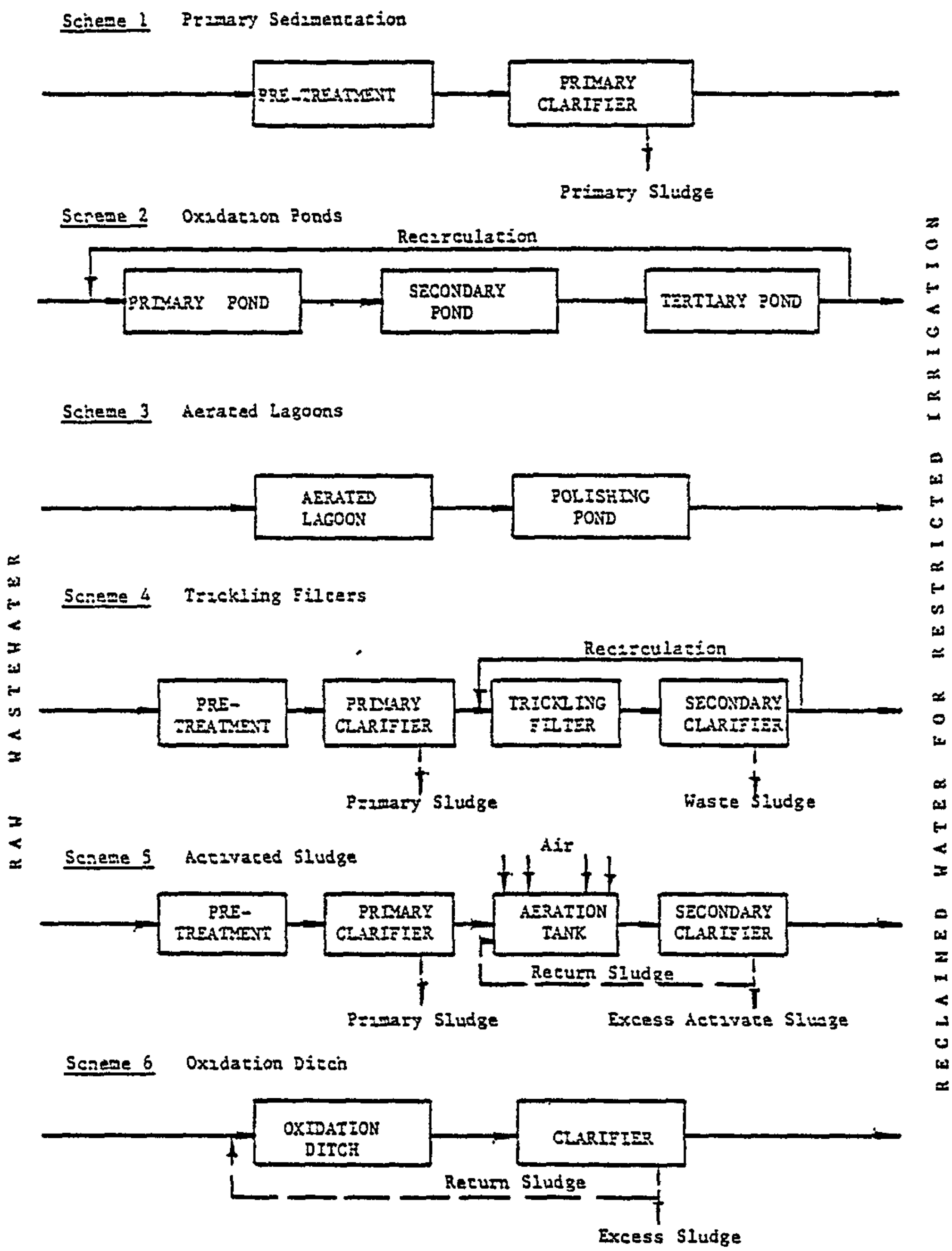

Fig. 2 Treatment Schemes for Restricted Irrigation

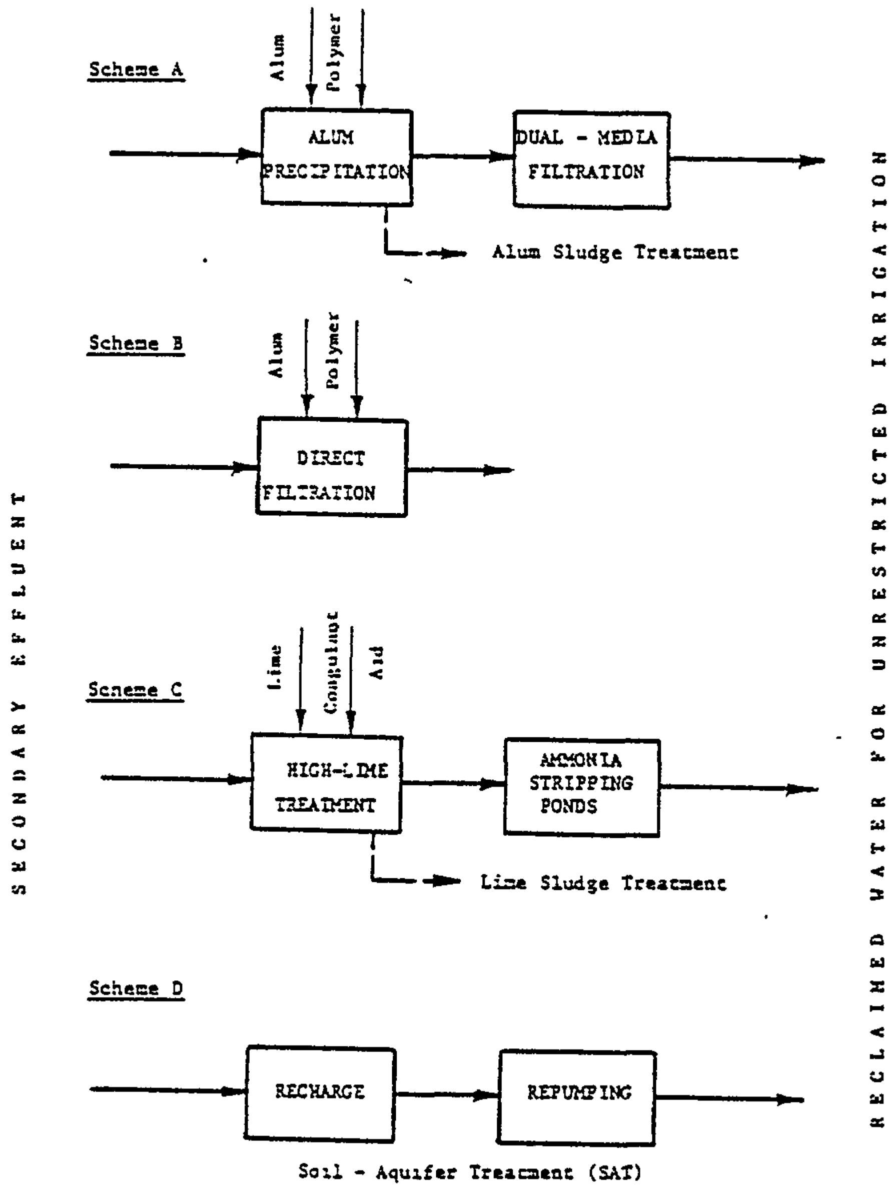

Fig. 3 Additional Treatment Schemes for Unrestricted Irrigation

innovative low cost treatment processes instead of more sophisticated and expensive processes has considerable advantages.

As a consequence of the water shortage in Israel, a country in which agriculture depends almost totally on irrigation, municipal wastewaters in this country are considered as an important source of water, mainly for irrigation. At present, about 45% of the total volume of the wastewater of Israel is utilized for irrigation. This amount will increase to 70% during the forthcoming months, when the second stage of the Dan Region Project (re-use of the wastewater of Tel Aviv Metropolitan Area) will go into full operation. The importance assigned to re-use of wastewater in Israel stimulated the development of innovative treatment systems. Two of these are briefly described below.

DRT (Deep Reservoir Treatment). A deep reservoir is, in fact, a deep facultative lagoon (7 to 10 m), with a variable water level over the year. The reservoir provides the detention time necessary for the seasonal storage of the effluent and combines seasonal storage with additional treatment. Purification is effected by aerobic bacteria and algae in the upper layer, as well as by anaerobic bacteria at the bottom of the reservoir. The design of such reservoirs is governed by the criterion of maximum organic loading per reservoir surface unit in order to minimize environmental nuisance. The most critical period is at the end of the irrigation season, when the water level in the reservoir is at its lowest, and thus its surface area is at its smallest. Deep reservoirs are very effective in the removal of helminths, protozoa and bacteria.

When effective secondary treatment is applied as pretreatment before the reservoir, the reservoir effluent may be used for unrestricted irrigation. When lower pretreatment is applied, the reservoir effluent is appropriate only for restricted irrigation. Treatment in deep reservoir is included in numerous small re-use schemes in Israel, and also in large-scale projects such as those of the wastewater re-use schemes of the cities of Haifa and Jerusalem.

A typical scheme that includes Deep Reservoir Treatment is presented in Fig. 4. Typical effluent quality of DRT is presented in Table II. These results refer to the wastewater re-use project of the city of Haifa, Israel, which includes activated sludge treatment followed by DRT (7). Additional information regarding the DRT process is presented in publication (8).

SAT (Soil-Aquifer Treatment). This innovative process which produces a high-quality effluent for unrestricted re-use involves the use of the soil and the aquifer as a treatment system, by the controlled passage of effluent through the unsaturated and saturated soil zones, and subsequent pumping from the aquifers. The effluent is allowed to percolate through the unsaturated soil zone and then to flow into the aquifer. The system consists of spreading basins on permeable soils, surrounded by a series of pumping wells. Observation wells located between the spreading basins and the pumping wells permit the continuous monitoring of the process. The spreading basins are flooded intermittently, in order to maintain high infiltration rates and allow oxygen penetration into the soil. The high purification capacity of the system is the result of a unique combination of physical, chemical and biological processes occurring in the soil and the aquifer (9).

Incorporation of the SAT Process in a re-use scheme has to include appropriate pretreatment and may include post-treatment. The pretreatment has to remove organic load and separate solids which may clog the spreading basins. Post-treatment may be used in case the effluent is aimed to be supplied for potable uses. Appropriate processes for post-treatment may be

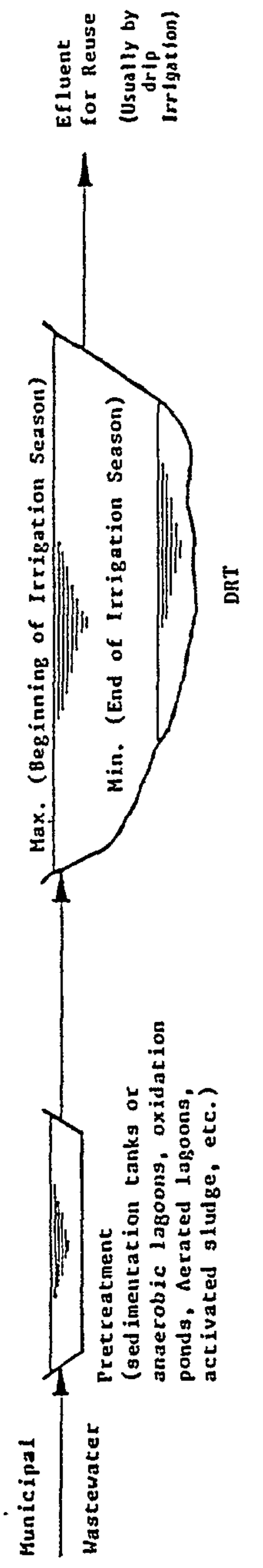

Fig. 4 Deep Reservoir Treatment (DRT) Scheme for Reuse

carbon absorption, ion exchange, reverse osmosis and disinfection. A general re-use scheme which incorporates the SAT process, both for non-potable purposes (unrestricted irrigation) and potable purposes, is presented in Fig. 5. A schematic diagram of the SAT process is presented in Fig. 6.

The concept of SAT has been applied on a large scale in the Phoenix area in Arizona (10) and in the Dan Region Project (re-use of the wastewater of Tel Aviv Metropolitan Area) in Israel (8, 11, 12). This project consists of two stages which differ in the pretreatment provided before the SAT unit. The treatment scheme flow diagrams of both stages of the Dan Region Projects are presented in Fig. 7.

Water quality data at various points of the Dan Region treatment plant - stage one - are presented in Table III.

6. AGRICULTURE, SOIL, CROPS AND IRRIGATION METHODS

Agricultural wastewater re-use projects are basically agricultural projects, operating on the same principles as conventional agricultural projects. The differences between the two types of projects arise from the difference in qualities of effluent and fresh water. The effluent quality affects the selection of crops and may affect the soil and the irrigation techniques, imposing an adequate approach towards re-use projects.

The selection of crops must take into account the public health effects of irrigation with effluents and agronomic aspects of the effluent composition. Guidelines for crop selection in respect of public health risks were discussed in preceding chapters and are presented in Table I. Effluents contain nitrogen, phosphorus and potassium (which serve as fertilizers) as well as important micronutrients. Organic matter in the effluent can also contribute to soil tilth and overall long-term fertility. But effluents may contain chemical constituents which may adversely affect crops. These include toxic chemicals such as heavy metals, or high concentrations of certain elements such as boron, salinity, etc. Irrigation with effluent means continuous fertilization which may present a problem for crops sensitive to excess nitrogen.

Factors affecting selection of crops are governmental regulations, crop tolerance of salts and specific ions, crop uptake of nitrogen and phosphorus, crop use of water, management requirements, economic value of the crop, climate and soil characteristics.

As in other agricultural projects, soil is an important factor in wastewater re-use projects. Physical, hydraulic and chemical characteristics of soil should be well defined at wastewater re-use sites. Important physical characteristics include texture, structure and soil depth. Important hydraulic characteristics are infiltration rate and permeability. Soil chemical properties of importance are pH, electrical conductivity, exchangeable sodium percentage, available phosphorus, organic matter and, in some areas, boron content. Irrigation with effluent may affect soil characteristics as a result of interaction with the effluent constituents. Suspended solids contained in the effluent may clog the soil surface and proper agrotechniques and irrigation regime may be required. High concentrations of sodium in the effluent can change soil texture, impermeabilize the soil and thereby reduce fertility. Identification of soil and effluent characteristics and analysis of their interaction is essential for selection of an effluent irrigation site. Concentration of nutrients (nitrogen and phosphorus) in soil irrigated with effluent is significantly higher than in soil irrigated with fresh water. The nutrient

Table II

Haifa Wastewater Re-use Project - Water Quality
At Various Points Along the Treatment Process

	Concentration - mg/l		
Parameter	Raw Wastewater	Activated Sludge Effluent	Seasonal Storage Reservoir Effluent
Suspended Solids	717	38	14
BOD_5	618	57	6.5
BOD_5 Filtered	115	13.3	3.0
COD	1272	116	58
COD Filtered	197	62	48
Detergents	7.1	0.5	0.5
NKT as Nitrogen	85	41	24.7
Ammonia as Nitrogen	55	34	20.6
Nitrate as Nitrogen	0.7	5.6	0.9
Phosphorus	12.8	6.1	5.6
pH (Units)	7.7	7.9	8.1
Total Coliform (MPN/100 ml)		10^7	$4x10^2$
Fecal Coliform (MPN/100 ml)		10^6	$1x10^2$
		Pre-treatment	Deep Reservoir Treatment

Table III

Dan Region Project Stage One - Water Quality at Various Points
Along the Treatment Process - Organic Matter Nutrients and Bacteria

	Concentration - mg/l				
Parameter	Raw Wastewater	Oxidation Ponds Effluent	Lime-Treatment Effluent	Polishing Ponds Effluent	Reclaim Well Water
Turbidity	-	-	-	24.8	0.4
Suspended solids	350	308	200	66	0.0
BOD^5	313	118	45	29	0.5
BOD^5 filtered	117	9	13	6	0.5
COD	641	423	198	126	9.6
COD filtered	219	84	67	57	9.6
TOC	229	149	98	59	3.5
Detergents	14	4	3	1.9	0.23
Ammonia, as N	37	25	25	7.2	0.02
Total Nitrogen	60	60	43	17.8	7.1
Filtered Nitrogen	-	-	-	12	7.1
Phosphorus	13.7	12.7	5	3.2	0.03
pH (units)	7.6	7.8	11.3	9.5	7.8
Total Coliform (MPN/100 ml)	10^8	10^6	$2x10^1$	10^2	0.0
Fecal Coliform (MPN/100 ml)	10^7	$3.2x10^5$	6.3	$2.8x10^1$	0.0
	Facultative Lagoons with Recirculation		Lime-Magnesium Treatment	Polishing Ponds	Soil Aquifer Treatment

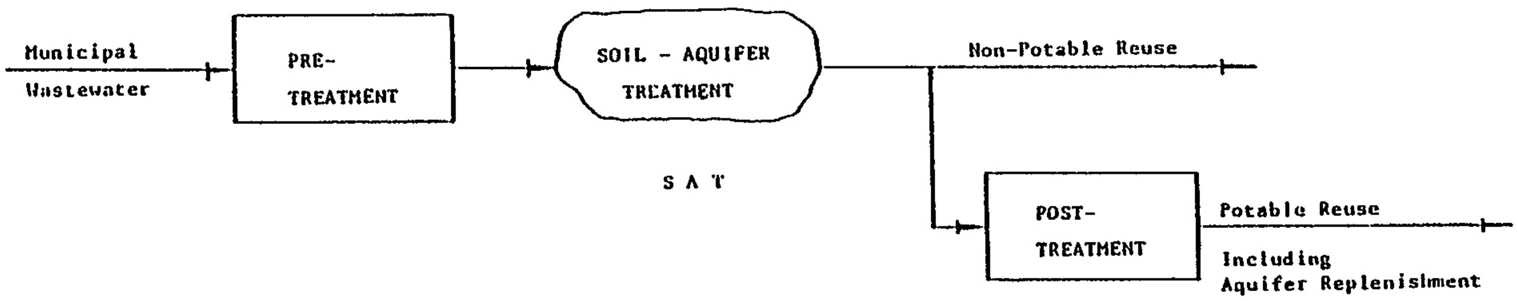

Fig. 5 Soil Aquifer Treatment (SAT) Schemes for Non-potable and Potable Re-use

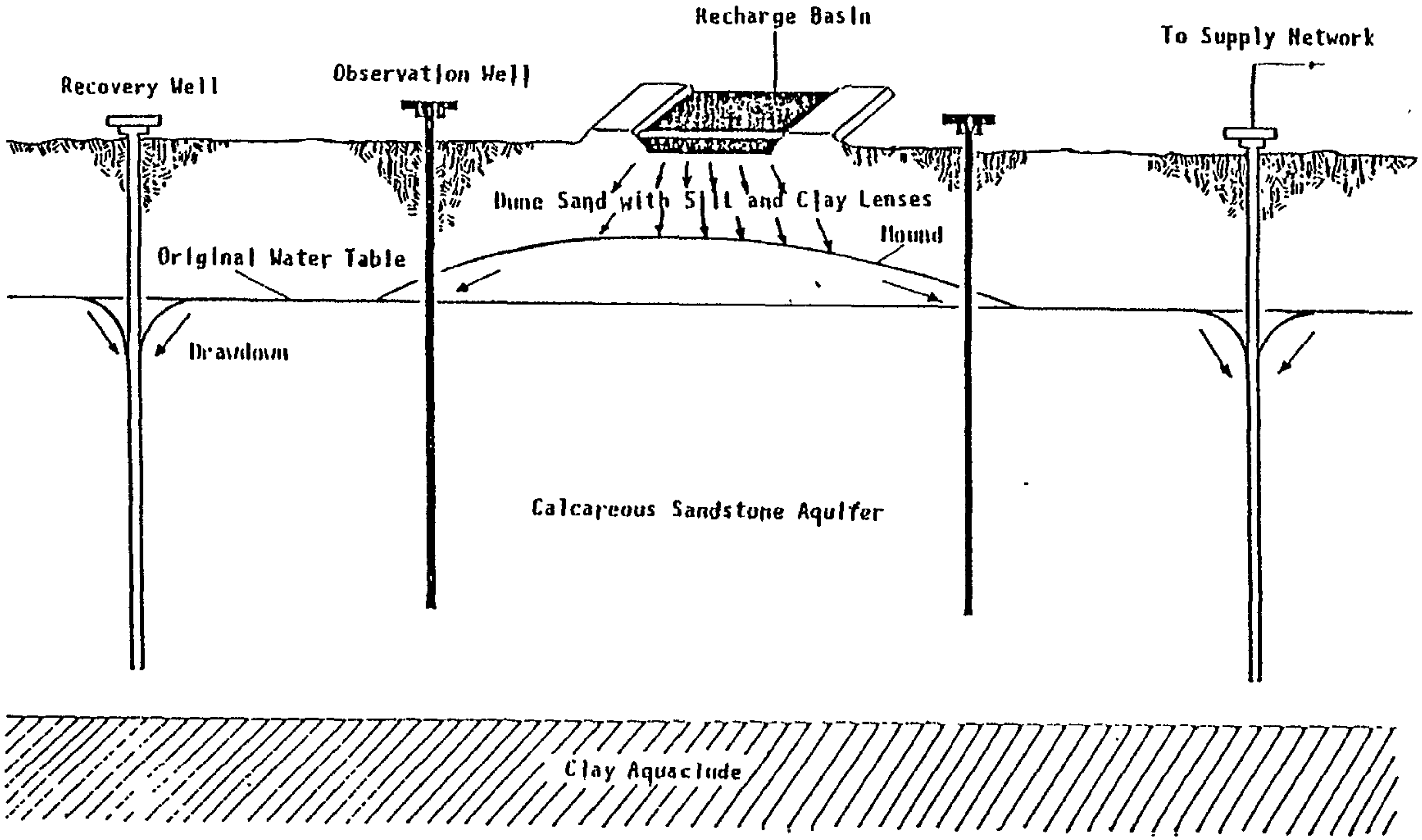

Fig. 6 Diagram of Recharge Recovery System by the SAT Process

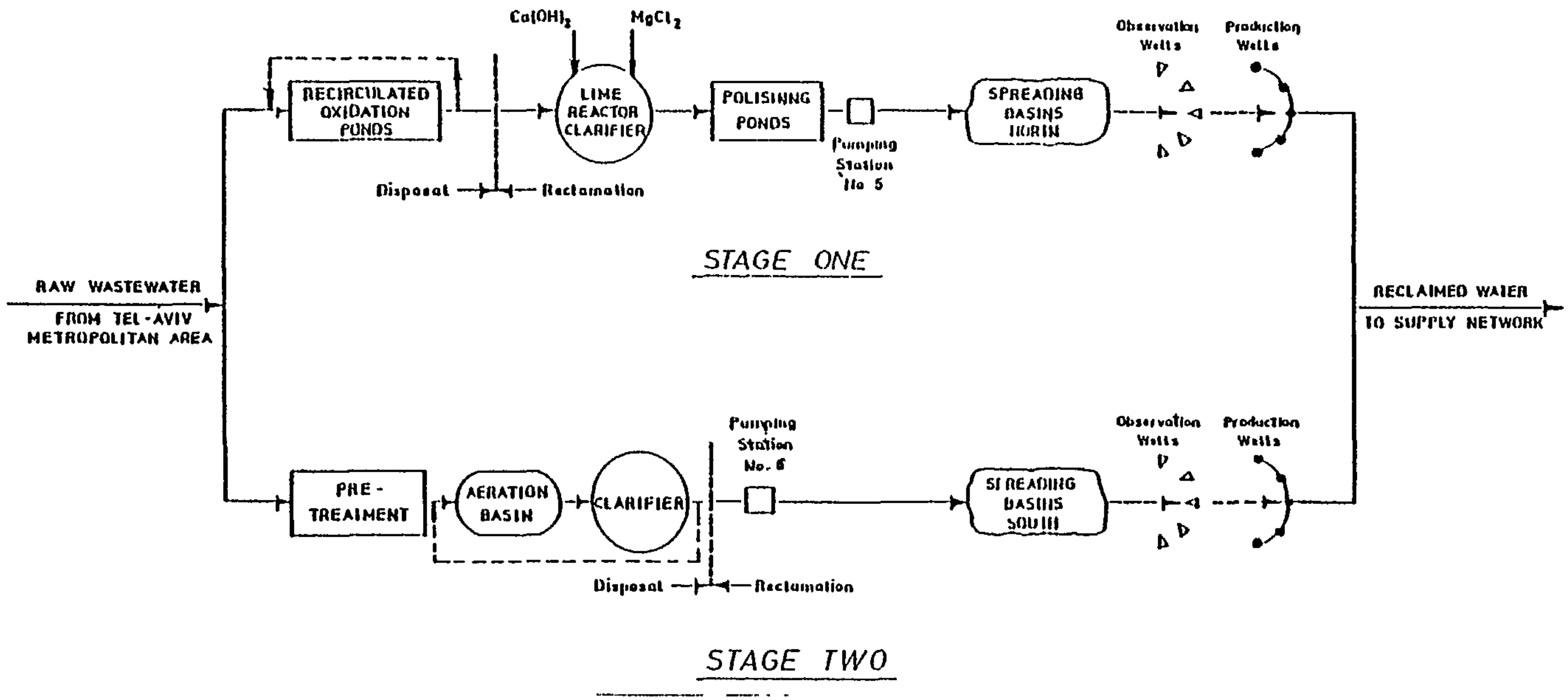

Fig. 7 Dan Region Wastewater Re-use Project - Treatment Schemes of the Two Project Stages

content of the effluent should be taken into account while programming the fertilizing regime. Failure to do so may result in migration of excess nitrate towards the water table and pollution of groundwater.

It is possible to achieve high crop yields in plots irrigated with effluents and the quality of products is usually good but as a result of the difference in qualities of effluent and fresh water, irrigation and fertilizing regimes should be adjusted to the utilization of effluent, in accordance with crop types.

All the commonly-used irrigation methods can be employed to apply sewage effluents under appropriate conditions. Irrigation methods can be classified into three broad categories: sprinkler systems, surface system and drip systems. Sprinkler and surface systems are in common use for effluent distribution, while drip irrigation is not recommended in the literature as an adequate method (for example reference 1). In Israel, however, drip irrigation is considered most appropriate for irrigation of effluent and is in widespread use for that purpose. A detailed description of various types of surface and sprinkler irrigation systems is presented in publications 1 and 2.

Flood irrigation is a low-efficiency water-use method which causes contamination of vegetable crops lying on the ground and exposes farmers to effluent more than any other irrigation method. Ridge and furrow irrigation is a surface method that can reduce plant contamination.

Sprinkler, or spray, irrigation has the dual advantage of being able to control the application rate of water while utilizing minimal manpower and thus is particularly appropriate for areas where labour costs are high. However, it requires a high-pressure supply of piped water and a sound technological infrastructure. In addition, ground crops and fruit trees become contaminated by the spray. Aerosols may also be transported to nearby residential areas. Of course, sprinkler irrigation can be set at low pressure so that water stays below the height of the fruit bearing branches and thus does not contaminate fruit.

Detailed information on the drip irrigation method is presented in publications 2 and 13. In addition to its advantages as an efficient irrigation method, drip irrigation serves as an additional treatment step, operating in a similar manner to that of a trickling filter. But the greatest advantage of incorporating drip irrigation in re-use schemes is the safety it provides by being most effective in minimizing contact between the effluent, the crops and the farmers. Pretreatment of effluent by straining and gravel filtration is required before its distribution by drip irrigation. Details on such pretreatment are presented in publication 8. A review of problems associated with effluent treatment before irrigation and their prevention is presented in publication 14. At certain periods, effluent chlorination is necessary for control of attached bacterial growth at the drippers' nozzles or for excess algae control. This is done by hypochlorination utilizing systems similar to those used for fertilizer dosing.

7. INTEGRATED PLANNING OF RECLAIMED WASTEWATER IRRIGATION PROJECTS

The basic condition for operation of a wastewater re-use project is the existence of a consumer for the effluent, i.e. an infrastructure for agricultural activity based on consumption of the effluent for irrigation. The agricultural activity can be based on farms owned by the wastewater-producing municipality, such as in the case of Melbourne (15) and Muskegon county (16), or by private farmers or agricultural communities as is the case in all wastewater re-use projects in Israel.

In order to achieve successful re-use schemes, the wastewater treatment system and the effluent re-use system should be regarded as an integrated agro-sanitary system. The operation of the treatment installation should be done in close co-operation and with the participation of the farmers. In many small-to-medium size re-use schemes in Israel, the farmers are in charge of operation of the treatment installations.

Wastewater re-use projects are integrated projects, combining a variety of components which include conveyance of raw wastewater, sewage treatment, effluent storage, effluent supply, irrigation and agriculture. Integrated planning of such projects requires specialization in a variety of related subjects. Several alternatives may be elaborated in the course of planning and the most appropriate alternative is selected on the basis of economic criteria or other considerations (such as socio-economic aspects, for example). The elaboration of each alternative is based on integrated planning of the systems which comprise the re-use project. Such a planning combines and integrates the following operations·

- identification of potential areas to be irrigated with the effluent
- collection of relevant information regarding the re-use area (climate, soil, agricultural practice in the zone)
- selection of irrigation method
- agricultural planning and establishment of water demand distribution of the project over the year
- selection of the wastewater treatment process, estimation of storage requirements and location of treatment and storage installations
- planning of raw wastewater conveyance, effluent supply and irrigation systems
- elaboration of an economic analysis of the project.

The above operations are inter-related and some are carried out in parallel while feeding information to each other. Detailed presentation of concepts and methodologies concerning integrated planning of re-use projects can be found in publications 1, 2, and 6. Some points of interest regarding the planning process will be mentioned at this stage.

The overall land extension required for a re-use project is estimated during the agricultural planning and depends on climate, raw wastewater flow, selected crops, irrigation method and utilization of seasonal storage. The selection of crops is based on climatic conditions, soils, market considerations and effluent quality (both from the public health and the agronomic points of view).

The effluent demand for the project and its distribution with time is calculated on the basis of the agricultural planning by estimation of water demand of each crop considering the extension of land allocated for its cultivation and the summation of individual water demands by each crop. The overall water demand incorporates consideration of the irrigation methods and its water use efficiency. The effluent use of each crop is estimated by the same methods applied for irrigation with water. A detailed presentation of the subject of crop water requirements can be found in a variety of publications (such as, for instance, 1, 6, 17, 18).

The selection of crop types is done in combination with the selection of treatment methods and alternative re-use schemes are based on combinations of crop types and appropriate treatment methods.

The wastewater conveyance systems and effluent supply system are elaborated on the basis of topographical conditions and location of treatment facilities and the re-use areas. It is recommended to utilize, as far as possible, the conventional agricultural practice and irrigation methods used in the zone of the project in order to facilitate the farmers' work, but the fact that effluent and not water is used for irrigation should not be ignored and the necessary conditions should be applied (crop types, irrigation and fertilization regimes, etc.).

8. ECONOMIC ASPECTS

General Considerations

Two approaches toward projects of wastewater re-use for irrigation may be outlined, from the economic point of view·

- According to the first approach, irrigation with treated wastewater serves in principle as a wastewater disposal method which may result, as a by-product, in production of crops and in the preservation and enlargement of green belts and open spaces.

- According to the second approach, wastewater serves as an unconventional water resource and its re-use for irrigation is aimed at water conservation by replacing potable water with treated effluent. In this case, an economic return is expected from the use of water and nutrients so as to produce marketable crops.

The first approach applies to zones in which water resources are abundant or in areas in which profitable agriculture is not feasible because of topographical restrictions (hilly or mountain zones) or marginal land quality. Irrigation is chosen in such cases because of advantages over other disposal methods.

The second approach applies in areas of limited water resources. In such areas, in addition to wastewater from the first approach irrigation disposal method, irrigation with effluent serves for supplementing available fresh water resources.

The difference between the two approaches is manifested by the fact that in the first one, a profitable project is usually not expected and in most cases cannot be achieved, whereas according to the second approach, a profitable project may be anticipated.

It should be noted that even in areas which are considered water-abundant, water may be scarce in the dry season, and irrigation with effluent may serve to increase agricultural production during that season.

The economic analysis of a wastewater re-use project usually consists of a cost-benefit analysis, similar to that applied in conventional agricultural projects. Such an analysis is based on elaboration of the cash flow during the lifetime of the project, taking into account all expenditures and income, and capitalization of all the cash flow components at various interest rates in order to calculate the Internal Rate of Return(IRR) of the project, the Net Present Value (NPV) at the interest rate at which credit is obtained for the project and the Benefit-Cost (B/C) ratio of the project, under the above credit conditions.

Project expenditure items include:

- investment in the physical components of the system (raw wastewater conveyance system, wastewater treatment and storage, effluent supply for irrigation);
- operation, maintenance and energy costs;
- agricultural costs (machinery, labour, fertilizers, pest-control materials, etc.);
- investment in irrigation system;
- operation and maintenance of the irrigation system.

Project income items include:

- income from marketing of crops;
- saving in purchase of fertilizers (as a result of the presence of nutrients in the effluent which reduces the dose of required fertilizers).

The differences between conventional agricultural projects and wastewater re-use projects, as reflected in the economic analysis, are the following: (i) the water supply system is much more complicated in re-use projects (ii) re-use projects benefit from the economic value of the nutrients contained in the effluent, which substantiate part of the fertilizers, and (iii) re-use projects have additional benefits which are not always quantifiable - such as environmental protection and the development of a supplementary water resource. These benefits may be of great importance, especially in areas whose economy is based on tourism and which suffer from water scarcity. Additional benefits which may accrue are the solution of socio-economic and political problems. An example worth mentioning is the case of a traditional agricultural zone which lost its groundwater resources as a result of salination caused by over-pumping. Sometimes the sole solution to such a socio-economic problem may be wastewater re-use.

The feasibility of a re-use project depends on various factors, most of which are specific to each project and which include soil type, climatic conditions and selected crops.

Three factors have to be taken into account when aiming at a feasible re-use project:

(i) distance of the re-use area from the wastewater source;

(ii) efficient water use;

(iii) deduction of alternative wastewater disposal costs from the project costs.

The closer the re-use area to the wastewater source, the more profitable the project can be, because of the lower investment in the conveyance system. But the distance of the re-use area from the wastewater source depends on land availability and is not an independent variable. In the case of small re-use projects, re-use areas are usually available in the vicinity of the point of wastewater collection.

Efficient water use is a factor which can be dictated by the project planners. Maximum efficiency of water use must be attempted in order to permit irrigation of the maximum possible areas and thus result in enlarged crop production. Efficient water use is inter-related with two factors· irrigation method and seasonal storage. High efficiency irrigation methods are preferable. Drip irrigation can serve as an example of an efficient irrigation method (which has also an advantage from the point of view of minimizing public health risks associated with effluent irrigation). Seasonal storage increases the amount of effluent which can be used for irrigation, thus permitting irrigation of increased areas (it is also advantageous from the point of view of function as a supplementary treatment process).

Deduction of alternative wastewater disposal costs is an important factor in re-use projects. In most cases, a re-use project can be economically feasible only if alternative disposal costs are deducted from the project costs. Such a deduction is justified because sewage disposal should be provided by the authorities which represent the wastewater producers, and not by the farmers.

In practice, participation of municipalities in financing re-use projects depends on local environmental protection regulations, on the power of authorities to enforce such regulations and on specific conditions. Finally, an additional factor which has a marked effect on re-use projects feasibility should be mentioned. This is the price of cultivated crops. Prices of crops are not always directly dependent on production costs and may vary as a result of developments in the international market. Such variations can affect and sometimes completely change the feasibility of projects. Fluctuations in prices of cotton during recent years may be mentioned as a relevant example, since cotton is an industrial crop suitable for irrigation with effluent.

On-Farm Economics of the DRT System in Israel

The case of a typical re-use scheme in Israel will be presented as an example for the economic analysis of a re-use project. The system is located in the central zone of Israel and serves a population of about 15,000 inhabitants. The scheme is based on the DRT treatment-storage system which was presented briefly in a preceding chapter and in greater detail in publication 8. The raw wastewater diverted to the project comprises part of the wastewater of a nearby town and the wastewater of a neighbouring agricultural community. The wastewater pretreatment installation includes two anaerobic ponds whose effluent is diverted to a 300,000 m^3 seasonal storage (and treatment) reservoir of 10 m maximum depth. The combination of the anaerobic ponds and reservoir comprises the DRT system. The anaerobic ponds are located in the reservoir's embankment. The couple of ponds provide the flexibility of operation of one pond while realizing maintenance activities, such as cleaning, in the other. The ponds are highly loaded, deep anaerobic ponds of short detention time, operating with an organic loading of about 3,000 kgBOD/day/ha and a detention time of about 1.5 days. Such operating conditions permit efficient BOD removal while preventing odour generation. Estimation of the required storage volume of the project is presented in Appendix I.

The project is located in a zone of light soil, in the vicinity of a regional road and at a distance of several hundred metres from residential suburbs of the population which contributes the wastewater. As a result, plastic lining was used for the impermeabilization of the reservoir and drip irrigation was applied for the prevention of dispersion of aerosols by air. In addition to the treatment-storage facilities, the project includes a raw wastewater main and a pumping station for supply of raw wastewaeffluent pumping station, central straining and rapid gravel filtration facilities for effluent treatment before drip irrigation, the main effluent supply system and the drip irrigation system.

The net annual flow supplied by the project is 460,000 m^3 and it is used for irrigation of 36 ha of cotton during summer. A part of this area is irrigated with effluent during winter for the cultivation of wheat for silage.

The annual water consumption for cotton irrigation is about 5,000 m^3/ha and its monthly distribution is presented in Appendix I. The annual water consumption of wheat depends on rainfall. In rainy years the consumption is 500 m^3/ha, while in regular years it is about 1,400 m^3/ha. Consequently, the extensions of wheat-cultivated areas vary from year to year according to rainfall and wheat requirements. In the presented economic analysis, the extension of cultivated wheat is 23 ha which is the area that may be irrigated when the annual wheat water consumption is 1,400 m^3/ha. The monthly distribution of wheat water comsumption is presented in Appendix I.

The agricultural programme may change over the years according to variations in crop prices. The above presented programme is utilized as an example of economic analysis.

The economic analysis presented herein is the farmer's point-of-view analysis, i.e. an on-farm economic analysis and not a national point of view analysis. Consequently, the presented costs are financial costs and not economic costs. The main purpose of the analysis is to establish the feasibility of the project. It includes the cash flow along the projects' lifetime, capitalization of all cash flow items and calculation of the Net Present Value (NPV) at various interest rates and of the Internal Rate of Return (IRR) of the project. The IRR is a criterion of project feasibility. Projects with IRR higher than 12% are considered feasible. Higher IRR values mean higher feasibility.

The investment in the wastewater conveyance, treatment-storage, effluent supply and irrigation systems (the physical components of the system) are presented in Table IV. The lifetime of each system component and the annual operation and maintenance costs of each component as a percentage of the investment are also presented in Table IV. Energy costs for raw wastewater and effluent pumping were based on a unit price of 0.07 $/KWh.

Table IV

Investments O&M Costs and Lifetime of Physical Components of the System

Item	Investment (1,000 US$)	Annual O&M Costs (% of investment)	Lifetime (Years)
Raw wastewater main	45	0.5	40
Raw wastewater pumping station	15	2.5	15
Anaerobic ponds and storage reservoir	370	0.5	40
Effluent pumping station	30	2.5	15
Effluent pretreatment for irrigation	20	2.5	15
Effluent distribution system	55	0.5	40
Drip irrigation system	172	3.0	10
Total Investment	707,000 US$		

The economic analysis was carried out for an overall project lifetime of 40 years. Distribution of investments and O&M costs were estimated based on Table IV. Energy costs were calculated on energy consumption of the pumping stations and on energy unit price costs. As part of the irrigation practice, hypochlorination is used from time to time to control biological growth, utilizing the fertilizing systems for hypochlorite dosing. The annual hypochlorite costs of 7,600 $/year were taken in account as part of the irrigation system annual costs. Duration of construction of the project components was about one year and agricultural production commenced in the second year.

Agricultural production costs for cotton (akala type) and wheat in the project zone are presented in Table V (based on data of Ref. 19).

Table V

Agricultural Production Costs
(US$/ha)

Item	Cotton	Wheat
Machine work	787.3	390.8
Seeds	25.0	84.0
Fertilizers	129.0	145.0
Pest-control materials	384.5	81.0
Labour	535.5	157.5
Product handling	100.0	105.0
Miscellaneous	165.5	114.6
Total Costs ($/ha)	2,126.8	1,077.9

Cotton yield in the project area is 5,500 kg/ha and wheat yield is 10,500 kg/ha. Total annual agricultural production costs were calculated on the basis of an extension of the area of each crop, its yield and the unit production costs (Table V).

Three benefit items can be considered in re-use projects (i) income from crop marketing, (ii) the saving in fertilizers and (iii) municipal participation in project financing to account for its duty to provide wastewater disposal.

The principal income in the project under consideration is that of cotton. The cotton product consists of 32% fibres and 55% seeds. The price of seeds in Israel is 0.25$/kg. The price of fibres is at present (1987) about 0.8 $/lb or 1.76 /kg. Thus the price of cotton is about 0.7 $/kg. The price during 1986 was 0.675 $/kg. The economic analysis was carried out using the two alternative cotton prices. The price of wheat is about 0.12 $/kg. The total agricultural income is the sum of cotton and wheat incomes.

The agricultural production costs presented in Table V include the total fertilizer costs, i.e. considering that water free of nutrients is used for irrigation. Since the effluent contains nutrients, a lower dose of fertilizers will be required and the equivalent value of fertilizers contained in the effluent may be considered as a benefit of the project. Estimate of the benefit of fertilizer savings is presented in Appendix II, yielding an equivalent annual income of 5,600$.

The town producing the wastewater has to provide appropriate disposal facilities, or in the present case, finance part or all of the treatment-storage facilities (storage should also be financed as it serves as the main treatment step). Such financing will increase project feasibility. The economic analysis was carried out in three cases:

(i) without municipal participation;

(ii) municipal participation in financing of the raw wastewater conveyance system and half of the treatment-storage facilities (including investments and annual costs);

(iii) municipal participation in financing the raw wastewater conveyance system and the entire treatment-storage facilities.

Cash-flow diagrams of the project at cotton price of 0.7 $/kg and town-financing participation according to items (i), (ii) and (iii) above, are presented, respectively, in Tables VI, VII and VIII.

Expenditure items in these diagrams are expressed by negative values and benefit items are expressed by positive values. Capitalization of each item (each column) at a certain cost of capital (interest rate) and summation of the capitalized costs yields the Net Present Value of the project at the same cost of capital. The cost of capital at which the net present value is nil (i.e. capitalized expenditure items equal capitalized income items) is defined as the Internal Rate of Return of the project (IRR). It can be graphically found by calculating NPV at several interest rates, drawing NPV against interest rate and identification of the interest rate at which NPV becomes nil. Such a procedure for the conditions defined in Table VI is presented in Fig. 8, yielding an IRR Value of 18.15%.

The results of the economic analyses of the project are presented in Table IX. The table contains NPV values at three interest rates (8%, 10%, 12%) and IRR values for each of the six cases analysed. The range of interest rates of 8 to 12% was chosen as it is a conventional range for credit granting.

All six versions for which the economic analyses were carried out resulted in IRR values higher than 12%, indicating a feasible project in all cases. The project under discussion is feasible even when the wastewater supply and conveyance system is financed by the farmers, because of certain features which are of advantage from the point of view of economics:

(i) the investment in the raw wastewater conveyance system is small because the re-use area is adjacent to the town;

(ii) the treatment and storage facilities are located within the re-use area, thus the investment in the effluent supply systems is also minimal;

(iii) the water-use efficiency of the project is high because a seasonal storage facility is incorporated and the drip irrigation method is utilized.

In common with other agricultural projects, feasibility depends on product prices. Present cotton prices are favourable for the project. A drop in cotton prices similar to that which occurred two years ago will render the project unfeasible.

Table VI

Project Cash-Flow Diagram

No Participation of Municipality in Project Financing

(Costs Expressed in units of 1000US$)

YEAR	INVESTMET WASTEWAT CONVEYANC SYSTEM	ANNUAL COSTS CONV.SYS O&M+ENER	INVEST TREATMEN & SEASON STORAGE	ANNUAL COSTS TREATMEN &STORAGE O&M	INVEST EFFLUENT STRAINER & CONV. SYSTEM	ANNUAL COSTS EFF.CONV SYSTEM O&M+ENER	INVEST IRRIG. SYSTEM	ANNUAL COSTS IRR.SYS O&M+ENER	AGRICULT. PRODUCTI ON COSTS	INCOME FROM AGRICULT	BENEFIT OF FERTILIZ SAVING	ALTERN. DISPOSAL INVEST.	ALTERN. DISPOSAL ANNUAL COSTS O&M+ENER	TOTAL
0	-60.00	0.00	-370.00	0.00	-105.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-535.00
1	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	0.00	-40.08
2	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
3	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
4	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
5	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
6	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
7	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
8	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
9	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
10	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	0.00	-40.08
11	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
12	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
13	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
14	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
15	-15.00	-1.70	0.00	-1.85	-50.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	66.92
16	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
17	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
18	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
19	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
20	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	0.00	-40.08
21	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
22	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
23	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
24	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
25	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
26	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
27	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
28	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
29	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
30	-15.00	-1.70	0.00	-1.85	-50.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	0.00	-105.08
31	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
32	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
33	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
34	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
35	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
36	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
37	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
38	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
39	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92
40	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	0.00	131.92

Note : cotton price 0.7 US$/KG

Table VII

Project Cash-Flow Diagram

Municipal Participation in Financing Half of the Treatment-Storage Facilities

(Costs Expressed in Units of 1000 US$)

YEAR	INVESTMENT WASTEWATER CONVEYANCE SYSTEM	ANNUAL COSTS CONV.SYS O&M+ENER	INVEST TREATMENT & SEASON. STORAGE	ANNUAL COSTS TREATMENT &STORAGE O&M	INVEST EFFLUENT STRAINING & CONV. SYSTEM	ANNUAL COSTS EFF.CONV SYSTEM O&M+ENER	INVEST IRRIG. SYSTEM	ANNUAL COSTS IRR.SYS O&M+ENER	AGRICULT. PRODUCTION COSTS	INCOME FROM AGRICULT.*	BENEFIT OF FERTILIZ SAVING	ALTERN. DISPOSAL INVEST.	ALTERN. DISPOSAL ANNUAL COSTS O&M+ENER	TOTAL
0	[illegible]	0.00	-270.00	0.00	-105.00	0.00	0.00	0.00	0.00	0.00	0.00	245.00	0.00	[illegible]
1	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	2.63	-37.45
2	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
3	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
4	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
5	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
6	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
7	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
8	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
9	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
10	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	2.63	-37.45
11	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
12	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
13	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
14	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
15	-15.00	-1.70	0.00	-1.85	-50.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	15.00	2.63	84.55
16	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
17	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
18	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
19	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
20	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	2.63	-37.45
21	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
22	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
23	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
24	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
25	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
26	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
27	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
28	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
29	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
30	-15.00	-1.70	0.00	-1.85	-50.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	15.00	2.63	-87.45
31	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
32	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
33	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
34	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
35	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
36	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
37	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
38	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
39	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55
40	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	2.63	134.55

* Note : cotton price 0.7 US$/KG

Table VIII

Project Cash-Flow Diagram

Municipal Participation in Financing Entire Treatment-Storage Facilities

(Costs Expressed in units of 1000 US$)

YEAR	INVESTMENT WASTEWATER CONVEYANCE SYSTEM	ANNUAL COSTS CONV. SYS O&M+ENERGY	INVEST TREATMENT & SEASONAL STORAGE	ANNUAL COSTS TREATMENT & STORAGE O&M	INVEST EFFLUENT STRAINING & CONV. SYSTEM	ANNUAL COSTS EFF. CONV. SYSTEM O&M+ENERGY	INVEST IRRIG. SYSTEM	ANNUAL COSTS IRR. SYS O&M+ENERGY	AGRICULT. PRODUCTION COSTS	INCOME FROM AGRICULT.	BENEFIT OF FERTILIZ. SAVING	ALTERN. DISPOSAL INVEST.	ALTERN. DISPOSAL ANNUAL COSTS O&M+ENERGY	TOTAL
0	[illegible]	0.00	-370.00	0.00	-105.00	0.00	0.00	0.00	0.00	0.00	0.00	[illegible]	0.00	[illegible]
1	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	3.55	-36.53
2	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
3	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
4	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
5	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
6	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
7	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
8	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
9	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
10	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	3.55	-36.53
11	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
12	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
13	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
14	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
15	-15.00	-1.70	0.00	-1.85	-50.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	15.00	3.55	85.47
16	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
17	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
18	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
19	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
20	0.00	-1.70	0.00	-1.85	0.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	0.00	3.55	-36.53
21	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
22	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
23	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
24	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
25	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
26	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
27	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
28	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
29	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
30	-15.00	-1.70	0.00	-1.85	-50.00	-9.75	-172.00	-12.76	-207.70	360.08	5.60	15.00	3.55	-86.53
31	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
32	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
33	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
34	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
35	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
36	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
37	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
38	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
39	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47
40	0.00	-1.70	0.00	-1.85	0.00	-9.75	0.00	-12.76	-207.70	360.08	5.60	0.00	3.55	135.47

Note : cotton price 0.7 US$/KG

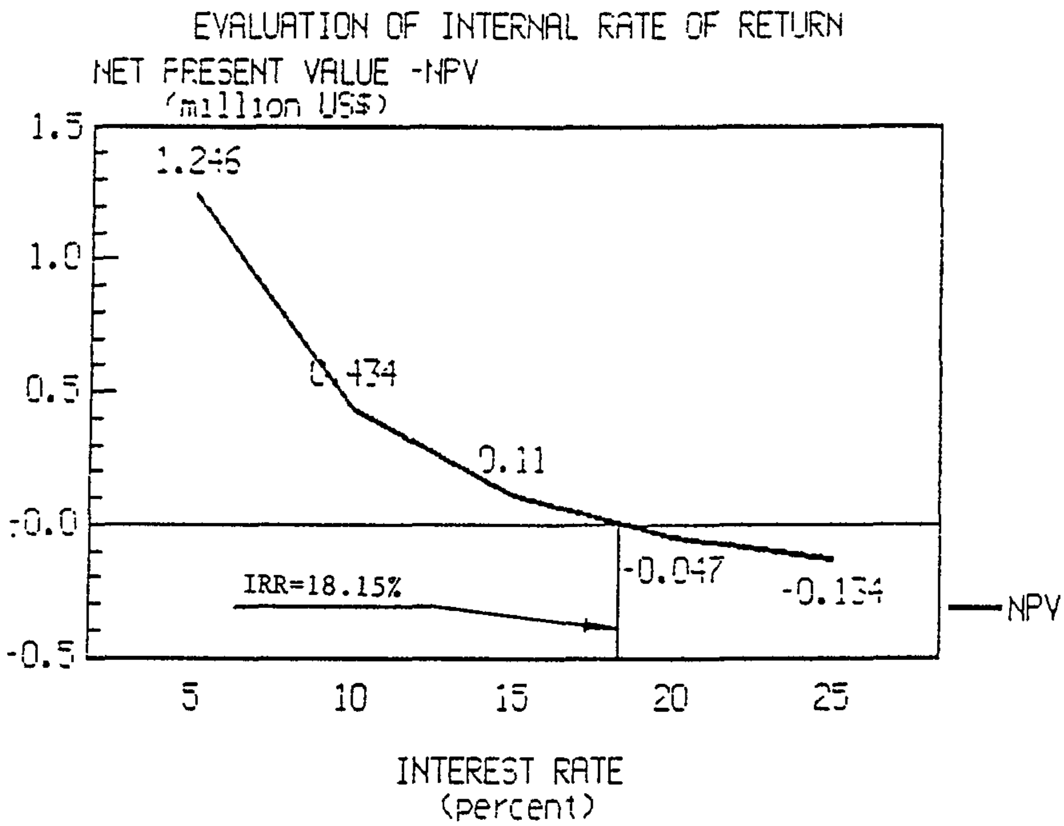

Fig. 8 Graphical Procedure for Evaluation of Internal Rate of Return (IRR)

Table IX

Results of Economic Analysis

(NPV Values Expressed in Units of 1,000 US$)

Economic Indicator	Cotton Price 0.675 $/kg			Cotton Price 0.7 $/kg		
	Municipal Financing Participation Nil	Municipal Financing Participation Half Treatment-Storage	Municipal Financing Participation Entire Treatment-Storage	Municipal Financing Participation Nil	Municipal Financing Participation Half Treatment-Storage	Municipal Financing Participation Entire Treatment-Storage
NPV at interest rate of 8%	534.5	796.1	977.6	655	926.7	1109.2
NPV at interest rate of 10%	329.2	579.3	755.7	434.3	648.4	860.8
NPV at interest rate of 10%	186.2	427.1	599.1	273.2	514.2	686.1
IRR (%)	16.2	27.75	57.1	18.15	30.95	64.26

NPV - Net Present Value
IRR - Internal Rate of Return

Municipal participation in project financing has a marked effect on the project economics and most re-use projects can be feasible only if such participation is guaranteed.

Wastewater re-use is technically feasible and may be economically feasible. The economic feasibility of a re-use project depends on a series of factors: (i) the distance of the re-use area from the wastewater source, (ii) efficient use of water (i.e. incorporation of seasonal storage and utilization of an efficient irrigation method), and (iii) deduction of alternative wastewater disposal costs from the re-use project costs.

9. ACKNOWLEDGEMENT

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10. REFERENCES

1. Pettygrove, G.S., Asano, T., "Irrigation with Reclaimed Municipal Wastewater - A Guidance Manual", Lewis Publishers, Inc., 1985.

2. Shuval, H., et al., "Wastewater Irrigation in Developing Countries - Health Effects and Technical Solutions", World Bank Technical Paper Number 51, The World Bank, Washington D.C., 1986.

3. Shuval, H., et al., "State of the Art Review: An Epidemiological Approach to the Health Effect of Wastewater Re-use", Wat. Sci. Tech. Vol. 18, pp. 147-162, 1986.

4. The Engelberg Report, "Health Aspects of Wastewater and Excreta Use in Agriculture and Aquaculture". The report of a review meeting of Environmental Specialists and Epidemiologists, held at Engelberg, Switzerland, July 1-4, sponsored by the World Bank and World Health Organization, 1985.

5. Gunnerson, G.C., et al., "Health Effects of Wastewater Irrigation and Their Control in Developing Countries", Water Re-use Symposium III, of the American Water Works Association, held at San Diego, California, 21-23 August, 1984.

6. Libhaber, M., et al., "Re-use of Wastewater for Irrigation of Arid Zones South of Lima, Peru", Feasibility Study prepared for SEDAPAL and BID, TAHAL Report No. 04/85/21, Lima, Peru, 1985 (in Spanish).

7. Rebhun, M., et al., "Monitoring of Tishlovet Hakishon Project", Annual Report No. 3, April 85-March 86, Technion - Israel Institute of Technology, Haifa, Israel, 1986 (in Hebrew).

8. Libhaber, M., "Wastewater Treatment for Agricultural Re-use in Israel", Paper presented in the UNEP, PAP/RAC Workshop on Treatment and Use of Effluent for Irrigation and Other Purposes, Split, Yugoslavia, November 25-27, 1987.

9. Idelovitch, E., and Michail, M., "Soil Aquifer Treatment - A New Approach to an Old Method of Wastewater Re-use", J. WPCF, August 1984.

10. Bower, H., "Wastewater Re-use Alternatives", Proceedings of Symposium of Water Conservation Alternatives for Groundwater and Surface Water Utilization, Arizona Section, American Water Resource Association, April 12, 1979.

11. Idelovitch, et al., "The Role of Groundwater Recharge in Wastewater Re-use· Israel's Dan Region Project", Journal AWWA, pp. 391, July 1980.

12. Arueste, G., "Advanced Municipal Wastewater Treatment by a Single Stage Activated Sludge System", Prog. Water Techn. Vol. 12, No. 5, pp. 533, IAWPR/Pergamon Press Ltd., 1980.

13. Dasberg, S., Bresler, E., "Drip Irrigation Manual", Publication No. 9, International Irrigation Information Centre, The Volcani Centre, Bet Dagan, Israel, 1985.

14. Adin, A., "Problems Associated with Particulate Matter in Re-use for Agricultural Irrigation and their Prevention", Wat. Sci. Tech. Vol. 18, pp. 185-195, 1986.

15. Seabrook, B.L., "Land Application of Wastewater in Australia - The Land Treatment System at Werribee, Victoria", U.S. EPA Report no. EPA-430/9- 75-017, Washington, D.C., May 1975.

16. EPA, "Wastewater· Is Muskegon County's Solution Your Solution?", U.S. EPA Report No. EPA-905/2-76-00, Region V, Chicago, 1976.

17. Doorenbos, J., Pruitt, W.O., "Guidelines for Predicting Crop Water Requirements", FAO Irrigation and Drainage Paper No. 24, revised 1977.

18. Hansen, E.V., Israelsen, W.O., Strigham, E.G., "Irrigation Principles and Practices", John Wiley and Sons, 1983.

19. Vizel, L., et al., "Field Crops Calculations", Israeli Ministry of Agriculture, Field Crops Division, Department of Production Economics, June 1986 (in Hebrew).

20. Libhaber, M., Boutin, P., "Report of UNEP - PAP/RAC Mission on Re-use of Municipal Wastewater for Irrigation in the Island of Mallorca", November 1985.

APPENDIX I

ESTIMATION OF THE RESERVOIR VOLUME

The present appendix deals with the procedure for estimation of the required volume of the reservoir which forms part of the re-use project for which the economic analysis was presented in a preceding chapter.

Establishment of the reservoir volume is based on the monthly distribution of inflow and outflow streams of the reservoir. Inflow streams include wastewater and rainfall while outflow streams include effluent withdrawn for irrigation and losses by infiltration and evaporation. The monthly distribution of water consumption for irrigation of 86 ha cotton and 23 ha wheat (field data based on calculation method used by the farmers) is presented in Table I.

Table I

Monthly Distribution of Water Consumption for Irrigation

Month	Cotton Water Demand (m^3/ha/month)	Wheat Water Demand (m^3/ha/month)	Total water consumption for 86 ha cotton and 23 ha wheat (10^3 x m^3/month)
10			
11		1,000	23.00
12			
1			
2		400	9.20
3			
4	9		0.77
5	250		21.50
6	945		81.27
7	1,510		130.29
8	1,781		153.17
9	440		37.84
Total	4,940 m^3/ha	1,400 m^3/ha	457,000 m^3/year

The water balance table of the reservoir is presented in Table II. Wastewater inflow is based on measured data and the procedures for estimates of rainfall and losses are mentioned in footnotes to Table II. The resulting required reservoir volume is 250,800 m^3 (249,500 + 1,300). The constructed reservoir volume is about 300,000 m^3. This assures a certain detention time in the reservoir even towards the end of the irrigation season.

Table II

Water Balance for Calculation of the Reservoir Volume

(Volumes are expressed in Units of 1,000 m^3)

Month	10	11	12	1	2	3	4	5	6	7	8	9	Total
Effluent Inflow	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	46.0	46.0	46.0	45.0	+ 502
Rainfall[1]	1.0	4.0	8.0	7.0	4.0	3.0	1.0						+ 28
Losses (Infiltration and Evaporation)[2]	4.0	4.0	4.0	4.0	5.0	6.0	8.0	9.0	9.0	8.0	7.0	5.0	- 73
Effluent Outflow for Irrigation		23.0			9.2		0.77	21.5	81.3	130.3	153.2	37.8	- 457
Total Volume of Reservoir at end of Month	37.0	54.0	98.0	141.0	170.8	207.8	240.0	249.5	205.2	112.9	-1.30	0.9	0

1 Rainfall estimated on basis of meteorological data in the zone (multi-annual averages).

2 Infiltration loss estimated on basis of 2 mm/day (lined reservoir).
Evaporation loss estimated at 70% of multi-annual evaporation in pan Class "A".

APPENDIX II

EVALUATION OF THE ECONOMIC VALUE OF NUTRIENTS IN THE EFFLUENT

Effluent contains the elements N, P, K which are consumed by crops during irrigation, thus less fertilizer is required while utilizing effluent for irrigation. The saving in fertilizer is an economic benefit in re-use projects. The evaluation of the economic benefit associated with effluent irrigation will be outlined using the project for which the economic analysis was presented in a preceding chapter, as an example. Most of the effluent of that project was consumed by cotton, thus the calculation will be based on consumption of 5,000 m^3/ha for irrigation of 86 ha of cotton.

The content of nutrients in the effluent is:

25 mg/l N (equivalent to 125 mg/l Ammonium sulphate)
5.6 mg/l P (equivalent to 74 mg/l Superphosphate)
24 mg/l K (equivalent to 45.8 mg/l Potassium chloride).

Assuming that 85% of the nutrients are available to crops, and an irrigation water-use efficiency of 80%, the resulting rate of nutrient applied by the effluent is:

Ammonium sulphate (kg/ha): 5,000 x 0.85 x 0.8 x 125 x 0.001 =425 kg/ha
Superphosphate (kg/ha): 5,000 x 0.85 x 0.8 x 74 x 0.001 =251 kg/ha
Potassium chloride (kg/ha): 5,000 x 0.85 x 0.8 x 45.8 x 0.001 =155.7 kg/ha

The required fertilizer application rates (according to the regular practice for cotton) versus the equivalent fertilizer applied with the effluent are presented as follows:

Fertilizer	Required Application Rate (kg/hg)	Applied by Effluent (kg/ha)	Percentage Applied by effluent
Ammonium Sulphate	800	425	53
Superphosphate	500	251	50
Potassium Chloride	500	156	31

From the above data, it is possible to calculate the cost of the fertilizer saved.

For the case under consideration, it was taken that 50% saving in fertilizers can be considered as an average figure. The cost of fertilizers for cotton is 129 $/ha, thus the saving is about 65 $/ha or about 5,600 $/year for the irrigated area of 86 ha.

REUTILISATION DES EAUX USEES URBAINES
Considérations sanitaires

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1. INTRODUCTION

Mer cernée de terres, la Méditerranée isole à son tour une multitude d'îles de taille inégale. Continents en miniature ou blocs rocheux, nombre d'entre elles partagent un trait commun, la précarité de leur alimentation en eau. Des zones littorales qui ne peuvent faire appel à des ressources éloignées connaissent des difficultés analogues.

Divers éléments permettent de justifier cette situation: précipitations réduites, géologie peu favorable à l'infiltration, dissociation des structures hydrogéologiques propices et des zones peuplées, relief inadapté à la création de réservoirs, contamination des nappes d'eau douce par les eaux marines, etc.

La situation s'est aggravée récemment: le développement du tourisme a entraîné une augmentation parfois spectaculaire de la consommation d'eau pendant les mois d'été et a suscité l'intensification des productions agricoles locales irriguées. Le délicat équilibre spontanément établi avec les prélèvements dans la nappe et la qualité des eaux pompées s'est ainsi trouvé rompu. Il en est trop souvent résulté une baisse du niveau des nappes, parfois un appel d'eau salée, catastrophiques aussi bien pour l'agriculture que pour le tourisme, évolution accélérée par l'intervention des techniques modernes de puisaterie et de pompage.

Dans une situation devenue conflictuelle entre une activité traditionnelle (l'agriculture) et une activité nouvelle soutenue par de puissants intérêts (le tourisme), il n'est pas difficile de prévoir qui finirait par l'emporter. Mais l'évolution vers une monoactivité touristique constitue un facteur de déséquilibre, générateur de risques économiques et sociaux.

La réutilisation agricole des eaux résiduaires fournit une possibilité d'échapper à cet enchaînement, d'autant plus que le maximum des besoins de l'agriculture coincide fréquemment avec la pleine période touristique. Il s'agit là d'une pratique ancienne, largement répandue pendant la seconde moitié du XIXème siècle qui a connu depuis une régression en partie due à des considérations sanitaires.

Les connaissances accumulées rendent maintenant possible la reconsidération du problème. L'irrigation avec des eaux usées permet simultanément d'améliorer le bilan hydrologique des zones déficitaires et d'échapper au déversement des effluents dans le milieu marin. A ce double titre, elle constitue un puissant outil d'aménagement. La limitation principale résulte de contraintes sanitaires, liées à l'origine même des eaux, dont l'appréciation objective a considérablement progressé ces dernières années (Prost, 1987).

2. LES PATHOGENES DANS LES EAUX RESIDUAIRES

Du fait de leur origine, les eaux résiduaires entraînent inévitablement une charge de formes pathogènes, principalement d'origine intestinale, dont la composition et l'importance sont le reflet de l'épidémiologie locale.

Les pathogènes sont accompagnés, en bien plus grand nombre, par des bactéries banales, habituellement inoffensives, parmi lesquelles on a sélectionné quelques groupes dont on estime qu'ils sont aptes à fournir des informations sur l'intensité de la contamination fécale (germes indicateurs ou "témoins" de contamination fécale = GTCF). Les coliformes ("totaux" et "fécaux" ou thermotolérants), les streptocoques "fécaux" sont universellement utilisés dans ce but. Ils ont été systématiquement recherchés et dénombrés à l'occasion de nombreuses études et on dispose en ce qui les concerne d'une information considérable, bien que géographiquement mal répartie. Les différences de consommation d'eau sont insuffisantes pour entraîner des variations géographiques appréciables. Les résultats tombent habituellement dans les plages suivantes (Boutin et al, 1979):

- Coliformes "totaux" : $10^7 - 10^9$,
- Coliformes "fécaux" : $10^6 - 10^8$,
- Streptocoques "fécaux" : $10^5 - 10^7$

La recherche des pathogènes dans les effluents bruts et traités est une tâche difficile, qui demande l'intervention - pour des résultats aléatoires - de techniques fastidieuses et complexes, hors de la portée de beaucoup de laboratoires de contrôle. Les données disponibles restent peu nombreuses; elles concernent surtout la bactériologie. L'information sur le contenu viral et parasitaire (kystes de protozoaires et oeufs de vers parasites) est déficiente, souvent difficilement interprétable du fait d'incertitudes sur la méthodologie de prélèvement et de l'absence de méthodes d'analyse normalisées.

Cette carence ne constitue pas en fait un handicap dirimant si on considère qu'un effluent urbain contient des pathogènes d'excrétion fécale ou urinaire, dont la nature et l'abondance sont le reflet de la pathologie locale humaine et, occasionnellement, animale (on n'oubliera pas le rôle des "porteurs sains", qui hébergent le germe sans en être apparemment affectés, et dont le nombre peut dépasser de beaucoup celui des malades recensés). Comme les données concernant l'épidémiologie sont plus abondantes et de meilleure qualité, la liste des pathogènes dont la présence doit être attendue est assez facile à établir. Possible ou reconnue, cette présence constitue un risque sanitaire potentiel.

Quelques points doivent être rappelés:

a) *Lorsque les pathogènes sont directement recherchés*, il faut considérer que, dans des eaux à forte teneur en matières en suspension comme le sont les eaux d'égout, la plupart des bactéries et des virus se trouvent absorbés sur des particules. Il n'existe actuellement aucune technique efficace de dissociation de ces agrégats. Lorsqu'une colonie est dénombrée, rien n'indique si elle trouve son origine dans un germe isolé ou dans un amas. Les effets de masque dûs à l'inclusion dans un flocon de matière organique, les inhibitions résultant du développement d'autres souches contribuent également à la sous-évaluation des effectifs.

b) Beaucoup de pathogènes, (certains virus, la plupart des oeufs de vers parasites, mais aussi des bactéries) sont plus résistants que les germes témoins de contamination fécale (les coliformes étant eux-mêmes plus fragiles que les streptocoques): la décroissance (naturelle ou provoquée) des pathogènes ne s'effectue pas au même rythme que celle des germes témoins. On ne doit donc pas juger de l'élimination des pathogènes à partir de données concernant les GTCF, qui constituent de médiocres indicateurs de traitement. A la limite, des pathogènes pourront toujours être mis en évidence malgré la disparition des GTCF.

Les pathogènes d'importance épidémiologique relèvent de cinq unités systématiques: bactéries (formes végétatives et sporulées), virus, champignons, protozoaires parasites (formes actives et kystes), vers parasites intestinaux (oeufs et adultes). Au cours d'épidémies, des bactéries pathogènes et des virus peuvent être décelés en nombre important, bien que très inférieur à celui des bactéries indicatrices. Dans les pays en développement, plusieurs milliers de salmonelles, de shigelles ou d'entérovirus par litre représentent des chiffres cohérents en situation "normale". On peut détecter plusieurs milliers de *V. cholerae* au cours d'une épidémie. On est susceptible de rencontrer des densités élevées de kystes d'amibes (quelques milliers par litre ?). Les oeufs de vers parasites sont plus rares, les genres communs étant *Ascaris* (jusqu'à quelques centaines d'oeufs/litre ?) et *Trichuris* (une centaine/litre ?); une dizaine d'oeufs d'*Ankylostoma* et quelques oeufs de *Schistosoma*/litre peuvent aussi être identifiés (Freachem *et al.*, 1983).

Les effectifs des pathogènes sont probablement moins nombreux au Nord de la Méditerranée du fait de conditions climatiques différentes et d'un meilleur état sanitaire. Ces formes sont cependant loin d'être absentes. En témoignent de nombreux résultats (par exemple, Leclerc *et al.*, 1971).

3. EVALUATION DU RISQUE

Il est bien connu qu'en majorité les germes ne s'installent pas durablement dans leur hôte humain lorsqu'ils sont ingérés en petit nombre; une faible contamination déclenche rarement les symptômes de la maladie correspondante. Beaucoup de sujets se sont ainsi trouvés en contact avec le germe sans même s'en apercevoir. D'autres n'ont été frappés que de manifestations peu caractéristiques, relativement bénignes. Les malades présentant l'ensemble des signes cliniques restent généralement l'exception.

Pour les germes entériques, une notion fondamentale est celle de dose minimale infectante (DMI): elle correspond à l'effectif susceptible de déclencher la maladie chez une proportion réduite de sujets exposés (on considère aussi la DI_{50}, correspondant à l'apparition des symptômes chez la moitié des sujets). Ce concept n'est certes pas à l'abri des reproches. Les données publiées concernent pour la plupart des échantillons réduits d'individus jeunes et en bonne santé. La susceptibilité des sujets à faible niveau immunitaire (enfants, vieillards, personnes naturellement ou secondairement immuno-déprimées, sujets malnutris, etc...) est certainement supérieure à celle des volontaires qui ont accepté de se prêter aux expériences. Ainsi, alors que les DI_{50} couramment avancées sont de l'ordre de $10^8 - 10^{11}$ pour le choléra, avec des signes cliniques allant de la simple diarrhée à des symptômes sévères, les enfants sous alimentés seraient vulnérables à des doses de l'ordre de 100 (Freachem et al, 1983). C'est pourquoi les chiffres disponibles doivent être considérés avec prudence, leur imprécision dépassant de beaucoup l'incertitude qui frappe habituellement les données statistiques.

Les déterminations microbiologiques se limitent trop souvent à des unités systématiques larges (p. ex. "salmonelles" ou même "enterovirus"). Une identification plus précise (au niveau de l'espèce ou même du sérotype) s'impose pour comparer les dénombrements aux doses infectantes.

Les shigelles figurent parmi les bactéries à faible DMI (de l'ordre de 100). Avec Salmonella typhi, on atteindrait $10^6 - 10^7$, et des niveaux encore supérieurs pour des salmonelles moins agressives. Habituellement, des effectifs aussi importants ne peuvent pas être absorbés directement, sauf dans l'hypothèse d'une contamination massive par des matières fécales non dilacérées. Un risque apparaît néanmoins dès que les conditions offertes permettent à des salmonelles de se multiplier dans une nourriture contaminée par des mouches, des mains sales ou par contact avec des produits souillés, et ensuite conservée à température ambiante pendant une durée suffisante. Il devient ainsi possible d'atteindre le niveau de la DMI à partir d'effectifs initiaux réduits.

Il n'en est pas de même avec les virus et les parasites humains d'excrétion fécale ou urinaire: à de très rares exceptions près, ils sont incapables de se multiplier hors de leur hôte spécifique. Pour les virus, la DMI serait de l'ordre de 100 par voie digestive, mais certains sujets seront probablement infectés par des doses plus faibles, quelques particules virales seulement. Les protozoaires parasites (giardia, entamoeba, etc.) donneraient des valeurs analogues. Pour les vers intestinaux, la DMI est très basse, un oeuf viable seulement.

Une première hiérarchisation du risque est obtenue en considérant, pour chaque germe, le rapport concentration/DMI, même si une forte incertitude en affecte les deux termes. Un autre facteur essentiel est la résistance du germe à un milieu hostile dès qu'il a quitté l'abri intestinal. La capacité de survie est variable: certains pathogènes présentent des formes de résistance (spores, kystes, oeufs) qui leur offrent la possibilité de persister longtemps dans l'environnement, exceptionnellement pendant plusieurs années (ascaris). Nombre d'autres pathogènes sont moins résistants (bactéries, virus). Une période d'attente peut se révéler nécessaire entre l'émission des fèces et l'invasion d'un nouvel hôte. Avec des modalités variées, c'est le cas pour certains vers parasites: passage obligé par un hôte intermédiaire (ténia - schistosome), maturation des oeufs (ascaris), phase de vie libre (ankylostome), etc.

Sur cette base, Freachem et ses collaborateurs (Freachem et al., 1983) ont proposé une nouvelle classification pragmatique des pathogènes. Elle ne fait plus guère appel à la systématique, mais opère un tri en fonction de facteurs physiologiques et d'environnement en faisant une large place à la dose infectante. Une conséquence de la classification de Freachem est de confirmer qu'une seule catégorie de mesures sanitaires est habituellement incapable d'assurer le contrôle d'une maladie. Une sécurité effective implique des actions combinées couvrant l'ensemble de la vie sociale, notamment l'hygiène individuelle et les équipements collectifs (WHO, 1981).

4. EFFETS DES TRAITEMENTS DES EAUX USEES SUR LES BACTERIES INDICATRICES ET LES PATHOGENES.

La plupart des pathogènes sont incapables de proliférer dans l'environnement, particulièrement dans une station d'épuration. C'est évident pour les virus, la plupart des vers parasites et nombre de protozoaires, qui exigent pour se développer leur hôte spécifique: au pire ils survivront, mais il est bien plus probable de constater leur décroissance. Pour les bactéries, on peut certes admettre une possibilité théorique de multiplication, mais elle n'a jamais pu être mise en évidence avec une méthodologie rigoureuse.

Dans les systèmes biologiques "intensifs" (lits bactériens, boues activées), l'effluent ne séjourne que peu de temps (une journée au maximum pour un effluent urbain). Les microorganismes s'y répartissent inégalement entre la phase liquide et les boues, qui concentrent la majorité des pathogènes. L'effluent traité n'entraîne que 10% environ de la charge bactérienne initiale, la boue 90%. On doit cependant considérer que le liquide reste très fortement contaminé.

Il y a quelques années, de nombreux hygiénistes voyaient dans la désinfection chimique (avant tout par le chlore et ses dérivés oxygénés) la garantie d'une sécurité absolue. On est maintenant plus réservé à l'égard de techniques peu actives à l'encontre de plusieurs classes de pathogènes (oeufs de vers intestinaux, nombre de virus, etc...) (Vial et al., 1980). Le contrôle des résultats est difficile pour les unités de traitement petites ou isolées. L'approvisionnement en réactif peut connaître des difficultés, les pannes sont fréquentes (Crook, 1985). Qui prendra alors la décision d'interrompre la distribution de l'eau aux agriculteurs? Globalement, la fiabilité de l'opération est donc sujette à caution, considération qui a conduit la plupart des pays d'Europe Occidentale à envisager avec réserve la décontamination chimique des effluents, malgré la popularité dont elle a naguère joui aux Etat-Unis.

Les traitements extensifs, au premier rang desquels le lagunage, imposent des temps de séjour prolongés qui garantissent un haut niveau d'épuration pour l'ensemble des pathogènes, particulièrement en climat chaud. Avec des températures de 25-30^{o}C, on atteint des abattements de 5 ou 6 U. log. (99,999 à 99,9999 %) à l'aval de systèmes à 4 bassins garantissant une rétention de 20 jours. Les lagunages ont également démontré leur efficacité pour retenir les oeufs d'helminthes.

Correctement conçus et exploités, ces équipements relarguent un effluent pratiquement dépourvu de pathogènes: ainsi, il n'a pu être mis en évidence de salmonelle (sur des échantillons de 1 à 10 litres) dans des effluents lagunés contenant moins de 1000 coliformes fécaux/100 ml (Alibou et Baleux, 1987). Ce niveau d'épuration est compatible avec la plupart des utilisations en irrigation. Tout en étant dépourvu des inconvénients de la désinfection chimique, le lagunage satisfait la plupart des exigences sanitaires. On prendra cependant garde au fait que la concentration résultant de l'évaporation peut suffire à altérer la qualité chimique des eaux.

Une autre technique intéressante, mais dépendante de la géologie locale, est l'infiltration contrôlée associée à une récupération ultérieure des eaux purifiées.

5. SURVIE DES PATHOGENES SUR LE SOL ET LES VEGETAUX

Ce difficile problème a fait récemment l'objet de plusieurs synthèses (Strauss, 1985, Shuval et al., 1986). Les données publiées sont nombreuses, mais la méthodologie suivie est trop souvent imprécise, et l'accent mis sur les valeurs exceptionnelles. Pour tous les germes, les expériences montrent deux phases de décroissance, rapide pendant les premières semaines, plus lente par la suite. Les facteurs positifs pour la survie des bactéries et des virus sont l'humidité (pluie ou irrigation), des sols riches en argile et matière organique, neutres ou légèrement alcalins, une température basse, une situation abritée. Il a été suggéré d'interrompre périodiquement l'irrigation jusqu'au dessèchement des couches superficielles du sol pour réduire le risque viral (Yeager and O'Brien, 1979). Freachem et ses collaborateurs (1983) admettent que la plupart des pathogènes (bactéries - virus - protozoaires) ne survivent guère au-delà de 2 semaines sur les plantes, 3 semaines sur le sol à 20 - 30°C. Les oeufs d'helminthes constituent la principale exception: ils peuvent conserver leur viabilité pendant des mois et même des années. Associé à une émission abondante dans les selles et à des doses infectantes minimes, ce fait est d'importance épidémiologique majeure.

6. LES RISQUES

6.1 Le risque pour les travailleurs agricoles

A la suite d'une synthèse de travaux récemment menés sur ce thème aux Etats-Unis, Jakubowski (1986) a conclu que le risque infectieux était apparemment très limité pour les travailleurs et leurs familles, ce que l'on peut en partie attribuer aux bonnes conditions d'hygiène des sujets. Les études spécifiques restant malgré tout peu nombreuses, il est intéressant de se reporter aux enquêtes portant sur d'autres travailleurs en contact professionnel avec des effluents, c'est-à-dire les égoutiers et les ouvriers de station d'épuration d'eaux usées. Pour les égoutiers, dont certains sont particulièrement exposés du fait de contacts prolongés en atmosphère confinée, on citera comme manifestations du risque infectieux en France un pourcentage anormalement élevé de porteurs de Giardia, Amoeba et Trichuris (Doby et al., 1979) et au Danemark une fréquence supérieure d'anticorps de l'hépatite A (81% chez les égoutiers, 48% chez des employés de bureau) (Skinhoj et al., 1981).

Un parallèle avec les employés de station de traitement d'eaux résiduaires est sans doute plus justifié. Récemment, des études épidémiologiques étendues et minutieuses ont confirmé un bas niveau du risque, qui ne se traduit que par des symptômes bénins et fugaces (maux de tête, nausées, diarrhées, frissons, etc.), décrits il y a plus de dix ans par les auteurs scandinaves comme "syndrome des eaux d'égout" (sewage workers' syndrome; (Rylander et al., 1976), et attribué par eux aux aérosols émis et aux endotoxines qu'ils véhiculent (Rylander, Lundholm, 1980), alors que d'autres préfèrent y voir des manifestations d'hypersensitivité ne faisant pas obligatoirement intervenir les endotoxines (Shuval et al., 1986, p. 93). L'absence d'une pathologie majeure est habituellement attribuée au renforcement de l'immunité chez des adultes en bonne santé pour des contacts répétés avec un matériel modérément infectieux.

6.2 Le risque pour les populations voisines d'épandages

Nous avons là affaire au contraire à une population permanente diversifiée, parmi laquelle la présence de sujets faiblement immunisés (enfants, vieillards, individus naturellement immunodéprimés ou auxquels un traitement immunodépresseur a été prescrit, etc.) est inéluctable. Il faut y ajouter les touristes: ils n'ont pu développer d'immunité spontanée à l'égard des agents pathogènes présents dans le milieu qui les accueille temporairement, et ils constituent de ce fait un groupe vulnérable. Un apaisement doit être trouvé dans les enquêtes menées aux abords des stations d'épuration, même s'il faut observer que le poids des facteurs socioéconomiques n'a pas favorisé la mise en évidence d'un éventuel impact sanitaire.

Il y a plus de dix ans, à la suite de la parution des résultats d'une enquête rétrospective en Israël (Katzenelson et al., 1976), on a pu croire - malgré la prudence dont faisaient néanmoins preuve les auteurs - que des arguments définitifs avaient été fournis en faveur d'une incidence mesurable de l'irrigation avec des eaux (partiellement) traitées sur le niveau de santé des populations voisines. Un réexamen des données a révélé des biais suffisants pour remettre en cause ces premières conclusions (Shuval et al., 1986). Une seconde enquête a concerné des sites où l'eau usée a été constamment utilisée pour l'irrigation pendant toute la période étudiée (à comparer avec des sites recourant à des eaux naturelles), ainsi que d'autres où les deux sortes d'eaux ont été successivement utilisées, situation qui a fourni les résultats les plus démonstratifs. Les périodes d'utilisation des eaux usées ont révélé chez les enfants de moins de 4 ans un accroissement significatif du risque pendant les mois d'arrosage, du moins en ce qui concerne les affections gastro-intestinales; la différence disparaît si on considère les moyennes annuelles.

Une troisième enquête a permis de mettre en évidence le rôle d'eaux usées provenant d'agglomérations proches dans la transmission du virus ECHO 4 vers une population agricole, à la suite d'une épidémie ayant frappé en premier les milieux urbains (Shuval et al., 1986). Transmis par les aérosols, infectieux par voie respiratoire, le virus a contaminé en premier les enfants (formation d'anticorps spécifiques, mais sans manifestations cliniques), qui l'ont ensuite communiqué aux adultes de leur famille. L'immunisation préalable des agriculteurs irrigants était vraisemblablement assez forte pour empêcher l'apparition de symptômes chez ces sujets exposés.

Par rapport aux enquêtes menées aux Etats-Unis, les travaux israëliens ont touché des effectifs importants, suffisants pour mettre en évidence de façon significative des effets mineurs. Ils indiquent la possibilité d'un risque, probablement d'origine virale, dont l'appréciation objective doit tenir compte de la bénignité des symptômes.

6.3 Le risque pour le consommateur humain

Son éventualité a été décelée dès 1898, quand Houston a mis en évidence le vibrion cholérique dans les effluents de Londres. Trois ans plus tard, Würz et Bourges observaient que dans les champs d'épandage, "il y a lieu de mettre en suspicion les végétaux qui doivent être contaminés par les eaux d'égout chargées de matières fécales contenant fréquemment des microbes pathogènes pour l'homme". En 1906, la réglementation française prohibait la culture de légumes destinés à être consommés crus, et étendait plus tard cette interdiction aux productions susceptibles d'être consommées sans cuisson préalable, malgré l'absence (à l'époque) de preuves épidémiologiques indiscutables.

Des certitudes ont été apportées en premier lieu à propos des vers parasites intestinaux. Que l'épandage puisse constituer une voie de transmission a été soupçonné à Darmstadt (RFA) en 1908-1909 et confirmé après la Seconde Guerre mondiale, lorsque la disette a conduit à alléger les prescriptions sanitaires concernant les légumes provenant des champs d'épandage (Sepp, 1971). D'autres éléments d'information proviennent de villes du Proche-Orient, Jérusalem (Shuval et al., 1985, 1986) et Alep (Bradley et Hadidy, 1981).

Des preuves indiscutables ont été fournies par Khalil (1931) qui a opportunément profité des conditions particulières d'une prison égyptienne pour démontrer que si l'incidence de la schistosomiase et de l'ankylostomiase décroissait avec la durée d'incarcération des prisonniers, en majorité d'origine rurale, rien d'analogue n'était observé pour Ascaris et Trichuris, très fréquents également chez les gardiens. Cette situation a été attribuée au fait que les uns et les autres partageaient la même nourriture, provenant en partie d'un champ d'épandage proche. Des oeufs de vers ayant été mis en évidence dans la terre adhérant aux racines, des manipulations sans précautions assuraient à la cuisine le transfert vers les plats cuits et entretenaient l'endémie. Khalil a pu également comparer l'incidence de l'ascaridiase à Port-Saïd, ville où les conditions sanitaires étaient acceptables, mais dotée de champs d'épandage, et celle de villages de Haute Egypte, où l'utilisation de l'engrais humain était ignorée. Sa conclusion d'ensemble a été que, à cette époque, les légumes contaminés constituaient la voie principale de transmission d'Ascaris dans le pays.

On dispose d'informations moins détaillées en ce qui concerne les maladies bactériennes et virales. Des eaux usées brutes ont été impliquées dans un épisode de choléra à Jérusalem (Shuval et al., 1985). De fortes présomptions existent pour les épidémies d'affections gastro-intestinales de Mexico (1959-60) et de typhoïde à Santiago du Chili. La possibilité d'une transmission de l'amibiase a été également fréquemment évoquée.

6.4 Le risque vétérinaire

La transmission de maladies au bétail par l'intermédiaire des eaux usées concerne essentiellement les salmonelloses, la cysticercose bovine (stade larvaire du ténia inerme, *T. saginata*), peut être aussi les sarcosporidioses.

Des cas de salmonelloses ont été attribués à l'épandage de boues, de matières de vidange et d'effluent brut, ainsi qu'à la contamination de cours d'eau (Jones, 1986). Il ne semble pas que des eaux traitées aient été mises en cause. Chez le bétail sain les données expérimentales font état de doses infectantes élevées par ingestion provoquée (10^8 - 10^{11}), mais on a supposé des doses inférieures à l'occasion d'incidents spontanés (Jones, 1986). La méfiance qui s'attache en Suisse, en Allemagne et aux Pays-Bas à l'épandage des boues sur prairies, en dépit d'une pratique a priori satisfaisante, contraste avec la position de la Grande-Bretagne et de la France, qui ne rapportent que des incidents dûs à des erreurs manifestes.

La cysticercose bovine est la maladie la plus répandue, avec des conséquences économiques importantes pour les éleveurs. L'homme seul héberge le ver adulte, qui émet des oeufs très nombreux. Ingérés par les bovins, ils donnent des formes larvaires (cysticerques) et l'homme se contamine en mangeant de la viande insuffisamment cuite. Des exemples concluants à partir d'eaux et de boues résiduaires ont été rapportés en Ecosse (Nanssen, 1986) et en Australie (Rickard et Adolph, 1977). En fait, bien d'autres voies sont offertes au parasite. Les oeufs de ténia sont très résistants dans la nature, mais on n'a retrouvé que des formes rétractées dans les ensilages.

Du fait de la résistance des spores de sarcosporidies, il n'est pas étonnant de constater l'infection généralisée de veaux sentinelles sur des herbages recevant des boues fraîches (Burgers et Wilkens, 1986). La contribution d'effluents bruts et traités reste à définir.

6.5 Le risque phytopathologique

On a évoqué une possibilité de transmission de nématodes parasites de la pomme de terre (Globodera rostochiensis notamment), mais aucune preuve n'a été apportée à partir d'eaux urbaines.

Dans l'ensemble, la pathologie attestée liée à la réutilisation agricole d'eaux usées résulte à l'évidence de l'épandage sans précautions d'effluents bruts ou très sommairement traités sur des récoltes consommées à l'état cru. Les mesures sanitaires préventives relèvent de plusieurs actions à mener simultanément:

- traitement des eaux usées afin de satisfaire à des exigences microbiologiques correspondant à un niveau accepté de risque sanitaire
- sélection de cultures convenables
- utilisation de modes d'irrigation appropriés
- hygiène professionnelle des agriculteurs.

7. VERS DE NOUVELLES REGLES

Jusqu'à ces dernières années, la tendance a été d'identifier le risque à la présence possible de pathogènes dans l'effluent, quels qu'en soient les effectifs. Cette confusion évidente entre risque potentiel et risque avéré s'est trouvée à l'origine d'exigences renforcées, culminant avec la réglementation adoptée en 1968 en Californie (Ongerth et Joplin, 1977; Richardson, 1985), qui aboutit à exiger pour l'irrigation de surface des végétaux comestibles (sans contact entre l'eau et la partie consommée) une qualité bactériologique analogue ou supérieure à celle que tolèrent occasionnellement les normes OMS pour l'eau potable dans les réseaux de distribution (3/100 ml) ou les distributions sans réseau (10/100 ml)! Pratiquement, de tels critères impliquent un traitement biologique complet suivi d'une filtration sur sable et d'une chloration à forte dose. Le coût de l'opération interdit la réutilisation agricole dans la plupart des pays tentés d'adopter ces normes. Quelques réalisations ont cependant vu le jour en dehors des Etats-Unis, notamment en Arabie Saoudite (Al-Dhuwaila et al., 1987). Il faut ajouter qu'une série d'opérations aussi sophistiquées n'est pas à l'abri de pannes, ce qui compromet en fait la sécurité apparente fournie par le dispositif.

La plupart des pays ne se sont pas engagés dans cette voie. La règle presque générale est l'absence d'un ensemble cohérent de prescriptions concernant la réutilisation agricole des eaux et des boues résiduaires. Il existe certes des dispositions légales, mais elles sont limitées à des indications pratiques (cultures exclues, intervalle entre l'épandage et la récolte, etc...), dont l'initiative est le plus souvent revenue aux autorités sanitaires. L'absence de "normes" chiffrées de qualité microbiologique est la règle quasi générale.

Ces dispositions peuvent comporter de nombreuses lacunes, qu'il s'agisse de textes anciens, promulgués à la fin du XIXe siècle ou au début du XXe, lors de la phase principale d'expansion des champs d'épandage, non réactualisés par la suite, ou de prescriptions plus récentes, destinées à porter remède à des situations considérées comme inacceptables. En outre, les règles ne concernent habituellement que la réutilisation directe d'effluents bruts ou traités. Elles ignorent le cas fréquent du puisage dans le cours d'eau à l'aval d'un rejet d'effluent, à une distance insuffisante pour assurer une auto-évaporation.

Il faut certes regretter cette situation, parfois proche du vide juridique, mais force est de constater que dans les pays du pourtour méditerranéen, elle n'a pas abouti à des situations dramatiques tant que les dispositions légales - même réduites à un minimum - ont été observées. Bien entendu, cela ne signifie pas que la pratique soit pour autant sans danger, et qu'elle ne mérite pas d'être soumise à un ensemole de règles cohérentes.

Le récent "Rapport d'Engelberg" (IRCWD, 1985) offre pour cela une approche qui s'efforce à l'objectivité en faisant un large appel à "l'évidence épidémiologique". Il aboutit à des conclusions qu'il sera impossible d'ignorer dans l'avenir, même si certaines des dispositions proposées en seront discutées ou feront l'objet d'adaptations pour s'appliquer à des conditions (naturelles, comportementales et socio-économiques) différant de celles des régions explicitement visées par ce document.

La proposition la plus spectaculaire est sans doute celle d'une limite de 1000 coliformes fécaux/100 ml (moyenne géométrique) en vue d'une utilisation agricole sans restrictions pour l'arrosage des denrées comestibles, des fourrages et des espaces verts. Ceci revient à appliquer un facteur d'environ 50 aux recommandations antérieures de l'OMS (WHO, 1973), dont il faut rappeler qu'elles n'avaient été avancées que faute d'enquêtes épidémiologiques (sur l'urgence desquelles insistaient les experts comme, plus tard, les participants à la réunion d'Alger en 1980) (WHO 1981). Il était reconnu par les auteurs du rapport qu'elles comportaient vraisemblablement un très important facteur de sécurité. A titre de comparaison, il est intéressant de noter que le nouveau chiffre est du même ordre de grandeur que les tolérances sur les eaux de baignade en Europe.

L'intérêt de ce critère est de pouvoir être atteint par des techniques simples d'épuration. Pour les pays chauds, l'exemple fourni est une installation de lagunage à 4 bassins avec un temps de séjour total de 20 jours. La limite bactériologique est complétée par un impératif parasitologique (moins de 1 oeuf viable de nématode par litre). Associé à une série de prescriptions sur le traitement à imposer (1 jour en bassin anaérobie et 5 jours en bassin facultatif, ou 2 fois 5 jours en bassin facultatif ou un procédé équivalent), celui-ci est le seul à subsister lorsque la pratique de l'irrigation est soumise à des obligations restrictives (choix des cultures, mode d'application de l'eau, distance des lieux habités, etc...).

Le choix du mode d'irrigation peut contribuer à réduire ou à localiser la contamination microbiologique du sol et du végétal: l'irrigation à la raie et plus encore le goutte à goutte limitent les occasions de contact entre le végétal et l'eau (Cadillon et Tremea, 1983). Les délais entre l'application de l'eau, la récolte et la consommation sont également des facteurs à faire intervenir (agrumes, fourrages).

Même à proximité, l'aérocontamination bactérienne résultant de l'épandage d'eaux conformes au plus rigoureux des "critères d'Engelberg" reste extrêmement limitée (Boutin et al., 1984; CEMAGREF, données non publiées).

Nul doute que les propositions du Rapport d'Engelberg méritent d'être discutées et adaptées pour répondre à des situations plus diversifiées que celles auxquelles se réfère ce bref document. L'OMS doit entreprendre incessamment un travail d'approfondissement aboutissant à des nouvelles recommandations. A partir de ce cadre rénové, les pays pourront créer ou mettre à jour leur réglementation sur la réutilisation agricole des eaux résiduaires urbaines.

8. CONTROLE SUR LE TERRAIN

Le point difficile sera le contrôle des mesures adoptées. Il nous semble personnellement peu souhaitable - parce que peu réaliste - de le baser sur la qualité bactériologique du produit. Il est clair maintenant que des traitements ne faisant appel qu'à des technologies simples, pour peu qu'ils aient été correctement conçus, bien réalisés et exploités de façon satisfaisante, sont capables de produire régulièrement des eaux de qualité sanitaire convenable pour l'irrigation, n'exigeant qu'un contrôle limité. L'inertie propre de la plupart de ces systèmes tolère de brèves surcharges, mais il faut insister sur le fait qu'une surcharge progressive constitue le risque principal: dans un système de bassins de stabilisation par exemple, un accroissement permanent du débit aura inévitablement pour résultat une détérioration de la qualité de l'effluent. La qualité finale de l'eau dépend de la fiabilité des équipements, et c'est la responsabilité spécifique des autorités d'y veiller. Les autres paramètres aisément contrôlables sur le terrain sont les cultures pratiquées et les méthodes d'irrigation: on peut s'en assurer directement, et il est difficile pour les agriculteurs d'échapper aux prescriptions qui les concernent.

Il est difficile d'en venir à plus de rigueur à partir d'une situation initiale de laxisme.

Des règles claires et précises sur les cultures autorisées et interdites en fonction de la qualité sanitaire de l'eau distribuée doivent donc être établies dès le départ. Les vérifications correspondantes exigent peu de technicité. Les contrôles plus complexes, comprenant des analyses de laboratoire, devraient être réservés à la recherche ou aux cas litigieux.

L'effort d'éducation portera aussi sur les pratiques d'hygiène corporelle et les mesures préventives (vaccination) auxquelles devront se plier les agriculteurs et leurs familles.

9. CONCLUSION

La considération objective des risques sanitaires résultant de l'irrigation avec des eaux usées a récemment permis de proposer des normes microbiologiques allégées pour la réutilisation d'effluents traités. Ces nouvelles tolérances peuvent être satisfaites par des filières simples de traitement.

Désormais, les eaux usées constituent de nouveau un potentiel pour l'irrigation des cultures vivrières et industrielles. A ce titre, partout où la disponibilité de l'eau est insuffisante, elles doivent devenir partie intégrante de la ressource en eau pour une gestion globale de celle-ci, et être efficacement protégées contre une altération irrémédiable de leur qualité. Les pays doivent tenir compte de cette situation et se doter de l'outil réglementaire efficace qui leur permettra de maîtriser le développement d'une pratique qui doit être simultanément encouragée et contrôlée.

REFERENCES BIBLIOGRAPHIQUES

Al-Dhuwaila Kh. et al (1987), Agricultural irrigation in Riyadh by untreated sewage water. Int. Comm. Irrig. Drain., 6th Afro-Asian Conf., Cairo, Egypt, 9-16 March 1987, 12 p.

Alibou J. et B. Baleux (1987), Etude de l'évolution des abondances et de la survie des Salmonellas et comparativement des indicateurs de pollution fécale (coliformes fécaux) dans différents ouvrages épurateurs et milieux aquatiques (Rapport final). Montpellier, Lab. d'Hydrogiologie/UA-CNRS69, Un. Sci. Technq. Languedoc, 70 p.

Boutin P. et al (1979), Charge microbienne des effluents urbains bruts et traités par voie biologique. Techn. Sci. Municip., 74, 2: 63-78.

Boutin P. et al (1984), Granulométrie des aérosols émis par des dispositifs d'aspersion d'eaux résiduaires traitées: interprétation sanitaire. Techn. Sci. Municip., 79, 3: 143-153.

Bradley R.M. and S. Hadidy (1981), Parasitic infestation and the use of untreated sewage for irrigation of vegetables with particular reference to Aleppo, Syria. Publ. Health Engnr, 9, 3: 154-157

Burger H.J. and S. Wilkens (1986), The infection risk of sarcosporidia in irrigating sewage (sludge). In "Epidemiological studies of risks associated with the agricultural use of sewage sludges: knowledge and needs" (Block J.C., Havelaar A.H., L'Hermite P., eds), London, Elsevier, 94-97.

Cadillon M. et L. Tremea (1983), Suivi microbiologique des sols irrigués avec des eaux issues d'un lagunage tertiaire sur l'île de Porquerolles. (Rapport d'etudes). Le Tholonet, Soc. Canal Prov. et Aménag. Rég. Provençale.

Crook J. (1985), Health and regulatory considerations. In "Irrigation with reclaimed municipal wastewater: a guidance manual" (Pettygrove, G., Asano T., eds), Chelsea (Mi), Lewis Publ. Inc., 10.1.-10.41.

Doby J.M. et al (1979), Résultats d'examens coprologiques systématiques effectués chez les égoutiers de la Ville de Rennes; fréquence de l'amibiase liée à l'exercice de cette profession. Méd. Mal. Inf., 1979, 9: 707-711.

Freachem R.G. et al (1983), Sanitation and disease: health aspects of excreta and waste management. J. Wiley & Sons, Chichester & New York.

I.R.C.W.D. (1985), Health aspects of wastewater and excreta use in agriculture and aquaculture: the Engelberg Report. IRCWD News, 23: 11-18.

Jakubowski W. (1986), U.S. EPA-sponsored epidemiological studies of health effects associated with the treatment and disposal of wastewater and sewage sludges. In "Epidemiological studies of risks aassociated with the agricultural use of sewage sludges: knowledge and needs" (Block J.C., Havelaar A.H., L'Hermite P., eds), London, Elsevier, 140-153.

Jones P.W. (1986), Sewage sludge as a vector of salmonellosis. In "Epidemiological studies of risks associated with the agricultural use of sewage sludges: knowledge and needs (Block J.C., Havelaar A.H., L'Hermite P., eds) London, Elsevier, 21-33.

Katzenelson E. et al (1976), Risk of communicable disease infection associated with wastewater irrigation in agricultural settlements. Science, 194: 944-946.

Khalil M. (1931), The pail closet as an efficient means of controlling human helminth infections as observed in Tura prison, Egypt, with a discussion on sources of Ascaris infection. Ann. Trop. Med. Parasit., 25: 35-62.

Leclerc H. et al (1971), Microbiological aspects of sewage treatment. In "Proc. 5th Int. Conf. Wat. Poll. Res., I.A.W.P.R., 1970", Adv. Wat. Poll. Res., Vol 1, I-23/1-8, Pergamon Press, London.

Prost A. (1987), Les dangers de maladies infectieuses liés à la réutilisation des eaux usées. Bull Qual. Eaux, 12: 78-83.

Richardson C.S. (1985), Legal aspects of irrigation with reclaimed wastewater in California. In "Irrigation with reclaimed municipal wastewater: a guidance manual" (Pettygrove G.S., Asano T., eds), (Chelsea (Mi), Lewis Publ. Inc., 11.1 - 11.23

Sepp E. (1971), The use of sewage for irrigation : a literature review, State of California. Bur. San. Engng (revised 2nd ed.).

Shuval H.I. et al (1985), Epidemiological evidence for helminth and cholera transmission by vegetables irrigated by wastewater. Wat. Sci. Techn., 17: 433-442.

Shuval H.I. et al (1986), Wastewater irrigation in developping countries: health effects and technical solutions. World Bank Techn. Pap. No. 51, New York, The World Bank, 324 p.

Skinhoj P. et al (1981), Infectious liver diseases in 3 groups of Copenhagen workers: correlation of Hepatitis A infection to sewage exposure. Arch. Environm. Health, 36, 3: 139-143.

Strauss M. (1985), Health aspects of nightsoil and sludge use in agriculture - Part II: pathogen survival. Dubendorf, IRCWD, 87 p.

Valiron F. (1983), La réutilisation des eaux usées - Orléans. BRGM/Paris, Lavoisier, 207 p.

Vial J. et al, (1980), Désinfection des eaux usées par le chlore: difficultés d'appréciation de l'efficacité de la décontamination microbiologique à travers les indicateurs habituels. Techn. Eau Assainiss. No. 399: 11-21.

W.H.O. (1973), Reuse of effluents: Methods of wastewater treatment and health safeguards. Technical report No. 517, Geneva, W.H.O.

W.H.O. (1981), The risk to health of microbes in sewage sludge applied to land. Copenhagen, WHO, EURO 54.

Yeager J.C. and R.T. O'Brien (1979), Enterovirus inactivation in soil. Appl. Environm. Microbiol., 38:694-701.

EFFECTS OF TREATED URBAN EFFLUENT ON SOIL SALINITY, SODICITY AND FERTILITY

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1. ABSTRACT

In arid and semi-arid regions, scarcity of water is a real constraint for irrigated agriculture and the use of treated effluent for irrigation is an efficient means of recycling scarce water resources. It is anticipated that about 6% of the total land presently under irrigation in Cyprus could be irrigated with treated effluent in the near future. Because of this, a multifaceted research has been undertaken since 1984 with the long-term objective of finding ways so that treated effluent can be used for irrigation safely in respect of public health and the environment and without undesirable effects on soils, crops, or animals fed with fodder crops irrigated with treated effluent. The results indicate the superiority of the treated effluent over fresh borehole water in respect of nutrient supply and yield of cotton, sunflower and sudax. Also, no serious problems associated with the presence in the treated effluent of soluble salts, NO_3-N, and of toxic elements on soil and crops were found. A balanced approach combining treatment methods capable of providing acceptable and reliable purification of wastewater, the use of advanced systems of irrigation (drip and minisprinklers), with restriction of crops to those presenting a low level of public health risk, is suggested as a promising approach in the achievement of the maximum social, economic and environmental benefits from treated effluent re-use.

2. INTRODUCTION

The re-use of reclaimed municipal wastewater for irrigation has gained attention as a result of two main driving forces - water supply shortage and wastewater disposal regulations aimed at protecting the environment and public health. In arid and semi-arid regions, water has always been regarded as a valuable commodity. The problem is not a new one, but during the last few decades, most countries in these regions have witnessed a rapid development of their urban and rural water domestic supplies to the extent that today, conventional water resources are seriously depleted. Furthermore, the rising population and continuing urbanization have generated increasing amounts of municipal wastewater and its disposal has become a serious problem. The need, therefore, to conserve water and protect the environment and the public health necessitates the development of more efficient irrigation systems and, furthermore, the use and re-use of marginal quality water. Reclamation and re-use of municipal wastes for irrigation is an easy, safe and useful disposal and an attractive, innovative alternative to meet the increasing demands for water.

Moreover, the arid and semi-arid zones have few streams with sufficient capacity to serve as natural repositories for even well-treated wastewater effluent. Thus, wastewater re-use in agriculture has provided almost the only feasible, relatively low-cost alternative for disposing of wastewater from municipal areas in a sanitary way. It also minimizes pollution of the water-ways in the region. All these factors, coupled with the rapid urban growth and the need to increase agricultural production, have helped to revive the interest of re-using wastewater for irrigation.

In addition to being a source of irrigation water, treated effluent used in this way is also a source of plant nutrients (Bielorai et al., 1984; Feigin et al., 1984; Day et al., 1979a; 1979b; Overman, 1975; Overman and Nguy, 1975; Papadopoulos and Stylianou, 1987; 1988a). However, irrigation with treated effluent may affect physical, chemical and biological properties of the soil, particularly the soil salinity and sodicity (Westcot and Ayers, 1984; Papadopoulos and Stylianou, 1988b). Control of the soluble salts in the soil solution of the rhizosphere and improved nutrient uptake efficiency by crop could help to reduce such hazards (Papadopoulos et al., 1987). Trickle irrigation is well suited for this purpose (Bar-Yosef, 1977; Feigin et al., 1984; Papadopoulos and Stylianou, 1987), due to its positive effect on water and nutrient uptake (Papadopoulos et al., 1987) and to the unique soil salinity profile developed by trickle irrigation (Papadopoulos, 1988). Moreover, this irrigation method has the potential to maintain or increase yield and water-use efficiency (Bernstein and François, 1973; Bresler, 1977; Nightingale et al., 1986). In addition, with trickle irrigation no aerosols, which are considered a health risk since they are likely to transport pathogens, viruses and parasites, are produced. Shuval (1975) reported several types of bacteria recovered up to 350 m downwind of fields where disinfected sewage effluent was applied by sprinkler irrigation.

In this respect, a long-term, multifaceted research programme has been initiated in Cyprus since 1984 with secondary treated effluent. The main objective of this research is to evaluate the agricultural use of treated municipal effluent for irrigation and fertilization and furthermore, to provide information concerning soil, underground water and plant contamination with contaminants present in the effluent such as pathogens, parasites, viruses, NO_3-N, soluble salts, and heavy metals. The objective of this paper is to discuss some effects of secondary treated urban effluent on soil chemical composition (salinity, sodicity) and soil fertility.

3. PROBLEMS ASSOCIATED WITH THE RE-USE OF TREATED EFFLUENT FOR IRRIGATION

3.1

Water having been used once for some purpose, can be re-used in agriculture. Such "used" water sources, termed tertiary sources (Dastane, 1987), include, for example, sewage effluent, industrial wastewaters and farm drainage waters. Apart from their salt content, these tertiary sources may pose such additional problems as undesirable trace elements and pathogens which can have a deleterious effect upon public health and hygiene.

In crop irrigation with treated municipal effluent, a critical issue is the impact of its quality on the soil and/or crop to which the effluent is applied. A fundamental question, however, is what constitutes marginal quality water, since water quality means different things to different people. Quality usually denotes "suitability" for use and is difficult to evaluate except in terms related to its specific use. The importance and the magnitude of the problem of marginal quality water and its use, therefore, can only be assessed properly if it is viewed as an integral part of an overall policy framework that includes water, land use and agricultural production. For irrigation, water suitability is related to its effect on soils and crops, and on the management that may be necessary to control or compensate for water quality related problems (Ayers, 1977). From the viewpoint of plant production, perhaps a more workable and appropriate definition of marginal quality water would be that for which there is moderate to severe restriction for irrigation use.

3.2 Salinity

Historically, the quality of irrigation water has been determined by the quantity and kind of salt present. As salinity in the reclaimed wastewater increases above a certain level, the probability of soil, water and cropping problems also increases. Potential problems are related to the total salt content, to the type of salt, or to excessive concentrations of one or more elements. These problems are not specific to treated effluent, but they also apply to freshwater irrigation and are of concern only if they restrict the use of the water or require special management to maintain acceptable yields. Guidelines of water quality for irrigation (University of California, Committee of Consultants, 1974; Westcot and Ayers, 1984; Ayers and Westcot, 1985) could be applied for assessing the chemical quality of the treated effluent. However, with the new systems of irrigation (particularly with trickle), the salinity critical levels as stated in these publications are only rough guidelines and higher yields can be achieved with those levels when modern irrigation systems are used (Papadopoulos, 1985). The salinity of the municipal wastewater depends to a great extent on the salinity of the municipal water supply, nature of the chemicals added during treatment, and the degree of treatment the wastewater has received. Generally, if the water supply used by the municipality is of acceptable salinity for irrigation, the treated municipal wastewater will also be of acceptable quality, although somewhat degraded.

In Cyprus, the EC_w of the domestic water supply, although variable at different places, is of the value of about 1.0-1.5 dS/m. With such an inflow water, the treated effluent in general has an average EC of about 2.5 dS/m and an SAR ranging between 10 and 15. Such a salinity of effluent used for irrigation would be expected to create greater management problems, particularly on heavy soils irrigated with effluent. However, experimental data and experience gained so far in Cyprus suggest that problems associated with salinity could be alleviated or even overcome with the use of modern irrigation and fertilization systems, with water management, and with an appropriate choice of crops semi-tolerant or tolerant to salinity. The adverse effect of salinity and specific ion concentration is usually associated with an increase in soil salinity and thereby with undesirable injurious effects on both crops and soil and considerable yield losses (Papadopoulos and Stylianou, 1987). It is vital, therefore, to prevent harmful concentration of salts in the root zone of the irrigated crops or at least to maintain a portion of the root zone below salinity levels that a given crop can tolerate (Papadopoulos and Rendig, 1983; Papadopoulos et al., 1985). To overcome this problem, an additional increment of water, above that required to meet evapotranspiration needs, must be passed through the root zone when irrigating to remove excess soluble salts and keep the EC of soil water at a level comparable to that of the irrigation water.

The rate of salt accumulation in the soil depends upon the quantity of salt applied with the irrigation water (salt in) and the rate at which salt is removed by leaching and crop uptake (salts out). Over an extended period, salts out must equal salts in. Fortunately, most salts in the municipal effluent are soluble and easily transported by the water added to soil. Leaching assures that salt removal takes place although it poses potential underground water contamination.

In Cyprus, the problem of secondary salinity is not new and extensive experimental work has been undertaken since 1964 (Stylianou and Orphanos, 1970) particularly with the modern irrigation systems. More recently, due to potential re-use of treated effluent for irrigation, some experimental work in this respect has been undertaken (Papadopoulos and Stylianou, 1987). However, the problem is manifold and often has regional peculiarities that repeatedly create the need for special research, since effluent with similar EC are very different in composition, affecting thereafter in a different manner crops and soil.

The guidelines, proposed in recent years for assessing permissible levels of salinity in irrigation water for various crops (Bernstein, 1967; Rhoades and Bernstein, 1971; University of California, Committee of Consultants, 1974; Maas and Hoffman, 1977; Ayers and Westcot, 1985), are those widely accepted and used in Cyprus for assessing the quality of effluents for irrigation. These guidelines are based on the assumption that plants respond primarily to average root zone salinity. Although this might be the case for crops irrigated infrequently, as is normal when using surface methods and conventional irrigation management for crops irrigated frequently with drip or minisprinkler systems, crop yield is better correlated to the EC of the irrigation water (Papadopoulos and Rendig, 1983) or with the water uptake weighed root zone salinity.

In Cyprus, modern irrigation systems (drip and minisprinkler) have become the predominant irrigation technique for all crops and with such an advance, reassessing criteria of water quality, as far as the salinity level is concerned, and its effects on crops, is needed (Papadopoulos et al., 1987). With modern irrigation systems, frequent localized irrigation creates such a salinity profile particularly where with drip irrigation a certain, although limited soil volume below the emitter depending on the amount of irrigation water, is at a high total water potential and salinity level comparable to salinity level of the irrigation water (Papadopoulos, 1985; Bielorai, 1985; Fereres et al., 1985). As a result, the salinity of the marginal quality water is more easily managed and the salinity critical levels for various crops as stated in the literature are only rough guidelines. Irrigating with modern irrigation systems, crops are grown successfully and higher yield is obtained with more saline waters than otherwise possible (Goldberg et al., 1971; Papadopoulos, 1985).

In addition, these modern irrigation systems, which are highly efficient for water application, are also ideally suited for combined irrigation and fertilization (fertigation) for controlling the timing, placement and supply of water-soluble fertilizers (Goldberg et al., 1976; Papadopoulos, 1985; 1986b). In this way with the irrigation water acting as a vehicle for the nutrients, the fertilizer is conveyed directly to the root zone through frequent applications of soluble fertilizers in small concentrations via the irrigation stream (Goldberg et al., 1971; Bar-Yosef and Sheikholslami, 1976; Phene and Beale, 1976; Phene and Sanders, 1976; Papadopoulos, 1985). Fertigation reduces nutrient losses but also fluctuations of soil solution EC and fertilizer concentration, thereby improving soil solution conditions, particularly for salt-sensitive crops (Papadopoulos, 1986b). Fertigation has been shown to have special advantages with saline irrigation waters and treated effluent, where besides the accurate control of water and nutrients, the soil solution salinity is critical (Goldberg et al., 1971; Papadopoulos, 1984; Papadopoulos and Stylianou, 1987). Because of this, when modern systems are used for irrigation, fertigation, in addition to leaching, is considered and is widely practised in Cyprus as providing the best means of overcoming adverse effects on crops due to fluctuations of soil solution salinity. With such an approach, reduction in yield due to salinity is alleviated and in most of the cases is even offset by the increase in yield due to better waterfertilizer management than with conventional methods of irrigation and fertilization.

Experimental results along this line and experience gained so far in Cyprus with the re-use of marginal quality water in general and of municipal effluent in particular, suggest that with proper irrigation and fertilization management, problems associated with salinity up to a certain level could be alleviated or even overcome with crops semi-tolerant or tolerant to salinity and high yield can be obtained.

Leaching by winter rainfall has been also shown to be extremely valuable in controlling salinity due to highly soluble salts, but only partially effective in controlling salinity due to sparingly soluble salts.

3.3 Specific Ion Toxicity

Plants may accumulate certain constituents from marginal quality water which may create toxicity within the plant. The ions of most concern in wastewater are sodium, chloride and boron. In contrast to heavy metals and other hazardous chemicals, which have potential health risks to humans and animals, these ions at concentrations normally found in effluents, are of concern primarily for plant production. The most prevalent toxicity from the use of reclaimed municipal wastewater is caused by boron originating from discharges of household detergents or from industrial plants. It is one of the essential elements to plants; however, at concentrations exceeding 1 mg B/L may be toxic to sensitive crops. Although boron compounds may be highly soluble, they are partly held by soil particles. With sensitive crops B-toxicity is difficult to correct without changing the crop or the water supply, although leaching may also help to maintain B concentration in soil at levels comparable to those of the water used for irrigation. In Cyprus the high B concentrations in urban effluents have been reduced considerably (to about 0.5 mg B/L) by prohibiting the local production or import of detergents based on B. Chloride and Na although less toxic than B, may also be a problem with wastewater re-use. In arid and semi-arid regions this might be a serious problem due to the relatively high Na and Cl content of the municipal water supply. Experimental results along this line and experience gained so far in Cyprus, suggest that with proper irrigation management, toxicity effects can be reduced significantly.

3.4 Soil Sodicity

Besides the direct effect on the plant, Na in irrigation water affects soil structure reducing the rate at which water can move into the soil as well as soil aeration capacity. The increase in soil sodicity that occurs with most wastewaters due to high Na concentration even though leaching is allowed, reduces soil permeability for water, particularly at the soil surface, since soil clays tend to disperse and swell from the increased level of exchangeable Na (Papadopoulos and Stylianou, 1988a). The permeability problem usually occurs in the surface layer of the soil and is mainly related to a relatively high Na or very low Ca content in the soil or the applied water. At a given sodium adsorption ration (SAR_{adj}) the infiltration rate increases or decreases with the salinity level. Therefore, SARadj and EC_w of applied water must be used in combination to evaluate the potential soil permeability problem. The permeability hazard although counteracted in some cases by the presence of sufficient electrolyte concentration in the irrigation water, necessitated the wide use of low capacity minisprinklers and drippers of low discharge rate. With such an approach, surface soil crusting is reduced and duration of irrigation is extended, allowing, therefore, sufficient time for water penetration into the soil.

3.5 Biological Standards

The most critical element in wastewater re-use is that of health (WHO, 1973; Feachem et al., 1982; Shuval et al., 1984). The effluent must be treated and then used in such a way that its contents will not be a danger to human beings or to the environment.

Although the limited experience of the use of treated effluent for irrigation over the years has not created serious problems, yet there is a strong awareness from the public, the health authorities, and the environmentalists of the direct and indirect hazards involved. However, experience indicates that such fears are exaggerated since the mere presence of an infectious agent in an effluent is not sufficient cause to declare the wastewaters unsafe (Pescod and Alka, 1984). Hutzler and Boyle (1980), have indicated that "even the most dreaded hazard poses no risk if people are not exposed to it". It is important, therefore, in assessing the health hazards of wastewater re-use to establish the relative importance of various routes of transmission, from direct contact with the wastewater through food or air, to indirect contact. Properly designed, managed and maintained sewage treatment plants, together with continuous monitoring of the effluent quality, and the strict compliance with a sound code of practice are the best means for safe use of effluent for crop irrigation.

In Cyprus, a Technical Working Committee was set up to study the issue of sewage effluent in all its aspects and propose appropriate standards. So far, the standards accepted in Cyprus are shown in Table I.

Table I

Provisional Standards for Effluent Use for Crop Irrigation in Cyprus

Use	BOD_5 80%	BOD_5 max	SS 80%	SS max	Fecal 80%	Coli. 100%
Amenity areas						
unlimited access	10	15	10	15	50	100
limited access	20	30	30	45	200	300
Fruit trees	10	15	10	15	50	100
Fodder crops	20	30	30	45	1000	5000
Industr. crops	50	70	--	--	1000	10000

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5. REFERENCES

1. AYERS, R.S., (1977), Quality water for irrigation. J. Irrig. Drain. Division. IR2· 135-154.

2. AYERS, R.S. and WESTCOT, D.W., (1985), Water quality for Agriculture. FAO Irrigation and Drainage Paper 29. FAO, Rome.

3. BAR-YOSEF, B., (1977), Trickle irrigation and fertilization of tomatoes in sand dunes· water N and P distribution in soil and uptake by plants. Agron. J. 69· 486-491.

4. BAR-YOSEF, B., and SHEIKHOLSLAMI, M.R., (1976), Distribution of water and ions in soils irrigated and fertilized from a trickle source. Soil Sci. Soc. Am. J. 40, 575-582.

5. BERNSTEIN, L., (1967), Quantitative assessment of irrigation water quality. Amer. Soc. Testing and Materials Spe. Tech. Publ. 416, p. 51- 65.

6. BERNSTEIN, L. and FRANÇOIS, L.E., (1973), Comparisons of drip, furrow and sprinkle irrigation. Soil Sci. 115· 73-86.

7. BIELORAI, H., VAISMAN, I., and FEIGIN, A. (1984), Drip irrigation of cotton with treated municipal effluents· I. Yield response. J. Environ. Qual. 13· 231-234.

8. BIELORAI, H. (1985), Moisture, salinity and root distribution of drip irrigated grapefruit. In Drip/trickle irrigation in action. Ed. Am. Soc. Agr. Eng. Vol. II, P. 562-567.

9. BRESLER, E., (1977), Trickle-drip irrigation· principles and application to soil water management. Adv. Agron. 29· 343-390.

10. DASTANE, N.G., (1987), Use of brackish water in horticulture Water Qual. Bul. 2· 64-72.

11. DAY, A.D., MCFADYEN, J.A., TUCKER, T.C. and CLUFF, C.B. (1979a), Commercial production of wheat irrigated with municipal wastewater and pump water. J. Environ. Qual. 8· 403-406.

12. DAY, A.D., MCFADYEN, J.A., TUCKER, T.C. and CLUFF, C.B., (1979b), Wastewater helps the barley grow. Water Wastes Eng. 8· 26-28.

13. FEACHEM, R., GARELICK and SLADE, (1982), Public Health Practice· Enteroviruses in the environment. World Health Forum 3(2)· 170-180.

14. FEIGIN, A., VAISMAN, I. and BIELORAI, H. (1984), Drip irrigation of cotton with treated municipal effluents· II. Nutrient availability in soil. J. Environ. Qual. 13· 234-238.

15. FERERES, E., CUEVAS, R. and ORGAZ, F. (1985), Drip irrigation of cotton in southern Spain. In Drip/trickle irrigation in action. Ed. Am. Soc. Agr. Eng. Vol. I, p. 187-192.

16. GOLDBERG, D., (1976), New techniques in the re-use of effluent. A report prepared for the World Bank, Washington, D.C.

17. GOLDBERG, D., GORNAT, B. and BAR-YOSEF, B. (1971), Distribution of roots, water and minerals as a result of trickle irrigation. J. Am. Soc. Hort. Sci. 96, 645-648.

18. GOLDBERG, D. GORNAT, B. and RIMON, D. (1976), Drip irrigation· Principles, design and agricultural practices. Drip. Irrig. Scientific Publ. Kfar. Shumaryahu, Israel.

19. HUTZLER, N.G. and BOYLE, W.G., (1980), Wastewater risk assessment, J. Env. Eng. Div., Am. Soc. Civil Eng. 106· 919-933.

20. MAAS, E.V. and HOFFMAN, G.J., (1977), Crop salt tolerance - Current assessment. J. Irrigation and Drain. Div. ASCE 103· 115-134.

21. NIGHTINGALE, H.I., DAVIS, K.R. and PHENE, C.J. (1986), Trickle irrigation of cotton· effect on soil chemical properties. Agric. Water Managem. 11· 159-168.

22. ORON, G., SHELET, G. and TURZYNSKI, B., (1979), Trickle irrigation using treated wastewaters. J. Irrig. Drain. Div., ASCE 105· 175-186.

23. OVERMAN, A.R., (1975), Effluent irrigation of pearl millet. J. Environ. Eng. 101· 193-199.

24. OVERMAN, A.R. and NGUY, N., (1975), Growth response and nutrient uptake by forage crops under effluent irrigation. Commun. Soil Sci. Plant Anal. 6· 82-93.

25. PAPADOPOULOS, I., (1984), Effect of sulphate waters on soil salinity, growth and yield of tomatoes. Plant and Soil 81· 353-361.

26. PAPADOPOULOS, I., (1985), Constant feeding of field grown tomatoes irrigated with sulphate water. Plant and Soil 88· 213-236.

27. PAPADOPOULOS, I., (1986a), Nitrogen fertigation of greenhouse-grown cucumber. Plant and Soil 93· 87-93.

28. PAPADOPOULOS, I. (1986b), Nitrogen fertigation of greenhouse-grown French beans. Com. Soil Sci. Plant Anal. 17· 893-903.

29. PAPADOPOULOS, I., (1988), Field salinity profile development under drip irrigation with high sulphate water. Soil Sci.

30. PAPADOPOULOS, I. and RENDIG, V.V., (1983), Tomato plant response to soil salinity. Agron. J. 75· 696-700.

31. PAPADOPOULOS, I. and STYLIANOU, Y., (1987), Ongoing research on the use of treated sewage effluent for irrigating industrial and fodder crops. In Proceedings of "FAO Middle-East Seminar on the Use of Sewage Effluent for Irrigation". Nicosia, Cyprus, 7-10 Oct. 1985.

32. PAPADOPOULOS, I. and STYLIANOU, Y., (1988a), Trickle irrigation of cotton with sewage treated effluent· II. Effect on soil fertility and yield response. J. Environ. Qual.

33. PAPADOPOULOS, I. and STYLIANOU, Y., (1988b), Trickle irrigation of cotton with treated municipal effluent· Effect on soil chemical properties and salinity. J. Environ. Qual.

34. PAPADOPOULOS, I., STYLIANOY, Y. and KRENTOS, V.D., (1987), Use of marginal quality waters for crop production in Cyprus. Water Qual. Bul. 2· 59-63.

35. PAPADOPOULOS, I., RENDIG, V.V. and BROADBENT, F.E., (1985), Growth nutrition and water uptake of tomato plants with divided roots growing in differentially salinized soil. Agron. J. 77· 21-26.

36. PESCOD, M.B. and ALKA, U., (1984), Urban effluent re-use for agriculture in arid and semi-arid zones. In Re-use of sewage effluent. Thomas Telford, London. 71-83.

37. PESCOD, M.B. and ALKA, U., (1987), Guidelines for wastewater re-use in agriculture. In Proceedings of "FAO Middle-East Seminar on the Use of Sewage Effluent for Irrigation", Nicosia, Cyprus, 7-10 Oct. 1985.

38. PHENE, C.J. and BEALE, D.W., (1976), High-frequency irrigation for water nutrient management in humid regions. Soil Sci. Soc. Am. J. 40· 430-436.

39. PHENE, C.J. and SANDERS, D.C., (1976), Influence of combines row spacing and high frequency trickle irrigation on production and quality of potatoes. Agron. J. 68· 602-607.

40. RHOADES, J.D. and BERNSTEIN, L., (1971), Chemical, physical and biological characteristics of irrigation and soil water. In Leonard L. Ciaccio, ed., "Water and Water Pollution Handbook". Marcel Dekker, Inc., New York. 1, p. 141-222.

41. ROMANENKO, N.A., (1970), on helminth eggs in crops grown on sewage farms. Hygienic and Sanitation. USA 35(11)· 257-259.

42. SHUVAL, H.I., (1974), Disinfection of wastewater for agricultural utilization. 7th International Conference on water Pollution Research. Paper. No. 7c (ii)· 9-13.

43. SHUVAL, H.I., (1975), Health considerations in water renovation and use. Mimeo. Environ. Health Lab., The Hebrew University of Jerusalem, Israel.

44. SHUVAL, H.I., YEKUTIEL, P. and FATTAL, B., (1984), Epidemiological evidence for helminth and cholera transmission by vegetable irrigated with wastewater· Jerusalem - a case study. Water Sci. Tech. 17· 433-442.

45. STYLIANOY, Y. and ORPHANOS, P.I., (1970), Irrigation of Shamouti oranges with saline water. Agr. Res. Inst. Cyprus, Techn. Bul. 6, 23p.

46. UNIVERSITY OF CALIFORNIA Committee of consultants (1974), Guidelines for interpretation of water quality for agriculture. University of California, Davis 13 p.

47. WORLD HEALTH ORGANIZATION (1973), Re-use of effluents· Methods of wastewater treatment and health safeguards. World Health Organization Technical Report Series No. 517 Geneva.

48. WESTCOT, D.W. and AYERS, R.S., (1984), Irrigation water quality criteria. Irrigation with reclaimed municipal wastewater· A guidance manual. Pettygrove, G.S., and Asano, T. (eds). California State Resources Control Board· 3.1-3.7.

APPENDIX I

Present Situation in Cyprus

At present, although the Nicosia treatment plant, covering part of the sewerage system of the town, is in operation with an outflow of about 3500 m^3/day, treated effluent is not yet used extensively for irrigation, since the effluent of the Nicosia treatment plant is disposed into the river. It is anticipated, however, that the whole amount (15 million m^3/year) of the effluent from the treatment plants of Limassol and Larnaca will be used for irrigation in the next five years. Because of this, a multifaceted research was undertaken by the Agricultural Research Institute with a long-term objective to find ways so that treated effluent be used for irrigation safely from the point of view of public health and the environment and without undesirable effects on soils, crops, or animals fed with fodder crops irrigated with treated effluent. However, cleaning the effluent to a very high quality in order to avoid contamination even though technically it is possible, is not the best solution for a specific type of water use because of the high cost involved in such high purification. A balanced approach combining treatment methods capable of providing acceptable and reliable purification of wastewater, the use of advanced methods of irrigation (trickle and minisprinklers), with restriction of crops to those presenting a low level of public health risk (industrial and fodder crops), as suggested by Shuval (1974), Pescod and Alka (1987), and Papadopoulos and Stylianou (1987), appears to be the most prudent policy and, therefore, of a priority in our research in order to achieve the maximum social and economic benefits from wastewater re-use. Trickle irrigation has the advantage of a lower possibility of contamination (Romanenko, 1970), and although Goldberg (1976) demonstrated that with such a system even untreated sewage is absolutely safe, research under our local conditions is in progress since a serious problem associated with trickle irrigation is emitter clogging, caused by chemical and biological build-up in the minute water passageways (Oron et al., 1979).

In this respect, secondary treated sewage water and fresh borehole water of similar quality are experimentally used with modern irrigation systems (trickle and minisprinklers) for irrigating fodder and industrial crops (alfalfa, sudax, barley, cotton, sunflower). Vegetables and fruit trees are not included in the crops tested since these crops are not to be irrigated with treated effluent in Cyprus. However, with re-use of treated effluent, the ultimate goal is to get maximum social and economic benefits and yet to protect soil and underground water from contamination with certain ions i.e. NO_3. To study these effects, treated effluent and fresh water intended for irrigating cotton, sudax, and sunflower are supplemented with N, injected continually through the trickle irrigation system. With such an approach the same experiments can be used to evaluate the fertility value of treated effluents and the additional N needed for maximizing yield and quality, but also to obtain all information needed concerning contamination with pathogens, viruses, heavy metals, salinity and specific ions.

With all crops (cotton, sunflower, sudax), higher yield was obtained with the treated effluent, relative to fresh water, at the lower N rates that indicates the value of treated effluent as a source of N (Table II). Furthermore, no contamination of underground water with NO_3-N is expected by irrigating cotton, sunflower and sudax with treated effluent supplemented with N up to 30 mg N/L, provided that water applied is within the crop's requirements (Table III).

TABLE II

Yield in kg/ha of Lint Cotton, Sunflower and Sudax irrigated with freshwater and Treated Sewage Effluent at four Nitrogen Levels

Water	N rate (kg/ha)			
	0	30	60	90
	Cotton			
Fresh	2896b*	4037b	4587a	4931a
	(1204)[1]	(1679)	(1816)	(2026)
Effluent	4455a	4431a	4516a	4627a
	(1786)	(1812)	(1788)	(1836)
	Sunflower			
Fresh	4146b	4680a	4408a	4589a
Effluent	4536a	4622a	4428a	4822a
	Sudax			
Fresh	64600b	127000b	121600b	127200b
	(17.5)[2]	(17.6)	(18.5	(18.5)
Effluent	117100a	137500a	141300a	139300a
	(19.2)	(17.8)	(18.7)	(18.5)

1 Fibre cotton 2 Dry weight (%)
* Significantly different at 5% level

Sewage Effluent Re-use Potential in Cyprus

The need for using treated sewage effluent for irrigation must be viewed as an integral part of the planning and development of the water resources of the Island and as an efficient means of recycling scarce water resources on economic, social and environmental grounds. Groundwater resources, on which both domestic and agricultural supplies depend, have been exhausted by exploitation beyond the rate of natural recharge. In devising policies for development of the water resources of the Island, the main strategy is to satisfy present and future demands by the various competing sectors.

Recognizing the key role of the water as the means for increasing agricultural production and although acknowledging the necessity to augment domestic water supplies, the Government allocated over 60% of the development budget for the agricultural sector, as a whole, for water development and increased efficiency of water use. Any increase in the presently irrigated area is wholly dependent on the extent to which surface water resources are developed, or to which extent treated effluent will be re-used for irrigation purposes.

In this respect, the increase in irrigated land, past , present and future is shown in Table IV. Apparently, an area of 6% of the total land presently under irrigation, could be irrigated with treated effluent, and contribute significantly to irrigated crop production.

Table III

Nitrate-N (mg/kg) distribution in a trickle-irrigated soil as influenced by freshwater and treated effluent, supplemented with four N levels (N_1=nil, N_2=30, N_3=60, and N_4=90 mg N/L) applied with irrigation water (cotton)

Depth (cm)	Distance from emitter															
	N_1				N_2				N_3				N_4			
	20	0	25	50	20	0	25	50	20	0	25	50	20	0	25	50
	Fresh water															
0-15	2	1	12	8	7	8	30	12	14	11	23	43	14	21	20	54
15-30	2	0	6	1	2	0	1	0	12	10	17	31	8	26	19	32
30-45	0	0	0	0	0	0	0	0	11	17	16	26	12	21	17	24
45-60	0	0	0	1	0	0	0	0	9	18	14	26	5	24	15	25
60-75	0	0	0	0	0	0	0	0	0	11	17	31	1	15	22	32
75-90	0	0	0	2	0	0	0	0	0	17	20	19	15	23	43	28
90-105		0				0				21				16		
120-135		0				0				7				10		
135-150		0				0				5				15		
150-165		0				0				6				14		
	Effluent															
0-15	5	6	0	10	2	10	17	36	24	19	28	40	76	26	24	41
15-30	0	4	1	5	1	2	6	16	22	10	87	29	21	18	24	34
30-45	0	2	0	3	2	1	5	2	11	16	26	33	31	31	26	29
45-60	0	1	0	3	0	1	4	4	11	16	25	26	15	34	27	28
60-75	0	1	0	6	0	0	13	15	10	10	24	26	17	30	31	27
75-90	0	2	0	10	3	5	19	12	10	10	19	24	14	29	31	21
90-105		2				8				16				35		
105-120		3				8				16				47		
120-135		2				27				11				57		
135-150		3				17				20				26		
150-165		6				20				30				29		

Moreover, for a small island like Cyprus, whose economy is largely based on tourism industry, the disposal of treated effluent into the sea should be ruled out and this is an additional reason to be involved in detailed studies concerning re-use of the treated effluent for irrigation.

General Aspects

By using trickle irrigation, to avoid exposure to effluent of the people working at the experimental site and with certain, although minimum, precautionary measures (using gloves, and wearing rubber boots) we faced no adverse health effects. Moreover, with trickle irrigation crops are not in direct contact with the effluent and furthermore, soil salinity and SAR are maintained at least in a certain volume of soil beneath the emitter at low level not severely affecting crops and/or soil (Table V).

Table IV

Trends in irrigated agricultural land in Cyprus (ha)

	1980	1985	1990	1995
Irrigated area	48000	52900	56060	60000
Sewage effluent re-use potential			3350	

A serious problem, however, associated with trickle irrigation, particularly with effluent, is caused by chemical and biological build-up in the minute water passageways (Oron et al., 1979). Under our experimental conditions with the quality of effluent used, and by installing gravel and ring filtres, no severe filtering problem or unusual emitter clogging occurred.

Conclusions

The wastewater re-use imposes a greater risk of public or worker exposure to pathogens or toxic substances than would the use of unpolluted waters of non-sewage origin. The objective, therefore, is to minimize the exposure and reduce the potential health and environmental hazards to acceptable levels. In general, using modern irrigation systems (particularly trickle irrigation) for irrigating crops presenting a low level of public health risk (industrial and fodder crops) appears as a promising means for reusing treated effluent in a profitable and safe way. With such an approach we have obtained from four year field experiments very encouraging results suggesting that treated effluent must be re-used for irrigation than to be disposed of in other ways. This is particularly important for arid and semi-arid regions because scarcity of water is a real constraint for irrigated agriculture.

Table V

EC (dS/m) distribution in a trickle-irrigated soil as influenced by freshwater and effluent, supplemented with four N levels (N_1=nil, N_2=30, N_3=60, and N_4=90 mg N/L) applied via the irrigation stream (cotton)

Depth (cm)	Distance from emitter															
	20	0	25	50	20	0	25	50	20	0	25	50	20	0	25	50
	N_1				N_2				N_3				N_4			
	Fresh water															
0-15	2.6	3.0	8.8	6.4	2.7	3.7	9.4	4.1	3.0	2.1	4.5	7.4	3.8	3.3	13.3	7.7
15-30	3.7	3.1	8.8	6.4	1.9	2.0	5.7	4.3	2.3	2.8	5.9	4.5	4.0	2.8	2.9	7.5
30-45	5.0	4.6	6.9	7.4	2.2	2.3	5.7	4.3	4.1	5.5	6.5	5.1	7.1	4.2	2.7	7.2
45-60	5.9	4.8	6.3	6.3	4.2	3.7	4.8	3.4	5.8	6.5	6.3	5.5	6.6	4.9	3.8	6.4
60-75	3.8	3.2	3.6	4.4	4.6	4.4	2.1	3.5	5.6	4.8	6.2	7.3	4.4	6.4	6.1	5.3
75-90	3.5	2.5	3.0	3.4	2.1	2.1	3.1	4.5	5.8	4.6	5.9	6.4	6.0	6.6	7.9	7.7
90-105		2.6				2.5				6.5				6.5		
105-120		3.2				3.3				6.3				6.4		
120-135		2.3				5.0				6.0				6.2		
135-150		2.8				4.5				6.1				6.3		
150-165		3.6				4.1				6.3				5.2		
	Effluent															
0-15	3.5	1.4	5.7	3.1	3.9	2.1	9.9	4.9	1.7	2.1	3.2	2.7	5.4	1.9	5.6	5.2
15-30	1.9	1.5	6.2	4.2	4.1	1.2	7.9	4.7	1.4	1.4	9.5	3.5	3.2	1.3	4.9	5.9
30-45	2.6	3.9	6.2	5.8	4.5	1.6	9.5	4.7	4.3	3.6	6.5	3.3	4.8	1.8	3.9	4.6
45-60	3.6	4.0	4.9	4.4	3.3	3.7	9.7	4.5	5.3	4.7	5.4	4.1	3.6	5.0	3.3	2.4
60-75	2.4	5.4	4.8	3.5	6.7	3.9	9.9	5.4	1.6	2.0	5.7	4.8	2.6	2.1	3.6	2.1
75-90	3.3	6.8	1.5	5.3	8.8	7.6	9.7	7.1	1.5	2.2	4.3	5.2	3.6	2.0	4.0	2.7
90-105		1.8				3.1				4.5				2.7		
105-120		1.4				3.0				5.2				4.3		
120-135		2.0				3.5				6.2				4.3		
135-150		2.2				4.0				7.2				4.8		
150-165		1.7				4.5				6.6				5.0		

LES CRITERES DE L'EAU D'IRRIGATION EN UTILISANT UN MODELE HYDROCHIMIQUE

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RESUME

La rareté des ressources en eau dans les pays à climat méditerranéen et surtout à climat aride ou semi-aride oblige ces pays à faire des investissements considérables pour mobiliser et transférer des ressources en eau pour l'alimentation des villes et des agglomérations. La réutilisation des eaux usées est apparue à ces pays comme la valorisation d'une ressource réputée sans valeur. C'est ainsi que cette technique s'est dévelopée très rapidement au cours des deux dernières décennies, même dans des pays bénéficiant de conditions climatiques tempérées et humides.

Des critères pour la qualité des eaux réutilisées ont été proposés pour les différent domaines. Le présent rapport traite de l'évaluation des critères de la qualité d'une eau aux fins d'irrigation et propose une méthode basée sur les principes géochimiques et en utilisant un modèle thermodynamique. Il compare les résultats de cette approche avec la méthode classique et il expose l'intérêt de la méthode géochimique afin d'économiser de l'eau d'irrigation.

1. INTRODUCTION

Dans les régions méditerranéennes à climat sec et dans les régions arides ou semi-arides en général, la mise en valeur des sols nécessite des apports d'eau par irrigation. Or l'importance grandissante des coûts d'exploitation des eaux, jointe à celle de leur évacuation qui va de pair avec la raréfaction des ressources en eau font de la réutilisation des eaux usées une ressource tentante. Cette ressource de seconde main qui s'accroît avec l'utilisation plus intensive des ressources naturelles, constitue une richesse réelle si on apprend à l'utiliser et à mettre en oeuvre à temps les mesures de sauvegarde qui s'imposent. En fait la réutilisation des eaux usées est la valorisation d'un produit réputé sans valeur pour faire face à une demande en eau sans cesse croissante, surtout en agriculture qui représente le principal secteur consommateur d'eau dans les régions méditerranéennes.

Les contraintes principales à la réutilisation des eaux sont celles posées par l'adaptation aux usages et aussi les obstacles psychologiques et culturels attachés à des eaux réputées dangereuses.

Si ces derniers sont surmontés, la réutilisation des eaux usées nécessite, comme pour les eaux naturelles, des normes pour les divers usages. En agriculture, ces usages peuvent être très variés et appeler des modalités de mise en oeuvre très différentes.

Il est connu que la qualité d'une eau pour l'irrigation ne lui est pas intrinsèquement liée; on ne peut juger d'une eau dans l'absolu, comme dans le cas de classification des eaux pour les différentes utilisations, eau potable, eau pour l'industrie ..., mais on doit au contraire prévoir comment évoluera l'ensemble eau-sol.

Le problème se complique évidemment si on a recours à la réutilisation des eaux usées pour l'irrigation, car ici d'autre facteurs interviennent, surtout les matières en suspension qui peuvent entraîner le colmatage physique et biologique du sol, outre un autre facteur aussi déterminant, à savoir celui des risques sanitaires qui sont dûs soit aux éléments chimiques toxiques contenus dans l'eau, soit aux agents pathogènes.

La plupart des problèmes qu'on rencontre dans l'agriculture irriguée proviennent de la composition chimique de l'eau d'irrigation. L'utilisation de différents types d'eau en irrigation, ainsi que la possibilité de prévoir les problèmes qui peuvent en découler font apparaître le besoin d'un système de classification de la qualité de l'eau pour l'irrigation.

Deux approches ont été adoptées à ce sujet:

- la méthode dite classique qui est essentiellement basée sur une approche empirique;

- la méthode géochimique qui découle d'une approche plus récente et plus théorique, et traite le système eau-sol comme une interaction physique-chimique entre une eau de qualité donnée et un sol de composition minéralogique donnée. Elle se base sur les lois de l'équilibre thermodynamique et nécessite l'utilisation d'un calculateur.

Pourtant la méthode classique, qui a négligé au départ la partie sol, s'est récemment dirigée vers l'idée que la qualité d'une eau pour l'irrigation n'était pas à définir par rapport à cette eau uniquement, et qu'il fallait donc inclure le sol, mais la démarche est toujours empirique.

2. METHODES D'APPRECIATION DE LA QUALITE D'UNE EAU D'IRRIGATION

2.1 Méthode Classique

Plusieurs propositions ont été avancées pour classer l'eau suivant son aptitude à l'irrigation. Elles varient entre un classement de l'eau pour une utilisation générale (U.S. Salinity Laboratory Staff 1954, Doneen 1967, Rhoades et Bernstein 1971, Rhoades 1972, Rhoades et Merril 1975, Ayers et Westcot 1976) et un classement selon une plante et une région spécifiques (Thorne et Thorne 1954, Doneen 1959, Carter 1969). Les efforts de la quasi totalité de ces auteurs se sont portés sur la sélection de paramètres caractérisant l'eau d'irrigation elle-même. Différentes classes sont ainsi délimitées, variables d'un auteur à l'autre selon le nombre de paramètres simultanément considérés et selon les seules valeurs attribuées. Les variables utilisées sont: la conductivité électrique, la T.D.S., le pourcentage de sodium, les teneurs en chlore et en sulfate, les teneurs en bore, le S.A.R. (Sodium Adsorption Ratio). Ces variables reflètent dans l'ordre les dangers de valeurs de pression osmotique de la solution du sol, de toxicité spécifique des ions sodium, chlore et sulfate pour la plante et d'alcalinisation du sol.

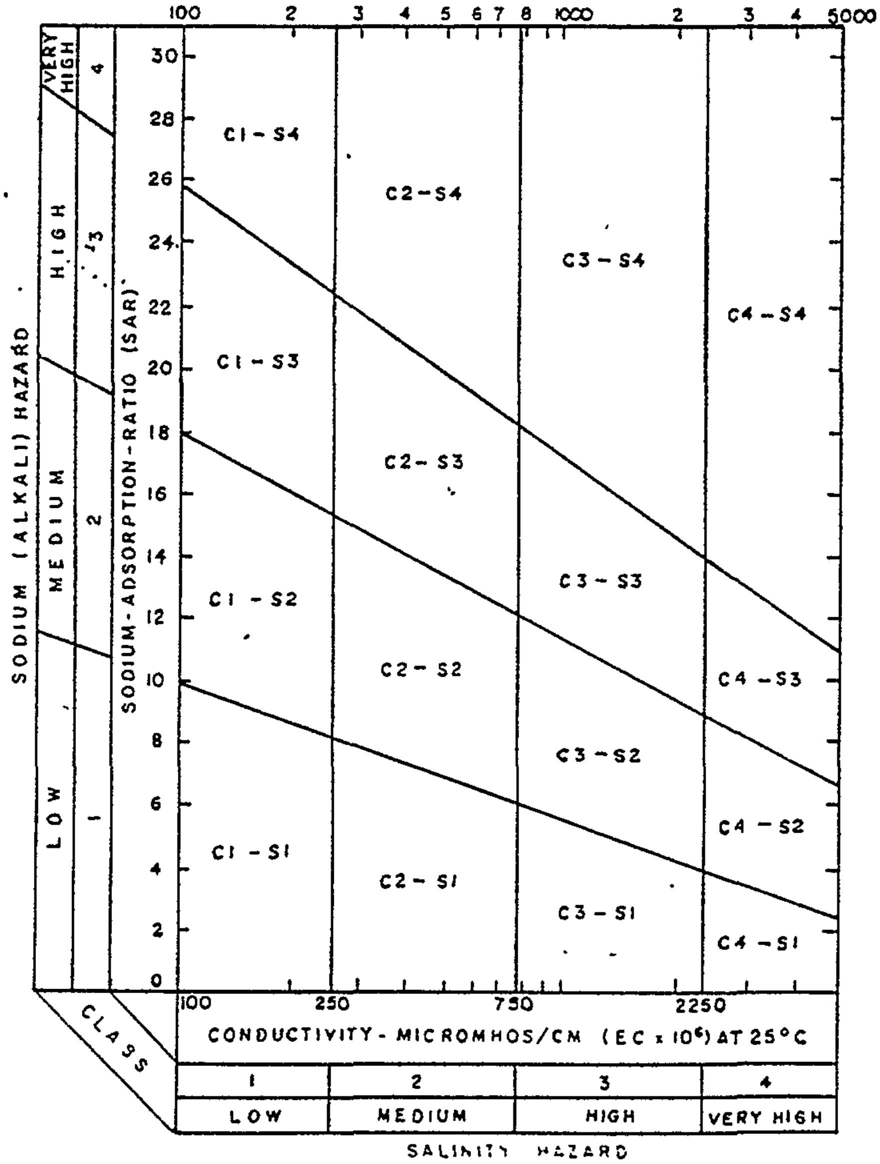
Mais le classement qui a fait autorité et a été très souvent utilisé depuis est celui de l'U.S. Salinity Laboratory (1954). Les eaux y sont décrites selon deux variables, la conductivité et le SAR; quatre domaines distingués sur l'échelle des SAR déterminent un ensemble de 12 classes bien connues permettant de juger de la qualité d'une eau pour l'irrigation (fig. 1 et tableau I).

En fait l'eau n'a pas une qualité propre inhérente, mais sa qualité se définit suivant le contexte dans lequel elle est utilisée. Son aptitude dépend de l'usage qu'on peut en faire sous les conditions spécifiques. Ces conditions comprennent la tolérance des plantes pour les sels, les méthodes d'irrigation appliquées (fraction lessivante, LF), les différentes propriétés physico-chimiques du sol et les conditions climatiques de la région.

Tout récemment, les recherches ont montré que l'interaction physico-chimique entre les propriétés des sols et l'eau d'irrigation est un facteur important pour la détermination de la qualité de l'eau pour l'irrigation. C'est justément sur ce facteur que l'approche géochimique est basée. Elle permet en outre, grâce à la compréhension de la base théorique qui régit ces intéractions, de prendre en compte des intéractions que la méthode classique néglige.

2.2 Méthode géochimique

Cette approche prolonge les idées développées par Eaton (1950) et Doneen (1954) et reprises depuis 1972. Le problème de l'irrigation est appréhendé en termes d'interaction physique et chimique entre une eau de qualité donnée et un sol de composition minéralogique donnée. Le concept de qualité d'une eau pour l'irrigation n'est donc plus uniquement lié à la composition chimique de cette eau caracterisée suivant les paramètres conductivité électrique, SAR et SAR ajusté, concentration en chlore et en bore, mais il s'agit de prévoir quelle sera l'évolution de la qualité de cette eau dans un milieu minéralogique donné, et dans des conditions d'évapotranspiration données. Car ces paramètres n'influent pas directement sur le sol et les cultures. En effet, la qualité de l'eau d'irrigation détermine en partie les caractéristiques de la solution du sol, et c'est cette dernière qui induit les comportements du végétal et du sol.



<u>Fig. 1</u>

Diagramme de classification des eaux pour l'irrigation

TABLEAU I

Classification des eaux Pour l'irrigation

Degré	Qualité	Classes	
1	"Excellente"	C1-S1	Eau utilisable sans danger pour l'irrigation de la plupart des cultures, sur la plupart des sols
2	"Bonne"	C2-S1 C2-S2	En général, eau pouvant être utilisée sans contrôle particulier pour l'irrigation de plantes moyennement tolérantes au sel, sur sols ayant une bonne perméabilité Principaux problèmes dûs aux plantes trop sensibles, au sodium et aux sols à forte capacité d'échange d'ions (sols argileux)
3	"Admissible"	C3-S1	En général, eau convenant à l'irrigation de cultures tolérantes au sel, sur des sols bien drainés. L'évolution de la salinité doit cependant être contrôlée. Principaux problèmes dûs aux plantes trop sensibles, au sodium et aux sols à faible perméabilité.
4	"Médiocre"	C4-S1 C4-S2 C3-S3	En général, eau fortement minéralisée pouvant convenir à l'irrigation de certaines espèces bien tolérantes au sel et sur des sols bien drainés et lessivés
5	"Mauvaise"	C3-S4 C4-S3 C4-S4	Eau ne convenant généralement pas à l'irrigation, mais pouvant être utilisée sous certaines conditions: sols très perméables, bon lessivage, plantes tolérant très bien le sel

Le problème de l'irrigation étant ainsi défini, son approche théorique est possible et passe par l'étude des équilibres minéraux - solutions. Cette démarche coïncide avec les souhaits du spécialiste de l'aménagement. En effet, la situation la plus fréquemment rencontrée lors de la décision de création de perimètres irrigués en zone aride est telle qu'on ne dispose en général que d'une ressource en eau limitée et le plus souvent salée, au contraire de la ressource en sol; les responsables ont donc besoin d'un outil qui permette d'indiquer quels sols valoriseront au mieux les qualités d'eaux disponibles et de prévoir leur évolution.

Ainsi, on a été progressivement amené à considérer le sol et la solution qui l'imprégne comme un système, à savoir un système minéraux gaz-solution où les relations entre ces trois phases sont des réactions de dissolution, précipitation et échange sous une atmosphère gazeuse de composition donnée.

2.3 Définitions et rappels

L'approche géochimique implique, entre autres analyses, celles des eaux et des solutions du sol. Les résultats d'analyse chimique, donnés par le laboratoire, représentent les concentrations totales de chaque élément; c'est à dire la somme des diverses formes, libres ou complexées, de l'élément;

$$(Na)\ total = (Na^+)_{libre} + \underbrace{NaCo_3 + (NAHCO_3) + NA_2\ SO_4}_{\text{ions complexés}}$$

- Les parenthèses désignent les molarités. Or, ce sont les quantités d'ion libres qui règlent les équilibres entre phase solide et phase liquide. Le rapport existant entre les formes libres et complexées d'un élément est régi par la loi d'action de masse appliquée aux activités des espèces dissoutes. L'activité et la molarité d'une espèce sont liées par la relation:

$$a = \gamma m$$

a : activité de l'espèce

m : molarité

γ : coefficient d'activité de l'espèce

Le pourcentage de complexation des différents ions peut atteindre 2-25% pour le sodium, 15-57% pour le calcium et 15-65% pour le magnésium (Shainberg et Shalhevet 1984). D'autre part la relation entre la solution et les minéraux (c'est-à-dire les réactions de dissolution et de précipitation) est aussi régie par la loi d'action de masse. Les ions impliqués dans ces réactions sont les ions libres et les concentrations sont les activités des ions. La saturation d'une eau vis-à-vis d'un ou plusieurs minéraux est calculée à partir de l'équation de la loi d'action de masse (pour plus d'informations consulter, Garrels and Crist, 1965, Droubi, 1976, Stumm et Morgan 1981).

Différents auteurs ont proposé des programmes de calcul de la distribution des ions entre les différentes formes simples et complexes, associés à des tests de saturation. On teste l'équilibre d'une solution par rapport aux différents minéraux susceptibles de précipiter: s'il y a sous-saturation, c'est qu'il y a possibilité de dissolution et la solution s'enrichit en ions correspondants; s'il y a sur-saturation, c'est qu'il y a possiblité de précipitation et la concentration de la solution en ions constitutifs du minéral diminue. On doit donc toujours raisonner sur des activités et non sur des concentrations totales lorsque on parle des réactions de dissolution et de précipitation. Le grand nombre de réactions et de paramètres pris en compte rend nécessaire l'emploi d'un calculateur. Pour une description détaillée de ces programmes et la liste des constantes thermodynamiques utilisées dans les équations d'équilibre, se référer à Fritz (1975).

2.4 Présentation du modèle géochimique de simulation

Dans les zones irriguées en général et dans les zones arides en particulier le principal facteur influençant la qualité de l'eau d'irrigation et par conséquent la salinité du sol est l'évaporation. C'est pourquoi le calcul du volume d'apport d'eau nécessaire à l'irrigation en tient compte. En fait, ce volume est égal à l'évapotranspiration additionnée du volume de lessivage et des pertes liées à la percolation, c'est-à-dire:

$$Vi = ETM + V_l + Vp$$

avec Vi volume d'apport

ETM évapotranspiration

V_l volume de lessivage

Vp percolation; la partie de l'eau d'irrigation qui s'infiltre directement sans se mélanger à la solution du sol et que l'on peut négliger

D'où $$Vi = ETM + V_l$$

et on appelle fraction lessivante (FL) le rapport

$$FL = \frac{V_l}{ETM + V_l}$$

Dans un sol irrigué les eaux de lessivage se concentrent par évaporation, au fur et à mesure de leur percolation; le facteur de concentration par évaporation serait donc maximal à la base du profil et on a

$$FC = \frac{1}{FL}$$

FC : facteur de concentration

FL : fraction lessivante.

Or la percolation des eaux de lessivage dans le sol ainsi que l'évaporation entraînent des dissolutions des sels et des minéraux déjà existant dans le sol et la précipitation de nouveaux sels.

Par conséquent, si on arrive à prévoir l'évolution d'une eau lorsqu'elle est utilisée en irrigation dans un sol donné, on aurait franchi une grande étape pour le choix de la qualité de l'eau à apporter pour l'irrigation.

Le modèle que nous présentons ici permet de prévoir l'évolution de la composition chimique d'un système minéraux-solution au cours de la concentration des eaux par évaporation ou de la dissolution des sels et minéraux par lessivage ainsi que les réactions d'échange. Ce modèle prend en considération l'équilibre entre la solution et les minéraux avec lesquels elle est en contact. Il calcule pour chaque variation de la composition chimique initiale de l'eau les nouveaux états d'équilibre, et il teste l'état de saturation de la solution vis-à-vis de différents minéraux et sels. Pour plus de détails se reférer à Fritz (1975), Droubi (1976), Dosso (1980), Perret (1982).

Il existe d'autres programmes et modèles de calcul de ces intéractions. Un inventaire de ces programmes et modèles est presenté par Fritz (1981). Mais le principe de tous ces modèles est le même, celui de l'équilibre chimique.

La méthode du calcul consiste précisement à simuler l'évaporation d'une eau d'irrigation. La simulation fournit en fonction du facteur de concentration FC (c'est-à-dire le rapport des nombres de moles d'eau à l'état initial et à l'état considéré) les activités et les molarités des espèces dissoutes, la nature et le nombre de moles des minéraux précipités.

Or on a vu que le facteur de concentration est lié à la fraction lessivante par la relation:

$$FC = \frac{1}{FL}$$

On peut alors tracer en fonction du facteur de concentration ou de la fraction lessivante les paramètres retenus qui caractérisent une eau, à savoir la charge totale dissoute (ou la conductivité électrique) équivalente à la conductivité électrique, le SAR et la teneur en chlore.

Les résultats obtenus par simulation de l'évaporation de l'eau d'irrigation sont portés sur la figure 2. Les valeurs tolérables, pour une culture donnée, de la charge totale dissoute, du SAR et de la teneur en chlore sont portées en ordonnée sur le même graphique. Ainsi, on détermine directement les valeurs limites des facteurs de concentration correspondant à chacune des contraintes définies: salinité, toxicité en chlore, toxicité en sodium et perméabilité.

Les tables de tolérance des végétaux à la salure sont exprimées en conductivités électriques moyennes sur le profil (CEe). Or la méthode géochimique utilise la conductivité électrique limitée à la base du profil. Mais le calcul de la fraction lessivante à partir de la conductivité de l'extrait de pâte saturée (CEe) n'étant pas possible, on peut calculer (CEe) induite par une fraction lessivante FL donnée avec les résultats de la simulation et l'hypothèse de la profondeur utile du sol. D'après cette hypothèse, 40% de l'eau absorbée par les plantes sont prélevés dans le premier quart, 30% dans le deuxième, 20% dans le troisième et 10% dans le dernier quart. Il faut donc établir pour une eau d'irrigation donnée un tableau FL-CEe: dans la plupart des cas, la formule de Rhoades (1972) permet de s'affranchir de ce calcul fastidieux. Elle relie la fraction lessivante à la conductivité de l'eau d'irrigation (CEe) et la conductivité d'extrait saturé moyenne sur la zone racinaire (CEe)

$$FL = \frac{CEi}{5\ CEe - CEi}$$

Elle est assez précise mais elle néglige des phénomènes de précipitation et de dissolution.

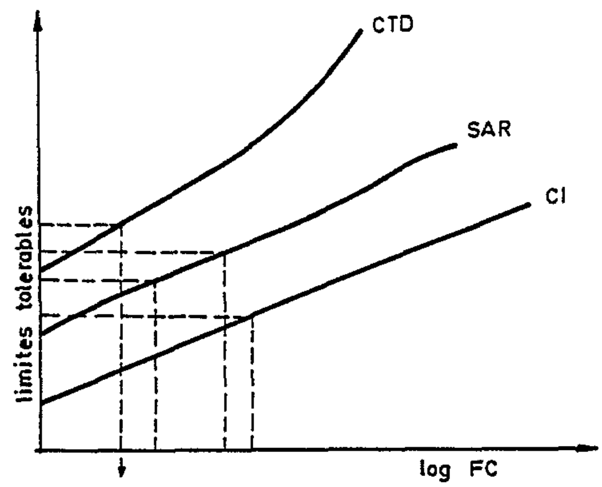


Fig. 2

Calcul de la fraction lessivante

2.5 Comparaison entre méthode classique et géochimique

Les principaux critères connus pour la détermination de la qualité d'une eau d'irrigation se résument en trois (Shainberg et Shalhevet, 1984):

- la salinité totale, qui induit:
  - la tolérance de la plante à la salinité
  - la précipitation des sels
  - la dissolution des sels et son effet sur la salinité de la solution du sol

- le risque d'alcalisation qui engendre:
  - la notion SAR
  - la relation ESP-SAR
  - le rôle du carbonate
  - la perméabilité

- l'effet néfaste de certains ions. Pour chacun de ces phénomènes des formules empiriques par la méthode classique ont été proposées pour déterminer la validité d'une eau pour l'irrigation. Nous allons prendre quelques exemples pour montrer l'intérêt de l'utilisation du modèle de simulation géochimique.

- Calcul du SAR

Le SAR (Sodium Adsorption Ratio) est un des éléments essentiels pour la détermination de l'aptitude d'une eau à l'irrigation.

$$SAR_i = \frac{1}{\sqrt{Ca^{2+} + Mg^{2+}}} \quad \text{exprimé en m'eq/l}$$

Or les concentrations des ions Ca^{2+}, et Mg^{2+} doivent être exprimées en activité et pas en m'eq/l. D'autre part les ions Ca^{2+} et Mg^{2+} sont les ions libres en solution, ce sont des ions qui entrent en réaction.

Par conséquent, lorsqu'on calcule les SAR d'une eau d'irrigation à partir de l'analyse chimique on obtient une valeur surestimée. Pour surmonter cette difficulté, une formule a été proposée pour distinguer entre le SAR_p pratique (sans tenir compte des ions paires) et le SAR_t vrai (Sposito and Mattigod, 1977).

$$SAR_t = 0,08 + 1,115 \; SAR_p \quad (r^2 = 0,99)$$

Pour les eaux carbonatées, un SAR est utilisé afin de tenir compte de la mise en equilibre de l'eau avec la calcite (Rhoades and Merill, 1976).

$$SAR_{aj} = SAR_i \; (1 + (8,4-PH_c))$$

SAR_i = de l'eau d'irrigation

D'autre part, l'eau d'irrigation infiltrée dans le sol peut dissoudre des minéraux carbonatés (au cas où elle est sous-saturée par rapport à ces minéraux) ou même dissoudre du gypse Caso4 - 2H20, présent souvent dans les sols des zones arides et semi arides, ce qui va changer la valeur du SAR de l'eau et influencer les réactions d'échanges, et on est alors amené à calculer une autre valeur du SAR de la solution du sol (SAR_{sw}).

Il existe d'autres formules de calcul pour tenir compte d'autres problèmes. Pour chacun de ces problèmes, la méthode classique propose une formule.

Par contre l'utilisation d'un modèle chimique pour simuler l'évolution d'une eau d'irrigation, en connaissant au départ sa composition chimique et les compositions minéralogiques du sol, permet à chaque étape de l'évolution de la concentration de calculer la valeur du SAR réel en tenant compte de toutes les interactions et réactions.

Dosso (1980), Valles et al. (1983) ont établi dans des études distinctes la validité de l'utilisation du modèle de simulation géochimique par comparaison avec la méthode classique pour l'utilisation des eaux salées en irrigation et les problèmes qui en découlent, calcul de la fraction de lessivage, calcul des doses d'irrigation.

Par example, Dosso (1980) dans son étude de l'eau de l'Euphrate en Syrie montre que les prévisions fournies par l'emploi des formules habituelles donnent des valeurs plus pessimistes que celles fournies par le modèle. Les valeurs de SAR prévues sont supérieures d'environ 12% aux valeurs fournies par le modèle. Valles et al (1983) ont testé les deux méthodes, classique et géochimique, pour l'estimation de la fraction lessivante en utilisant des données de l'Euphrate en Syrie, du Chari au Tchad et de la station de Cherfech en Tunisie.

Ils en sont arrivés aux conclusions que la faiblesse de la méthode classique tient en grande partie à l'utilisation des paramètres globaux tels que la conductivité éléctrique (CE), la charge totale dissoute et le SAR.

La méthode géochimique permet d'améliorer considérablement la précision du calcul de la fraction lessivante qui est un facteur déterminant pour l'utilisation d'une eau en irrigation. La démarche géochimique présente un intérêt évident mais il paraît néanmoins nécessaire de tester sa validité sur d'autres parcelles expérimentales. Elle pourra ainsi permettre de procéder à l'autocritique de l'évolution d'un projet d'aménagement d'irrigation.

3. PRINCIPAUX CRITERES DE QUALITE A RESPECTER POUR L'EAU USEE REUTILISEE EN IRRIGATION

3.1 Nous avons, dans les paragraphes précédents, traité des critères d'appréciation de la qualité d'une eau pour l'irrigation dans sa forme générale, c'est-à-dire la qualité chimique et les paramètres qui la définissent ainsi que les méthodes de calcul de ces paramètres. Or, dans le cas de la réutilisation des eaux usées en irrigation, d'autres paramètres interviennent. Ces paramètres peuvent être divisés en deux catégories, paramètres liés à la composition chimique de l'eau, et paramètres liés au risque sanitaire.

3.2 Influence des éléments chimiques

Les eaux réutilisées proviennent souvent des rejets d'eaux urbaines, c'est-à-dire d'eaux domestiques résiduaires auxquelles sont susceptibles d'être mélangées en proportion plus ou moins importante des eaux résultant d'activités diverses (notamment industrielles) raccordées au réseau d'assainissement. Généralement, ces eaux sont utilisées soit brutes, soit après traitement d'épuration de type primaire, effluents decantés, résiduaires ou traitement secondaire (boues activées ou lagunage le plus souvent) avec ou sans chloration.

3.3 Composition minérale

Etant donné que la qualité des eaux usées réutilisées en irrigation dépend de plusieurs facteurs, comme les espèces végétales, la texture et la composition du sol, le drainage et les techniques d'irrigation, il existe plusieurs critères pour définir l'aptitude d'une eau usée pour l'irrigation. Ces critères dépendent de la composition minérale des eaux usées, c'est-à-dire salinité totale, sodium, calcium, magnésium, éléments toxiques et fertilisants.

Le tableau ci-dessous donne les limites des concentrations de certains éléments pour l'utilisation des eaux municipales en agriculture (D'Itri et al 1981).

Paramètre	Fourchette des concentrations
pH	6,5 - 8,0
T^o	15 - 25°C
DBO_5	100 - 500 mg/l
Solides dissous	750 -1500 =
Résidu sec	800 -1500 =
N. organique	5 - 40
N. ammoniacal	0.5 - 40 =
Phosphates totaux	5 - 150 =
Conductivité	400 -2500 mhos/cm
Ca	10 - 85 mg/l

Mg	10 - 150 =
Na	40 - 400 =
SO_4	15 - 150 =
Cl	40 - 500 =
SAR	3,0 - 8,5=
Huile et matières grasses	20 - 150 =

3.4 Matières en suspension

La teneur en matières en suspension doit être aussi faible que possible en raison d'une part des risques d'obstruction des systèmes d'irrigation utilisés, d'autre part du colmatage possible des sols. Car il y a des matières qui peuvent obstruer les pores et provoquer, tout au moins en surface, une imperméabilisation. Les teneurs indiquées dans la littérature donnent des valeurs limites comprises entre 20 et 30 mg/l qui correspondent en fait aux teneurs contenues dans un effluent urbain ayant subi un traitement secondaire. En ce qui concerne les obstructions du matériel d'arrosage, il y est remédié par le choix le plus adéquat possible du diamètre des orifices, ainsi que par un entretien régulier.

3.5 Les éléments fertilisants (N, P, K)

Leur présence dans les eaux usées urbaines en quantités notables leur confère une valeur fertilisante. Pour des eaux ayant une teneur en azote de l'ordre de 15 mg/l, une application de 100 mm correspond à un apport azoté d'environ 15 Kg/h. Cette valeur correspond en moyenne aux fertilisants usuels.

3.6 La salinité

Les problèmes liés à la salinité de l'eau, à la teneur en Ca, Ng, Na et au SAR ont été clairement traités aux paragraphes précédents.

3.7 Les éléments traces

Il s'agit essentiellement des métaux lourds et du bore. Certains éléments traces sont des microfertilisants essentiels pour les plantes. Il y a aussi des éléments traces dont les fonctions physiologiques sont inconnues. Cependant, tous les éléments traces peuvent être néfastes à des concentrations élevées.

On a identifié 17 éléments qui peuvent avoir une certaine toxicité pour le consommateur. Les tableaux suivants donnent les teneurs maximales en métaux lourds tolérables dans les eaux d'irrigation (Page, 1974 cité dans Valiron, 1983) en mg/l:

Eléments	Eaux destinées à l'irrigation utilisation continue		utilisation discontinue
	tous types de sol .	sols à texture grossière	sols à texture fine
Cr	5,0	0,1	20,0
Hg			
Cu	0,2	0,2	5,0
As	1,0	0,1	10,0
Ni	0,5	0,2	2,0
Zn	5,0	2,0	10,0
Cd	0,005	0,01	0,05
Pb	5,0	5,0	20,5
Co	0,2	0,05	10,0
B	0,75	0,75	2,0
Se	0,05	0,02	0,05

En comparant ce tableau avec les valeurs obtenues pour les concentrations moyennes des éléments traces après traitement des effluents recensées dans le tableau ci-dessous (d'après d'Itrie, 1980) on constate qu'à deux exceptions près (Cd, et Hg) pour lesquelles il n'est pas fait mention de valeurs limites, la moyenne des teneurs est inférieure aux maximums indiqués. Cela tient en grande partie au fait qu'une proportion importante des métaux lourds se trouve concentrée dans les boues.

Elément	Traitement primaire (mg/l)	Traitement secondaire (mg/l)
As	0,005	0,005
B	1,0	0,7
Cd	0,02	0,005
Cr	0,05	0,02
Cu	0,1	0,04
Hg	0,0009	0,0005
Mo	0,007	0,007
Ni	0,10	0,004
Pb	0,02	0,008
Se	0,005	0,005
Zn	0,12	0,04

3.8 Risques sanitaires

Les risques sanitaires inhérents à la pratique de l'irrigation avec des eaux usées sont dûs aux éléments chimiques toxiques, les métaux lourds essentiellement, qui pourraient provenir de l'accumulation de ceux-ci dans les cultures (effet de concentration) et de leur transmission aux consommateurs.

Ils peuvent provenir des bactéries pathogènes et des virus qui trouvent des milieux favorables dans les eaux usées. Il existe plusieurs études qui traitent de ce sujet, notamment D'Itri et al., 1980, Valiron et al., 1983, Bize, 1986, Prost, 1986).

4. ROLE DU MODELE HYDROCHIMIQUE

A part le traitement des problèmes liés à la salinité de l'eau d'irrigation et à son influence sur l'évolution du sol irrigué par ces eaux, il est possible d'appliquer ce modèle pour la réutilisation des eaux usées en irrigation.

Nous avons vu que les principaux critères pour la qualité de l'eau réutilisée, à part la salinité et les teneurs en Ca, Mg, Na pour lesquels l'évolution peut être prévue par le modèle, sont les teneurs en éléments lourds. En connaissant les constantes d'équilibre des réactions de ces éléments on peut prévoir leur évolution dans le sol par simulation des réactions qu'ils peuvent subir dans celui-ci.

5. RECOMMENDATIONS

Le modèle présenté dans ce rapport, dont l'efficacité a eté demontrée en l'appliquant à plusieurs reprises au Tchad, en Syrie, et en Tunisie pour prévoir l'évolution d'un sol soumis à l'irrigation, peut constituer un outil utile pour étudier l'évolution du sol lors de la réutilisation des eaux usées en irrigation.

Pour y parvenir, il convient d'effectuer des recherches dans les domaines des éléments traces, et des réactions qui les régissent dans le sol. Il faut aussi avoir une station pilote, ou disposer au moins de données pratiques sur la réutilisation des eaux usées dans des fermes pilotes, c'est-à-dire: analyses chimiques des eaux, analyses des profils des sols, quantité d'eau utilisée. Toutes ces données peuvent être obtenues en utilisant des champs expérimentaux. Une fois ces données acquises, des simulations peuvent être testées en utilisant ces données pour calibrer le modèle et étudier les différentes variables.

REMERCIEMENTS

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REFERENCES

Ayers, R.S. and D.W. Estcot (1976), Water quality for agriculture. Irrigation and drainage Paper 29, FAO, Rome, 174 p.

Bize, J. (1986), Réutilisation des eaux usées épurées, principes et pratique. Séminaire atelier sur les technologies appropriées pour l'eau et l'assainissement en zones arides. Rabat. 24-28 Nov. OMS, Genève.

Carter, D.L. (1969), Managing moderately saline (salty) irrigation waters. Univ. Idaho Curr Inf. Center 107.

D'Itri, F.M., Martinez, J.A., Lambarri, M.A. (1981), Municipal Wastewater in Agriculture. Academic Press, p. 492

Doneen, L.D. (1954), Salination of soil by salts in irrigation water. Trams. Am. Geophys. Union, 35, pp. 943-950.

Doneen, L.D. (1959), Evaluating the quality of irrigation water in Ventura County. Calif. Bull. Dept. Water Resour., 75: F11-F33.

Doneen, L.D. (1967), Water quality requirements for agriculture. Natl Symp. Qual. Stand. Nat. Waters, Ann Arbor, MI, Educ Ser. 161, pp 213-218.

Dosso, M. (1980), Géochimie des sels et des eaux d'irrigation. Aménagement de la basse vallée de l'Euphrate en Syrie. Thèse UPS, Toulouse, p. 181.

Droubi, A. (1976), Géochimie des sels et des solutions concentrées par évaporation. Application aux sols salés du lac Tchad. Mem. Sci. Geol., 46, p. 177.

Eaton, F.M. (1950), Significance of carbonate in irrigation waters. Soil Sci. 69, pp 123-133.

Fritz, B. (1975), Etude thermodynamique et simulation des réactions entre minéraux et solutions. Applications à la géochimie des altérations des eaux continentales. Mem. Sci. Geol., 41, p. 152.

Fritz, B. (1981), Etude thermodynamique et modélisation des réactions hydrothermales et diagénétiques. Mem. Sci. Geol. 65, p. 197.

Garrels, R.M. and C.L. Crist (1965), Solutions, minerals and equilibria. Freeman, Cooper and Co., San Francisco, p. 450.

Page, A.L. (1974), Fate and effects of trace elements in sewage sludge when applied to agricultural lands. A literature review study. Environ. Prot. Agency, NTIS, U.S. Department of Commerce, p. 96.

Perret, D. (1982), Calcul d'équilibre géochimique par minimisation d'énérgie libre. Thèse Doct. Ing. Rennes, p. 120.

Prost, A. (1986), Les risques infectieux liés à la réutilisation des eaux usées - Division de l'hygiène du milieu, DMS, Génève. Séminaire maghrebin sur la réutilisation des eaux usées après traitement en agriculture. Tunis, Avril.

Rhoades, J.D. (1972), Quality of water for irrigation. Soil Sci. 113, pp 227-284.

Rhoades, J.D. and Bernstein, L. (1971), Chemical, physical and biological characteristics of irrigation and soil water. In Water and Water pollution handbook (Ed. Ciaccio, L.L.), Vol. I, Dekker, New York, pp. 141-222.

Rhoades, J.D. and Merril, S.D. (1975), Assessing the suitability of water for irrigation: Theoretical and empirical approaches. FAO, Soil Bull. 31, pp.69-109.

Shainberg, I. and J. Shalhevet (1984), Soil salinity under irrigation. Springer - verlag p. 349.

Sposito, G. and S.V. Mattigod (1977), On the chemical foundation of the sodium adsorption ratio. Soil Sci. Soc. Am. J. pp. 323-329.

Stumm, W. and J.J. Morgan (1981), Aquatic chemistry, end edn. John Wiley, New York, p. 780.

Thorne, D.W. and J.P. Thorne (1954), Changes in composition of irrigated soils as related to the quality of irrigation waters. Soil Sci. Soc. Am. Proc. 18, pp 92-97.

U.S. Salinity Laboratory Staff (1954), Diagnosis and improvement of saline and alkali soils. U.S. Dept. Agric. Handbook 60.

Valiron, F. (1983), La réutilisation des eaux usées, BRGM, p. 208.

CHECK LIST FOR THE PREPARATION OF A SYSTEM APPROACH TO THE IMPLEMENTATION OF WASTEWATER RE-USE

Projects of agricultural wastewater re-use (AWWR) are long-term operations, often very costly. Failures are punitive in local economies and jeopardize the possibility of resumption of dozens of years, as well as inevitably weighing heavily on all similar projects.

It is, therefore, important to approach the projects correctly, which implies relatively long and prudent steps. The steps to be taken are described below. This proposal presents neither the obligatory adaptations to the local conditions nor the retroactions to supplement the previous steps.

1) Inventory of "hydrologically critical or delicate" situations in which the AWWR is susceptible to bringing about a significant improvement of hydrological balance-sheet. Inventory of the situations in which the AWWR could contribute to the protection of the environment (suppression of discharge into the sea, reduction of aquifer contamination, etc.). Selection of cases of major interest.

2) Attitude (of producers and consumers) towards the AWWR[possible socio-cultural blocks.

3) Analysis of existing local practices· Origin and quality of waters, irrigated surfaces, crops cultivated, irrigation methods, commercialisation of products. Collection of available data on soil evolution. If possible, retrospective enquiry, economy of the actual production.

4) Improve the knowledge of usable waters, including the probable spontaneous evolution and the possibilities of improving the chemical quality of the waters (improvement of the quality of distributed waters, monitoring of industrial wastewaters, prevention of brackish or sea waters intrusion into the network, etc.).

5) Evaluation of the sanitary risk

6) Inventory of possibilities of effluent treatment· local opportunities and constraints, relief, selection of admissible systems, possible effects of treatment on quantity and chemical quality of reclaimed water.

7) Inventory of agronomical possibilities· actually irrigated areas, soil quality, sensitivity to sodium, identification of possible crops, economic interest and requirements regarding the level of sanitary treatment of water.

8) Integration of wastewater in the general water resources· crops to be irrigated by "natural" water / crops irrigable by wastewater.

9) Irrigation methods (with regard to traditional practices, available financial resources, agronomical and sanitary objectives, requirements of water saving, technical level of irrigation water, framing, maintenance).

10) Possibilities offered by wastewater re-use

- extension of the existing perimeters, creation of new perimeters;
- intensification of agricultural production;
- possible advantage of an over-irrigation on the basis of groundwater aquifers in course of salination;
- advantage of regular supply throughout the year (winter storage).

11) Environmental and sanitary impacts of the project (impact study)

12) Economic feasibility and identification of financial sources

- Financial intervention of the community producing wastewaters.

13) Establishment of AWR system

- definition of the perimeter
- management structure
- selection (and limitations) of crops cultivated — in agreement with concerned farmers
- irrigation method(s) and materials
- technical and sanitary education of farmers

14) Establishment of sanitary control system·

- control of effluent treatment methods
- control of crops cultivated
- control of commercialization circuits

in the beginning, by the application of WHO recommendations of local regulations (in absence of national regulations)

- preparation (and periodic revision) of a "Code of Practice" for farmers and local officers in charge of exploitation structures.

15) Long-term follow-up (implying the existence of adequate and available study structures)·

- evolution of farmers' attitude towards the topic of AWR;
- hydraulic balance-sheet (including the influence of AWR on aquifers);
- agronomical balance-sheet (evolution of soil quality, crops yield, etc.);
- economic and socio-economic balance-sheets (modifications of financial flow induced by AWR, and of farmers' way of life);
- microbiological monitoring and epidemiological enquiry in a number of areas considered characteristic.

16) Diffusion of gained experience·

- periodic synthesis of the monitoring results;
- information circulation (role of international organizations);
- contribution to the preparation of national regulation, guidelines or recommendations based upon gained experience.

PART III

COUNTRY REPORTS AND CASE STUDIES

WASTEWATER TREATMENT FOR AGRICULTURAL RE-USE IN ISRAEL

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1. ABSTRACT

Agriculture in Israel - a semi-arid country in its northern part and arid in the south- depends almost completely on irrigation. In view of the scarcity of natural water resources in Israel, municipal wastewater is considered to be an important water resource used mainly for irrigation. Since 1970, numerous wastewater re-use schemes have been in operation. The importance assigned to wastewater re-use on a national level stimulated development of innovative treatment systems for re-use. A key element in a system of wastewater re-use for agriculture is the seasonal storage installation, either on the surface or underground, which receives effluents of varying quality and releases them for irrigation during the dry season. The Israeli experience demonstrates that seasonal storage installations can act as efficient treatment processes which may provide, in addition to storage, either polishing of highly treated effluents or can serve as the main treatment step of the wastewater.

Two innovative treatment concepts which combine treatment and storage have been developed and are in widespread use in Israel, serving as the basis for most of the existing re-use schemes. These are the DRT (Deep Reservoir Treatment) concept and the SAT (Soil Aquifer Treatment) concept. The principles of both concepts are presented in detail, including descriptions of various projects based on the two concepts and presentation of quality data of effluents.

2. INTRODUCTION

In areas of limited natural water resources, wastewater represents an unconventional water source which may be utilized for agriculture, industry, recreation and recharge of aquifers. The use of treated municipal wastewater for irrigation of crops is one of the most attractive and practical re-use options. In addition to serving as a supplementary water source, agriculture utilizes other resources found in wastewater such as organic matter and nutrients (nitrogen and phosphorus) which are thus converted from an environmental nuisance to an asset. Moreover, re-use of wastewater for irrigation prevents its discharge to receiving water bodies and considerably decreases the risk of pollution of natural water resources and of coastal waters.

Re-use of wastewater for potable purposes, after an appropriate advanced treatment, is also possible and it is practised elsewhere in certain situations. However, this type of re-use is usually opposed by authorities responsible for public health because of uncertainties related to possible long-term adverse effects, and faces psychological resistance from public opinion.

Agriculture in Israel - a semi-arid country in its northern part and arid in the south - depends almost completely on irrigation. Water demand for irrigation represents about 65% of the national demand (Fig. 1).

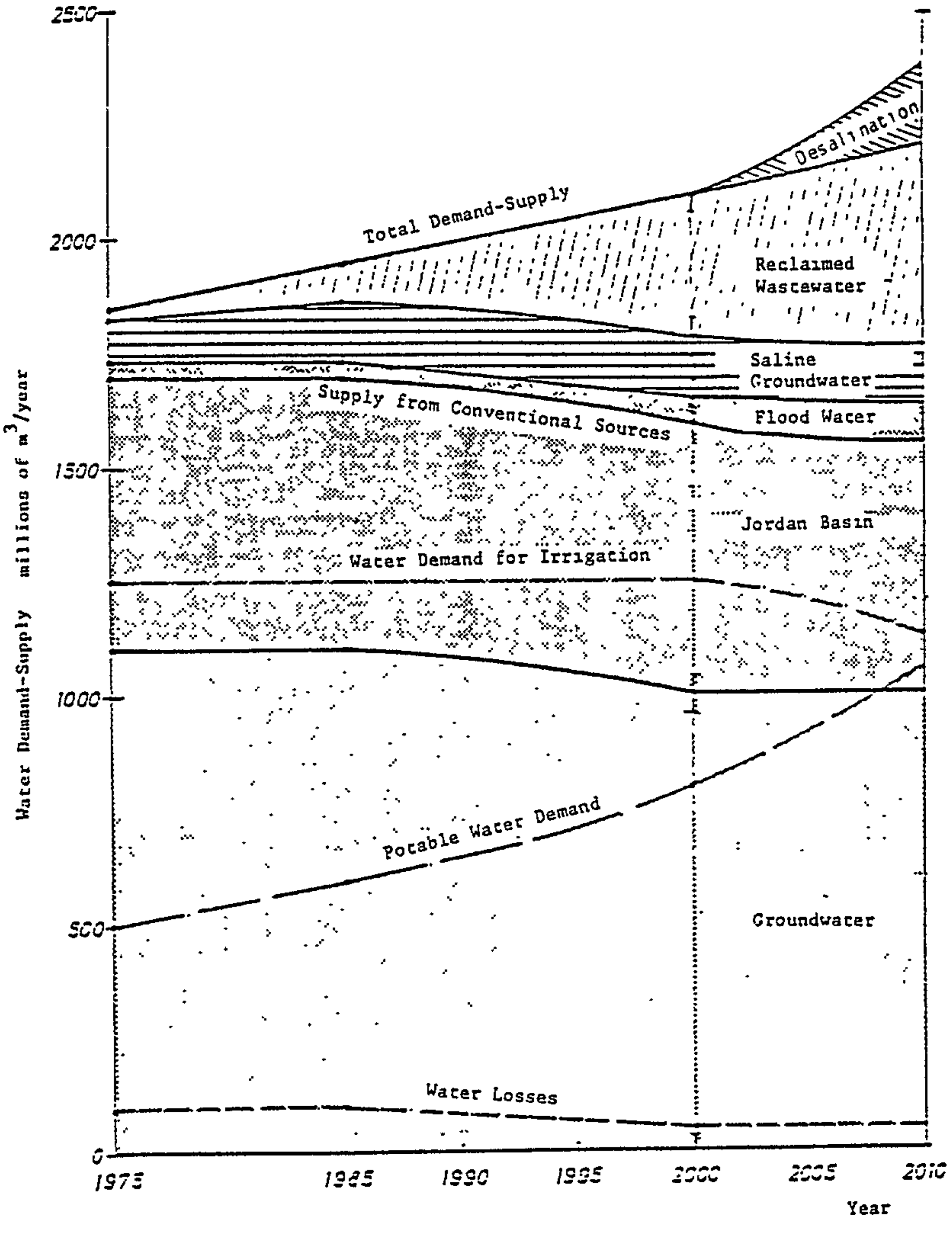


Fig. 1 Water Demand and Supply Sources in Israel

In view of the scarcity of natural water resources in Israel, municipal wastewaters are considered to be an important water resource, especially for irrigation. Since 1970, numerous wastewater re-use schemes have been put into operation and others are at the stage of design and construction. The importance assigned to wastewater re-use on a national level has stimulated development of innovative treatment systems for re-use.

At present, about 110 million cubic metre per year of effluents, which exceed 45% of the total volume of municipal wastewater in Israel, are already utilized for irrigation. The above figure will increase to about 70% during the forthcoming months when the second stage of the Dan Region (Tel Aviv metropolitan area) wastewater re-use project, which has been recently inaugurated, goes into full operation (Table I).

Table I

Re-use of Wastewater in Israel

	Million m^3/year	
Available municipal wastewater	260	
Seweraged municipal wastewater	240	
Treated wastewater	150	(215)
Sea disposal of raw sewage	65	(0)
Discharge of raw sewage to water courses	30	
Septic tanks	15	
Re-use		
- Irrigation	90	
- Dan Region project	20	(80)
Total Re-use	110	(170)
Percentage re-used of total seweraged wastewater	46%	(71%)

Note: Numbers in brackets include the second stage of the Dan Region Project which was operated on April 1987.

The intensive re-use of wastewater for irrigation in Israel permits conservation of potable water resources by replacing water of potable quality (which was used for irrigation) with treated effluents thus liberating the replaced water to be used for the public municipal supply.

In addition, re-use of wastewater on a national scale and at a relatively low cost permits considerable deferment of large investments required for desalinization of sea water, which is the ultimate available water resource in Israel.

Although in the majority of cases re-use of wastewater in Israel is aimed at the cultivation of marketable crops, there are some cases in which effluent irrigation is practised as a disposal method by slow rate land application. This is done in areas in which profitable agriculture is not feasible because of topographical restrictions (hilly or mountain zones) or marginal land quality, usually at small settlements in desert and mountain zones. A by-product of such land application of effluent is the preservation and enlargement of green belts in the vicinity of the wastewater-producing settlements.

3. RESTRICTED VERSUS UNRESTRICTED IRRIGATION

When considering wastewater treatment for agricultural re-use in Israel, two terms of basic importance should be recognized. These are the terms "Restricted Irrigation" and "Unrestricted Irrigation".

- **"Restricted Irrigation"** refers to the use of low-quality effluent in specific areas, where certain crops only should be cultivated. The restrictions imposed usually refer to the types of crops to be cultivated, the irrigation methods, the harvesting method, fertilizer application rates, distance of irrigated fields from residential areas and paved roads and the distance between non-potable and potable water supply mains.

- **"Unrestricted Irrigation"** refers to the use of high-quality effluents for irrigation of all crops on any soil type, without any adverse environmental effect on the soil, crops, animals and persons involved in the production process or persons consuming agricultural products.

4. EFFLUENT QUALITY CRITERIA FOR IRRIGATION

Establishment of regulations for effluent quality for irrigation is, in Israel, the responsibility of the Ministry of Health, whose concern is to prevent risks to public health as a result of irrigation with effluents. In 1979 the Ministry published a draft of standards for irrigation with sewage effluent, a summary of which is presented in Table II. According to these standards effluent qualities for irrigation are classified into four categories (A,B,C and D) according to crop type. For certain crops, restrictions are also imposed on the irrigation system. In addition, treatment requirements are also prescribed. Biological treatment is required in all cases (as manifested by low BOD values and by the requirement of a dissolved oxygen concentration of at least 0.5 mg/l, which can be maintained practically only after secondary treatment). For food crops to be consumed raw (category D), sand filtration is required as polishing treatment. Chlorination is required for crop categories C and D.

In 1981, the Ministry of Health published only the standards for category A crops as an official law, indicating that for irrigation of other crops, specific permission must be obtained. In granting such permission, the Ministry is presumably guided by the recommendations presented in Table II.

It is worthwhile to mention at this point some recent developments concerning the quality of effluent for irrigation. Too strict regulations could price effluent re-use for irrigation out of the market and , hence, cause a valuable water resource to go to waste. Potentially, there are definite health risks associated with the use of sewage effluent for irrigation. In practice, however, these risks may not be too severe as evidenced by the dearth of documented cases relating disease outbreak to irrigation with reasonably treated sewage effluent. This does not include, of course, such blatant violations of basic health rules as irrigation of vegetables consumed raw with untreated or poorly treated sewage, as is practised in some countries.

Table II

Standards for Irrigation with Reclaimed Wastewater in Israel

Crop category	A	B	C	D
Principal crops	Industrial crops (Cotton, sugar beet, etc.) cereals, dry fodder, seed, forest irrigation	Green fodder, olives, peanuts citrus, bananas, almonds, nuts, etc.	Deciduous fruits[c] fruit and vegetables for processing, vegetables to be cooked, peeled vegetables and fruit, woodlands, green belts, soccer fields and golf courses	All crops without restrictions including crops to be consumed raw, municipal parks, lawns
Effluent Quality[a]				
BOD, total, mg/1	60[b]	45[b]	35	15
BOD, dissolved, mg/1	-	-	20	10
Suspended solids, mg/1	50	40	30	15
Dissolved oxygen, mg/1	0.5	0.5	0.5	0.5
Coliform count, MPN/100 ml	-	-	250	12 (80%) 2.2 (50%)
Residual available chorine, mg/1	-	-	0.15	0.5
Mandatory treatment				
Sand filtration[d]	-	-	-	required
Chlorination, minimum contact time, minutes	-	-	60	120
Distances				
Minimum distance from residential areas, m	300	250	-	-
Minimum distance from paved road, m	30	25	-	-

a All values refer to the 80-percentile, except for total coliforms in category D where the 50-percentile is also specified.
b Not applicable to effluent from oxidation ponds with detention times of more than 15 days where most BOD and suspended solids are of algal origin. Different standards will be set for such a case.
c Irrigation must stop two weeks before fruit picking; no fruit should be picked from the ground.
d Sand filtration or equivalent treatment with respect to effluent quality and operational reliability.

Source: Israeli Ministry of Health 1979, 1981 (1, 2)

Recent publications (3, 4, 5, 6) conclude that previous public health orthodoxy which held that every excreted pathogen that can persist in the environment, in soil or on crops irrigated with wastewater is a potential cause of serious disease in humans, is basically overly conservative because human infection is not dependent only on the presence of pathogens in soils and crops. It depends also on the minimum dose of a pathogen necessary to cause infection (which varies greatly for different types of organisms), on the persistence duration of the pathogens in the environment and on the level of immunity to endemic diseases.

A combination of the above factors led to the conclusion that the amount of excess infection and diseases, caused by various classes of pathogens when irrigating with untreated wastewater is of the following order of descending magnitude:

- intestinal nematode infections (Ascaris, Trichuris and the hookworms)
- excreted bacterial infection (bacterial diarrhoeas and typhoid)
- excreted viral infections (rotavirus diarrhoea and hepatitis A).

According to the Engelberg Report (5) the first quality criterion for wastewater use in agriculture is the complete, or almost complete removal of the eggs of intestinal nematodes (to a geometric mean of less than 1 viable nematode egg per litre). In addition, a major reduction (to a geometric mean of less than 1,000 fecal coliforms per 100 ml) in the concentration of excreted bacteria is recommended for unrestricted use of wastewater in agriculture. If these standards are met, other pathogens such as trematode eggs and protozoal cysts are also reduced to undetectable levels.

The priority criteria for effective wastewater treatment for the specific purpose of pretreatment for agricultural irrigation, as based on publications 3,4,5,6 are of the order:

- maximum removal of helminths and protozoa
- effective reduction in bacterial and viral pathogens
- freedom from odour and objectionable appearance (i.e. effective reduction of BOD).

These specific design criteria and their order of priority differ from those for reducing surface water pollution from BOD and COD, and thus result in different optimal treatment strategies.

Based on the above findings a series of practical alternative remedial measures for controlling negative health effects may be considered as follows:

- restrictions on types of crops irrigated so as to prevent consumers from being exposed directly to infection through contaminated vegetables or salad crops eaten raw;

- selection of irrigation techniques and procedures so as to minimize direct contact between wastewater and crops;

- wastewater treatment and/or storage practice, aimed at effectively reducing first the concentrations of priority pathogens to low levels, and in subsequent stages to levels below which the incidence of excess infection is essentially controlled.

5. EFFLUENT IRRIGATION AS A DISPOSAL METHOD

In some cases, especially in mountainous and desert zones, effluent irrigation is practised in Israel as a disposal method, and not for irrigation of marketable crops. The method is applied in small settlements of up to a few thousand inhabitants. The irrigated areas are usually steep-sloped, isolated areas of difficult access. As a result of the isolation and of the fact that no marketed crops are irrigated, it is possible to use low-quality effluents, for irrigation of woods, forests, perennial grasses and natural vegetation. Seasonal storage is not used and irrigation takes place throughout the year. Effluent application rates are adjusted to supply just over the evapotranspiration requirements and range between 50 m^3/d/ha in winter to 100 m^3/d/ha in summer. Such application rates do not present groundwater pollution risks, even in karstic zones.

The pretreatment of wastewater before land application is minimal and consists of either septic tanks or anaerobic ponds. In certain cases oxidation ponds are utilized and in cases of land restrictions, such as in areas of very steep slopes, compact activated sludge treatment units are utilized.

The effluent application system is a gravity or low-pressure surface distribution system. The effluent is distributed by 050 mm perforated polyethylene pipes with fixed openings of 5 mm at intervals ranging from 0.5 to 1.5 m. These pipes must be levelled to achieve uniform distribution. Details on wastewater irrigation for disposal are given in publications 7 and 8, and are summarized schematically in Fig.2. Follow-up of such systems performance is not carried out systematically but it may be stated that attractive greenbelts develop in the irrigated areas and no odour problems are reported. The effluent distribution systems do not tend to clog the operation and maintenance of the combined treatment-irrigation system is quite simple. In general it is considered as a successful disposal solution for small systems in mountain zones.

A recent development is the utilization of the effluent of small communities for irrigation of gardens and parks. It is practised in isolated desert communities of up to a few hundred inhabitants. Compact activated sludge units are used for wastewater treatment and the effluent is chlorinated and distributed by drip irrigation only, usually in fenced greenbelts with no access to the public. Effluent quality is in accordance with the requirement for irrigation of Category C crops (Table II).

6. EFFLUENT IRRIGATION FOR CROP CULTIVATION

6.1 Introduction

In the great majority of the cases, effluent irrigation in Israel is practised not only as a disposal method but also for crop cultivation. The basis of such an approach is efficient use of water which dictates incorporation of seasonal storage and efficient irrigation systems.

Every re-use scheme is an integrated system consisting of three elements: pretreatment, seasonal storage and irrigation.

The key element of such a re-use system is the storage installation which compensates between the relatively constant supply of wastewater throughout the year and the variable seasonal water demand for irrigation, which is required mainly during the dry season.

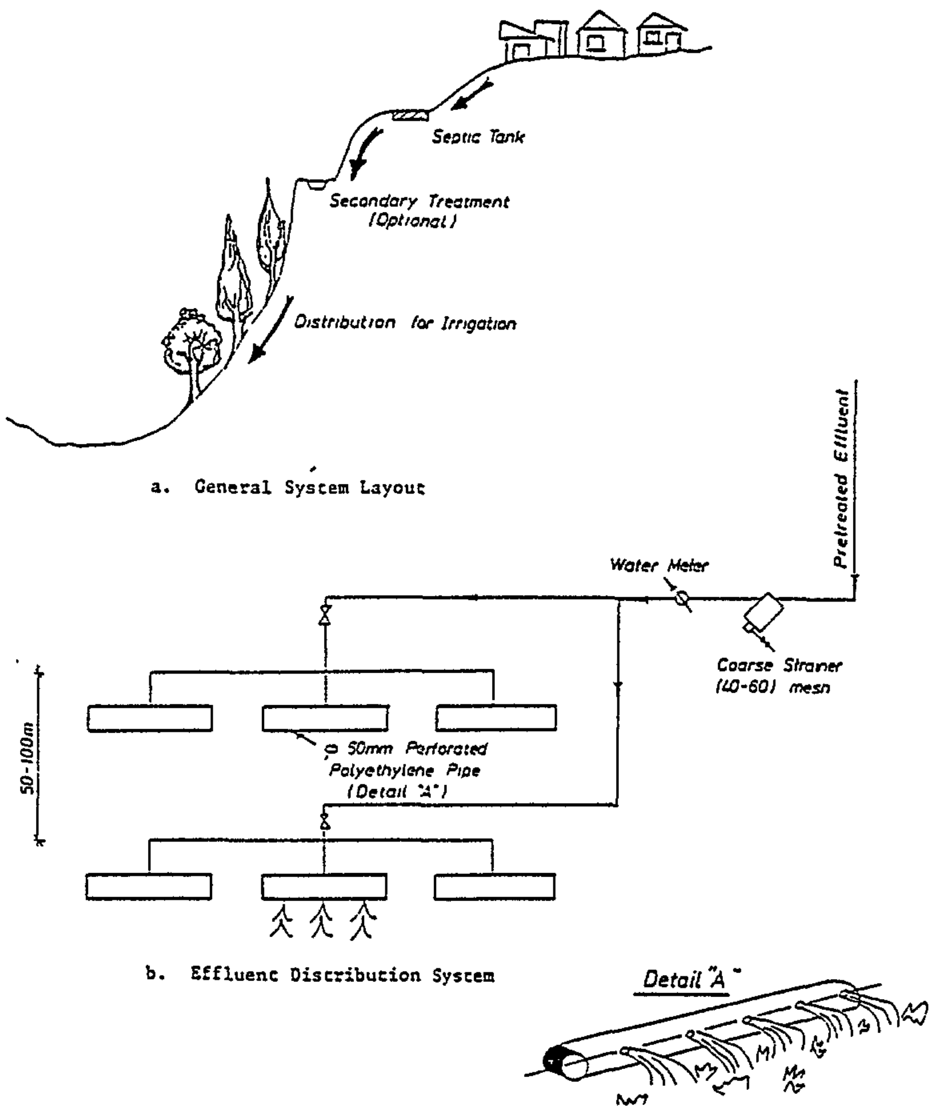


Fig. 2 Disposal of Wastewater by Irrigation in Mountainous Zones

There are two possibilities for storage: surface storage and underground storage. The Israeli experience demonstrates that in both cases, seasonal storage installations act as efficient treatment processes which may provide, in addition to storage, either polishing of highly treated effluents or serving as the main treatment step of the wastewater.

Most of the wastewater diverted to irrigation of marketed crops is treated prior to irrigation by one of two treatment trains, each of which represents a treatment concept combining treatment and storage. These are: (i) the SAT (Soil Aquifer Treatment) concept which incorporates underground storage and (ii) the DRT (Deep Reservoir Treatment) concept which incorporates surface storage.

The Dan Region (Tel-Aviv metropolitan area) Project, which is the largest wastewater treatment and re-use project in Israel is based on the SAT concept. This project which serves a population of about 1.2 million inhabitants, handles at present about 80 million cubic metres per year of wastewater, a figure representing 47% of the total re-used wastewater. Two smaller scale SAT projects for populations in the range 100,000-150,000 inhabitants are under way, one at a construction stage and the other at a preliminary design stage.

Seventy million cubic metres per year of wastewater for re-use are handled by a large number of variable size installations based on the DRT concept. The DRT treated wastewater represents 41% of the total re-used wastewater.

6.2 The SAT (Soil Aquifer Treatment) Concept

The SAT concept combines a series of processes which produce an effluent of very high quality, adequate for unrestricted irrigation of all types of crops including those consumed raw. It involves the use of the soil and the aquifer as a treatment step, by controlled passage of effluent through the unsaturated and saturated soil zones, and its subsequent pumping from the aquifer. The system consists of recharge basins on permeable soils, surrounded by a series of pumping wells. Observation wells located between the recharge basins and the pumping wells permit the continuous monitoring of the process. The high purification capacity of the system is the result of a unique combination of physical, chemical and biological processes occurring in the soil and the aquifer (9). More about this method was reported in my previous paper (Part II).

As previously mentioned, the Dan Region Wastewater Re-use Project is based on the SAT concept (9,11,12). The project consists of two stages which differ in the pretreatment processes provided before the SAT. The treatment scheme flow diagrams of both stages are presented in Fig. 3. The first stage of the project has been in full operation since 1977 and serves the southern zone of Tel-Aviv, treating an annual flow of about 25 million cubic metres. The second stage, which is in a start-up phase, serves the northern and eastern zones and is designed for treating, at present, an annual flow of about 65 million cubic metres.

The project serves two purposes: (i) production of a significant volume of usable water, helping to compensate for the difference between the increasing national water demand and the limited available natural water resources, and (ii) prevention of the contamination of the Tel-Aviv beaches and Mediterranean waters by wastewater discharge. The project is the largest and most advanced municipal wastewater re-use project in Israel: its pretreatment facilities are located about 20 km south of the centre of Tel-Aviv. The layout of both project stages is presented in Fig.4.

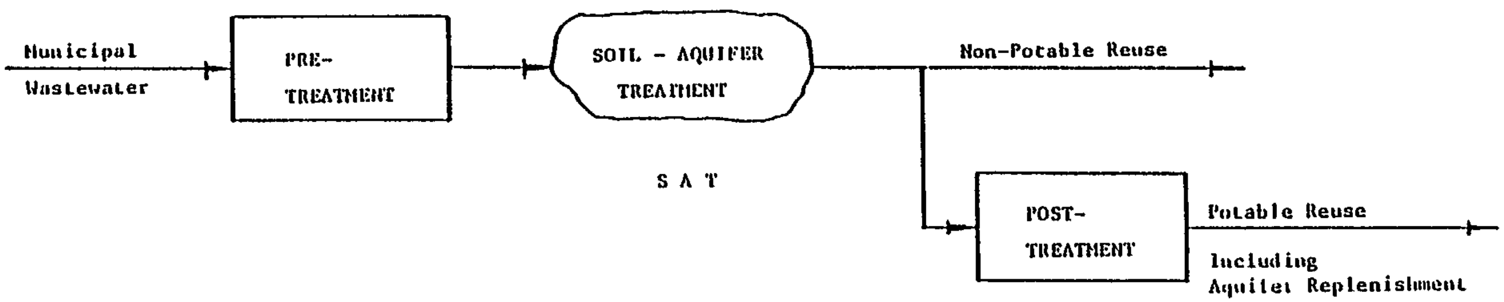


Fig. 3 Dan Region Wastewater Re-use Project - Treatment Schemes of the Two Project Stages

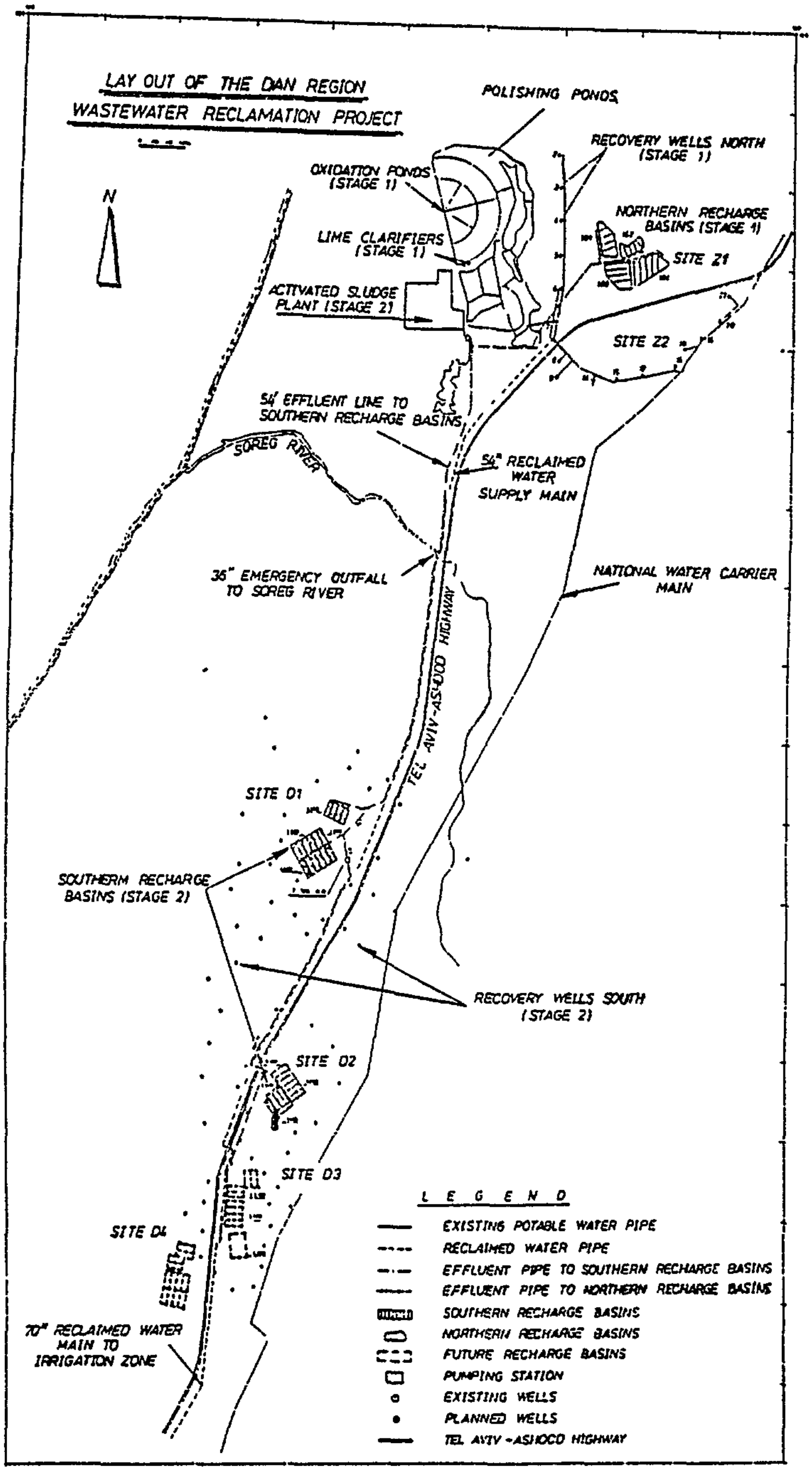


Fig. 4 Layout of the Dan Region Wastewater Reclamation Project

The pretreatment step of the project's first stage consists of biological treatment in facultative recirculated oxidation ponds and chemical treatment by the high lime-magnesium process, followed by detention of the high pH effluent in polishing ponds, for the purpose of stabilization and free ammonia stripping. The layout of the first stage treatment facilities is presented in Fig.5. Ponds A, B, G and 1, 2, 5, 6 are primary oxidation ponds. Ponds D, E and 3, 4, 7, 8 are secondary oxidation ponds. Ponds 9, 10, 11, 12, 18 and pond F are polishing ponds. The polishing ponds effluent undergoes the SAT process by recharge to the regional aquifer through the northern recharge basins (site Z1) located about 1.5 km east of the oxidation ponds. The recharge basins are surrounded by a chain of recovery wells (the Dan wells) which create an isolated zone in the aquifer, dedicated to treatment and storage of the recharged effluent.

The detention time in the oxidation ponds varied during the year 1986 from 24 to 38 days, of which 11 to 18 days consist of detention in the primary ponds. The detention time in the polishing ponds usually varied from 11 to 15 days. The yearly average organic load in 1986 (13) was about 438 kg BOD/ha/day in the primary oxidation ponds, and 180 kg BOD/ha/day in all the oxidation ponds. The average recirculation ratio was 1.5 (effluent) to 1 (raw sewage).

The average lime dose used for chemical treatment in 1986 was about 500 mg/l as CaO and that of $MgCl_2$ solution about 50 mg/l. The low magnesium dose is a result of utilization of a recycling process. The lime sludge is disposed of in a natural depression found in the vicinity of the plant.

The total area of the northern recharge basins is about 25 ha. The recharge operation is carried out by intermittent flooding of the spreading basins. Normally the recharge cycle consists of one day flooding followed by two or three days of drying, but it may vary according to climatic conditions, the number of basins in operation and the amounts of effluent available for recharge. The average hydraulic load varied over the past few years from 100 to 120 m/year, having different values at different basins, as a result of differences in infiltrated rates.

Groundwater elevations in the centre of the recharge zone have risen about 6 m since the project came into operation. The thickness of the unsaturated zone is in the range of 15 to 27 m (being different at each basin in accordance with local hydrogeological conditions). The transient time of recharge water in the unsaturated zone varies between 11 to 21 days. The travel time in the aquifer to the various observation wells located between the recharge basins and the recovery wells varies between 8 and 34 months, thus the travel time to the recovery wells is longer than the above range. At the end of 1986, the front of 100% recharged water extended about 1 km south, north and east of the centre of the northern recharge zone and about 750 m west of it.

Water quality data (13) at various points along the treatment processes of the first stage Dan Region Project are presented in Tables III and IV. Table III is related to organic matter, nutrients and bacteriological parameters, while Table IV refers to heavy metals and toxic elements.

Analysis of the water quality data demonstrates that in the over-the-surface treatment facilities (i.e. in the pretreatment stage of the SAT) good to very good overall removal (above 70% efficiency) is obtained for: suspended solids, BOD, COD, TOC, detergents, mineral oil, phenols, ammonia, and phosphorus; for the following trace elements: Cd, CN, Pb, Cr, Ag, Cu, Fe, Mn, Zn, Ni, Al and Sn; as well as for turbidity and Hg. Moderate removal (between 40% and 70%) is obtained for: alkalinity, hardness, total

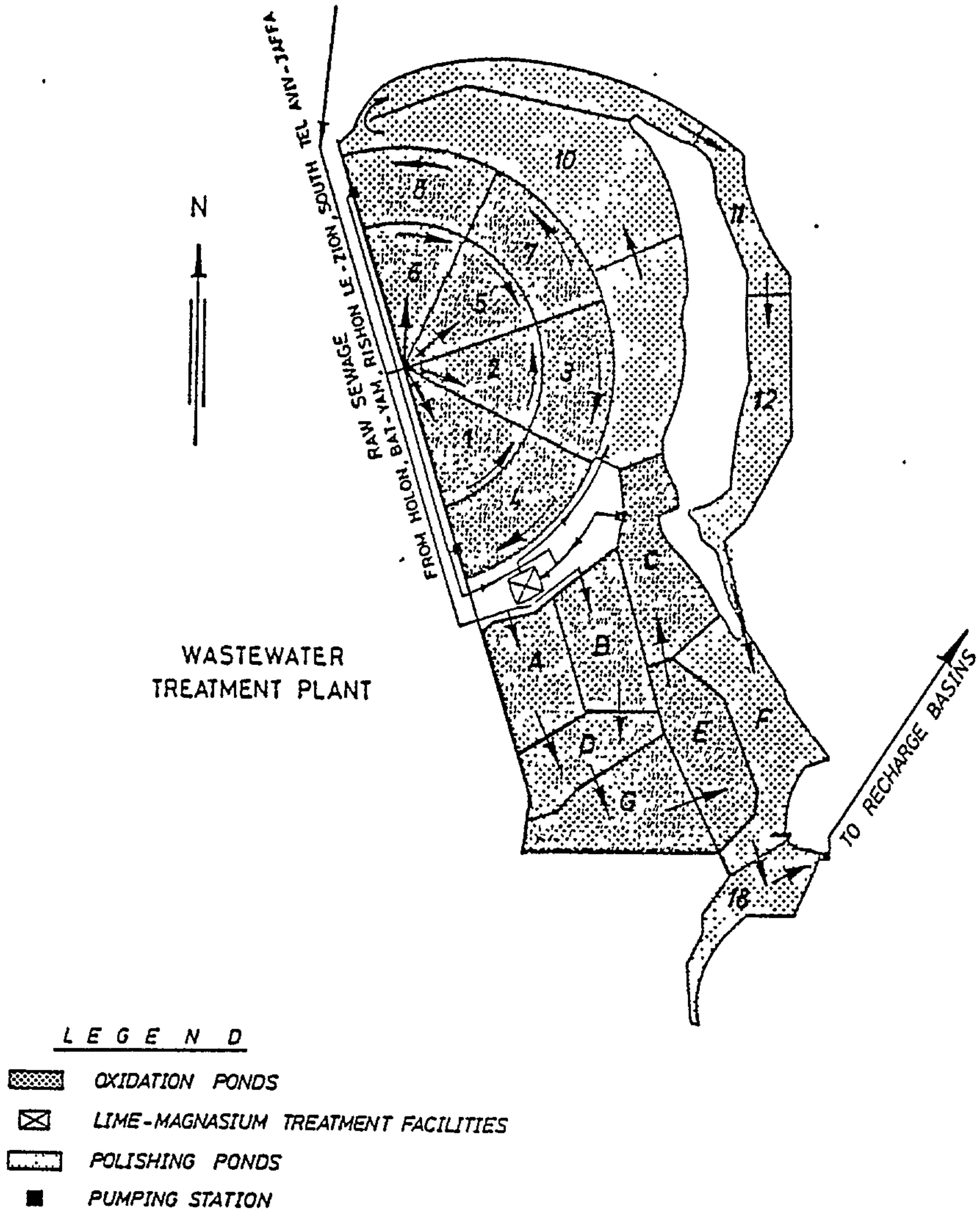


Fig. 5 Layout of the First-Stage Treatment Facilities of the Dan Region Project

Table III

Dan Region Project Stage One - Water Quality at Various Points
Along the Treatment Process - Organic Matter Nutrients and Bacteria

Parameter	Raw Wastewater	Oxidation Ponds Effluent	Lime-Treatment Effluent	Polishing Ponds Effluent	Reclaimed Well Water
	Concentration - mg/1				
Turbidity (NTU)	-	-	-	24.8	0.4
Suspended solids	350	308	200	66	0.0
BOD^5	313	118	45	29	0.5
BOD^5 filtered	117	9	13	6	0.5
COD	641	423	198	126	9.6
COD filtered	219	84	67	57	9.6
TOC	229	149	98	59	3.5
Detergents	14	4	3	1.9	0.23
Ammonia, as N	37	25	25	7.2	0.02
Total Nitrogen	60	60	43	17.8	7.1
Filtered Nitrogen	-	-	-	12	7.1
Phosphorus	13.7	12.7	5	3.2	0.03
pH (units)	7.6	7.8	11.3	9.5	7.8
Total Coliform (MPN/100 ml)	10^8	10^6	2x10^1	10^2	0.0
Fecal Coliform (MPN/100 ml)	10^7	3.2x10^5	6.3	2.8x10^1	0.0
	Facultative Lagoons with Recirculation	Lime-Magnesium Treatment		Polishing Ponds	Soil Aquifer Treatment

Table IV

Dan Region Project Stage One - Water Quality at Various Points
Along the Treatment Process - Heavy Metals and Toxic Elements

Parameter	Raw Wastewater	Oxidation Ponds Effluent	Lime-Treatment Effluent	Polishing Ponds Effluent	Reclaimed Well Water
	Concentration - mg/1				
Boron B	500	500	430	400	250
Cadmium cd	28.0	3.0	1.0	0.7	0.2
Chromium cr	100	22	8	5	3
Copper cu	133	21	17	9	4
Phenols	91	6	14	6	0.9
Manganese Mn	59	43	14	6	31
Mercury Hg	1.3	0.5	0.7	1.0	0.6
Nickel Ni	107	41	29	21	12
Lead pb	75	6	5	4	5
Selenium	5	7	5	3	1
	Facultative Lagoons with Recirculation	Lime-Magnesium Treatment		Polishing Ponds	Soil Aquifer Treatment

nitrogen, Se, Ba, Mo, Si and F. Concentrations of coliforms and fecal coliforms are reduced by about six logs, streptococcus faecalis by about four logs and total bacteria by about 1.5 logs. No enteroviruses were detected in the treated effluent.

The purification occurring by means of SAT was evaluated from the results of water quality analyses carried out in the recharge effluent and in a representative observation well pumping 100% recharged effluent (well 54).

In the SAT system, good to very good removal (above 70% efficiency) is obtained for: suspended solids, BOD, COD, TOC, UV absorbance, $KMnO_4$ consumption, detergents, phenols, ammonia, phosphorus, and Cd; as well as for turbidity and K. Moderate removal (between 40% and 70%) is obtained for total and filtered nitrogen, mineral oil, Cr, Cu, Hg, Ni and Se.

Coliform and fecal coliform bacteria were not detected in the reclaimed water, nor were streptococcus faecalis and enteroviruses.

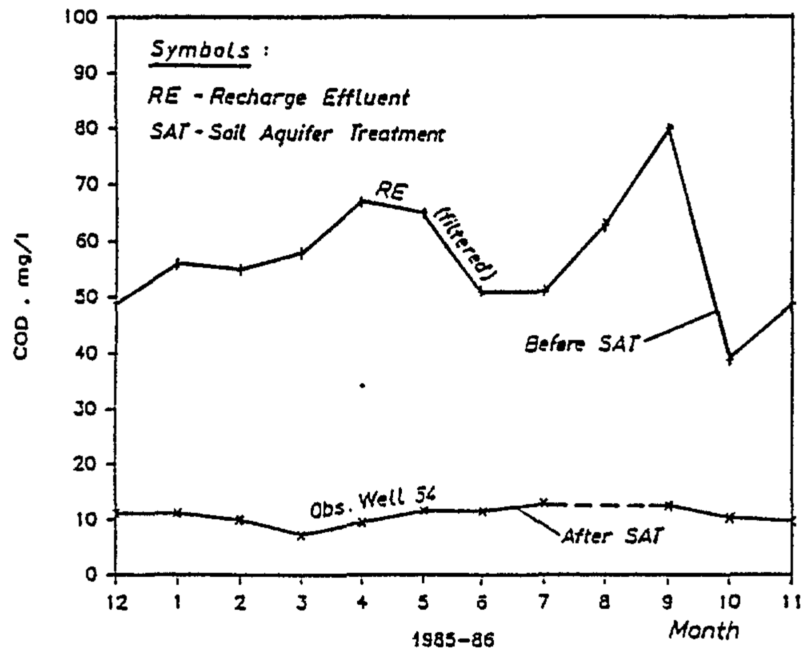
Removal capacity of organic matter by the SAT process is presented in Fig.6 in which organic matter is represented by both COD and permanganate consumption.

Removal capacities of nitrogen and phosphorus by the SAT process are presented in Fig.7. The nitrogen appears in the recharge effluent in ammoniacal and organic forms. During the recharge operation, it is almost completely transformed to nitrate, presumably by nitrification in the upper (aerobic) layer of the unsaturated zone. Part of the nitrate is decomposed by denitrification in lower (anoxic) layers of the unsaturated zone, in such a manner that about 40% of the recharged nitrogen is removed by passage through the unsaturated zone. The phosphorus removal level by the SAT process is around 99%.

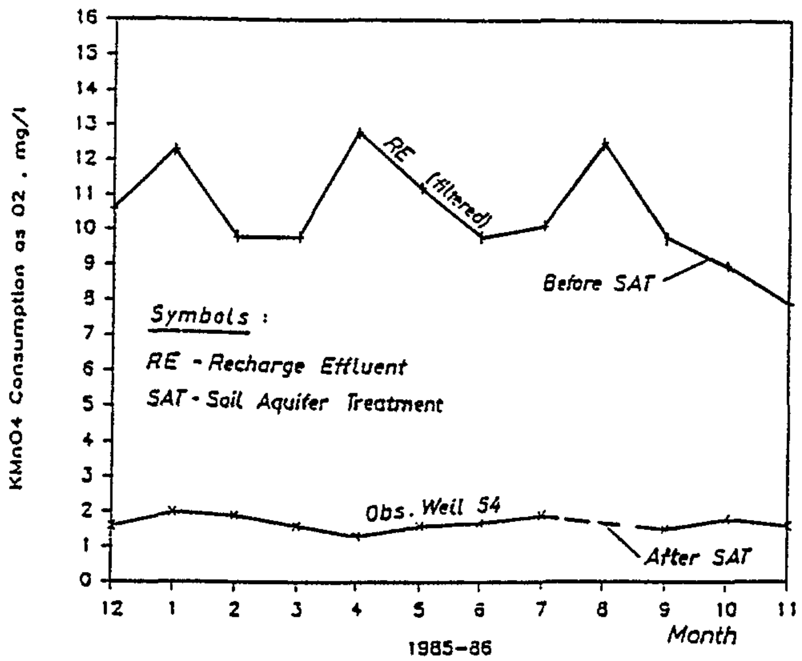
Up to the year 1984, the polishing ponds effluent contained lower concentrations of suspended solids of around 20 mg/l (against around 70 mg/l at present). Since 1985, the suspended solids concentration in the polishing ponds effluent increased as a result of a conceptual operation change. It was recognized that the high level of treatment achieved by the SAT system permits reduction of the pretreatment level without affecting the quality of the reclaimed water. Thus, the lime dose was reduced from about 650 to about 550 mg/l as CaO. As a result, the polishing ponds effluent quality was reduced, but reclaimed water quality was not affected.

The operating costs of the first stage of the Dan Region Project are 13.3 US cent/m^3 reclaimed water, out of which 1.3 US cent/m^3 are the operating costs of the biological treatment plant.

The SAT reclaimed water is of very high quality, as can be seen in Tables III and IV. The reclaimed water is free from suspended solids, coliform bacteria and of viruses and its organic matter content is very low. According to the effluent irrigation standards presented in Table II, which refer to adequacy from the public health risk point of view, the reclaimed water is suitable for unrestricted irrigation of all types of crops, even those eaten raw and unpeeled. The reclaimed water is adequate for unrestricted irrigation also from the agronomic point of view. Chloride, dissolved solids, electrical conductivity, sodium, SAR, boron and trace elements contained in the water are of values which do not present risks to any kind of crops. Moreover, accidental drinking of the reclaimed

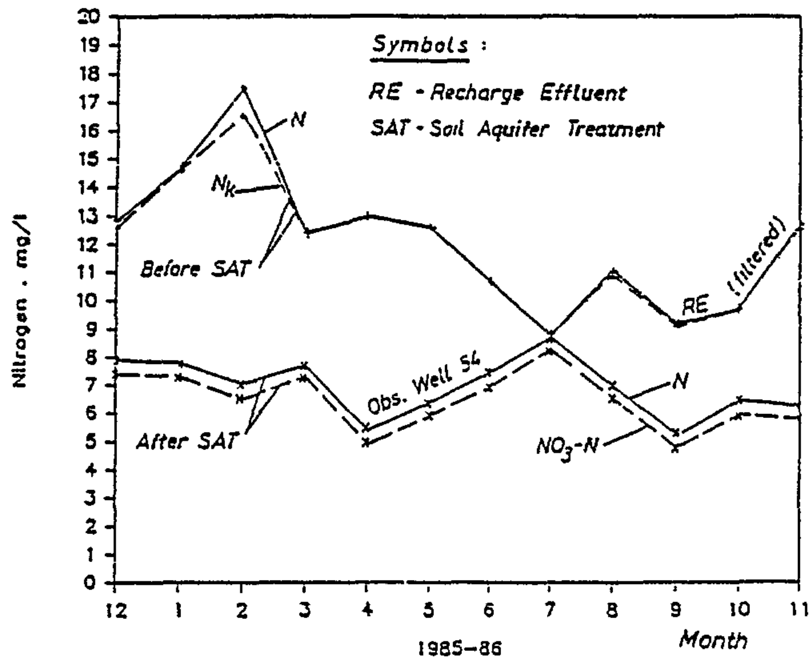


a. Soluble COD Before and After SAT

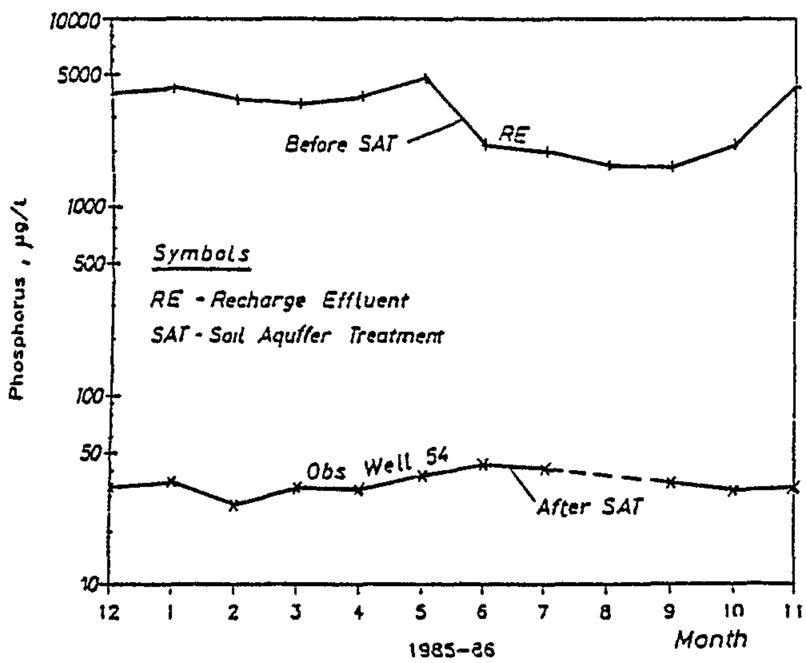


b. Soluble Permanganate Comsumption Before and After SAT

Fig. 6 Soluble Organic Matter Reduction by the SAT Process



a. Soluble Nitrogen Before and After SAT



b. Phosphorus Before and After SAT

Fig. 7 Nitrogen and Phosphorus Reduction by the SAT Process water would not involve major health risks. The concentrations of six toxic substances (cadmium, lead, mercury, selenium, chromium, cyanide) are below those recommended for drinking water. The concentrations of substances affecting the acceptability of water (turbidity, pH, detergents, mineral oil, phenols, chloride, copper, manganese, iron, etc.) are also within recommended limits.

Turbidity is reduced by the SAT from about 25 NTU to 0.4 NTU, a value which fulfills the most stringent drinking water standards. Supplementary treatment of the water pumped from the recovery wells by granular activated carbon will remove dissolved organic matter and may permit potable re-use of the water after disinfection if and when necessary.

At present, the bulk of the effluent recharged by the first stage Dan Region Project is stored in the aquifer, where it has displaced native groundwater towards the production wells which surround the recharge zone and which pump water to the national potable supply network. The majority of the production wells still pump mainly natural groundwater and the water of the supply network contains less than 5% of the effluent- originated water as a result of dilution with natural groundwater and with potable water of the supply network. In the near future, the reclaimed water of both stages of the project will be distributed exclusively for irrigation by means of a separate conveyance system. The construction of this conveyance system is under way and consists of the laying of a main 70" pipeline to the south of the country.

The judicious operation of the recovery wells creates a hydrological barrier, which prevents the effluent from flowing out of the recharge zone, so that wells located in the vicinity of this zone can continue to pump background water for potable use.

The flow diagram of the second stage of the Dan Region Project is presented in Fig.3 and its layout is presented in Fig.4. The pretreatment applied before the SAT in the second stage consists of an extended aeration activated sludge treatment which combines nitrogen removal by nitrification-denitrification in a single sludge system. The principle of nitrogen removal in the system is presented in Fig.8. The system consists of a single biological reactor which is divided into two zones: an anoxic (non-aerated) zone and an aerobic (aerated) zone. A recycle stream (internal recirculation) is operated from the aerobic to the anoxic zone, at a recycle ratio of about 20 to 1 in relation to the raw wastewater flow. Unsettled raw wastewater is introduced to the anoxic zone. The mixed liquor which leaves the biological reactor is diverted to a clarifier in which sludge settling takes place and from which the settled sludge is recycled (external recirculation) to the anoxic zone of the reactor. In the anoxic zone, the raw wastewater is mixed with the two recycle streams. The internal recycle arrives from a zone in which nitrification has already taken place, thus the nitrogen in this stream is in the form of nitrate. Since aeration does not take place in the anoxic zone, a denitrification process develops, as a result of which the nitrate is transformed to molecular nitrogen which is released to the atmosphere. The denitrified mixed liquor, which still contains the ammonia introduced with the raw wastewater, arrives at the aerobic zone. In this zone, the organic matter which remains in the mixed liquor is decomposed and nitrification, which transforms ammonia to nitrate, takes place. Nitrification conditions are assured by maintaining a sludge age long enough to permit development of nitrifying bacteria (Nitrosomonas and Nitrobacter). The organic load utilized in the process is around 0.1 Kg BOD/d/Kg MLSS. Additional information concerning the process can be found in publication 14.

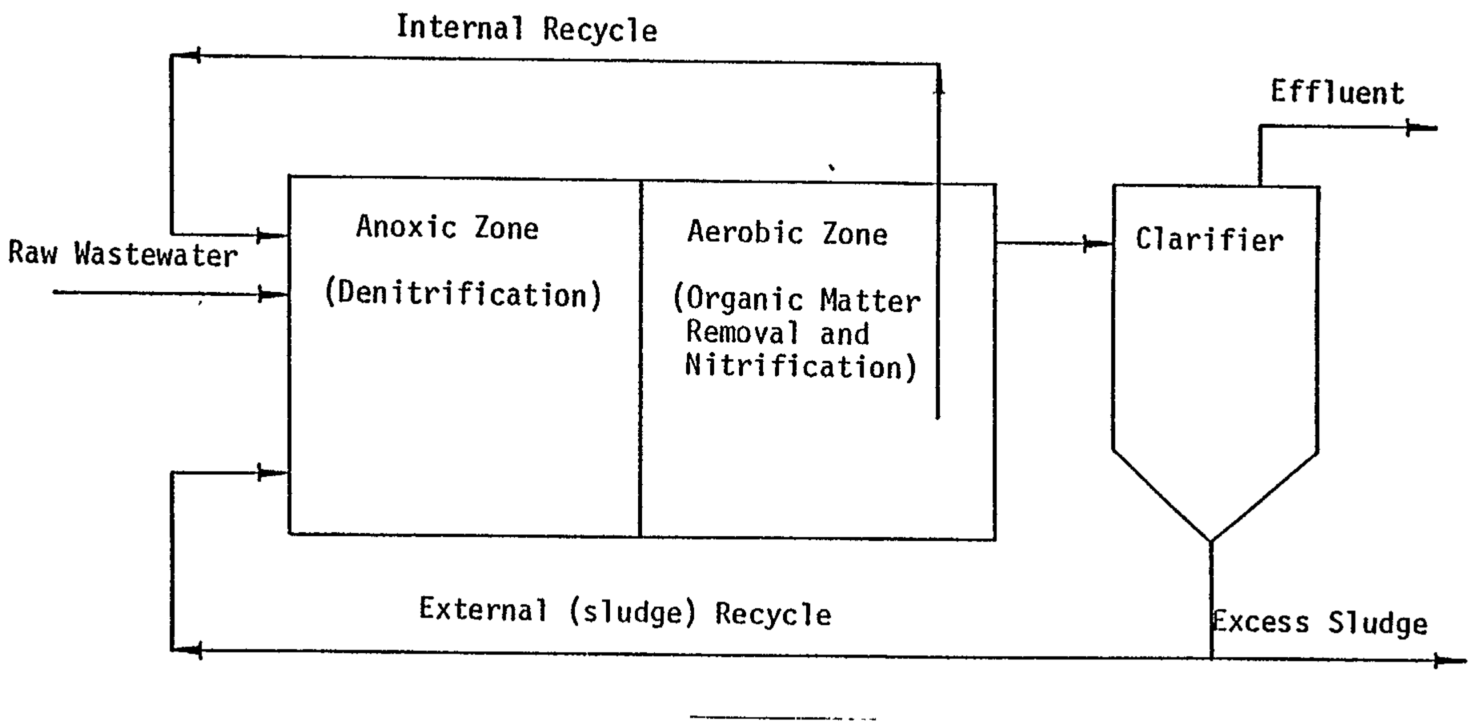


Fig. 8 Flow Diagram of the Combined Sludge System for Organic Matter and Nitrogen Removal

The layout of the second stage treatment plant of the Dan Region Project, is presented in Fig.9. The plant consists at present of two biological reactors of 40,000 m^3 volume each, and 5 clarifiers, common to both reactors, each of 55 m diameter. Each reactor has the form of an endless channel. Aeration is effected by horizontal brush-type aerators (mammoth rotors) which in addition to the introduction of oxygen, cause the endless movement of the mixed liquor in the channel. The liquor flowing in the channel constitutes the internal recirculation stream, to which the raw wastewater and the sludge recycle are introduced in the zone of the reactor which contains no aerators.

The effluent of the activated sludge plant is pumped to the southern recharge basins which consist of two sites (D1, D2) located 8 to 13 km south of the treatment plant (as can be seen in Fig.4). The total area of recharge basins is about 50 ha. At present, only site D1 (of about 25 ha area) is in operation while site D2 is under construction. Sites D3 and D4 might be constructed in the future if necessary.

Although the second stage of the project was only recently put into operation, the treatment process was thoroughly tested in a pilot plant. Typical composition of raw wastewater and effluent based on pilot plant results (12, 14) are presented in Table V.

Table V

Typical Composition of Raw Wastewater and Effluent in the Pilot Plant of the Second Stage Dan Region Wastewater Treatment Process

	Concentration - mg/l	
Parameter	Raw Wastewater	Effluent
BOD_5	357	5.7
BOD_5 filtered	171	4.3
COD	716	68.5
COD filtered	263	49.5
Suspended solids	319	9.6
Total Nitrogen	53.6	3.1
Ammonia (as N)	41.8	0.9
Nitrate (as N)	-	1.2
Phosphorus	12.6	3.7
Chlorides	309	311
Alkalinity	409	311
pH (units)	8.0	8.1

The pilot plant operating results demonstrated the efficiency and reliability of the treatment process for the full scale of local conditions (diurnal and seasonal variations of temperature, flows, and composition of the raw wastewater), with effective BOD and COD removal of 98% and 90% respectively. The total nitrogen removal ranged between 85 to 95% and phosphorus removal between 63 to 95%.

It is anticipated that the water reclaimed by the second stage of the Dan Region Project will be of a quality similar to that of the first stage reclaimed water (Tables III and IV), except for nitrogen which will be of lower content in the second stage reclaimed water, because of the efficient nitrate removal which will take place in the second stage treatment plant.

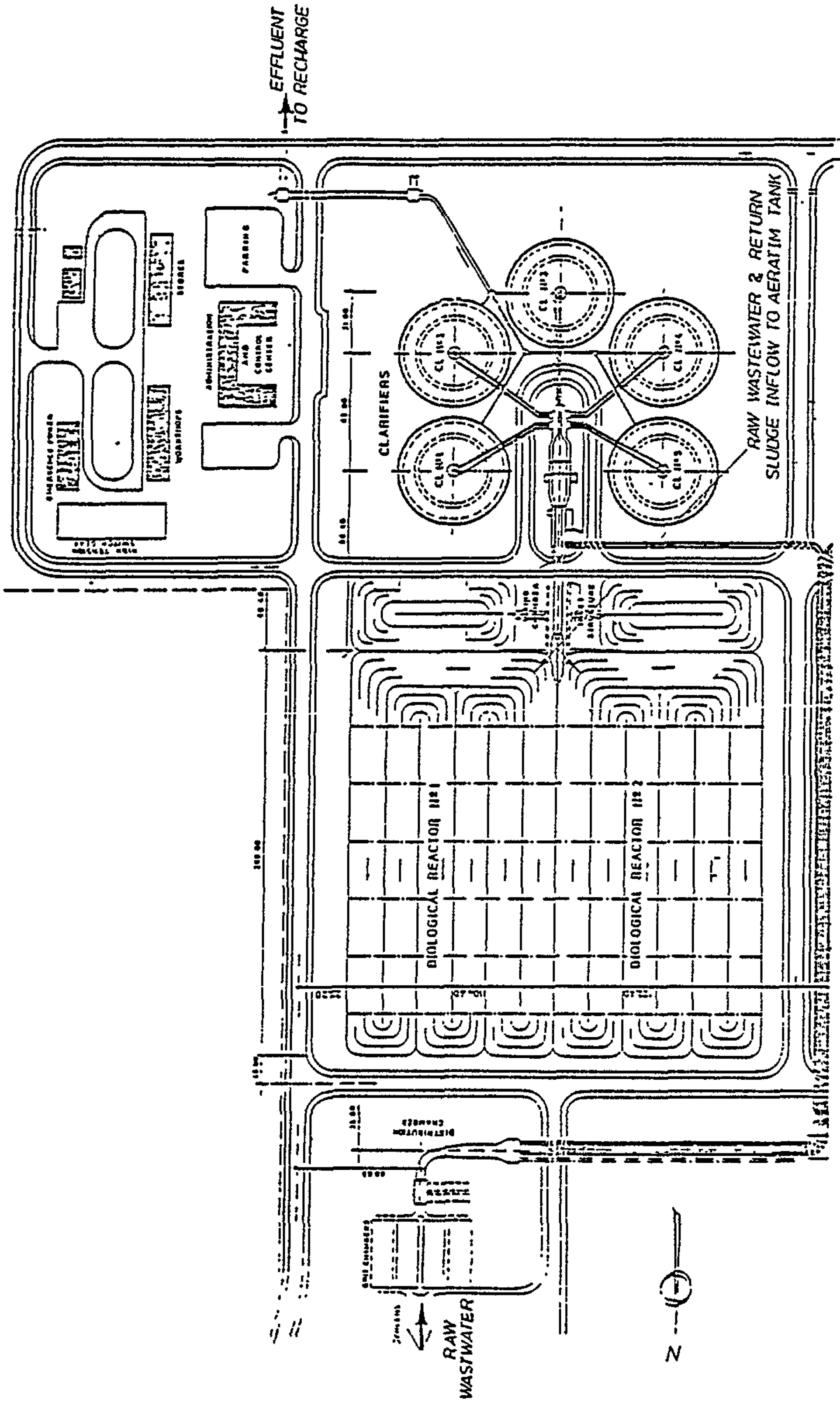


Fig. 9 Layout of the Second Stage Treatment Plant of the Dan Region Project

Activated sludge was selected as the second stage treatment process because of land availability limitations which did not permit adoption of an oxidation ponds treatment as in the first stage. The extended aeration nitrification-denitrification process was chosen because of two reasons: (i) the process yields a high-quality, low suspended solids effluent which will ascertain efficient and reliable groundwater recharge without basin clogging problems, and (ii) as the effluent is to be distributed among a large number of farmers, it was decided to supply water of the highest possible quality in order not to impose any restrictions on types of crops. (Certain crops are sensitive to nitrogen during part of the growth period and could not be cultivated without nitrogen removal.)

A considerable degree of technical skill is required for the operation and maintenance of the spreading basins and the production wells of the SAT system, but the advantage of the process is that it yields an effluent of excellent quality. This may be an important factor in areas which suffer from water scarcity and for which reclaimed water of such a high quality may have an appreciable economic value, as happens in the case of Israel.

6.3 The DRT (Deep Reservoir Treatment) Concept

A deep reservoir is in fact a deep facultative lagoon (7 to 10 m deep) with a water level which varies throughout the year. The reservoir provides the detention time necessary for seasonal storage of the effluent and combines storage with supplementary treatment.

The reservoir is filled throughout the year with effluent at a relatively constant flow while water is withdrawn from it only during the dry season. The water withdrawal period ranges from 5 to 8 months, depending on the type of irrigated crops. During the detention period of effluent in the reservoir, which varies between two to several months, a series of physical, chemical and biological processes takes place and affects the water quality. These processes can improve the quality of stored water, but may also result in quality deterioration and generation of odours.

The objectives of design of an efficient deep reservoir, in addition to providing seasonal storage volume, are: (i) to achieve a high level of supplementary treatment in terms of removal of organic matter, suspended solids, enteric bacteria, viruses and parasites, and (ii) to prevent the generation of odours and adverse environmental effects.

The processes which take place in the reservoir include sedimentation, organic matter decomposition, nitrogen transformation by nitrification, denitrification and ammonia stripping, and biological growth. Biological populations which develop in the reservoir ecosystem include bacteria, algae and zooplankton. Water purification is affected by the activity of aerobic bacteria and algae in the upper layer as well as by anaerobic bacteria in the bottom of the reservoir.

The key to the proper functioning of the reservoir is the prevention of anaerobic incidents at the water surface. The existence of aerobic conditions, at least in the upper layer, prevents the generation of odour problems and ascertains improvement of water quality. Decomposition of organic matter is an oxygen-consuming oxidation process. If the quantity of oxygen supplied by algal photosynthesis and re-aeration is smaller than consumption for bacterial respiration, anaerobic conditions may develop. Such conditions can be prevented by control of the organic loads diverted to the reservoir.

Pano (15) and Lokiec (16) developed oxygen balance models to establish the maximum permissible organic loads which still prevent generation of anaerobic conditions in reservoirs. They estimated that loads of 30 to 50 kg BOD/day/ha during winter and of 60 to 100 kg BOD/day/ha during autumn and summer will prevent the development of anaerobic conditions.

These models take into consideration seasonal effects which include temperature, radiation, water level and surface area, release of dissolved organic matter during summer from anaerobic decomposition of bottom sediments accumulated during winter, and thermal stratification which occurs in summer. It should be noted that the embankments of surface reservoirs are sloped and surface area varies significantly as a function of water level. Towards autumn (around November, i.e. the end of irrigation season) the water level is at its lowest and the surface area is smallest, consequently oxygen production is small and this is a critical period from the point of view of organic loading. Another critical period occurs towards the end of the filling season (April-May) when anaerobic decomposition of bottom sediments starts. The organic surface loading of reservoirs can be correlated with the depth of the daily filled layer (multiplication of that daily depth and BOD concentration in the influent represents the organic surface loading). The maximum permissible depth of daily filled layer is limited, in the range 0.2 to 0.5 m, in accordance with the month and influent quality. The lower value applies in the critical periods mentioned above.

Design of a deep reservoir should take into account, in addition to oxygen balance criteria, specific conditions such as topography, soil type and climatic conditions. Proper design and operation of a seasonal reservoir will result in a significant improvement of the quality of stored water by further reduction of BOD, suspended solids and enteric bacteria.

Treatment in deep reservoirs is included in numerous small re-use schemes in Israel and also in large scale projects such as those of the cities of Haifa (Tishlovet Hakishon Project) and Jerusalem. Over 200 reservoirs of volumes ranging from 20,000 m^3 to 12 million m^3, are in operation under a wide range of operating conditions from low to heavy organic loads, and respectively yielding a wide range of effluent qualities, mainly used for restricted irrigation of cotton, fodder and seed crops.

When effective secondary treatment is applied as pretreatment and the reservoir is properly designed, its effluent may be utilized for unrestricted irrigation. When lower pretreatment is applied, the reservoir effluent is appropriate only for restricted irrigation.

The volume of a seasonal reservoir for a given wastewater flow depends on the types of irrigated crops and on the land occupation scheme (which dictates the distribution of water consumption for agriculture). Under Israeli conditions, the required reservoir volume for irrigation of cotton is about 65 to 70% of the yearly wastewater volume, while for irrigation of orchards, only 40 to 50% of the yearly wastewater volume is required for storage.

The dimensions of the reservoir (surface area and height) depend on permissible BOD surface loading and on topographical conditions, and are to be established in coordination with the selected pretreatment. Proper design of the reservoir and the pretreatment system is a result of an optimization process which takes into account crop types and their land occupation, land availability for reservoir construction and design criteria required to maintain an aerobic upper layer in the reservoir.

Reservoirs should not be completely emptied even towards the end of the irrigation season. The lowest water level should permit a detention time of about two months, allowing sufficient effluent quality improvement at all times and maintaining rich bacterial and algal population right from the beginning of the filling period.

Some typical reservoir types and construction details are presented in Fig.10. Water losses in reservoirs occur through infiltration and evaporation. Infiltration is minimized by lining the reservoir's bed with packed clay or plastic sheets. Evaporation losses can be decreased by increasing depth. Common values of water losses in a lined reservoir are 10 to 15% of the yearly water flow. The embankment cross section presented in Fig.10 refers to the case in which clay is used for lining. Plastic lining is gaining popularity in recent years and no rip-rap nor clay grain in the embankment are needed when exposed plastic lining is used.

Suspended solids concentrations in the upper layer of the reservoir are variable with time as a function of the dynamics of algal populations. The best point for withdrawal of effluent from the reservoir is about 1 to 2 metres beneath water surface level. Light penetration at such depth is limited, resulting in a limited presence of algae and minimal concentrations of suspended solids. Effluent withdrawal is in most cases accomplished by a floating outflow installation (raft pipe) as shown in Fig.10.

Effluent quality data of some DRT schemes is presented in the following. The wastewater re-use scheme of the city of Haifa incorporates a 12 million m^3, 10 m deep reservoir located about 20 km from the city. The reservoir receives a mixture of activated sludge-trickling filtre effluents which are chlorinated within the city limits. The applied pretreatment is an effective one, though coliform count of the inflow to the reservoir is about 10^5 MPN/100 ml as a result of regrowth in the conveyance pipe. According to the study carried out by Rebhum et al.(17), the reservoir effluent contains 6.5 mg/l total BOD, 14 mg/l suspended solids, 25 mg/l ammonia, 4 x 10^2 MPN/100 ml total coliform bacteria and 10^2 fecal coliform bacteria (average values - Table VI). Such effluent is of very high quality and after being chlorinated it is used for irrigation of all type of crops except those eaten raw and unpeeled.

Such a high level of pretreatment is uncommon in DRT systems in Israel. Usually a lower level of pretreatment is applied, generally consisting of anaerobic ponds, oxidation ponds or aerated lagoons while reservoirs' effluents are permitted only for restricted irrigation of category A crops (Table II).

Pano (15) investigated two reservoirs: Sarid and Mizra. (Maximum volumes 390,000 and 325,000 m^3 respectively.) During the investigated period, the Sarid reservoir received a mixture of oxidation ponds effluent of the city of Afula and surface runoff water. The filling period started in September and was stopped in March. Withdrawal of effluent for irrigation of cotton started in May. From March to the end of the irrigation season (October) the reservoir did not receive any inflow. BOD concentration of Afula effluent was about 120 mg/l, and the BOD loading on the reservoir was around 35 kg BOD/day/ha throughout the filling period. 63% of the stored water was of Afula effluent origin. Measured quality parameters of the water stored in Sarid reservoir are presented in Fig.11.

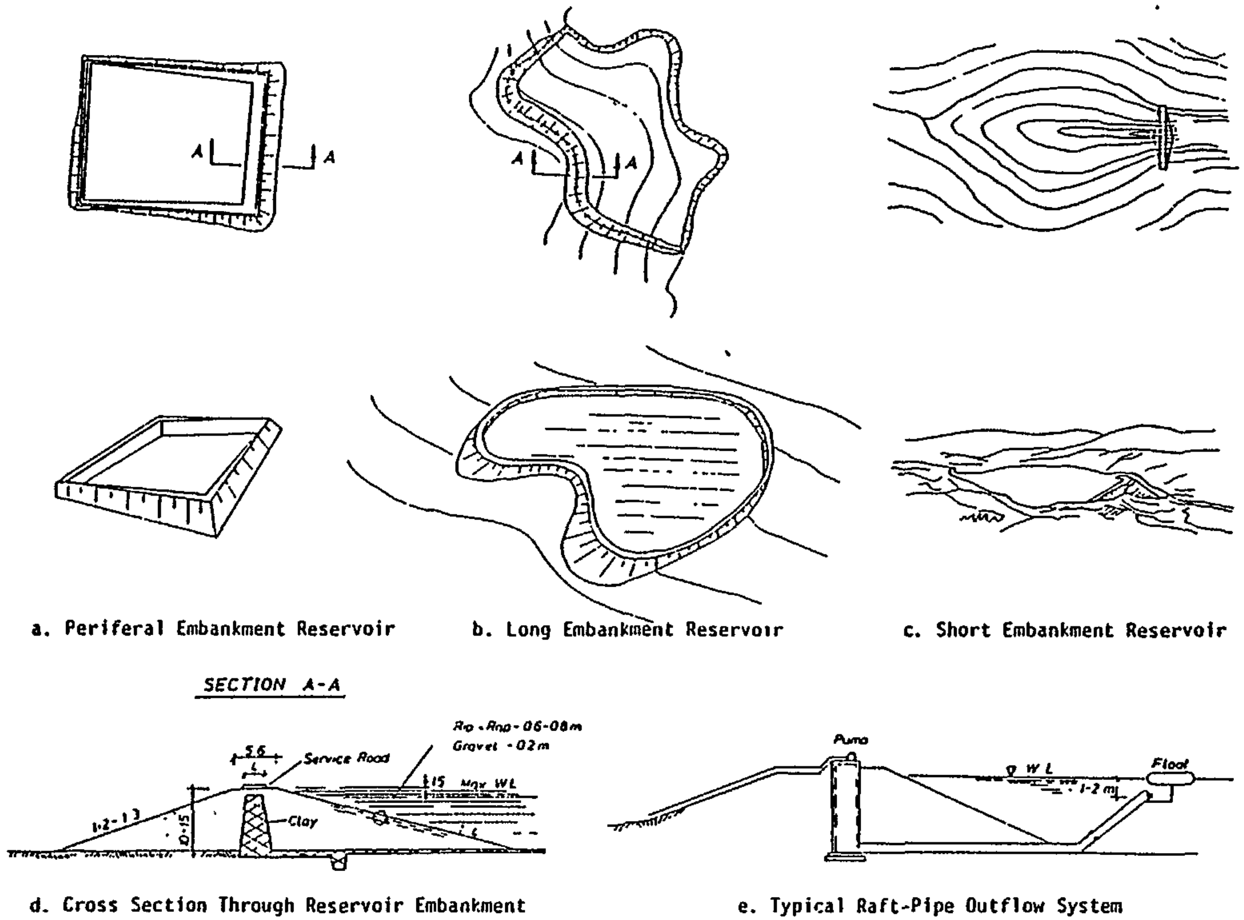
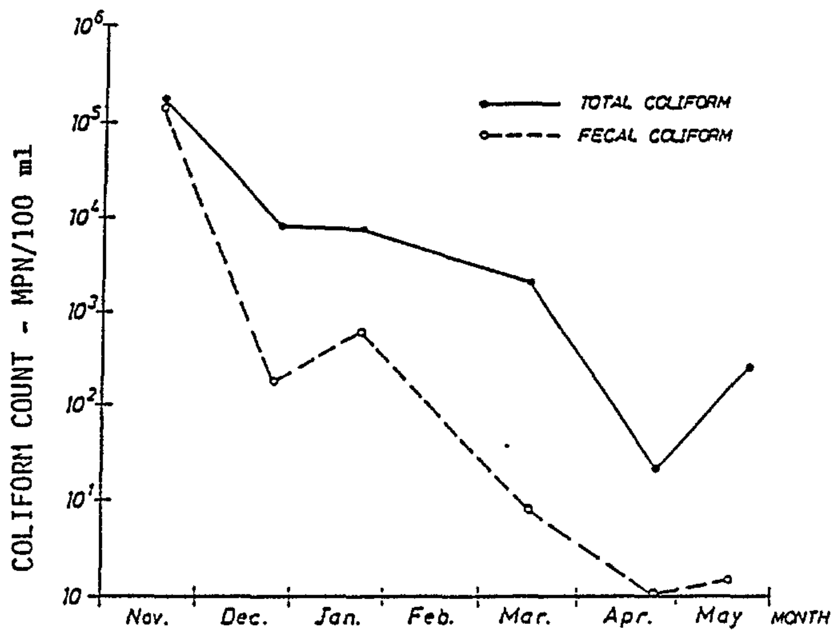
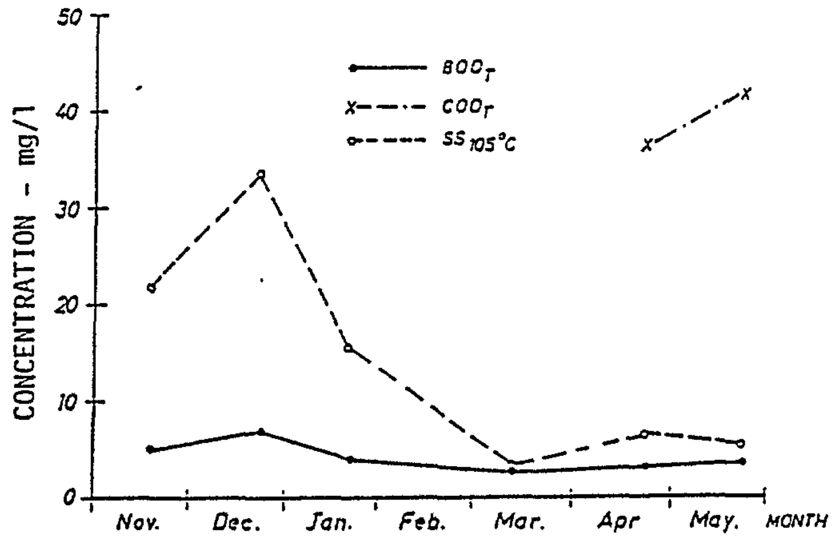


Fig. 10 Seasonal Storage Reservoirs: Types and Construction Details



a. Total and Fecal Coliform Bacteria



b. Total BOD, Total COD and Total Suspended Solids

Fig. 11 Variation of Quality Parameters in the Water Stored at Sarid Reservoir. Adopted from Pano (15) (Samples withdrawn from Water Surface)

Table VI

Haifa Wastewater Re-use project - Water Quality At Various Points Along the Treatment Process

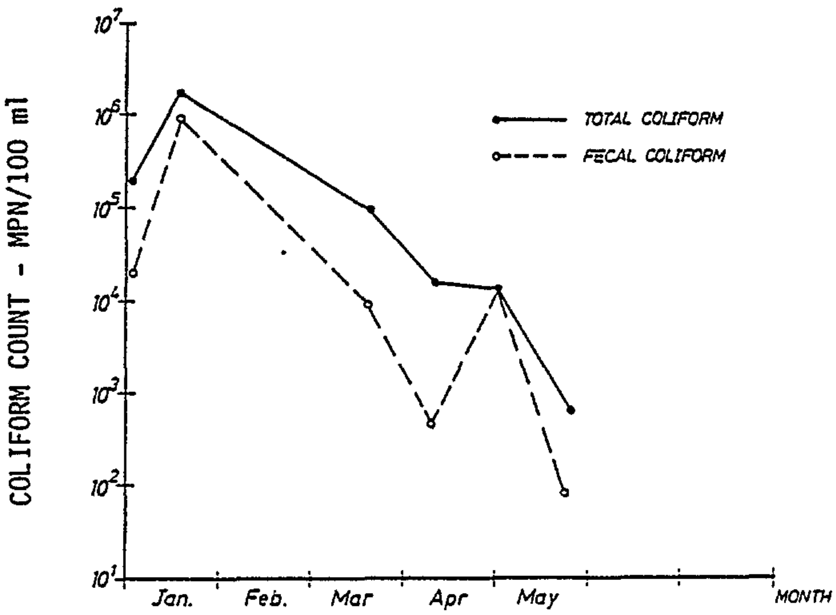
Parameter	Concentration-mg/l		
	Raw Wastewater	Activated Sludge Effluent	Seasonal Storage Reservoir Effluent
Suspended Solids	717	38	14
BOD_5	618	57	6.5
BOD_5 Filtered	115	12.3	3.0
COD	1272	116	58
COD Filtered	197	62	48
Detergents	7.1	0.5	0.5
NKT as Nitrogen	85	41	24.7
Ammonia as Nitrogen	55	34	20.6
Nitrate as Nitrogen	0.7	5.6	0.9
Phosphorus	12.8	6.1	5.6
PH (Units)	7.7	7.9	8.1
Total coliform (MPN/100 ml)		10^7	$4x10^2$
Fecal Coliform (MPN/100 ml)		10^6	$1x10^2$
		Pretreatment	Deep Reservoir Treatment

Mizra reservoir received a mixture of three types of water: primary effluent from the city of Nazareth, oxidation ponds effluent from Kibbutz Mizra and surface runoff water. The BOD concentrations of both effluents were high because both treatment installations were overloaded. The effluent from Nazareth contained about 600 mg/l of BOD and Mizra oxidation ponds effluent contained COD concentrations of about 600 mg/l (it treats also wastewater of a meat processing plant). Only 23% of the stored water was of effluent origin. During December-January, the organic loading was about 7 kg BOD/day/ha whereas from February on, the loading decreased as the portion of runoff water in the reservoir influent increased. Irrigation of cotton with reservoir water started in June, but the reservoir filling did not stop before and during the irrigation season (as opposed to the operation regime of Sarid reservoir which was not filled during the irrigation season). Measured quality parameters of the water stored in Mizra reservoir are presented in Fig.12.

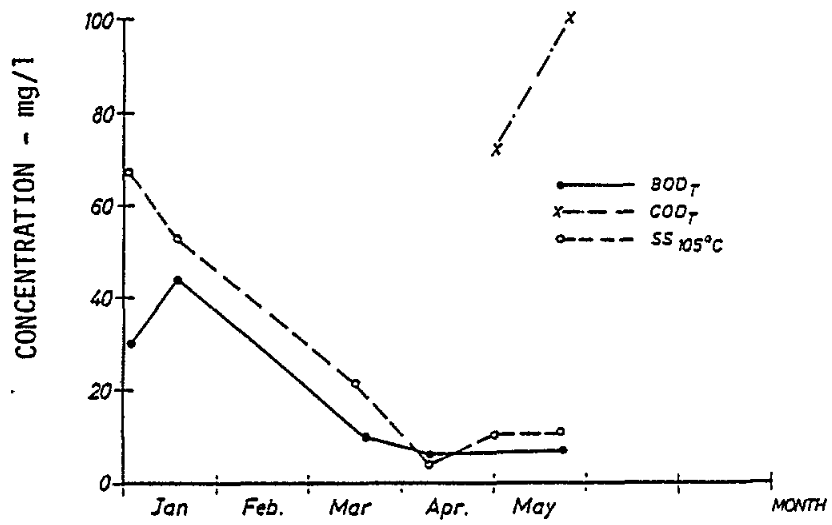
The physico-chemical quality of the water in both reservoirs was excellent. Organic matter decomposition took place in both reservoirs and BOD concentration towards the start of the irrigation season was in the range 5-7 mg/l. Suspended solids concentrations were around 10 mg/l. These values were measured in samples collected at the water surfaces. In samples withdrawn 1 m beneath surface, both BOD and suspended solids were lower.

Coliform reduction in Sarid reservoir was very marked. Towards the beginning of the irrigation season, total coliform count in the stored water was in the range 30-240 MPN/100 ml while fecal coliform count was in the range 0-2 MPN/100 ml.

Coliform reduction in Mizra reservoir was lower than that of Sarid reservoir. Total coliform count in Mizra stored water at the beginning of the irrigation season was around 10^3 MPN/100 ml and fecal coliform count



a. Total and Fecal Coliform Bacteria



b. Total BOD, Total COD and Total Suspended Solids

Fig. 12 Variation of Quality Parameters in the Water Stored at Mizra Reservoir, Adapted from Pano (1976) (Samples withdrawn from Water Surface) around 10^2 MPN/100 ml. The difference in coliform bacteria reduction may be explained by the fact that effluent inflow to Sarid reservoir was stopped two months before the irrigation season while the Mizra reservoir received an inflow of water, part of which was of effluent origin, throughout the irrigation season and did not enjoy a period of two months without a heavily bacteria-loaded inflow stream.

The above data led to the conclusion that in order to achieve an effective reduction of fecal coliform bacteria, seasonal reservoirs should be constructed of two or more cells in such a manner that effluent inflow to each cell is stopped two months before the start of water withdrawal for irrigation. But most reservoirs in Israel are single-cell reservoirs because their effluents are utilized for irrigation of category A crops (Table II), which do not require coliform-free effluents. As a result of his work, Pano concluded (15) that for properly designed and operated single-cell reservoirs, the expected effluent quality is: BOD 5-10 mg/l, suspended solids 5-20 mg/l, fecal coliform count 10^2-10^3 MPN/100 ml and 50-25% ammonia removal.

Random samples of the two Hafetz-Haim reservoirs, withdrawn and analyzed by the Ministry of Health staff in August, 1984 (18), indicated total coliform counts of 3 x 10^2 and 16 MPN/100 ml and fecal coliform counts of 10 and nil in the northern and southern reservoirs respectively. The filling regime and operating conditions of the reservoirs were not mentioned in the report, but these random samples give an indication of the high bacteria removal levels which may be achieved by DRT.

Kott et al. (19) estimated that ponding of secondary effluents for a period of a few weeks will cause E. Hystolytica cysts to settle, Salmonella to die away and enteric viruses to be inactivated.

The presented data and additional studies carried out in Israel demonstrate that in addition to a substantial improvement in the physico-chemical effluent quality, a reduction of 2 to 4 orders of magnitude in coliform bacteria count may be achieved in DRT under regular operating conditions and even higher reduction levels may be achieved if influent flow is stopped before the irrigation period. Reduction of enteric bacteria and viruses may be explained by the influence of radiation and predation by other organisms.

According to Shuval et al. (3), oxidation ponds with a retention time of 20 days will achieve effective control of helminths and protozoa. It may be assumed that deep storage reservoirs in which the retention time is much higher than 20 days, will completely remove parasites.

Considering effluent quality requirements by the Engelberg report (5), deep reservoir effluent may be supplied under certain conditions (adequate pretreatment, and sometimes post-chlorination) for unrestricted irrigation. Construction of multiple-cell reservoirs may ascertain effluent quality for unrestricted irrigation according to the Engelberg report requirements and perhaps also according to the Israeli regulations.

Most of the wastewater reservoir effluent in Israel is distributed for irrigation utilizing the drip irrigation method. The drip irrigation system is regarded as a component of the re-use scheme and the combination of DRT and drip irrigation comprises the combined agro-sanitary system. Detailed information on the drip irrigation method is given in the manual by Dasberg and Bresler (20). In addition to its advantages as an efficient irrigation method, drip irrigation serves as an additional treatment step, operating in a similar manner to that of a trickling filter. But the greatest importance of incorporating the drip irrigation in the re-use scheme is the safety it provides in terms of preventing dispersion of bacteria and viruses in the air and on irrigated crops. Recently, a sub-surface drip irrigation system has been developed which in addition to a series of agronomic advantages, as presented in publication 20, its use in effluent irrigation may present an outstanding advantage by further diminishing and almost eliminating health risks associated with wastewater re-use.

Pretreatment of the reservoir effluent is required before its distribution by drip irrigation. A typical treatment system is presented in Fig.13. A complete system includes a primary straining stage (40 to 60 mesh), rapid gravel filtration (at ranges of 40 to 70 m/hr) and a secondary finer straining stage (80 to 150 mesh). In certain cases, depending on effluent quality, primary straining or gravel filtration is omitted. Usually, secondary straining is not accomplished by a central unit but rather by small diameter strainers located on the main pipes at their entrance to the plots. Strainers and filters are available with automatic or manual control modes. Additional information concerning such filters and strainers utilized before irrigation is presented in publication 20. A review of the problems associated with effluent treatment before drip irrigation and their prevention is presented by Adin (21), but it may be stated that farmers in Israel have learned to overcome the problems and drip irrigation with effluents is in widespread use. It should be noted that similar filtration-straining is required even when drip irrigation is practised with fresh water, thus irrigation with effluent does not imply a significant additional burden on farmers from the irrigation pretreatment point of view.

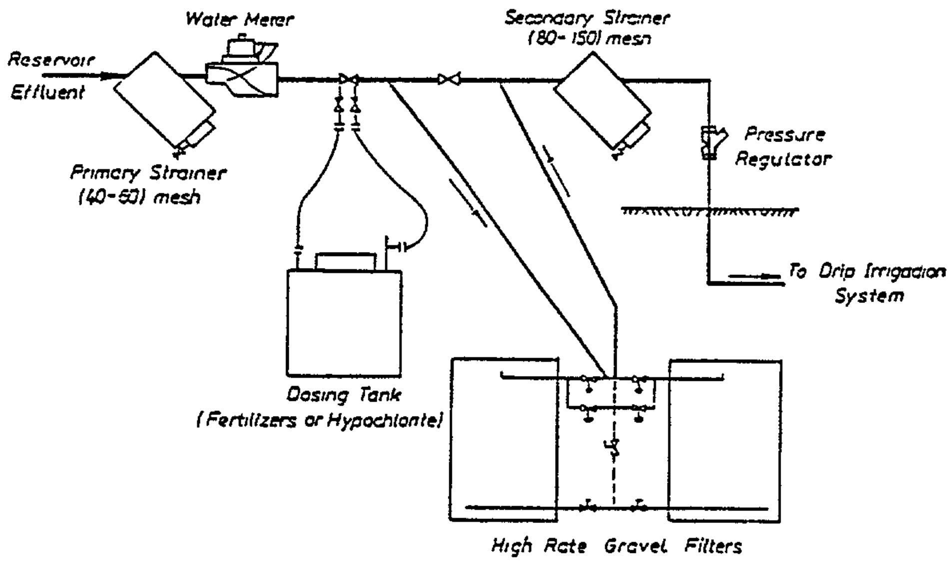


Fig. 13 Treatment of Reservoir Effluent Before Drip Irrigation

At certain periods, effluent chlorination is necessary to control attached bacterial growth at the dripper's nozzles or for excess algae control. This is done by hypochlorination utilizing systems similar to those used for fertilizer dosage, as described in Fig.13. This type of chlorination may also be constantly applied for upgrading effluent quality to that adequate for unrestricted irrigation.

Recent economic estimates for a specific DRT system indicated that effluent cost at the field, including all treatment and conveyance systems from the point of wastewater discharge to the point of influent to the drip irrigation pipes, (including cost of drip irrigation pretreatment but excluding the cost of the drip irrigation system itself) is 0.14 US$/$M^3$. This includes capital recovery and all annual costs.

The combined DRT-drip irrigation re-use scheme is a simple, economic wastewater disposal and re-use method. It does not require high skills for operation and maintenance and may yield effluents adequate for either restricted or unrestricted irrigation, in accordance with pre-and post-treatment applied. It is in widespread use in Israel, mainly for the restricted irrigation of cotton, forage crops, orchards and citrus groves.

7. INFLUENCE OF EFFLUENT IRRIGATION ON CROPS AND SOIL

Irrigation with secondary and seasonal storage reservoirs effluents has been successfully practised in Israel for many years. Research and follow-up of such irrigation practice from the agronomic point of view is performed frequently. Findings of such a research (22) indicate that:

1. Under soil and climate conditions prevailing in Israel and when utilizing typical municipal effluents, no significant increase was detected in the salinity of soils irrigated with effluents, and such irrigation does not present a specific problem for crop yield and quality.

2. A tendency towards soil sodification was detected. The rate of the process depends on effluent quality, irrigation regime, crop type, soil characteristics and climatic conditions. No damage to soil and crops as a result of sodification was registered after several years of irrigation with typical municipal effluents and the same results are anticipated for irrigation over extended periods (20 years).

3. Irrigation with common municipal effluents (which do not contain heavy industrial loads) did not cause the soil and crop damage which is associated with heavy metals contribution.

4. Concentration of nutrients (nitrogen and phosphorus) in soil at plots irrigated with effluent is significantly higher than in plots irrigated with well water. Nutrients contained in the effluent can substitute for those supplied in fertilizers and thus save fertilization expenses. The fertilization value of the effluent should be incorporated in the programming of the fertilizing regime. Failure to do so may result in migration of excess nitrates towards the water table and pollution of groundwater (in addition to waste of money for unnecessary fertilizer purchase). But irrigation with effluent means continuous fertilization, which may present a problem for crops sensitive to excess nitrogen.

5. It is possible to achieve high crop yields in plots irrigated with effluents and the quality of products is usually good (depending on crop type). But there is a difference in the qualities of effluent and fresh

water. As a result, irrigation and fertilizing regimes should be adjusted to the utilization of effluents, in accordance with the type of crops. Proper irrigation and fertilizing regimes result in high crop yields even in effluent irrigation of sand dunes under soil and water conditions which are considered marginal.

As a consequence of the above findings, it may be concluded that successful effluent irrigation-based agriculture may be developed by adopting irrigation-fertilizing regimes based on effluent quality and on characteristics of soil and crops.

8. REFERENCES

1. Israeli Ministry of Health, "Recommendations for Treatment of Wastewater to be Used for Crop Irrigation", Second Draft, November 1979.

2. Israeli Ministry of Health, "Public Health Law No. 4263: Purification of Sewage Water to be used for Irrigation", 27 August, 1981.

3. Shuval, H., et al., "Wastewater Irrigation in Developing Countries - Health Effects and Technical Solutions", World Bank Technical Paper Number 51, The World Bank, Washington, D.C., 1986.

4. Shuval, H., et al., "State of the Art Review: An Epidemiological Approach to the Health Effect of Wastewater Re-use", Wat. Sci. Tech., Vol. 18, pp. 147-162; 1986.

5. The Engelberg Report, "Health Aspects of Wastewater and Excreta Use in Agriculture and Aquaculture". The report of a Review Meeting of Environmental Specialist and Epidemiologists, held at Engelberg, Switzerland, July 1-4, sponsored by the World Bank and World Health Organization, 1985.

6. Gunnerson, G.C., et al., "Health Effects of Wastewater Irrigation and Their Control in Developing Countries", Water Re-use Symposium III, of the American Waterworks Association, held at San Diego, California, 21-23 August, 1984.

7. Mintzker, N., Sas, N., "Yehuda and Shomron Region - Master Plan for Development of Systems for Treatment and Disposal of Wastewater", TAHAL Report No. 01/13/28, 1983 (in Hebrew).

8. Libhaber, M., et al., "Segev-Tefen Region - Regional Master Plan for Wastewater Disposal and Re-use", TAHAL Report No. 01/84/118, 1984 (in Hebrew).

9. Idelovitch, E., Michail, M., "Soil Aquifer Treatment - a New Approach to an Old Method of Wastewater Re-use", J.WPCF, Vol. 56, No. 8, pp. 936-943, 1984.

10. Rice, C.R., Bouwer, H., "Soil Aquifer Treatment Using Primary Effluents", J. WPCF, Vol. 56, No. 1, pp. 84-88, 1984.

11. Idelovitch, E., Terbeltaub, R., Michail, M., "The Role of Groundwater Recharge in Wastewater Re-use: Israel's Dan Region Project", Journal AWWA, July, pp. 391-400, 1980.

12. Arueste, G., "Advanced Municipal Wastewater Treatment by a Single Stage Activated Sludge System", Prog. Wat. Tech. Vol. 12, No. 5, pp. 533-550, 1980.

13. Michail, M., Goldman, B.Z., Kanarek, A., Sherer, D., "Treatment and Groundwater Recharge of Municipal Wastewater", Dan Region Project, Year 1986 Annual Report, Tahal Ltd., Mekorot Ltd., TAHAL Report No. 01/86/64, Tel Aviv, April 1987.

14. Libhaber, M., "Dynamic Simulation of Nitrification Denitrification Processes in an Activated Sludge System", Ph.D. Thesis, Technion-Israel Institute of Technology, Haifa, Israel, August 1979 (in Hebrew).

15. Pano, A., Berend, J., "Winter Storage of Effluents", TAHAL Report No. 01/76/15, 1976 (in Hebrew).

16. Lokiec, E.F., "Behaviour of a Reservoir for Seasonal Storage During the Filling and Storage Period (Winter and Spring)", M.Sc. Thesis, Technion-Israel Institute of Technology, Haifa, Israel, 1983 (in Hebrew).

17. Rebhun, M., et al., "Monitoring of Tishlovet Hakishon Project", Annual Report No. 3, April 85-March 86, Technion-Israel Institute of Technology, Haifa, Israel, 1986 (in Hebrew).

18. Ministry of Health, "Field Survey of the Performance of Wastewater Treatment Installations at Kibbutz Hafetz-Haim", Report No. TB/MM-8/84, Ministry of Health, Ramla Regional Office, August, 1984 (in Hebrew).

19. Kott, Y., et al., "Lagooned Secondary Effluents as Water Source for Extended Agricultural Purposes", Water Research, Vol. 12, pp. 1101-1106, 1978.

20. Dasberg, S., Bresler, E., "Drip Irrigation Manual", Publication No. 9, International Irrigation Information Centre, The Volcani Centre, Bet Dagan, Israel, 1985.

21. Adin, A., "Problems Associated with Particulate Matter in Re-use for Agricultural Irrigation and their Prevention", Wat. Sci. Tech., Vol. 18, pp. 185-195, 1986.

22. Feigin, A., et al., "Utilization of Effluents for Irrigation of Agricultural Crops", Final Report for the period 1978-1981, Research Programme No. 714000, Agricultural Research Organization, The Volcani Centre, Bet Dagan, Israel, 1981 (in Hebrew).

L'EXPERIENCE TUNISIENNE EN MATIERE DE TRAITEMENT ET D'UTILISATION DES EFFLUENTS URBAINS POUR L'IRRIGATION ET POUR D'AUTRES FINS

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RESUME

En Tunisie et dans les régions arides et semi-arides, l'eau constitue un facteur limitatif de la production végétale. L'introduction des eaux usées traitées comme ressource complémentaire peut contribuer à la satisfaction des besoins en eau d'irrigation. Par ailleurs, l'utilisation des boues résiduaires comme amendement organique pourrait concourir à l'amélioration de la fertilité des sols.

Ainsi, la valorisation agricole des eaux usées et des boues résiduaires, évoquée depuis longtemps en Tunisie, s'impose à l'heure actuelle. La connaissance approfondie de ces deux composantes et la maîtrise des techniques relatives à leur utilisation impliquent la mise en place d'une infrastructure expérimentale.

L'inscription de ce thème à vocation multidisciplinaire dans les programmes de recherche du C.R.G.R. (Tunisie) a permis principalement la mise au point d'une stratégie de travail qui intègre l'expérimentation au champ et des analyses de laboratoire. Les principaux résultats obtenus, relatifs à la caractérisation physico-chimique et bactériologique des eaux et des boues et à l'incidence de leur utilisation sur le système sol-plante, sont développés dans la présente note.

1. INTRODUCTION

Dans les zones arides et semi-arides, l'intensification de l'agriculture nécessite d'épargner et de valoriser des ressources en eau et d'améliorer la fertilité des sols. Les ressources hydriques et organiques conventionnelles étant limitées eu égard aux besoins futurs, l'introduction des eaux usées traitées et des boues résiduaires s'avère essentielle et même prioritaire.

Les volumes d'eaux usées traitées, en Tunisie en 1985, ont été de 43 millions de m^3. Ils s'élèveront probablement à 180 millions de m^3 en l'an 2000. La superficie irrigable avec les eaux usées traitées pourra atteindre alors 18000 ha environ, soit 7% de l'ensemble des terres irriguées. A l'heure actuelle, elle couvre 1140 ha.

L'assainissement et le traitement des eaux usées sont pratiqués depuis 1940 à la station de la Cherguia (Tunis). Actuellement, l'Office National de l'Assainissement (ONAS) prévoit l'augmentation du nombre de stations d'épuration de 26 en 1986 à 54 en 1996. Toutes les stations sont du type biologique et traitent les eaux jusqu'au niveau secondaire. Les différents procédés utilisés sont les boues activées à moyenne et faible charge, le lit bactérien, le lagunage facultatif ou aéré.

Cependant, l'utilisation en agriculture des eaux et des boues soulève différents problèmes d'ordre agronomique et sanitaire qui exigent des recherches préalables et la mise en place d'une infrastructure expérimentale.

Ce travail a été réalisé par une équipe pluri-disciplinaire dans le cadre d'un projet de recherche CRGR-PNUD (RAB 80/011) intitulé "Utilisation des eaux usées après traitement en agriculture".

Si de nombreux travaux ont été réalisés sur ce sujet en Europe et ailleurs: INRA-SCP (1979), Boutin et al (1979), Cohen (1979), CEE (1979), Henin (1980), OMS (1983), Bradley et Hadidy (1981), CEE (1981), Bouwer (1982), Boutin (1982), Cottenie et al (1981), Juste (1983), IAWPRC (1983), Prost (1986), les études effectuées dans ce domaine restent limitées dans le Maghreb.

Aussi, nous avons entrepris par l'expérimentation en plein champ et par des analyses de laboratoire:

- l'étude de la variabilité spatio-temporelle de la composition chimique et microbiologique des eaux et boues;

- la comparaison des effets séparés et conjugués des eaux usées traitées, des boues résiduaires et de la fertilisation minérale sur le sol et la plante;

- l'évaluation de la valeur fertilisante et de la charge polluante de ces deux milieux et leurs limites d'utilisation.

2. MATERIELS ET METHODES

2.1 Les eaux et les boues

Les eaux proviennent des stations d'épuration biologique par boues activées de la Cherguia (Tunis) et de Nabeul (SE_4). Elles sont à 90% d'origine domestique. Ces stations traitent respectivement 40.000 et 4.600 m^3/j. d'eau usée et produisent quotidiennement 155 et 30 m^3 de boues digérées humides. Les boues, séchées sur lits, sont à 65% environ de matière sèche et sont utilisées en agriculture.

2.2 Le sol

Le sol de la station expérimentale de la Soukra (proche de la Cherguia) est peu évolué, alluvial: il présente une texture sablo-argileuse à sableuse (Tableau I) et repose sur une croûte calcaire dure de 20 cm d'épaisseur et de profondeur variable (Chaabouni, 1986).

L'analyse des caractéristiques chimiques montre que le sol est riche en carbonate de calcium, pauvre en carbone, en azote et a des teneurs moyennes en phosphore assimilable. La composition de l'extrait de pâte saturée indique que ces sols ne sont pas chargés en sels, ce qui est en rapport avec leur texture. Les concentrations en éléments traces sont moyennes; la séquence trouvée dans le sol est:

Mn > Zn > Pb > Ni > Cu > Cr > Co > Cd

2.3 Le protocole expérimental

Les expérimentations réalisées consistent à comparer les effets d'apports d'eau usée traitée, de boue résiduaire et d'une fertilisation minérale.

Le protocole expérimental comporte 4 traitements:

A. : Irrigation eau usée traitée
B. : Irrigation eau usée traitée + boue
C. : Irrigation eau usée traitée + fertilisation minérale
D. : Irrigation eau usée traitée + boue + fertilisation minérale.

Le dispositif en blocs randomisés complets comporte 6 répétitions par traitement sous forme de parcelles de 100 m^2.

Les essais entrepris ont été effectués sur une culture fourragère, le sorgho, et une culture maraîchère, le piment.

TABLEAU I

Caractéristiques physiques et chimiques du sol

	% terre fine					%		% terre fine			
	A% 0-2 μ	L% 2-20 μ	STF% 20-50 μ	SF% 50-200 μ	SG% 200-2000 μ	CaCo,t	CaCo,a	C	N	C/N	P_2O_5ass.
0-20cm	13,6	6,0	5,8	60,0	14,3	20,0	3,7	8,0	0,80	10,0	0,21
20-40cm	15,1	3,9	5,1	61,7	14,3	19,0	3,5	7,1	0,65	10,7	0,21

			meq./l (P.S.)								ppm terre fine							
	pH (P.S.)	$E.C_e$ (P.S.)	Ca	Mg	K	Na	HCO_3	SO_4	Cl	S.A.R.	Cd (P.S.)	Co	Cr	Cu	Mn	Ni	Pb	Zn
0-20 cm	7,8	0,89	5,5	2,3	0,2	1,9	4,4	3,1	2,4	0,96	0,27	15,5	25,8	26	218	34	39	44
20-40 cm	7,6	0,96	4,7	2,5	0,1	2,2	2,9	3,5	3,2	1,16	0,15	16,3	27	25	211	32	35	40

$E.C_e$: Conductivité électrique en mmhos/cm à 25°C
S.A.R. : Indice d'adsorption du sodium
P.S. : Extrait de pâte saturée

A : Argile
L : Limon
SG : Sable grossier

STF : Sable très fin
SF : Sable fin

Les volumes d'eau apportés, durant les deux campagnes 1984 et 1985, ont été respectivement de 640 mm et 610 mm pour le piment et de 1350 mm et 630 mm pour le sorgho.

Les quantités de boues épandues chaque année pour le traitement B, en début de campagne, sont égales à 40 t/ha soit 30 t.MS/ha environ. Ces apports, au nombre de 2, ont été effectués durant deux années.

La fertilisation minérale, pour le traitement C, a été la suivante :

- en 1984, 85 unités d'N sous forme de nitrate d'ammonium, 90 unités de P_2O_5, sous forme de superphosphate, 100 unités de K_2O sous forme de sulfate de potassium;

- en 1985, seules les quantités ont été modifiées, soit 70 unités d'N, 110 unités de P_2O_5, 100 unités de K_2O.

Le traitement D a reçu des quantités de boues et d'engrais minéraux équivalentes à ceux des traitements B et C.

2.4 Mesures effectuées

Des analyses sont faites sur les eaux usées traitées, les boues et les sols avant et après traitement. Parallèlement, des eaux provenant d'un puits situé dans la station expérimentale sont analysées et comparées aux eaux usées traitées.

Les paramètres mesurés sont principalement: humidité (105°), pH, conductivité électrique (25°), carbone organique (méthode Anne et Carmhograph), azote total (méthode Kjeldahl), NH_4^+(distillation ou bleu d'indophénol), NO_3^- (réduction sur colonne Cd amalgame Hg), NO_2^-

(diazotation de la sulfanilamide), phosphore total (minéralisation $Na_2S_2O_8$ - H_2SO_4, dosage selon Murphy et Riley), phosphore assimilable (méthode Joret-Hebert, dosage selon Duval); éléments majeurs sur extrait de pâte saturée dans les sols, après minéralisation acide (HNO_3) dans les boues; dosage des éléments traces (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) par absorption atomique (Perkin Elmer 2380 + four graphite HGA 400), directement dans les eaux (milieu acide HNO_3), après minéralisation diacide (HF-$HClO_4$) dans les sols et les boues.

Dans les végétaux et aprés une attaque HNO_3 -$HClO_4$, les éléments suivants ont été analysés: P, K, Ca, Mg, Na, Cd, Co, Cu, Fe, Mn, Pb et Zn. K, Ca et Na ont été dosés par photométrie de flamme; P par colorimétrie au vanadomolybdate; Cd, Co, Cu, Fe, Mg, Mn, Pb et Zn par spectroscopie d'absorption atomique de flamme. L'azote total a été déterminé selon la méthode Kjeldahl et les chlorures au chloridmètre après attaque HNO_3 (Rejeb, 1986).

Quant aux analyses bactériologiques, elles ont été réalisées sur les eaux, les boues, les sols et les végétaux selon différentes méthodes (Trad-Rais et Saillet, 1986). Un dénombrement des germes appartenant au groupe des coliformes fécaux (C.F.) et des streptocoques fécaux (S.F.) a été effectué sur ces divers milieux. Ce dénombrement a été fait par calcul du nombre le plus probable de germes (N.P.P.) après répartition de l'inoculum et de ses dilutions dans les milieux de culture liquides. L'analyse des échantillons d'eau a comporté, de plus, un dénombrement des coliformes totaux (C.T.) et des recherches de bactéries pathogènes (Salmonella, Shigella, vibrions cholériques).

3. RESULTATS ET DISCUSSION

3.1 L'étude de la composition chimique des eaux, des boues et des sols a porté sur la détermination de leur teneur en sels, en éléments fertilisants et en éléments traces.

3.2 Les eaux

3.2.1 Composition chimique

Les analyses ont porté sur 30 à 55 échantillons pour les eaux usées et les eaux de puits de la Soukra. Celles des eaux de puits de Nabeul ont été effectuées sur une quinzaine d'échantillons.

Les résultats d'analyse (Tableau II) montrent que les eaux usées traitées présentent les caractéristiques d'un effluent de qualité relativement bonne. Elles contiennent, en effet, peu de matières en suspension (MES $\approx$ 14 mg/l) et leurs demandes chimique et biochimique en oxygène sont respectivement: DCO $\approx$ 50 - 70 mg/l, $DBO_5 \approx$ 18 - 20 mg/l. Par ailleurs, les eaux sont caractérisées par un pH proche de la neutralité et par une salinité moyenne à élevée; leur conductivité électrique varie entre 2,5 et 4 mmhos/cm et la valeur du résidu sec (R.S.) est de 2g/l.

TABLEAU II

Caractéristiques moyennes des eaux usées traitées (E.U.) et des eaux de puits (E.P.) utilisées en irrigation (en mg/l)

PARAMETRES	SOUKRA		NABEUL	
	E.U.	E.P.	E.U.	E.P.
pH	7,6	7,6	7,7	7,9
E.C.	2,97	2,61	3,65	2,24
R.S.	1,82	1,71	2,24	1,43
M.E.S.	13,4	4,3	13,5	2,89
D.C.O.	51	-	69	-
HCO_3	370,0	228,5	578,5	390,0
SO_4	363,0	87,5	417,5	269,5
Cl	554,0	648,0	687,5	376,5
CA^{++}	154,5	249,0	131,5	140,5
Mg^{++}	56,5	48,5	73,5	66,0
NA^{+}	366,0	214,0	487,5	211,0
K^{+}	36,5	3,0	58,0	9,0
N_t	31,5	21,0	54,5	15,0
P_t	4,1	0,02	2,5	0,02
(S.A.R.)	6,4	3,2	8,4	3,7

E.C.:mmhos/cm à 25°C R.S.:g/l (SAR): indice d'adsorption du sodium

Comparées aux eaux de puits, les eaux usées traitées présentent une charge saline plus forte et un indice d'adsorption du sodium (SAR) plus élevé.

Les compositions cationiques et anioniques (en méq/l) sont telles que:

. dans les eaux usées : $NA^{+} \gg Ca^{++} > Mg^{++} > K^{+}$
$Cl^{-} > SO_4^{=} = HCO_3^{-}$

. dans les eaux de puits: $Ca^{++} = Na^{+} \gg Mg^{++} > K^{+}$
$Cl^{-} \geqslant HCO_3^{-}$ et $SO_4^{=}$

Le faciès des eaux usées traitées est donc chloruré-sodique; celui des eaux de puits est chloruré-calcique et sodique.

S'agissant des éléments fertilisants, les eaux usées traitées se distinguent des eaux de puits par leur teneur relativement élevée en N, P, K. Les concentrations mesurées varient d'une station à l'autre. Les concentrations en azote total des eaux usées traitées de Nabeul sont plus élevées que celles de la Soukra. Ces concentrations varient dans un rapport égal à 2 entre l'hiver et l'été, (20 - 40 mg/l) à la Soukra, (35 à 70 mg/l) à Nabeul. L'azote est présent essentiellement sous forme de sels ammoniacaux pendant la période hivernale et de nitrates pendant la saison estivale. Les nitrites sont présents en faible concentration. En outre, dans les eaux de puits, l'azote est présent sous forme de nitrates. Quant au phosphore total, il est, dans les eaux usées traitées, essentiellement sous forme assimilable par les plantes. On note l'absence de phosphore dans les eaux de puits. La comparaison entre les éléments fertilisants dans les eaux usées traitées montre que le phosphore serait apporté en faible quantité par rapport à l'azote: le rapport $N/P_2O_5/K_2O$ est de 1/0,3/1,4 à la Soukra et de 1/0,1/1,3 à Nabeul (N = 1).

Pour ce qui est des éléments traces, les concentrations mesurées dans les eaux usées traitées sont faibles (Tableau III). Elles sont toutes inférieures aux valeurs seuils fixées par la FAO (Ayers et Westcot, 1985). Les séquences trouvées sont les suivantes:

Soukra : Fe > Pb > Zn > Ni > Co = Mn > Cu > Cr > Cd

Nabeul : Fe ≫ Pb > Mn > Zn > Co = Ni > Cu > Cr > CD

Dans les eaux de puits, la séquence des éléments traces est différente et leurs concentrations sont moindres.

TABLEAU III

Teneur moyenne en éléments traces des eaux usées traitées (E.U.) et des eaux de puits (E.P.) utilisées en irrigation (en mg/l)

PARAMETRE		SOUKRA		NABEUL		Valeurs limites
		E.U.	E.P.	E.U.	E.P.	F.A.O. (1)
Cd		traces	traces	traces	traces	0,0,1
	min	0,00	0,00	0,00	0,00	
Co	m	0,05	0,04	0,04	0,03	0,0,5
	Max	0,14	0,09	0,09	0,06	
	min	0,00		0,00		
Cr	m	0,02	-	0,01	-	0,1
	max	0,06		0,03		
	min	0,00	0,00	0,00	0,00	
Cu	m	0,03	0,02	0,02	0,02	0,1
	max	0,08	0,05	0,07	0,03	
	min	0,03	0,05	0,04	0,16	
Fe	m	0,033	0,11	0,29	0,19	5
	max	1,7	0,29	0,78	0,25	
	min	0,00	0,00	0,01	0,01	
Mn	m	0,05	0,01	0,06	0,02	0,2
	max	0,11	0,04	0,10	0,03	
	min	0,00	0,01	0,00	0,01	
Ni	m	0,06	0,05	0,04	0,02	0,2
	max	0,14	0,09	0,11	0,04	
	min	0,07	0,10	0,01		
Pb	m	0,19	0,16	0,07	-	5
	max	0,30	0,19	0,13		
	min	0,00	0,00	0,00	0,00	
Zn	m	0,12	0,04	0,05	0,03	2
	max	0,46	0,11	0,21	0,05	

min : minimum m : moyenne max : maximum

3.2.2 Qualité bactériologique

La qualité bactériologique des eaux a été suivie en entrée et sortie de station d'épuration et sur les parcelles expérimentales (Trad-Rais et Saillet, 1986). Les eaux usées brutes de la Cherguia contiennent en moyenne $7,10^7$ C.F./100 ml et $8,10^6$ S.F./100 ml. Les concentrations des eaux de Nabeul sont du même ordre de grandeur. Dans les eaux usées traitées, la concentration en CF et SF est de l'ordre de 10^5 germes/100 ml. Ces valeurs correspondent à celles que l'on trouve habituellement dans un effluent urbain.

La recherche des bactéries pathogènes (salmonelles et vibrions cholériques) n'a pas permis de mettre en évidence ces germes, opération en général difficile; leur isolement, sur des échantillons ponctuels est, de plus, hasardeux.

3.3 Les boues

3.3.1 Composition chimiqué

L'analyse des échantillons de boues prélevés, lors des épandages, sur les deux sites de la Soukra et de Nabeul (Tableau IV), montre que leur humidité (H: 25 - 50%) varie largement d'une station d'épuration à l'autre et dans la même station au cours du temps (le coefficient de variation est compris entre 10 et 40%). Le pH est voisin de la neutralité et leur conductivité électrique traduit une salinité excessive.

La détermination des teneurs totales en éléments majeurs met en évidence une teneur élevée en Ca, moyenne en Mg et faible en K et Na. Cette pauvreté en K serait liée à la grande solubilité des composés potassiques éliminés lors du traitement des eaux.

La teneur en matière organique des boues, comprise entre 20 et 40%, reflète leur origine urbaine. La concentration en azote fluctue entre 1 et 2,5%; le rapport C/N, de l'ordre de 8, indique que ces boues ont été correctement stabilisées et reflète leur aptitude à libérer de l'azote (Chaussod *et al.*, 1981).

Les boues étudiées présentent l'avantage d'être riches en phosphore total (0,5 - 1%) et en phosphore présumé assimilable (0,15 - 0,5%). Elles sont donc suffisamment pourvues en phosphore pour offrir un certain intérêt agricole.

TABLEAU IV

Composition chimique moyenne des boues résiduaires

PARAMETRE	SOUKRA 1984 JUIN	SOUKRA 1985 AVRIL	SOUKRA 1985 DECEMBRE	NABEUL 1984 JUIN	NABEUL 1985 DECEMBRE
H %	25,0	23,3	32,0	25,0	48,6
pH	7,4 (P,S.)	7,9 (1/5)	7,7 (1/5)	7,2 (P.S.)	7,4 (1/5)
E.C.	15,9 (P.S.)	4,0 (1/5)	3,8 (1/5)	11,5 (P.S.)	7,1 (1/5)
$CaCO_{3\,t}$%	25,0	17,8	20,1	13,2	20,4
M.V.	30,2	22,8	17,5	33,4	27,1
C.orga.	10,2	13,4	10,2	19,6	15,3
N_k%	1,48	2,02	1,03	2,27	2,28
C/N	7	6,6	9,9	8,5	6,7
M.S.					
P_t	0,66	0,76	0,54	0,65	0,95
Ca	11,43	6,98	5,10	6,46	7,58
Mg	0,43	0,11	0,45	0,60	0,30
K	0,23	0,17	0,26	0,31	0,20
Na	0,17	0,14	0,21	0,41	0,14

P.S. : extrait de pâte saturée
1/5 : extrait au 1/5
E.C. : conductivité électrique en mmhos/cm à 25°C
$CaCO_{3\,t}$: calcaire total
M.S. : matière sèche
M.V. : matières volatiles

S'agissant des éléments traces, les teneurs totales trouvées (Fig.1) sont inférieures aux limites fixées par la norme AFNOR (NF U 44 - 041 (1985)) et subissent des fluctuations notables au cours du temps. Les différents éléments s'organisent selon la séquence suivante:

Fe ≫ Zn > Pb > Cu > Mn > Cr > Ni > Co > Cd > Hg

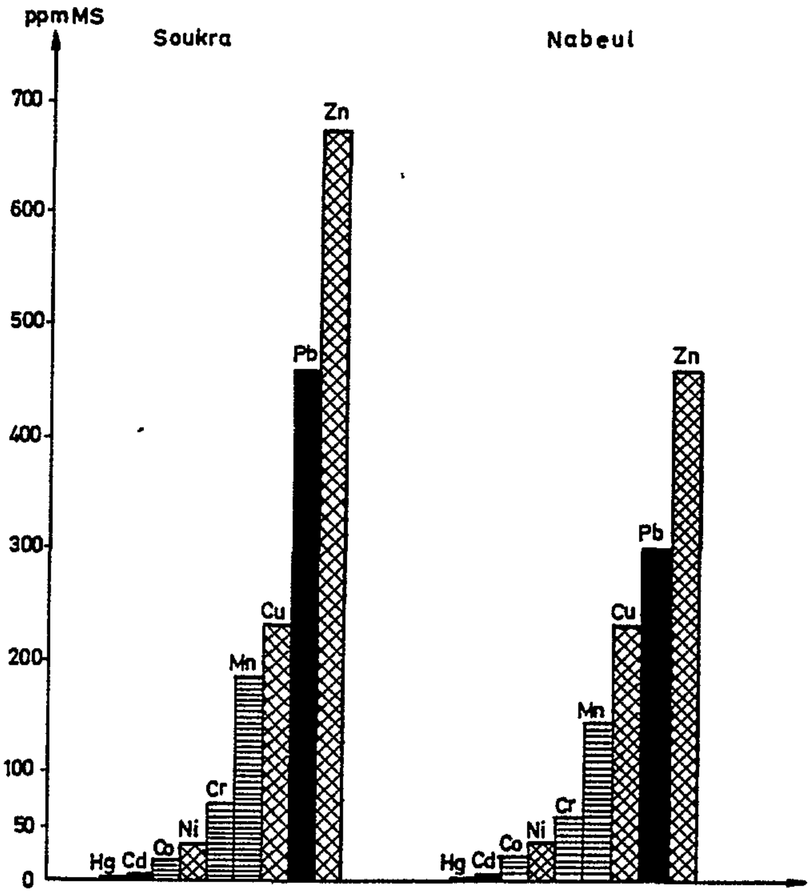

Fig. 1 - Teneur en éléments traces des boues résiduaires

3.3.2 Qualité bactériologique

La qualité bactériologique des boues montre que les concentrations en coliformes fécaux (C.F.) et en streptocoques fécaux (S.F.) sont sensiblement du même ordre lors des différent épandages. Les S.F. sont légèrement plus nombreux que les C.F.; soit par g. de boue fraîche, 9,2 19^3 CF et 4,6 10^4 SF (Trad-Rais et Saillet, 1986).

Afin de comparer la quantité de germes apportée par les boues à celle apportée par les eaux usées traitées, nous avons pris comme exemple la campagne d'été 1985 pour la station de la Soukra. Les quantités de germes ont été estimées pour une unité de surface de 1 cm^2 de sol. Les eaux usées traitées ont apporté, pendant cette campagne, environ 280 fois plus de CF et 20 fois plus de SF que les boues.

	Boue (40 t / ha)	Eaux usées traitées (600 mm)
C F/ cm^2 de sol	1,8 10^3	5,2 10^5
S.F./cm^2 de sol	1,8 10^4	4,2 10^5

3.4 Interactions eaux-sols-boues

3.4.1 Evolution des propriétés physico-chimiques du sol

L'incidence de l'apport des eaux usées traitées et des boues résiduaires sur le sol n'a été enregistrée qu'au niveau des paramètres chimiques. En effet, l'étude de l'évolution de certaines caractéristiques physiques du sol, stabilité structurale, densité apparente et perméabilité, n'a pas permis de mettre en évidence des variations nettes entre les différents traitements (Chaabouni, 1986). Certains effets temporaires ont pu être notés tels qu'une amélioration de la structure du sol après épandage des boues. Etant donné la texture du sol et les doses d'eaux et de boues apportées, un suivi à plus long terme est nécessaire pour observer des changements.

Les modifications de la composition chimique du sol suite à l'épandage des eaux usées traitées et des boues résiduaires concernent essentiellement la teneur en sels, en matière organique et en éléments traces (Tableau V). Les prélèvements d'échantillons de sol ont été effectués, à la Soukra, au début (S_I) et à la fin de l'expérimentation.

TABLEAU V

Composition chimique du sol après traitement (A, B, C, D)

		I. Terre Fine				Extrait de pâte saturée									
							E. C_e	meq/1							
		C	N	C/N	P_2O_5ass	pH	mmhoa/cm	Ca++	Mg++	K+	NA+	HCO_3	SO_4	Cl^-	S.A.R.
A	(1)	10,3	0,82	12,6	0,21	7,8	1,98	5,1	2,8	0,3	12,7	2,8	8,5	9,5	6,4
	(2)	8,8	0,72	12,2	0,21	7,9	1,84	5,4	1,9	0,1	12,7	2,6	8,0	9,1	6,6
B	(1)	12,0	0,97	12,4	0,36	7,9	2,30	7,5	2,7	0,2	14,0	3,3	11,0	11,1	6,2
	(2)	10,1	0,81	12,5	0,36	7,8	2,20	5,6	3,5	0,1	14,7	2,8	11,0	10,8	6,9
C	(1)	11,8	0,90	13,1	0,28	7,8	2,07	6,5	1,5	0,6	12,7	3,3	8,5	9,6	6,4
	(2)	11,2	0,81	13,8	0,23	7,8	1,98	4,8	3,1	0,1	13,1	2,9	10,0	9,3	6,6
D	(1)	14,5	1,15	12,6	0,54	7,4	2,24	5,7	3,3	0,3	12,4	3,0	9,0	8,3	5,8
	(2)	12,3	0,97	12,7	0,37	7,5	2,31	5,1	3,1	0,3	12,4	2,8	8,3	9,4	6,1

S.A.R. : Indice d'adsorption du sodium

		ppm terre fine								
		Cd	Co	Cr	Cu	Hg	Mn	Ni	Pb	Zn
A	(1)	0,27	17	31	24	0,32	248	35	45	45,3
	(2)	0,23	17	28	25	0,30	243	36	45	46,4
B	(1)	0,30	18,5	31	29	-	250	34	57	63,4
	(2)	0,27	21	32	25	-	252	34	63	48,7
C	(1)	0,29	19,5	32,5	27	-	252	34	50	50,8
	(2)	0,27	21	42	32	-	254	42	-	50,8
D	(1)	0,29	20,5	31	34	-	251	34	62	81,8
	(2)	0,28	19	27	29	-	260	36	60	65,8

(1) : 0 - 20 cm
(2) : 20 - 40 cm
A : eau usée traitée
B : eau usée traitée + boue
C : eau usée traitée + fumure minérale
D : eau usée traitée + boue + fumure minérale

3.4.1.2 Effet de la salinité des eaux usées et des boues

La salinité moyenne à élevée enregistrée dans les eaux (Tableau II) et les boues (Tableau IV) se traduit après épandage par une augmentation de la salinité des sols. La conductivité électrique croît notamment dans les traitements qui reçoivent des apports de boue. On note également un enrichissement en ions sodium, chlorure et sulfate qui s'exprime par un changement du faciès chimique de la solution du sol. Celui-ci évolue du faciès bicarbonaté-calcique vers un faciès chloruré-sulfaté-sodique comme celui des eaux usées. L'indice d'adsorption du sodium augmente de même sur l'ensemble des traitements.

3.4.1.3 Evolution des teneurs du sol en C, N, P

Par rapport à la composition initiale du sol, les traitements (A, B, C, D) entrainent une augmentation des taux de carbone, d'azote et de phosphore assimilable. Les teneurs les plus élevées sont enregistrées dans le traitement qui reçoit des apports de boue.

Concernant la teneur du sol en carbone organique, on constate une augmentation, faible dans le traitement A, et presque équivalente dans les deux autres traitements. Pour l'azote, on note un effet modéré des boues qui confirme toutefois leur action en tant que fumure azotée. Le rapport C/N augmente légèrement après traitement; cependant, les valeurs trouvées dénotent une bonne minéralisation de la matière organique apportée. L'étude du rythme de minéralisation de cette matière organique en vue d'une meilleure adéquation des apports par rapport aux besoins présente un intérêt certain.

En ce qui concerne la fertilité phosphorique des sols, les valeurs présentées dans le tableau V montrent une augmentation marquée des taux de phosphore assimilable dans les traitements B et D et laissent supposer une disponibilité plus importante des ions phosphate pour la plante. La valeur phosphatée des boues est ainsi confirmée.

3.4.1.4 Incidence des apports des boues sur la composition du sol en éléments traces

Si l'apport des eaux usées traitées n'a pas entraîné de modifications sensibles, l'apport des boues, par contre, tend à accroître la concentration des éléments traces. Les concentrations mesurées dans le sol, notamment pour le zinc, le plomb et le cuivre, sont en rapport avec celles trouvées dans les boues et dénote un pouvoir fixateur important du sol. Ces résultats sont similaires à ceux de Sposito et al. (1982) qui montrent que les taux de Zn, Pb, et Cu, enregistrés dans les sols, sont en relation directe avec les doses de boue épandues.

L'accumulation du zinc, du plomb et du cuivre dans les horizons de surface suggère que la matière organique joue le rôle de piège géochimique pour ces éléments traces. Les associations de ces éléments avec les composés humiques seraient sous forme de complexes organiques de stabilité variable (Guillet et al. 1980). D'autre part, la charge carbonatée des sols et des boues serait à l'origine d'une immobilisation des éléments traces, notamment le zinc (Emmerich et al, 1982).

3.4.2 Evolution bactériologique des sols

L'étude bactériologique des sols a été entreprise en vue d'évaluer les risques de contamination des végétaux à partir du sol après apport d'eaux usées traitées et de boues résiduaires (Trad-Rais et Saillet 1986).

Du fait du nombre plus élevé de streptocoques fécaux (SF) par rapport à celui des coliformes fécaux (CF) dans les sols des parcelles étudiées et de leur plus grande résistance hors de leur habitat fécal habituel, les CF semblent être, dans le sol de meilleurs germes test de contamination fécale.

La comparaison du niveau de contamination de la couche superficielle du sol (0-5 cm) provenant des parcelles des traitements A (EU) et B (EU+B) avec celui d'un sol non irrigué prélevé hors du dispositif expérimental montre que la contamination des sols recevant des apports d'eaux usées seules ou accompagnées de boues est supérieure mais non significative au cours de l'été (seuil de signification de 2 unités log) (Fig. 2). L'apport des boues ayant lieu au début de la campagne estivale en une seule fois et les conditions climatiques étant défavorables, la survie des germes est donc limitée.

On constate que le niveau de la couche superficielle du sol est soumis à des variations saisonnières. En été, ce niveau est faible du fait de la dessication rapide du sol; il augmente à l'automne et le sol pourrait alors jouer un rôle important dans la contamination du végétal; il diminue par la suite lentement au cours de l'hiver, les conditions climatiques devenant à nouveau défavorables pour la survie des germes. Ceux-ci ont toutefois survécu durant le mois de novembre après l'arrêt des irrigations.

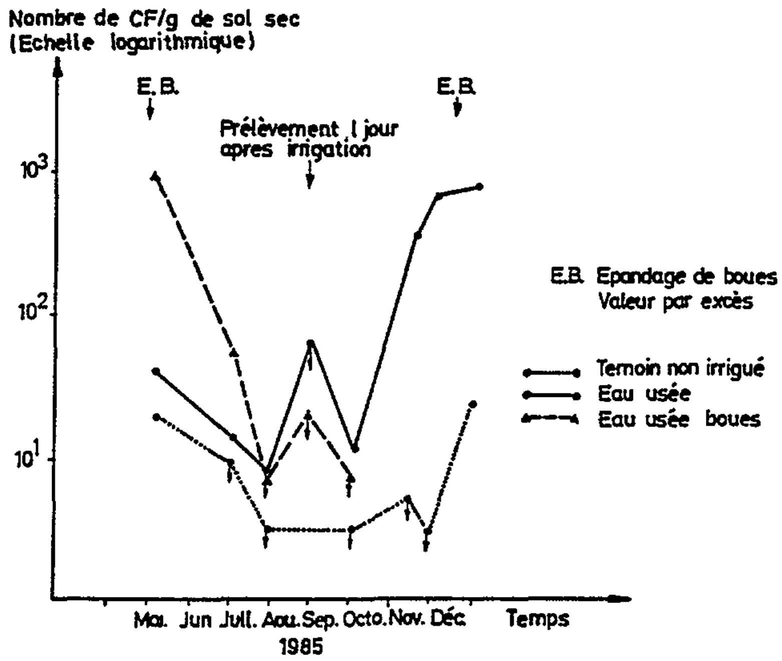

Fig. 2 - Evolution de la quantité de coliformes fécaux dans le sol

La texture du sol semble également intervenir dans la survie des germes. La comparaison des niveaux de contamination des parcelles ayant reçu des eaux usées traitées montre que les sols de texture sableuse sont globablement moins contaminés que les sols de texture sablo-argileuse. En été, la différence n'est pas sensible, mais à l'automne la décontamination du sol sableux semble être plus rapide; la faible capacité de rétention de l'eau des sols sableux et l'adsorption des germes sur les particules argileuses pourraient expliquer ces différences.

3.5 Interactions eaux-boues-plantes

3.5.1 Effet des boues résiduaires et des engrais minéraux sur le rendement du sorgho fourrager et du piment

3.5.1.1 Le sorgho fourrager

Les résultats présentés sur le tableau VI montrent une augmentation du rendement en faveur du tráitement D en 1984. Cette augmentation n'a pas été confirmée en 1985 à cause des perturbations qui ont affecté les irrigations. En tout état de cause, il y a lieu de noter que l'utilisation des eaux usées traitées permet d'obtenir de bons rendements; toutefois, l'augmentation enregistrée est plus importante avec un apport de boues résiduaires ou d'engrais minéraux (Bouzaidi et Cherif, 1986).

TABLEAU VI

Effet des trasitements sur le rendement du sorgho fourrager (en t/ha)

	1984		1985	
	MV	MS	MV	MS
A	67	11,7	40	9,9
B	78	13,1	47	11,6
C	86	14,8	45	11,5
D	90	15,6	42	11,1
Effet Traitement	S		NS	

M.V.: matière verte   S : significatif
M.S.: matière sèche   NS : non significatif

3.5.1.2 Le piment

Les rendements obtenus au cours des deux campagnes et résumés sur le tableau VII montrent un effet significatif des traitements en 1984; le classement des traitements dans le sens D B C A observé en 1984, s'est confirmé en 1985. La comparaison des traitements A et C nous conduit à dire que le piment n'a pas valorisé les apports d'engrais minéraux. Les taux de déchets, d'autre part, ne semblent pas liés à l'utilisation des eaux usées traitées et/ou des boues résiduaires.

TABLEAU VII

Effet des traitements sur le rendement du piment (en t/ha MV)
et sur le taux de déchets (en % du poids total récolté)

	1984		1985	
Traitement	Rendement	Déchets %	Rendement	Déchets %
A	8,1	14,5	10,2	7,2
B	10,4	12,5	10,6	7,6
C	9,0	13,5	10,5	6,7
D	11,8	13,0	11,2	10,5
Effet Traitement	S		NS	

S : significatif NS : non significatif

3.5.2 Effet des traitements sur la composition minérale du sorgho fourrager et du piment

L'analyse minérale (Rejeb, 1986) des différentes parties du sorgho montre que pour la campagne 84, les modifications apportées par les boues sont significatives pour l'azote, le phosphore et le potassium au niveau de la partie aérienne mais pas pour toutes les coupes. L'application de la fumure minérale provoque les mêmes modifications que celle des boues. Lors de la seconde année d'expérimentation, les traitements boues et fumure minérale provoquent une augmentation significative de la teneur en azote à la deuxième coupe. Les teneurs en K et P, par contre, ne sont pas modifiées.

D'autre part, l'apport de boues se traduit par une augmentation de la concentration en fer pour toutes les coupes durant les deux années d'expérimentation, en zinc et cuivre en particulier en 1985. Par ailleurs, en 1984, l'apport de boues augmente la teneur en manganèse des feuilles sans que cet effet soit noté l'année suivante. Cette observation pourrait être reliée au fait que, les boues épandues en 1985 étant plus riches en fer que celles épandues en 1984, l'absorption du manganèse a pu être limitée par phénomène d'antagonisme. En ce qui concerne les autres éléments traces, aucune influence de l'apport des boues n'a pu être mise en évidence de manière significative.

En ce qui concerne le piment, les mêmes observations ont été faites pour N, P, K, Fe, Zn et Cu. Ainsi, l'apport de boues permettrait une meilleure alimentation de la plante en oligo-éléments. Les quantités d'éléments traces apportées n'ont cependant pas été suffisantes pour entraîner des augmentations significatives de Cd, Co ou Pb.

3.5.3 Qualité bactériologique du sorgho fourrager et du piment

Dans le cas des deux cultures étudiées, l'utilisation des boues résiduaires n'a pas entraîné une dégradation de la qualité bactériologique des produits. Le niveau de contamination fécale a été du même ordre pour les traitements A et B (Trad-Rais et Saillet, 1986). Les résultats de l'essai réalisé sur le sorgho sont présentés sur le tableau VIII.

TABLEAU VIII

Effet de l'utilisation des boues sur le niveau de contamination fécale du sorgho

		CAMPAGNE 84		CAMPAGNE 85	
		Juillet 84	Septembre 84	Août 85	Septembre 85
A	CF/g	$8,8.10^3$	$1,3.10^4$	$6,4.10^1$	$6,0.10^2$
	SF/g	$5,0.10^3$	$1,3.10^5$	$6,0.10^3$	$2,8.10^5$
B	CF/g	$9,5.10^4$	$7,2.10^4$	$9,5.10^1$	$2,2.10^3$
	SF/g	$1,7.10^5$	$1,8.10^5$	$1,1.\ 0^4$	$1,5.10^5$

CF/ : coliformes fécaux par gramme de sorgho
SF/g : streptocoques fécaux par gramme de sorgho

L'étude de la décontamination naturelle du sorgho fourrager a montré que la disparition des germes fécaux apportés par les eaux usées traitées est rapide en début de campagne. A partir de l'automne et en raison des conditions climatiques plus favorables, ces germes survivent plus longtemps sur les plantes. Par conséquent, une culture fourragère irriguée avec des eaux usées ne doit pas être tardive.

L'essai réalisé sur piment a montré qu'avec ce type de culture (plantes espacées donc bien ensoleillées, fruits lisses ne favorisant pas l'adhérence des bactéries), la survivance des germes indésirables sur les fruits est limitée. La plus forte concentration en coliformes fécaux, obtenue sur les piments au cours des deux campagnes, est de $2,5.10^4$ germes par 100 g de piment. Cette valeur limite est du même ordre de grandeur que celle des échantillons de piment achetés au marché. Cela signifie que la contamination bactérienne qui résulte de l'irrigation avec des eaux usées traitées et de l'apport de boues est au maximum égale à celle qui peut survenir lors de la manutention des produits agricoles. Il a été également démontré que pour les piments les plus contaminés, un lavage avec une eau propre abaisse significativement leur niveau de contamination fécale; la qualité bactériologique de ces piments lavés était équivalente à celles des fruits témoins.

3.6. Valeur fertilisante et charge polluante des eaux usées traitées et des boues résiduaires

L'étude de l'évolution de la composition chimique du sol suite à l'épandage des eaux usées traitées et des boues soulève le problème des avantages et des risques présentés par leur utilisation en agriculture. Il importe donc d'évaluer la valeur fertilisante, la charge polluante de ces deux milieux et leur limites d'utilisation.

Une estimation des unités fertilisantes (N, P_2O_5, K_2O), et des éléments traces apportés par une hauteur d'eau de 600 mm (valeur correspondant à une irrigation estivale moyenne) et par 30 t MS/ha environ de boues à chaque épandage conduit aux valeurs suivantes (Tableau IX).

Compte tenu des exportations en N, P_2O_5 et K_2O par le sorgho qui ont été respectivement de 100, 30 et 140 kg/ha/an (Rejeb, 1986), on remarque donc que les unités fertilisantes apportées par les eaux usées traitées peuvent être en excès. Si des doses importantes de phosphore et de potassium ne sont pas un obstacle pour leur utilisation, des apports d'azote, supérieurs aux besoins, pourraient présenter des risques pour les plantes et/ou les nappes.

Quant aux boues, si les doses en N et P_2O_5 sont excédentaires, celles de K sont par contre déficitaires; un complément en engrais potassiques serait, dans certains cas, souhaitable. L'utilisation conjugée des eaux usées traitées et des boues résiduaires permettrait ainsi d'obtenir une composition equilibrée. En effet, l'utilisation des eaux usées traitées a permis d'obtenir de bons rendements; toutefois, l'augmentation enregistrée, pour les deux cultures expérimentées, est plus importante avec un apport de boues résiduaires ou d'engrais minéraux.

TABLEAU IX

Quantités d'éléments fertilisants et d'éléments traces (en kg/ha) apportées par les eaux (600 mm) et les boues (30 t/ha/an) sur les sols de la station expérimentale de la Soukra

MILIEUX / PARAMETRE	EAUX E.P.	EAUX E.U.	BOUES
M.S.	-	-	30,350
C	-	-	3,588
N	126	189	532
P_2O_5	0,3	5,.4	494
K_2O	23,2	262,2	73
Cd	traces	traces	0,17
Co	0,24	0,30	0,53
Cr	-	0,12	1,96
Cu	0,12	0,18	6,34
Fe	0,66	1,98	375
Hg	-	-	0,06
Mn	0,06	0,30	4,49
Ni	0,30	0,36	0,86
Pb	0,96	1,14	11,87
Zn	0,24	0,72	20,55

L'analyse minérale des différentes parties du sorgho et du piment a montré (Rejeb, 1986) que les modifications apportées par les boues sont significatives pour l'azote, le phosphore et le potassium au niveau de la partie aérienne, notamment pour la campagne 1984, mais pas pour toutes les coupes ou récoltes. L'application des boues a entraîné des augmentations du même ordre ou supérieures à celles de la fumure minérale.

Cependant, la question du devenir et de l'efficacité de ces unités fertilisantes dans le sol se pose. Si 20 à 40% de l'azote des boues était minéralisé pendant l'année qui suit l'épandage (NF U 44-041(1985)) et 50% du phosphore total utilisé par les végétaux (Cohen, 1979), les doses apportées par 30 t. MS/ha/an seraient équivalentes à celles apportées sous forme d'engrais minéraux.

Par ailleurs, l'épandage des eaux et des boues est également conditionné par leur teneur en éléments traces. Etant donné les faibles quantités apportées à l'hectare par les eaux usées traitées, les risques de pollution des sols et des nappes sont réduits. L'utilisation des boues doit par contre obéir à certaines normes. Afin de protéger les sols d'une éventuelle pollution, nous nous sommes référés à la norme AFNOR (1985). Le calcul du nombre maximum d'années d'épandage des boues en tenant compte du stock initial en éléments traces du sol de la Soukra conduit aux valeurs suivantes (tableau X).

TABLEAU X

Nombre maximum d'années d'épandage des boues (30 t/MS/ha/an) sur les sols de la Soukra

Eléments	Stock initial du sol en kg/ha	Stock maximal admissible dans le sol en kg/ha	Nbre max. années à la dose de 30t MS/ha/an
Cd	0,81	6	27
Cr	77,4	450	183
Cu	78	300	33
Hg	1,2	3	45
Ni	102	150	48
Pb	117	300	13
Zn	132	900	54

Le sol, soumis à des apports successifs de 30 t/MS/ha/an de boues, atteint donc rapidement des valeurs seuils en particulier pour le plomb. Il est par conséquent nécessaire de réaliser des simulations afin de définir les doses et les fréquences d'apport en relation avec les pratiques agricoles.

4. CONCLUSION

L'utilisation des eaux usées traitées et des boues résiduaires comme ressources additionnelles en agriculture s'avère intéressante dans les zones arides et semi-arides.

Les premiers résultats obtenus en Tunisie au cours de nos essais se rapportent à l'étude de la composition chimique des eaux, des boues et de leurs effets sur le sol.

L'évaluation de la valeur fertilisante et de la charge polluante de ces deux composantes, montre que:

- les eaux usées traitées et les boues présentent une charge saline moyenne à élevée sans toutefois présenter de risques d'alcalinisation;

- la fraction solide, soit les boues, constitue un potentiel de matières organique et minérale fertilisantes. Ce potentiel subit toutefois des variations spatio-temporelles notables;

- les teneurs en éléments traces des eaux et des boues demeurent en dessous des seuils de toxicité;

- les eaux usées traitées et les boues résiduaires présentent un niveau "normal" de contamination fécale;

- l'action conjuguée des eaux usées traitées et des boues permet d'obtenir une composition équilibrée en éléments fertilisants mais cependant excédentaire dont il faudra tenir compte.

L'épandage des eaux usées traitées et des boues résiduaires sur la parcelle expérimentale de la Soukra, caractérisée par les sols alluviaux de texture argilo-sableuse à sableuse entraîne:

- des modifications peu importantes des propriétés physiques et du niveau de contamination bactériologique des sols; les effets enregistrés au cours des deux campagnes d'essai ne sont pas significatifs;

- les différents traitements expérimentaux se traduisent par des modifications importantes de la composition chimique du sol. On observe une augmentation de la conductivité électrique et une évolution du faciès géochimique de la solution du sol (bicarbonaté-calcique chloruré-sodique). Parallèlement, on note une augmentation modérée des taux de C, N, et de phosphore assimilable dans le sol. Les éléments traces se concentrent dans les horizons de surface, notamment Zn, Pb et Cu, mais ils ne constituent pas à court terme une charge polluante.

L'apport des boues résiduaires se traduit, par rapport à la fertilisation minérale classique, par une amélioration des rendements du sorgho et du piment et un accroissement de leurs teneurs en N, P et K et en oligo-éléments Fe, Zn, Cu.

La décontamination naturelle du sorgho fourrager est rapide en été et lente en automne. Quant au piment, l'essai réalisé ne montre pas une contamination particulière des fruits.

La détermination de la durée maximale d'épandage des boues montre que leur utilisation rationnelle nécessite l'élaboration de normes fixant les concentrations limites en éléments traces pour les boues et les sols dans nos conditions spécifiques.

BIBLIOGRAPHIE

Ayers, R.S. and D.W. Westcot (1985), Water Quality for Agriculture, FAO Irrigation and Drainage Paper, No. 29, FAO, Rome 174 p.

Boutin, P., Boudot, J., Etienne, M. (1979), Charge microbienne des effluents urbains bruts et traités par voie biologique, T.S.M. L'EAU, No. 2: 63 - 78.

Boutin, P. (1982), Risques sanitaires provenant de l'utilisation d'eaux polluées ou de boues de stations d'épuration en agriculture - T.X.M. - L'EAU, No. 12: 547 - 557.

Bouwer, H. (1982), Water Reuse, Ed. Joe Middlebrooks, Ann Arbor Science. Publishers INC, The Butterworth Group.

Bouzaidi, A. et B. Cherif (1986), Effet de l'irrigation avec les eaux usées traitées et de l'application de boues résiduaires, sur le rendement du piment, du sorgho fourrager et des agrumes. Séminaire maghrébin sur la réutilisation des eaux usées après traitement en agriculture, 23-26 Avril 1986, 8p. + carte.

Bradley, R.M. and S. Hadidy (1981), Parasitic infestation and the use of untreated sewage for irrigation of vegetables with particular reference to Aleppo, Syria. Public Health Engineer, Vol. 9, No. 3: 154-157.

C.E.E. (1979), Treatment and use of sewage sludge. First European Symposium, Cadarache, 13-15 February 1979.

C.E.E. (1981), Treatment and use of sewage sludge, Concerted Action, Final Report, May 1981.

Chaabouni, Z. (1986), Caractéristiques physiques des sols et leur évolution sous l'effet d'apport d'eaux usées traitées et de boues résiduaires - Cas des stations de la Soukra et Oued Souhil, Séminaire maghrébin sur la réutilisation des eaux usées après traitement en agriculture, 23-26 avril 1986, Tunis, 28 p.

Chaussod, E., Germon, J.C., Catroux G. (1981), Essai de détermination au laboratoire de l'aptitude à la minéralisation d'azote des boues résiduaires urbaines. C.R. Acad. Agri., 67, No. 9: 762-771.

Cohen, F. (1979), Connaissances actuelles en matière d'utilisation agricole des boues résiduaires urbaines. Ministère de l'Environnement et du Cadre de Vie, IRH, 177 p.

Cottenie, A., Velghe, G. Verloo, M. Kiekens, L. (1981), Biological and analytical aspects of soil pollution. 53 p.

Emmerich, W.L., Lund, L.J., Page, A.L. Chang, A.C. (1982), Solid phase forms of heavy metals in sewage - sludge treated soils. J. Environ. Qual. Vol. 11, No. 2: 178-181.

Guillet, B., Jeanroy, E., Rougier, C., Souchier, B. (1980), Le cycle biogéochimique et la dynamique du comportement des éléments traces (Cu, Pb, Zn, Ni, Co, Cr) dans les pédogenèses organiques acides. Rapport A.T.P. "Formation et distribution des gisements". Note Techn. et Sci. du Centre de Pédologie, Nancy, No. 27, 49 p.

Henin, S. (1980), Activités agricoles et qualité des eaux, Ministère de l'Agriculture et Ministère de l'Environnement, Tome 1, Octobre 1980.

IAWPRC STUDY GROUP ON WATER VIROLOGY (1983), The health significance of viruses in water, Water Res. Vol. 17: 121-132.

INRA - SCP (1979), Possibilités d'épandage des eaux usées urbaines. Etude bibliographique. Agence de Bassin Rhône - Méditerranée - Corse, 371 p.

Juste, C. (1983), Problèmes posés par l'évaluation de la disponibilité pour la plante des éléments traces du sol et de certains amendements organiques. B.A.F.E.S., No. 2: 109-122.

ORGANISATION MONDIALE DE LA SANTE (OMS) (1983), Les problèmes de santé posés par la réutilisation des effluents traités. Rapport sur une réunion de l'OMS, Alger, 1-5 Juin 1980, OMS, Bureau Régional pour l'Europe, Copenhague, EURO 42, 45 p.

Prost, A. (1986), Les risques infectieux liés à la réutilisation d'eaux usées. Séminaire maghrébin sur la réutilisation des eaux usées après traitement en agriculture, 23-26 avril 1986, Tunis, 18 p.

Rejeb, S. (1986), Conséquences de l'irrigation avec des eaux usées traitées et de l'application des boues résiduaires sur la composition minérale du piment, du sorgho fourrager et des agrumes. Séminaire maghrébin sur la réutilisation des eaux usées après traitement en agriculture, 23-26 avril 1986, Tunis 23 p.

Sposito, G., Lund, L.J., and Chang, A.C. (1982), Trace metal chemistry in arid-zone field soils amended with sewage sludge: I. Fractionation of Ni, Cu, Zn, Cd and Pb in solid phases. Soil Sci. Am. J., Vol. 46: 260 - 264.

Trad-Rais, M. et H. Saillet (1986), Etude de la contamination bactérienne de la nappe, du sol et des cultures par l'apport d'eaux usées traitées et de boues résiduaires. Séminaire maghrébin sur la réutilisation des eaux usées après traitement en agriculture, 23-26 avril 1986, Tunis, 33 p.

RE-USE OF WASTE WATER FOR LAND RECLAMATION AND IRRIGATION IN EGYPT

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1. RE-USE OF SEWAGE FOR IRRIGATION AND LAND RECLAMATION

Domestic sewage in Egypt contains about 0.2% of total suspended, soluble organic and inorganic solids and about 1000 million pathogenic and non-pathogenic bacteria per 100 ml in addition to viruses, unicellular and multicellular parasites.

The discharge of raw sewage into water streams leads to pollution and severe deterioration in the quality of the water.

The pollution may be so severe that there is complete depletion of dissolved oxygen in the stream leading to the disappearance of aquatic life and anaerobic reactions prevail leading to unpleasant odours.

The extent of the pollution is aggravated if untreated industrial wastes containing heavy metals are discharged to public sewers. Some industrial wastes contain toxic chemicals which can give rise to serious environmental problems if the industrial wastes are not pre-treated before being discharged to public sewers.

Conventional wastewater treatment does not lead to complete avoidance of health risks as the treated wastewater still contains about 10 million E.coli / 100 ml (99% removal of bacteria). Also, the secondary treatment cannot remove soluble heavy metals and toxic chemicals; on the contrary, it may be affected if they exceed certain limits which are detrimental to biological treatment.

This necessitates the pretreatment of industrial wastes before they are discharged into public sewers. In addition, tertiary treatment is called for and/or disinfection before discharge of treated sewage into water streams. The re-use of treated wastewater for irrigation needs careful study of the suitability of this water for irrigation, the avoidance of any health risks due to propagation of disease or the build-up of heavy metals and refractory organics into irrigated soil and their accumulation in edible parts of certain genotypes of plants. This also calls for a careful selection of the proper type of irrigation, crops to be cultivated and the disinfection of treated sewage before being re-used.

2. FUNDAMENTAL CONSIDERATIONS IN RE-USE OF WASTEWATER FOR IRRIGATION

Irrigation, the predominant land treatment process in use today, involves the application of effluent to the land for treatment and to meet the growth needs of plants. The applied effluent is treated by physical, chemical and biological means as it seeps into the soil.

The percolation of primary treated effluent through 1.5 metres of soil in Abu Rawash has shown the following quality.

Constituent	Concentration
B.O.D.	25 mg/l
Suspended Solids	30 mg/l
Ammonia Nitrogen as N	10 mg/l
Total Nitrogen as N	18 mg/l
Total Phosphorus as P	0.15 mg/l

The high quality is due to the fact that soil surface and profile can provide physical and chemical treatment of wastewater and a habitat for micro-organisms that can provide biological treatment. The ability of land treatment systems to remove organics, Nitrogen phosphorus, exchangeable cations, trace elements and micro-organisms from applied wastewater depends on a variety of factors.

Organic Matter. Organic matter is filtered by topsoil and is reduced by biological oxidation.

Because high organic loading may create anaerobic conditions in the soil and matrix and result in the production of odours, an intermittent loading schedule is used. This allows air to penetrate the soil and to supply oxygen to the bacteria that oxidize the organic matter.

Nitrogen. Crop uptake is the main mechanism. The quantities of uptake vary widely according to the crop planted. The relationship between organic matter measured as B.O.D., N is important to the removal of total constituents (Table I).

Table I

Typical Ratios of B.O.D. to Nitrogen for Various Types of Wastewaters

Type of Wastewater	B.O.D./N Ratio	Effects on Biological Decomposition
Many food-processing wastewaters	80 - 100	Carbon assimilation relatively slow. available soil nitrogen immobilized and made less available to plants.
Livestock manure	20	carbon assimilation not limited; nitrogen available to plants.
Untreated municipal wastewater	5	Nitrogen in excess of bacterial needs for carbon assimilation; released to soil and plants.
Secondary effluent	1 - 2	Carbon limited for denitrification, nitrogen released to soil and plants.

Phosphorus. The major phosphorus removal in land application by irrigation is by chemical precipitation and adsorption although plants do take up some phosphorus.

The removal of both nitrogen and phosphorus by different crops is shown in Table II.

Table II

Nitrogen and Phosphorus Removal by Crop

Type of Vegetation	Description	Nitrogen kg/hy	Phosphorus kg/ha
Field Crops			
Barley	Winter annual	70	17
Corn	Summer annual	174	19
Cotton	Summer annual	74	13
Milomaize	Summer annual	91	16
Soybeans	Summer annual legume	105	12

The phosphorus which occurs mainly in the form of ortho-phosphate is adsorbed by clay material and certain organic soil fraction in the soil matrix. Chemical precipitation with calcium (in neutral to alkaline ph) and iron or aluminum in acid ph occurs at a slower rate.

Adsorbed phosphorus can be held tightly and is generally resistant to leaching.

Exchangeable Cations. Exchangeable cations, particularly sodium calcium and magnesium ions, deserve special consideration because high sodium concentrations in clay-bearing soil disperse soil particles and decreases soil permeability. To determine the sodium hazard, the SAR is used.

$SAR = Na/1\ (ca + mg)0.51^{0.5}$

High SAR value > 9 may adversely affect the permeability of fine textured soils. Occasionally, high sodium concentrations in soil can be toxic to plants although the effects on permeability occur first.

Generally speaking, wastewater SAR in Egypt is reasonable (Table III). It is very high in some coastal cities like Suez and Alexandria, due to the infiltration of subsoil water into the sewerage system.

Table III(a)

Comparison of S.A.R. and Salinity of Different Surface, Underground and Wastewaters in Egypt

	S.A.R.	E.C. mus mohs/cm^3	T.D.S. ppm
River Nile	0.86	260	195
Port Said Raw Sewage	7.4	1200	850
Ismailia Raw Sewage	3.8	800	630
Alexandria Raw Sewage	9	2200	1800
Suez Raw Sewage	15	5000	4240
Abu Rawash Sewage (used for irrigation)	2.8	1700	1350
Helwan Raw Sewage	5.1	1500	1200
Underground Water Sample taken from El Saf	14	5000	5050
Gabel El-Asfar Raw Wastewater	2.9	1250	1120

S.A.R. • Sodium Adsorption Ration
Salinity • Total Dissolved Solids
E.C. • Electric Conductivity micro mohs/cm

Table III(b)

Different Parameters for the Suitability of Wastewater for Irrigation

	Value		
Parameters	Suitable	Moderately Suitable	Unsuitable
Salinity estimated in terms of E.C micromohs	Lower than 750	750-3000	More than 3000
S.A.R.	0 - 3	3 - 9	More than

<u>Trace Metals</u>• Although many trace elements are essential for plant growth, some become toxic at higher levels to both plant life and micro-organisms. Retention of trace metals, especially heavy metals, in the soil matrix occurs mainly through adsorption (the term includes adsorption and precipitation reactions) and ion exchange.

The retention capacity for most soils is generally high, especially for pH values above 7. Under low pH conditions, some metals can be leached out of soils.

<u>Micro-organisms</u>: Bacterial removal mechanisms common to most methods of land application include straining, die-off, sedimentation, entrapment and adsorption. In the wastewater sprinkling system, some bacteria are intercepted by vegetation where disinfection, die-off and predators eliminate them.

<u>Public Health</u>: Aspects of public health related to re-use of wastewater for irrigation include:

i) bacteriological agents and the possible transmission of disease to higher biological forms including humans
ii) chemicals that may reach groundwater and pose risks to health if injected
iii) crop quality when crops are irrigated with wastewater effluent.

<u>Groundwater Quality</u>: The U.S. Environmental Protection Agency regulations on interim primary water standards are listed in Table V. Because nitrate has been demonstrated to be the causative agent of methemo globinemia in children, its concentration in drinking water is limited in the standards to 10 mg/l as nitrate nitrogen. As indicated, nitrogen can be managed in land treatment systems by promoting growth uptake or denitrification to maintain the nitrate nitrogen below 10 mg/l in the groundwater. The trace elements are usually removed by adsorption or by chemical precipitation within the first few metres of soil. In many cases, however, the concentrations of trace metals in the effluent prior to application are usually below those limits set in Table IV.

Table IV(a)

Recommended Maximum Concentrations of Trace Elements and Toxic Substances; Heavy Metals in Irrigation Water

Element Symbol	For waters used continuously on all soils mg/l	For use up to 20 years on fine to textured soils of pH 6.0 to 8.5 mg/l
Aluminium (Al)	5.0	20.0
Arsenic (As)	0.1	2.0
Beryllium (Be)	0.1	0.5
Boron (B)	(See Table VII)	2.0
Cadmium (Cd)	0.01	0.05
Chromium (Cr)	0.1	1.0
Cobalt (Co)	0.05	5.0
Copper (Cu)	0.2	5.0
Fluoride (F)	1.0	15.0
Iron (Fe)	5.0	20.0
Lead (Pb)	5.0	10.0
Lithium (Li)	2.5	2.5
Manganese (Mn)	0.2	10.0
Molybdenum (Mo)	0.01	0.05
Nickel (Ni)	0.2	2.0
Selenium (Se)	0.02	0.02
Vanadium (V)	0.1	1.0
Zinc (Zn)	2.0	10.0

Source: Environmental Studies Board, National Academy of Science, National Academy of Engineering, "Water Quality Criteria", 1972.

These levels will normally not adversely affect plants soils. No data available for Mercury (Hg), Silver (Ag), Tin (Sn).

Recommended maximum concentration for irrigation citrus is 0.075 mg/l. For only acid fine-textured soils or acid soils with relatively high iron oxide contents.

Table IV(b)

Recommended Dose
Heavy Metals/Hectare/30

Metal	
Cr	Not more than 1000 kg per hectare per 30 years.
Ni	Not more than 70 kg per hectare per 30 years.
Cu	Not more than 280 kg per hectare per 30 years.
Cd	Not more than 5 kg per hectare per 30 years.

Zinc Equivalent = Z_n mg/l + Cu mg/l x 2 + Ni mg/l x 8
Not more than 7.7 kg/acre per year.

Table V

Proposed Regulations of the U.S. Environmental Protection Agency
On Interim Primary Drinking Water Standards, 1975 (73)

Constituent or Characteristic	Value	Reason for Standard
Physical Turbidity units Chemical, mg/l	1[a]	Aesthetic
Arsenic	0.05	Health
Barium	1.0	Health
Cadmium	0.01	Health
Chromium	0.05	Health
Fluoride	1.4-2.4[b]	Health
Lead	0.05	Health
Mercury	0.002	Health
Nitrates as N	10	Health
Selenium	0.01	Health
Silver	0.05	Cosmetic
Total coliform per 100 ml	1	Disease
Pesticides, mg/l		
Endrin	0.0002	Health
Lindane	0.004	Health
Methoxychlor	0.01	Health
Toxaphene	0.005	Health
2,4-D	0.1	Health
2,4,5-TP	0.01	Health

a Five mg/L of suspended solids may be substituted if it can be demonstrated that it does not interfere with disinfection.

b Dependent upon temperature, higher limits for lower temperatures. Note mg/L=g/m^3

Average, Maximum and Minimum Heavy Metal Content in Sewage in Abu Rawash
(Settled Sludge Issued for Irrigation)

Element	Maximum Raw	Maximum Settled	Minimum Raw	Minimum Settled	Average Raw	Average Settled
Cadmium	0.06	0.02	0.011	0.008	0.03	0.01
Chromium	5.9	1.95	1.9	0.33	3.62	0.89
Cobalt	0.51	0.20	0.13	0.12	0.30	0.16
Lead	2.37	1.48	0.26	0.18	1.08	0.67
Manganese	1	1	0.40	0.33	0.70	0.67
Nickel	0.35	0.26	0.17	0.17	0.25	0.22
Zinc	2.30	0.67	0.35	0.28	1.40	0.48
Lead	3	2.5	0.62	0.15	1.51	1.32
Copper	0.61	0.35	0.11	0.07	0.4	0.22

Bacterial removal from effluents passing through fine soils is quite complete. It may also be extensive in the coarse, sandy soil used for irrigation.

Sprinkle irrigation for re-use of treated wastewater is limited because it needs a very high quality of effluent due to the fact that sprinkler irrigation leads to the formation of aerosols which may travel for more than 2 kilometres by air depending on the humidity and temperature of the environment.

It has been reported from research using fluoroscine and similar compounds that about 0.5% of the used wastewater is transformed into aerosols. This may lead to the threatening of large areas of domestic dwellings in the vicinity of the irrigated land if the amount of sewage used is substantial or if no buffer zones are taken into consideration before application. Disinfection with chlorine does not eliminate the health risks because some viruses are very resistant to its action. Also, chlorine may result in the formation of chlorinated organic compounds, some of which are carcinogenic.

The tertiary treated and disinfected effluent may suit sprinkle irrigation if cost is not the limiting factor.

Sand filtration is the best tertiary treatment for virus and spore bacteria removal. To avoid chlorinated organics, ozone may be preferred for disinfection.

The use of sprinkle irrigation may be recommended if the proper treatment is adopted to meet the quality standards needed and if the amount of treated sewage is limited.

The quality standards of effluents used vary in different countries and are generally tailored according to the kind of crop and the kind of climate prevailing. Strict quality standards are needed when the climate is hot, humid and windy and when the inhabitants live close to the irrigated area or when they have access to the irrigated landscape or when raw edible crops are grown. On the contrary, the standard of 1000 E coli per 100 ml is acceptable when surface or drip irrigation is applied.

3. RE-USE OF WASTEWATER IN LAND RECLAMATION IN CAIRO CITY

The re-use of primary treated wastewater in Cairo City has been practised for more than 60 years in the Gabal El-Asfar Sewage Farm. About 4,000 acres of desert land has been reclaimed and irrigated by surface irrigation using primary treated sewage.

The re-use of primary treated wastewater was adopted for 20 years but for the next 40 years almost entirely raw sewage was re-used when the flow reaching Gabal El-Asfar exceeded double the capacity of the primary treatment works. Citrus, pecan and palm trees were grown on sewage-irrigated desert land. Although the productivity of the land increased gradually due to the increased field capacity and other physical, chemical properties, organic matter of the soil, yet it became less productive with the continuous irrigation using raw sewage due to the clogging of soil·particles as a result of the accumulation and retention of fat and grease on the top surface layer which led to ponding of sewage and prevention of re-aeration of soil matrix.

The underground water became polluted and the community living in the farm suffered from various wastewater-borne diseases. Since the flow reaching Gabal El-Asfar Farm far exceeded the reclaimed area, the flow discharged directly to the drain without land treatment was substantial and the Gabal El-Asfar drain became grossly polluted. Heavy metals built up in the soil and their presence in the crops grown due to the lowering of the soil pH was noticeable.

It is estimated that the Cairo sewage flow is at present 2 million cubic metres and it is predicted to reach 4 million m^3/day in the year 2000. A large project is now under way comprising a deep tunnel (5 metres in diameter) on the eastern bank of the River Nile which will deliver its wastewater to a new pumping station constructed in Ameria which will pump wastewater to a new activated sludge treatment plant adequate to treat 3 million m^3/day by the year 2000. The chlorinated secondary effluent will be re-used for irrigation of reclaimed desert land on the eastern side of the Nile. On the western side of the Nile, another project is now being constructed, comprising new collectors and a new pumping station in Giza district which will pump wastewater to a new activated sludge plant on the western side in Abu-Rawash. The chlorinated secondary effluent will also be used in the irrigation of reclaimed desert land.

A new project for Helwan is now being constructed and the secondary chlorinated effluent will be re-used for irrigation of reclaimed desert land on the southern eastern part of Greater Cairo. The treated and disinfected flow for the industrialized Helwan city will reach 1/2 million m^3/day and will be mixed with surface water from the Nile prior to re-use, because of the high salinity of the sewage.

New projects of sewerage and purification works are now also designed and will be carried out covering most of the country by the year 2000. It is estimated to reach 5 million m^3/day. Hopefully, this wastewater will also irrigate the desert land on both sides of the river Nile in Upper and Lower Egypt.

It is estimated that the green area to be added to the Nile Valley will reach 1 million acres by the year 2000. The situation is at present, the discharge of raw or primary treated sewage to the different drains but gradually, according to the strategy adopted, the disposal of sewage by land application after secondary treatment and disinfection will increase. Pollution of drains should decrease (Fig.1).

A new quality standard for land treatment will be issued limiting the E. Coli to be 1000/100 ml in the chlorinated effluent before re-use by irrigation using drip and surface irrigation.

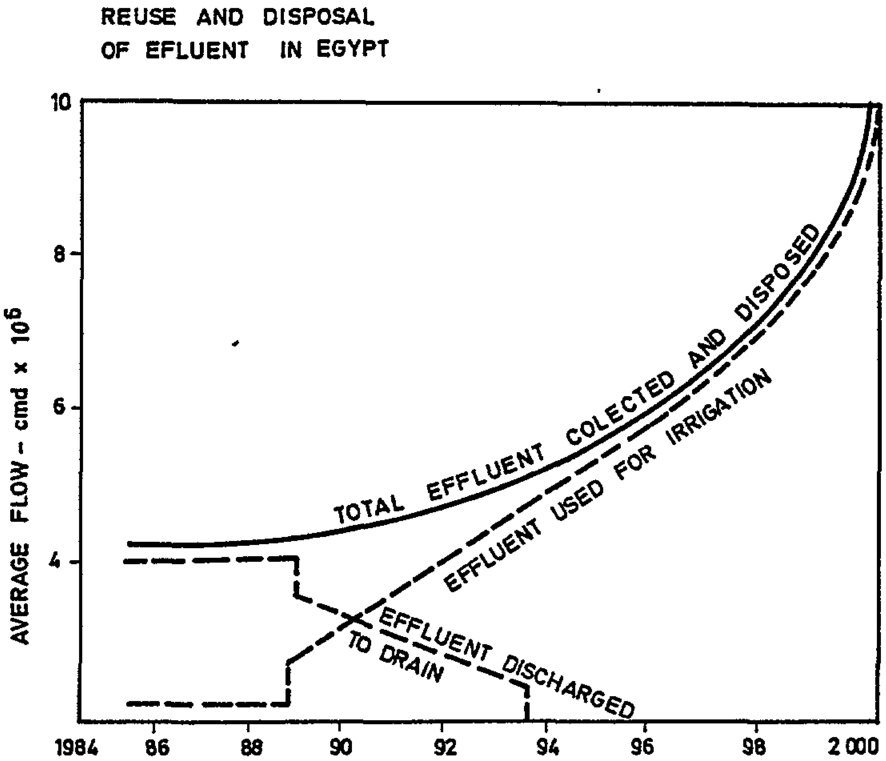

Fig. 1 Re-use and Disposal of Effluent In Egypt

4. CASE STUDY

Research has been carried out in Abu Rawash using raw sewage with a B.O.D. of about 700 ppm, equivalent to raw sewage from communities where the per capita consumption of water is about 70 litres. The re-use of this effluent for four years has shown the following findings·

i) organic matter increased in the surface layer of the soil from 0.1 to 0.46%

ii) pH decreased from 8.5 to 6.5

iii) the water holding capacity of the soil increased from 8.92% to 30.4%

iv) field capacity increased from 7.12 to 17.42%

v) exchangeable sodium percentage (E.S.P.) decreased from 12.85 to 3.79%

vi) cation exchange capacity (C.E.C.) increased from 1.4 to 4.75 meq/100 gm of soil, leading to soil fertility and its water holding capacity, and the available elements are readily absorbed by plants

vii) productivity of different crops (e.g. beans, termis and maize) reached a peak after four years of continuous surface irrigation (e.g. production of maize kg/acre)

Year	1980	1981	1982	1983	1984
Production	700	1620	1700	1750	2000

viii) some heavy metals accumulated in plant tissue (for example, Zn in beans reached 171 ppm on the basis of dry weight and in termis, 58 ppm -Table VI)

ix) some heavy metals accumulated in the surface layer of the soil (for example, Cd increased from 0.05 to 0.15 ppm, Co increased from 1.67 to 1.76 ppm, Cr increased from 0.56 to 0.67 ppm, Iron increased from 1.6 to 65 ppm, lead increased from 0.88 to 7.25 ppm and Ni increased from 0.29 to 0.99 ppm (Figs. 2,3,4,5).

Table VI

ppm Heavy Metals in Edible Parts of Different Crops Grown in Abu Rawash (on Dry Weight Basis)

Name of Plant	Zinc	Iron	Copper	Nickle	Chromium	Cobalt	Cadmium
Beans Irrigated by Surface Water	58	335	14	22	24	29	4
Beans Irrigated by Sewage	171	218	9	23	19	13	2
Barley Irrigated by Surface Water	42	133	6	27	20	30	3
Barley Irrigated by Sewage	40	101	4	25	21	35	3
Termis Irrigated by Surface Water	43	332	7	23	25	24	3
Termis Irrigated by Sewage	58	249	7	43	26	28	3
Citrus Irrigated by Sewage Water	23	56	3	14	11	15	2
Citrus Irrigated by Sewage	20	127	1.4	21	14	15	2

In Cairo, there are many wastewater P.S., one of which is Abu Rawash, 18 km NW of Cairo. The wastewater pumped to Abu Rawash is primary and secondary wasted sludge extracted from Zenien purification works diluted with normal sewage. After primary sedimentation, the effluent is re-used. B.O.D. of raw water reaching Abu Rawash is of the order of 2000 ppm so it cannot be used for irrigation, owing to its high organic load.

After primary sedimentation, the effluent of about 600 to 700 ppm B.O.D. which is equivalent to raw sewage in communities with relatively low consumption (60-70 litres/capita/day) was used for the last four years by surface irrigation. The following parameters which are the limiting factors in waste re-use were determined·

i) salinity and T.D.S.
ii) sodium absorption ration
iii) organic load and biodegrade ability
iv) heavy metals content.

Samples of sewage taken from different locations and surface and underground water were taken and analysed and compared with wastewater re-used in Abu Rawash, are shown in Table III(a).

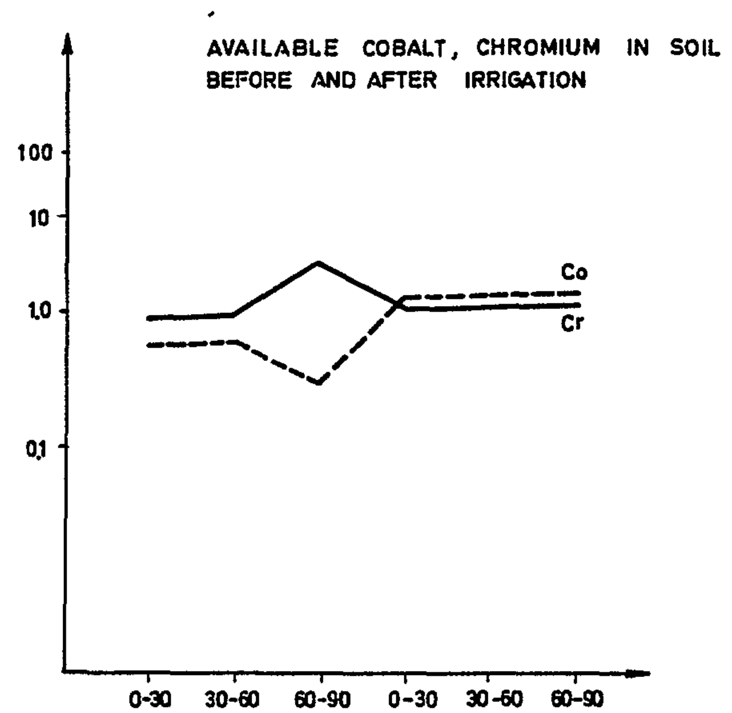

Fig. 2 Available Cobalt Chromium in Soil Before and After Irrigation

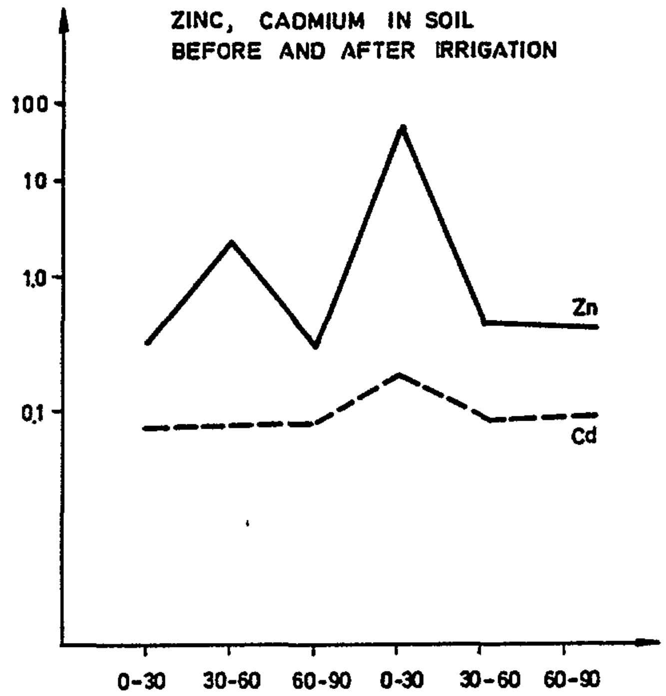

Fig. 3 Zinc and Cadmium in Soil Before and After Irrigation

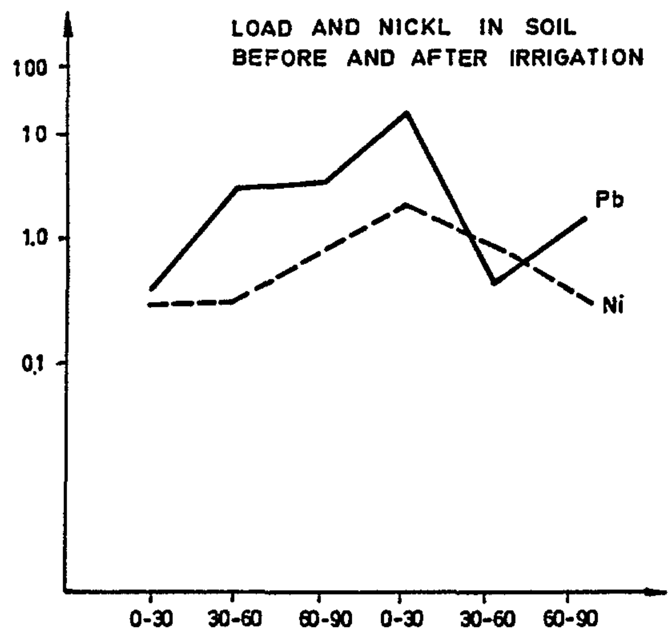

Fig. 4 Lead and Nickel in Soil Before and After Irrigation

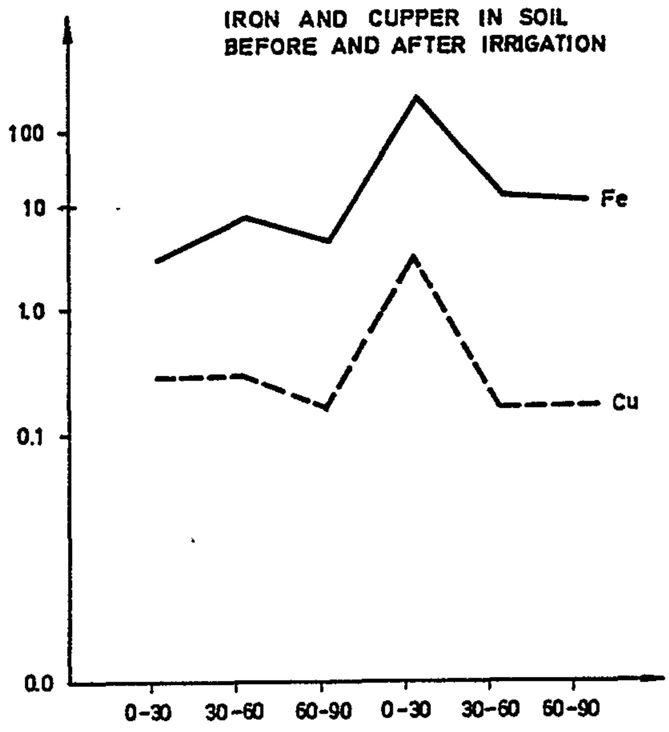

Fig. 5 Iron and Copper in Soil Before and After Irrigation

It is obvious that the majority of raw sewage is suitable for irrigation from the salinity and S.A.R. and heavy metal content point of view. The sewage from some coastal cities (e.g. Suez) is high in salinity and S.A.R. (S.A.R. 15 and E.C. 5000) due to infiltration of subsoil salt water into the sewerage system and this leads to the unsuitability of wastewater for irrigation and land reclamation (Table IIIa). Analysis of subsoil water in a coastal city is attached. Table III also indicates that wastewater is sometimes more suitable for land reclamation than some underground water (for example El-Saf, 70 km south of Cairo).

Table IIIb indicates the limiting factors for re-use of wastewater for irrigation. Table IVb indicates that heavy metals should not increase more than a certain dose/hectare/30 years.

As shown in Table VII, heavy metals find their way to wastewater from the discharge of certain industrial wastes to the sewerage system if not eliminated at the source. Cadmium is the most toxic element to man and some crops have the a tendency to accumulate this element in their tissue more than others . It has been proven medically that a continuous intake of cadmium in the diet and by the respiratory tract in certain doses (more than 616 ug/day for 50 years) leads to failure in the kidney function and if the dose exceeds 3000 ug/day, leads to toxication. Cd unites with the soluble protein thionein (11000 molecule weight) which leads to deterioration of the kidney function.

Table VII

Industrial Waste	Cadmium	Chromium	Mercury	Copper	Lead	Zinc
Metallurgical Wastes	x	x	x	x	x	x
Paint and Dyeing Wastes	x	x	x	x	x	x
Electroplating Wastes	x	x		x		x
Rubber and Plastic Wastes	x		x			
Battery Wastes	x		x		x	x
Textile Wastes		x		x		
Paper Industry Wastes			x			
Tannery Wastes		x			x	
Pharmaceutical Wastes			x			

Cadmium in Abu Rawash wastewater is still below the limit (about .01 ppm). Also, its concentration in dry sludge is about 1.7 ppm (the same concentration in faeces) which indicates that its main source is domestic sewage but this may increase in the future due to discharge of some industrial wastes. This will necessitate its elimination at source and careful selection of the crops to be grown by wastewater. Some phosphatic fertilizers contain high concentration of cadmium which may threaten human health if used continuously, for it will accumulate in the surface layer of the soil and may enter the food chain (Table IX).

Table IIX shows the concentrations of some heavy metals discharged to sewage reaching Abu Rawash. Although no iron is yet present in industrial wastes finding their route to Abu Rawash, its concentrations in the sewage are relatively high leading to its accumulation in the soil and some plant tissue. Its source is the rising main due to the low pH and high hydrogen sulphide content of liquid sludge pumped to Abu Rawash.

Table VIII

Heavy Metals in Industrial Wastes Discharged Abu Rawash (ppm)

Factory	Cadmium	Chromium	Lead	Zinc
Tannery Wastes	0.02	65	1.5	
Battery Factory	0.02	--	25	1.5
Natienal Co. for Plastic			4.5	

If sewage is used for irrigation 50 m^3/d containing 0.01 mg cd
Annual Dose=

Table IX
Heavy Metals in a Sample of Triple Phosphate

Cd	6.7
Co	14
Cr	111
Ni	27
Cu	25
Fe	1038
Zinc	124
Pb	15

If a sample of phosph Ferti contains 100 ppm Cd and a dose of 200 kg of Fert. applied/Acre Cd dose
100 x 200= 20000 mg/day=20 gm/day.

Normally about 50% of heavy metals are precipitated with the sludge by primary sedimentation as insoluble phosphates and bicarbonates and sulphides (Table V).

Standards should be strictly observed in relation to maximum concentrations of heavy metals discharged to public sewers, in order to prevent their accumulation in the soil and plant tissues. The problem of their availability to be absorbed by the plant may be increased by the relatively low pH of the soil, by continuous irrigation with wastewater. Other factors affecting their absorption are cation exchange capacity of the soil and some other factors such as the presence of certain cations (the presence of Zn, k and Ca decreases the available cadmium in the soil, in contrast, the presence of Cl anion increases its availability from the soil.

Although lead is poisonous to plants and humans, and is accumulated in the surface layer in Abu Rawash (Fig.4), due to the industrial waste discharges from tannery and battery, no lead has been noted poisoning the plants grown in Abu Rawash. Table VII indicates the heavy metals in different industrial wastes.

Health Hazards

The following cases of disease were reported from irrigation workers with raw sewage.

- 6 cases of infective hepatities
- 7 cases of dysentery
- 2 cases of Ankly stoma
- 4 cases of Ascares
- 3 cases of Typhoid
- 4 cases of Shigella.

Conclusion

Due to the health hazards and the propagation of diseases and accumulation of some heavy metals in the soil and some plant tissues, the re-use of crude wastewater will be stopped in Gabal El-Asfar, Abu Rawash and elsewhere. The national programme for the construction of adequate sewerage systems and purification works will very soon take place to prevent pollution of the soil and water streams. Industrial wastes will be pretreated before their discharge to public sewers to prevent the detrimental effect of heavy metals on the biological treatment of sewage and to prevent their accumulation in the soil and plant tissues.

Biological Treatment and its Re-use in Abu Rawash

A) By Oxidation Ponds.

Owing to the fact that land is available in many small communities situated in the desert in upper Egypt east and west of Delta and also due to the fact that solar energy is available in Egypt about 4000 hours/year, it was necessary to study the behaviour of oxidation ponds in Egypt's climate.

A pond of about 40 acres with an average depth of 1.5 metres and with a detention period of about 10 days was constructed and in operation by the end of 1984.

The pond treated an average flow of 25000 m^3/day with a total B.O.D. load of 17500 kg B.O.D.$_5$/day which is equivalent to 437 kg/acre/day.

Although the B.O.D. loading per acre, per day was very high and the detention period relatively short (normally it is recommended to be not less than 21 days), the comparisons of different parameters of analysis obtained during 3 years were encouraging. They are as follows (average arithmetic).

	Influent to the Oxidation Pond	Effluent to the Oxidation Pond
pH Value	6.7	7.9
Electric Conductivity (micromohs/cm^3)	1800	1850
Total Alkalinity as Ca Co_3 mg/l	580	470
Chlorides cl mg/l	310	320
Total Suspended Solids mg/l	850	200
Biochemical Oxygen demand B.O.D.$_5$ mg/l	700	120
Chemical Oxygen demand C.O.D. mg/l	1200	200
Dissolved Oxygen	0	2.5
% B.O.D. Reduction	83%	

Another pilot, very small scale oxidation pond was constructed and was operated with a longer detention period (21 days). The B.O.D. loading was 90 kg/acre/day $\simeq$ 20 gr/m^2 with a depth of 1.5 metres.

The pond was lined with an asphalt lining composed of bitumin 70/80 20% by weight and 80% sand to prevent water percolation from the pond. The pond operated efficiently for one year giving a high quality effluent of 30 ppm of B.O.D. and suspended solids (after separation of algae) and without any water infiltration. The amounts of dissolved oxygen during the various hours of the day were recorded and are shown in Fig.7.

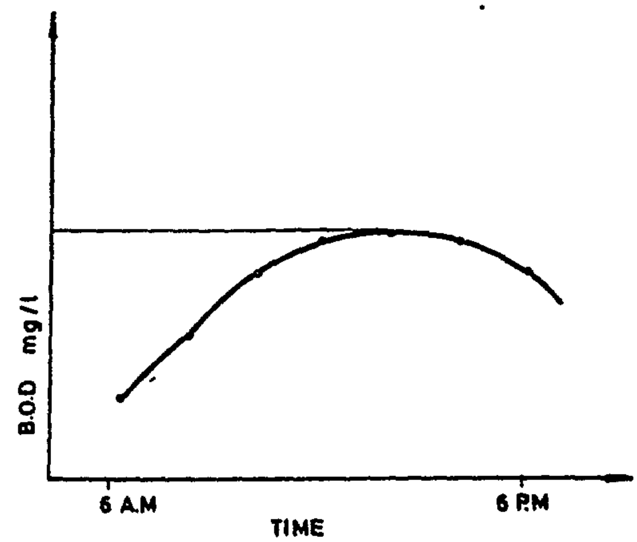

Fig. 7

B) <u>by Aerated Lagoons</u>:

A night storage tank with the following dimensions:

60 metres length
40 metres width
1.75 metres depth

was used as an aerated lagoon after fixing a surface aerator (Fig.8) of 40 HP, adequate to supply 800 kg O_2/day.

3 and 5 day detention periods were tried and the average analysis of the influent and effluent were as follows:

Parameter	Influent	Effluent 3 days	Effluent 5 days
pH (units)	6.5	8	8.3
Sulphides as S mg/l	25	-	-
Chlorides as Cl mg/l	330	340	345
Alkalinity as Ca Co_3 mg/l	560	520	480
Electric Conductivity (Umohs/cm^3)	1700	1700	1700
Suspended Solids (mg/l)	850	65	45
B.O.D.$_5$ days mg/l	700	55	35
T.O.C. mg/l	625	40	30
Dissolved Oxygen	-	5	6

The effluent of the oxidation pond (ten days' detention period) has been used since 1984 to irrigate a virgin desert land and results of re-use show until now, that the effluent is as fertile as raw sewage, the heavy metals are now being recorded both in the effluent and in the soil and in plant tissue.

The average heavy metals of the effluent of the oxidation pond are shown in the following table.

	Influent of the Oxidation Pond	Effluent of the Oxidation Pond
Chromium	0.6	0.6
Cobalt	0.08	0.04
Zinc	0.4	0.05
Manganese	1.0	0.3
Lead	0.17	0.08
Copper	0.8	0.245

The M.P.N. of E. Coli in the effluent of the oxidation pond used for irrigation was about 120 000/100 ml (the effluent M.P.N. is 2.4 x 10^8) i.e. more than 99% removal and this is due to the penetration of Ultraviolet rays (2500-2650 Angstrem) which has a detrimental effect on the desoxy nucleic acid (DNA) of the nucleus and the ribonucleic acid in the cytoplasm and can affect the pathogenic bacteria through gene mutation.

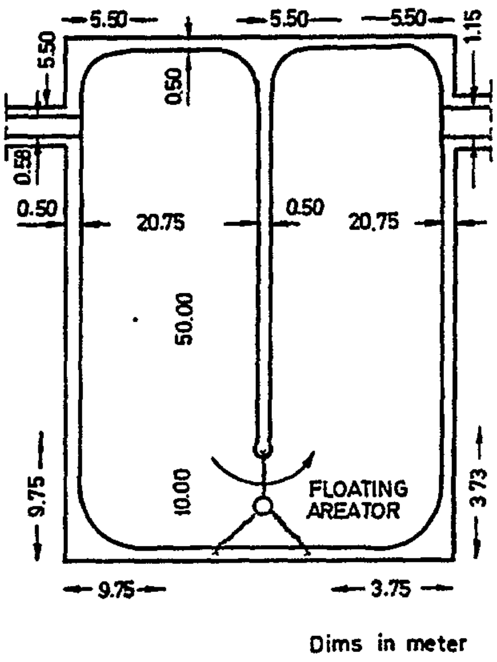

Fig. 8

The presence of certain ions leads to the increased effect of ultraviolet rays for example, chloride ion and Fe ion. Also it has been reported that the Algae Chlorella (which is the most predominant Algae in the oxidation pond constructed) secretes chlorellin which has a bactericidal effect on E. Coli.

Analysis of soil and plant tissues grown by the effluent of the oxidation pond has shown 1/3 the value obtained before by re-using raw sewage.

Workers irrigating the plants did not acquire any of the known diseases associated with wastewater.

5. SUMMARY

It is now well understood in Egypt that re-use of sewage effluent for land reclamation and irrigation will be adopted in the future, only after secondary treatment and disinfection which is preferably preceded by maturation ponds to reduce the cost of chlorine and avoid its toxicity to plants. Selection of crops should be based upon the results obtained from the research project in Abu Rawash, taking into consideration the cost/benefit value, the minimum pollution of the environment and the genotypes of plants to be grown which will have the least accumulation proven of the heavy metals which may impose risk to human health. The type of irrigation to be used will be drip or surface irrigation according to circumstances.

EXPERIENCES FRANCAISES SUR LES SOLUTIONS, DANS DIFFERENTS CONTEXTES GEOLOGIQUES, QU'APPORTENT DES TECHNIQUES D'EPURATION PAR LE SOL DES EAUX USEES (TECHNIQUES D'INFILTRATION CONTROLEE, OXYDATION DES EFFLUENTS ET DECONTAMINATION DES EAUX)

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RESUME

L'utilisation du sol comme système épurateur a fait récemment l'objet de progrès importants, tant dans la connaissance des processus et leur modélisation mathématique, que dans celle des modalités de fonctionnement des dispositifs hydrauliques.

L'excellente qualité des eaux usées épurées par bassin à "infiltration contrôlée" autorise la réutilisation de ces eaux dans des conditions sanitaires très satisfaisantes et permet ainsi une meilleure protection de l'environnement.

1. INTRODUCTION

Pour les agglomérations à vocation touristique de la frange littorale des pays déficitaires en eau, l'assainissement a intérêt à comporter les axes suivants:

- protection, notamment sanitaire, des eaux de baignade (ou encore de parcs conchylicoles);
- adaptation des techniques d'épuration aux variations saisonnières de population;

- économies d'eau (réutilisation);

- fiabilité des dispositifs (laquelle passe par la recherche de systèmes à maintenance simple).

Dans un tel contexte, le schéma classique des pays tempérés (stations biologiques avec rejet de la pollution résiduelle dans un cours d'eau) n'est plus valable. Deux solutions répondent au problème posé: le lagunage et l'épuration par le sol.

2. LA REUTILISATION DES EAUX USEES EN CONTEXTE LITTORAL

Les organismes internationaux collaborent actuellement à la rédaction de nouvelles directives concernant les mesures de protection sanitaire et les méthodes de réalisation à appliquer au recyclage des eaux usées. L'essentiel de ces directives tient en cette phrase: "Seul un traitement des eaux usées qui élimine efficacement les helminthes et réduit en même temps le nombre des bactéries et des virus pathogènes à un niveau acceptable peut diminuer les effets néfastes de l'irrigation non contrôlée par eaux usées sur la santé des agriculteurs et des consommateurs".

Or, les stations d'épuration classique n'éliminent pas les micro-organismes pathogènes (décontamination). Dès lors que, par exemple en agriculture, l'irrigation vise des cultures sensibles sur le plan sanitaire (donc autres que céréales, maïs, etc...), la réutilisation des eaux usées se heurte à un problème de procédures de traitement.

Le plus souvent, on met en avant la technique du lagunage (ou bassins de stabilisation). De fait, ce système d'épuration possède des performances bien supérieures aux systèmes classiques. Ces performances s'étendent jusqu'à la décontamination des eaux usées et ouvrent à ces dernières un large domaine d'utilisation. Mais le lagunage demande de grandes surfaces (au moins 5 m^2 par équivalent-habitant) et son coût d'investissement devient carrément prohibitif lorsqu'on est en présence de terrains perméables (calcaires karstiques ou sables de dunes) qui nécessitent de réaliser un étanchement des bassins.

L'infiltration contrôlée dans le sol est l'autre technique d'épuration qui permet d'amener les eaux usées à un haut degré de qualité tant sur le plan physico-chimique que sur le plan sanitaire. BURGEAP a contribué à sa mise au point et à son développement, en particulier en élaborant des outils mathématiques de simulation de l'infiltration et de l'épuration en milieu non saturé, qui sont maintenant utilisés pour la conception des aménagements.

3. PRINCIPE, PARAMETRES ET PERFORMANCES DES DISPOSITIFS D'EPURATION DES EAUX USEES PAR INFILTRATION CONTROLEE DANS LE SOL

3.1 Principe

L'épuration par infiltration contrôlée dans le sol consiste en une bio-filtration sur un support poreux aéré.

C'est un système aérobie où l'énergie nécessaire à l'activité bactérienne épuratrice est fournie par l'oxygène de l'air. L'assainissement individuel par épandage souterrain appartient à cette catégorie mais en assainissement collectif, la maîtrise de l'infiltration s'effectue au moyen de bassins d'infiltration.

Le support poreux peut être constitué par un sol naturel ou un sable de granulométrie donnée.

L'efficacité du procédé découle des propriétés physiques de ce filtre, véritable réacteur d'épuration biologique au travers duquel percolent lentement les eaux usées. Ce filtre non saturé, c'est-à-dire non immergé, permet, grâce à la finesse de ses pores, un contact intime entre l'oxygène de l'air et l'eau polluée divisée en fines goutelettes lors de la percolation. On a ainsi l'assurance que l'activité bactérienne agit en tout point de la masse du fluide tant qu'elle disposera d'oxygène en quantité suffisante.

L'art de l'infiltration contrôlée consiste donc à gérer l'oxygène de l'air au travers d'un massif filtrant. L'originalité de la technique est qu'on y parvient sans <u>consommation d'énergie "externe"</u> en pratiquant l'infiltration alternée, ce qui nécessite au moins un double système d'infiltration.

Le matériau filtrant n'est pas seulement le siège des processus d'oxydation poussés. Du fait de sa non saturation, il est doté d'un pouvoir de rétention élevé à l'égard de composés chimiques (métaux lourds, etc...) et des micro-organismes pathogènes. Ces derniers, une fois retenus dans la zone aérée où les conditions ne leur sont pas favorables, y dépérissent en raison de la présence de micro-organismes prédateurs aérobies (protozoaires).

Les systèmes d'épuration par infiltration contrôlée possèdent donc le pouvoir de décontaminer les eaux usées.

3.2 Paramètres

3.2.1 La mobilisation de la capacité épuratrice d'un milieu granulaire par infiltration contrôlée, autrement dit la transformation d'un système inerte en biofiltre dépend de règles de dimensionnement et de fonctionnement précises.

Au départ, on dispose de deux "matériaux de base" : le massif granulaire et l'effluent, qu'il s'agît de mettre en contact selon un mode séquentiel.

3.2.2 Le massif granulaire est un système qui laisse passer l'eau plus ou mois vite et qui permet les échanges d'air entre les pores et l'atmosphère : échange convectif lorsque l'eau est en mouvement dans le massif granulaire ("pompe à air"), échange diffusif lorsqu'elle est au repos (profil d'humidité à l'équilibre). Le massif granulaire est donc un réacteur où se mélangent, d'une part l'eau et l'air, d'autre part des eaux de différentes dates car aucun milieu filtrant ne fonctionne en système piston parfait (caractéristiques dispersives du matériau). Par ailleurs, le massif granulaire est un système de rétention.

- L'effluent, est constitué d'un flux liquide qui active le massif granulaire sous certaines conditions (apport contrôlé) et d'un flux polluant.

- Le mode séquentiel est déterminé par deux ensembles de grandeur mesurables, directement ou indirectement, et modélisables, qui définissent:

  . d'une part, le bilan d'oxygène à l'intérieur du massif filtrant

  . d'autre part, le temps de séjour de l'eau dans ce même massif. Ces grandeurs sont autant de paramètres de l'épuration par infiltration contrôlée pour un effluent de caractéristiques données. Considérant que le massif granulaire est le coeur du système, on distinguera deux lots de paramètres selon qu'ils lui sont intrinsèques ou extrinsèques.

3.2.3 Paramètres intrinsèques en massif granulaire: Ils en définissent les caractéristiques hydrauliques, dispersives et géométriques (conductivité K (θ) et succion ψ (θ) en fonction de la teneur en eau, épaisseur).

Dans la pratique, la caractérisation du massif filtrant s'étend à d'autres phénomènes:

  . gestion du colmatage: par sa granulométrie le matériau granulaire doit empêcher la migration en profondeur des matières en suspension de l'effluent et favoriser un nettoyage aisé de la plage d'infiltration après son sèchage (cas des bassins)

  . inter-actions chimiques entre l'effluent et la matrice du massif granulaire, dues principalement à la présence de carbonates et de particules argileuses gonflantes.

Au stade des études préliminaires, ces paramètres servent à sélectionner le massif granulaire et à déterminer si le sol en place convient ou si l'on doit faire appel à un sol rapporté.

3.2.4 Paramètres extrinsèques: ils caractérisent les conditions d'apport de l'effluent sur le massif granulaire (charge hyudraulique et charge de pollution). L'apport élémentaire est la "bâchée" dont on détermine la dose et le rythme.

L'expérience montre que si le sol peut être un système épurateur puissant et complet (performances au moins égales aux dispositifs biologiques classiques auxquelles se surajoutent une limpidification totale des eaux et une décontamination poussée), l'épuration n'atteint un niveau intéressant que pour des plages de valeurs assez étroites de combinaison de ces paramètres.

3.3. Performances

Dans les meilleurs cas, c'est-à-dire lorsqu'il est possible techniquement et économiquement, de s'inscrire dans les plages de valeurs recommandées des paramètres, l'épuration par infiltration contrôlée donne les performances épuratoires suivantes:

- épuration physico-chimique

  . matières en supension: limpidification totale
  . D.C.O. : épuration à 90-95%
  . nitrification : quasi totale
  . dénitrification : de l'ordre de 50%
  . composés phosphorés : épuration à 10-20%

- épuration des micro-organismes pathogènes

  . germes-tests de contamination fécale:

  - coliformes fécaux: abattement de 5 à 6 unités logarithmiques. Dans les eaux épurées les CF sont inférieurs à très inférieurs à 1000/100 ml.
  - streptocoques fécaux: abattement de 4 U-log. Dans les eaux épurées les SF sont inférieurs à très inférieurs à 100/100 ml.

  . parasites : épuration totale
  . salmonelles: absentes dans 66% des prélèvements sur eaux épurées.

4. MODALITES DE MISE EN OEUVRE

4.1 Types de dispositifs

Les dispositifs peuvent être drainés ou non drainés.

4.1.1 Dispositif non drainé

La Figure 1 représente ce cas (sables dunaires par exemple).

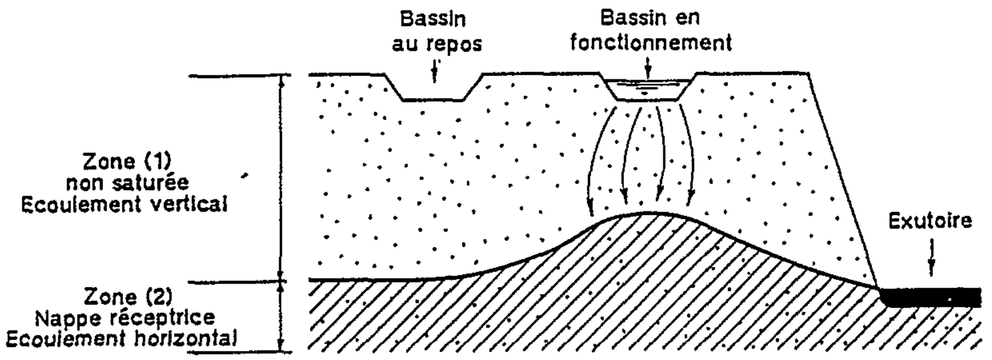


Schéma de Principe du Fonctionnement des Bassins d'Infiltration

Fig. 1

Le milieu épurateur par excellence est constitué par la zone non saturée à transit vertical. Une reconnaissance hydrogéologique des sites est nécessaire au préalable à la conception des projets. On devra s'assurer, essentiellement, que le niveau de la nappe souterraine est au moins à 3 m de profondeur sous le sol et que l'aquifère est capable de véhiculer horizontalement le débit infiltré vers un exutoire naturel ou des puits de reprise.

4.1.2 Dispositif drainé

Pour diverses raisons: économie de repompage ou encore conditions géologiques défavorables, le dispositif peut comporter un niveau de drain sous la zone à transit vertical.

4.2 Dimensionnement de la plage d'infiltration des bassins

Les dispositifs d'épuration par infiltration contrôlée nécessitent 0,50 à 0,75 m^2 par équivalent-habitant (10 à 15 fois moins que le lagunage).

4.3 Entretien - Prétraitement

Les bassins d'infiltration sont nettoyés par ratissage après leur séchage. Leur entretien est donc extrêmement simple et peut faire appel sans problème à une main-d'oeuvre nombreuse et peu qualifiée. Au demeurant, un des intérêts majeurs des systèmes d'infiltration est de soulager l'exploitation du difficile problème de la géstion de boues liquides. Reste le maillon du prétraitement qui doit s'inscrire dans la même logique de simplification des procédures de gestion. En s'inspirant de réalisations existantes tant dans les pays tempérés que dans les pays arides, on doit s'orienter vers des bassins décanteurs à grand temps de séjour (2 jours minimum) assurant une digestion anaérobie des boues et permettant d'espacer dans le temps (1 fois par an ?) les opérations d'élimination des boues "primaires".

4.4 Souplesse de fonctionnement

Les dispositifs d'épuration par infiltration contrôlée admettent sans problème des variations de charges hydraulique et polluante (journalières ou saisonnières). Les eaux pluviales urbaines peuvent être traitées en mélange avec les eaux usées domestiques.

4.5 Coûts

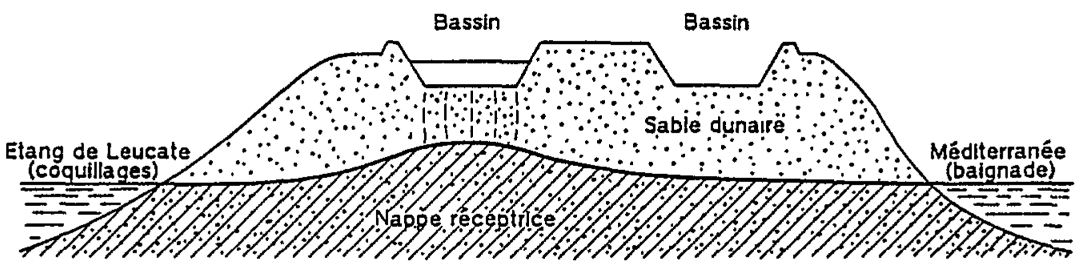
Selon les conditions de site et le type de dispositif (drainé ou non drainé), les coûts d'investissement oscillent entre 200 et 500 F.F. par équivalent-habitant.

Les frais d'entretien sont inférieurs à ceux d'une station classique à boues activées.

5. QUELQUES AMENAGEMENTS D'EPURATION PAR INFILTRATION CONTROLEE

5.1 Port-Leucate (Aude, France)

Site : littoral méditerranéen, cordon dunaire entre l'étang de Leucate et la Méditerranée (Fig. 2).



Coupe Schématique de l'Aménagement de Port-Leucate

Fig. 2

Objectif: protéger l'étang et les cultures de coquillages et les zones de baignade contre la pollution bactérienne par les rejets de la station d'épuration de Port-Leucate; économie d'un émissaire en mer.

Nature des effluents: effluent de la station d'épuration physico-chimique.

Dispositif: 6 bassins d'infiltration de 750 m^2 chacun, creusés dans le sable dunaire, capacité de 30.000 équivalent-habitants (eq-hab), 5.000 m^3/j (Fig. 3).

Coût investissement: 70 FF par habitant (traitement tertiaire).

<u>Résultats épuratoires:</u> les résultats suivants ont été obtenus avec l'infiltration directe d'effluents bruts (avant mise en service de la station d'épuration). Suivi de la qualité de l'eau par des piézomètres dans la nappe sous les bassins. La Figure 4 montre que 35% de la matière organique est éliminée (dont 60% pendant le transfert en non saturé). La Figure 5 montre que, dans les conditions de l'expérimentation, le nombre de germes témoins de contamination fécale est réduit de 4 à 5 unités logarithmiques (Ulog) pendant le transfert vertical puis de 2 Ulog pendant le transfert horizontal.

Fig. 3

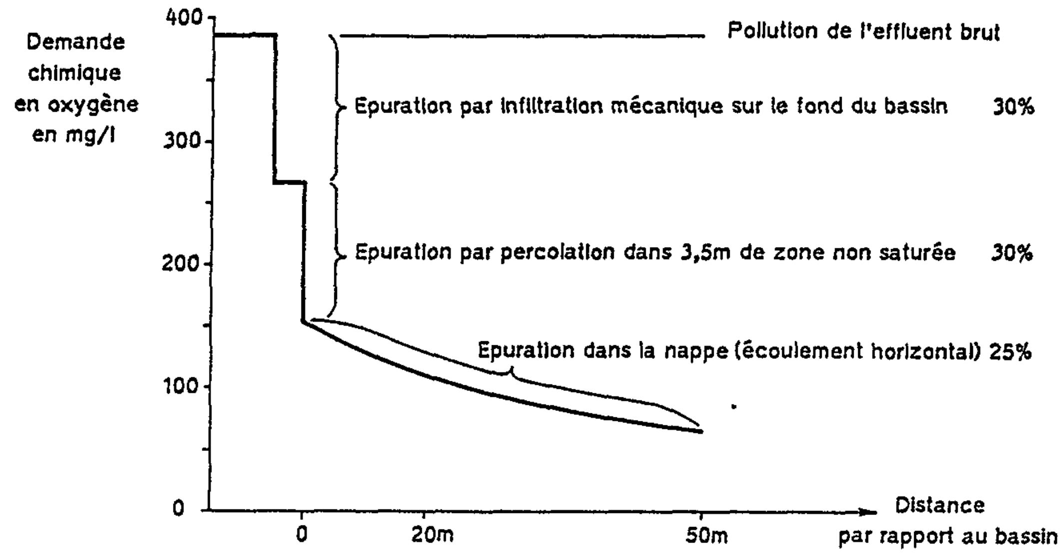


Fig. 4 - Epuration de la Matière Organique à Port-Leucate

5.2 Créances (Manche, France)

Site: massif dunaire sur le littoral de la Manche.

Objectif: épuration des eaux usées domestiques, protection des cultures de coquillages contre la pollution bactérienne.

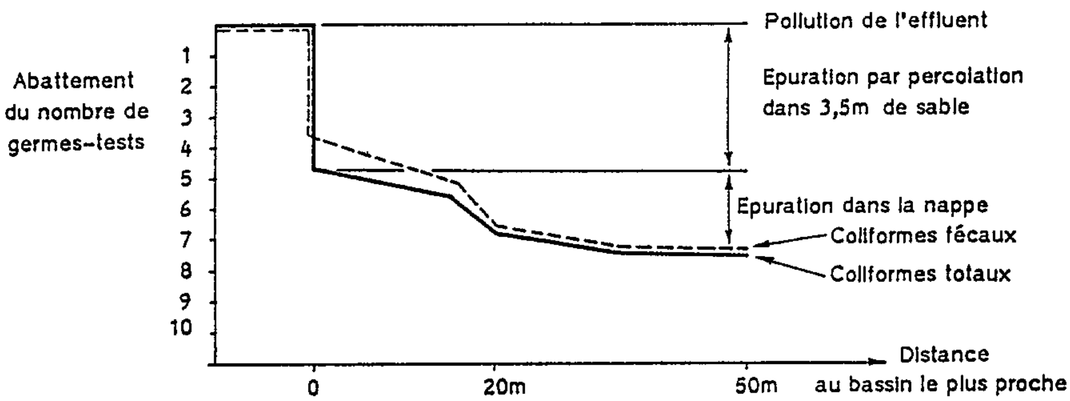
Nature de l'effluent: eaux usées domestiques.

Dispositif: dégrillage, déshuilage, dessablage, tamisage puis inflitration dans 4 bassins de 600 m^2 chacun, creusés dans le sable dunaire, 600 m^3/j (Fig. 6).

Coût d'investissement: 300 FF par habitant (traitement complet).

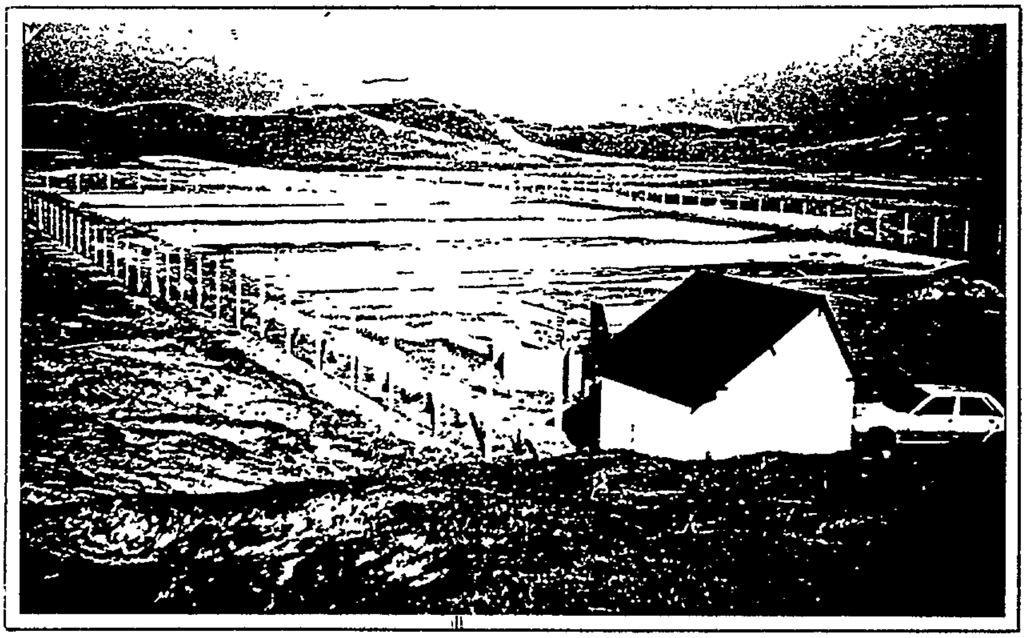
Résultats hydrauliques: Le tamisage est insuffisant pour assurer des vitesses d'infiltration satisfaisantes, nécessité de décanter les effluents avant infiltration (temps de séjour 2 jours).

Résultats épuratoires: après 3 ans de fonctionnement, aucune modification de la qualité de la nappe située à 8 m de profondeur (absence totale de germes, pas de variation de la DCO).



- Epuration des Germes Témoins de Contamination Fécale

Fig. 5



- Créances - Vue d'Ensemble de la Station d'Epuration

Fig. 6

5.3 Montpeyroux (Hérault, France)

Site: plateau marneux, zone de vignobles.

Objectifs: traitement conjoint des eaux usées domestiques et des effluents vinicoles; absorption des à-coups de pollution dûs aux rejets de la cave coopérative; réutilisation des eaux épurées pour l'irrigation.

Principe: prétraitement des effluents puis épuration par infiltration contrôlée dans des bassins draînés à sable rapporté sur les marnes, rejet de l'effluent épuré au cours d'eau.

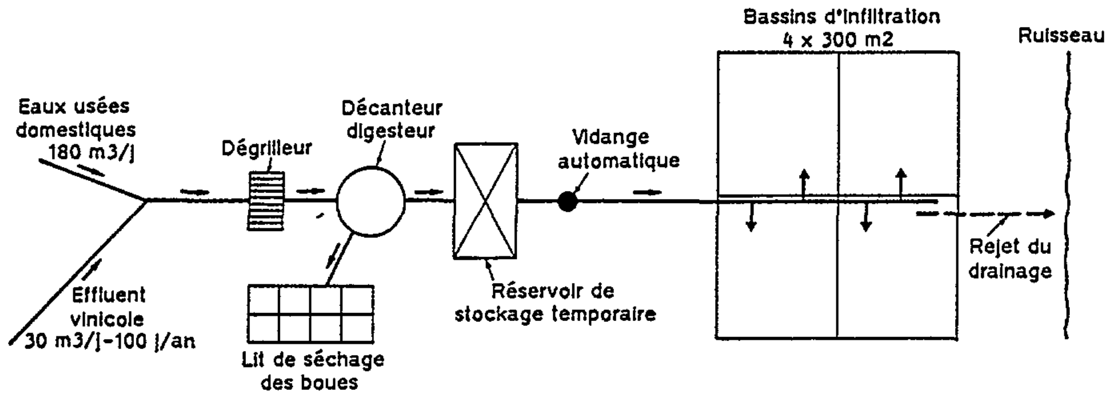


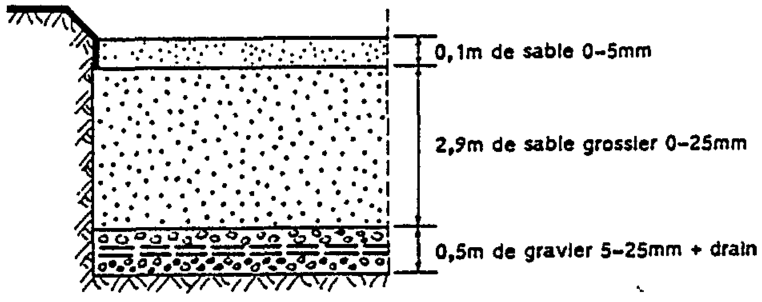
Schéma de l'Aménagement de Montpeyroux

Fig. 7

Nature de l'effluent: eaux usées domestiques (fortes variations saisonnières) et effluents vinicoles.

Dispositif: décanteur-digesteur, 4 bassins infiltration draînés de 300 m^2 chacun et garnis de 3 m de sables, capacité 1200 équivalent-habitants, 180 m^3/j (Figs. 7, 8 et 9).

Coût investissement: 600 FF par habitant (traitement complet).



- Coupe Schématique des Bassins d'Infiltration de Montpeyroux

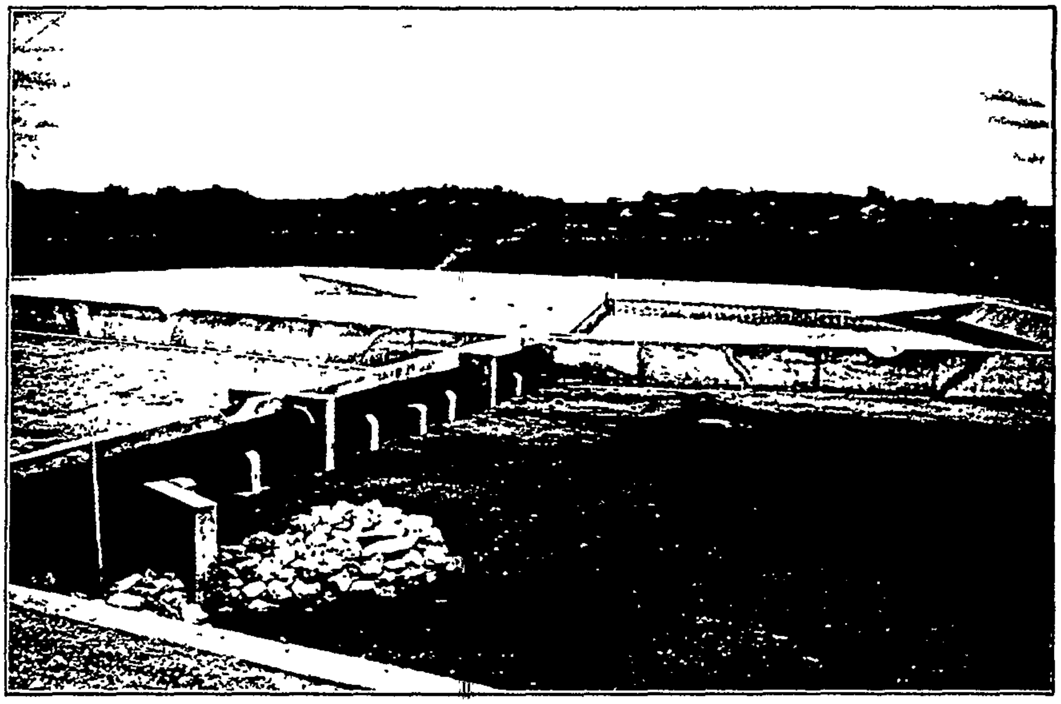
Fig. 8

Résultats épuratoires: la DCO est éliminée à plus de 80%. On observe une nitrification, même à une température de 9°. L'abattement des germes n'est que de 2 à 2,5 Ulog. Deux phénomènes en sont responsables: mauvaise répartition de l'effluent à la surface des bassins (débit de vidange du bassin de stockage insuffisant) et temps de séjour insuffisant dans le sable grossier dont la granulométrie est trop étalée pour assurer un écoulement type piston. Un sable à granulométrie serrée (type sable dunaire) convient mieux.

5.4 Céreirède - Montpellier (Hérault, France)

Objectif: réutilisation des eaux usées épurées pour l'irrigation de cultures maraîchères (expérimentation suivie en collaboration avec l'Université de Montpellier).

Principe: décontamination d'un effluent secondaire de station d'épuration par infiltration dans des bassins à sable rapporté, drainés, et repompage des effluents épurés puis irrigation goutte à goutte de cultures maraîchères (tomates).



- Montpeyroux Vue des 4 Bassins d'Infiltration
1er plan : Bassin en Phase de Séchage

Fig. 9

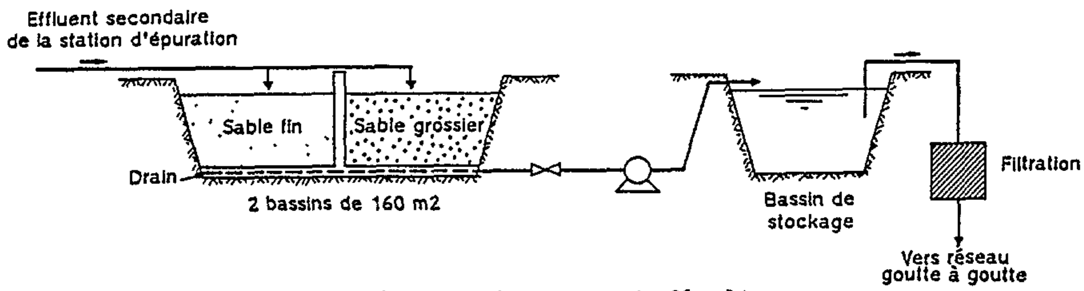


Schéma de l'Aménagement de La Céreirède

Fig. 10

Capacité: 430 m^3/j en 1985.

Dispositif: deux bassins drainés de 160 m^2 chacun, un des bassins est garni de sable fin, l'autre de matériau plus grossier. L'eau épurée est repompée vers un bassin de stockage puis vers un réseau goutte à goutte irrigant 3 à 4 hectares (Fig. 10 et 11).

<u>Résultats</u>: l'eau drainée au fond des bassins a la qualité suivante: MES 1 mg/l; DCO < 30 mgO_2/l; N kjeldhal 12 mg/l; N nitrique 3 mg/l; coliformes fécaux 8.10^3/100 ml; streptocoques fécaux 3.10^3/100 ml.

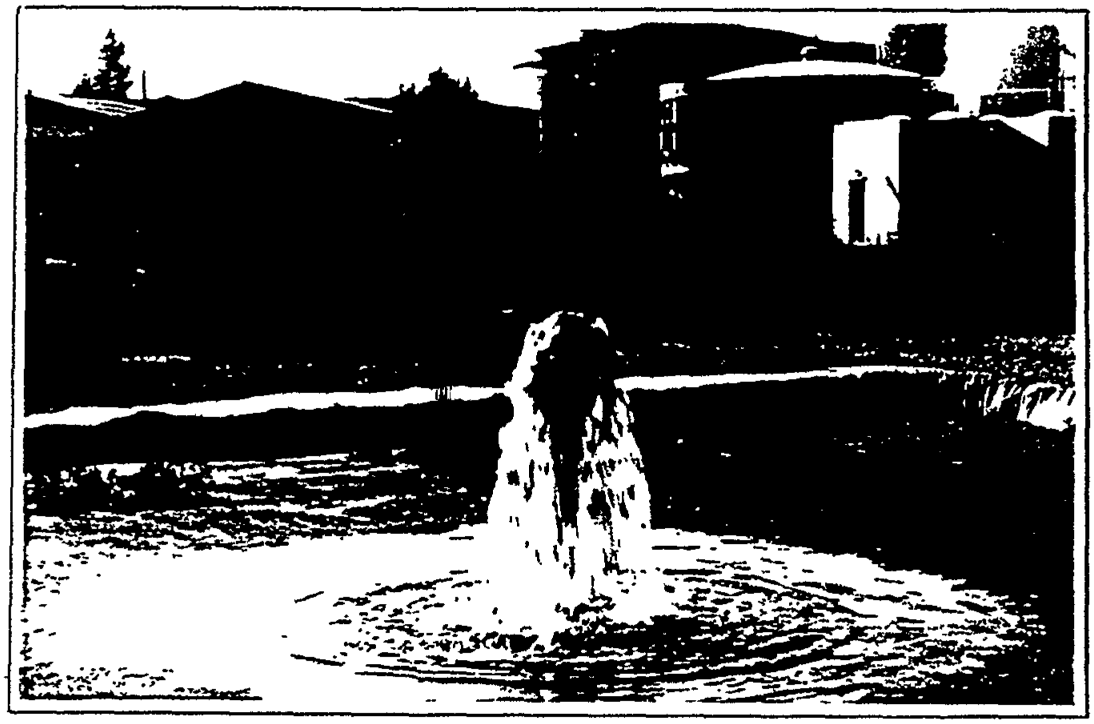
L'irrigation localisée (goutte à goutte) de 0,5 ha de tomates de conserve s'est déroulée sans incident et a conduit à une production satisfaisante dans ce contexte (32 tonnes). La qualité sanitaire des tomates produites, contrôlée par le Service de la Consommation et de la Répression des Fraudes, est jugée "correcte" ou "acceptable" selon que les tomates touchent ou ne touchent pas la terre. Cette qualité est dans les 2 cas, meilleure que celle d'un échantillon de référence, prélevé sur un marché. Sans doute la qualité sanitaire des produits doit-elle beaucoup au mode d'irrigation au goutte à goutte.

5.5 <u>Aménagement pilote de Ben-Sergao Agadir (Maroc)</u>

Site: massif dunaire sur socle calcaire peu perméable.

Objectifs: dispositif expérimental d'épuration contrôlée dans le sol du Grand-Agadir (400.000 équivalent-habitants): protection de la zone de baignade contre la pollution par les effluents domestiques, économie d'un rejet en mer par émissaire et réutilisation des eaux épurées pour irrigation, notamment de cultures maraîchères.

Nature des effluents: eaux usées urbaines.



La Céreirède Arrivée de l'Eau dans un des Bassins d'Infiltration

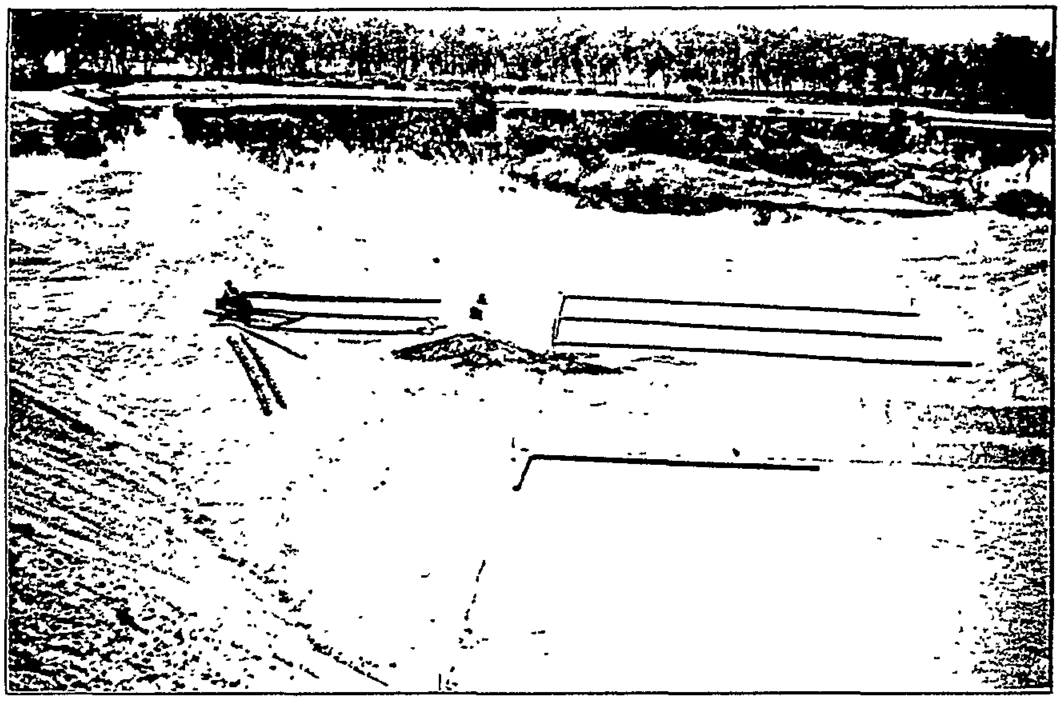
Fig. 11

Dispositif pilote: dégrillage - dessablage - déshuilage, prétraitement par décantation horizontale ou tamisage 750 microns, infiltration alternée dans 3 bassins draînés de 100 m^2 chacun et garnis de 2 ou 3 m de sable dunaire (0-2 mm) (Figs. 12 et 13).

Résultats du prétraitement: le tamis ne retient que 4% des matières en suspension alors que 31% sont éliminés par décanteur horizontal (12 m/j); la décantation permet ainsi d'obtenir des vitesses d'infiltration plus élevées dans les bassins.

Résultats hydrauliques: les meilleurs rendements d'épuration ont été obtenus par des apports journaliers de 10 à 15 m^3/m^2 (apport par bâchée). Le temps de vidange et de séchage n'excède pas 24 h au bout de 20 jours. La surface des bassins est nettoyée par ratissage tous les 20 jours.

Epuration physico-chimique: les principales caractéristiques de l'effluent à l'entrée et à la sortie des bassins sont présentées au Tableau I.



-Ben Sergao - Agadir -Construction du Fond Drainant de Bassins Pilotes

Fig. 12

-Ben Sergao - Agadir - Bassins en Phase d'Infiltration
(Mesure du niveau de l'eau par sonde à ultrasons)

Fig. 13

TABLEAU I

Caractéristiques chimiques de l'effluent de Ben Sergao avant et après épuration par inflitration

	MES mg/l	DCO mg O_2/l	azote total mg/l	phosphore mg/l
Entrée bassin (effluent décanté)	200 à 350	800 à 1400	100 à 250	20 à 30
Sortie bassin	< 1	45 à 100	50 à 150	3,5
Rendement	99%	90 à 95%	50%	15-20 %

MES: matière en suspension. DCO: demande chimique en oxygène.

Pour les apports importants (40 $m^3/m^2/j$) les rendements sont moins bons car le temps de séjour est trop faible pour une bonne épuration.

L'azote de l'effluent est essentiellement de l'azote Kjeldhal. En sortie des bassins on retrouve des traces d'azote Kjeldhal et essentiellement de l'azote nitreux et nitrique. Le phosphore est retenu de façon remarquable dans le massif sableux.

Décontamination de l'effluent: les résultats globaux du tableau II laissent apparaître une grande variabilité de l'efficacité épuratoire du dispositif d'infiltration. Outre la variabilité naturelle inhérente à tout phénomène biologique, cette variabilité est le résultat de la modification de certains paramètres. On a pu montrer que l'efficacité de la décontamination est, en première approximation, proportionnelle à la hauteur de massif filtrant; décroît fortement avec la hauteur des bâchées unitaires (Fig. 14); dépend du taux d'oxygénation du milieu (meilleur abattement quand le milieu est bien oxygéné); croît avec le temps de séjour dans le massif filtrant (Fig. 15).

Elimination des parasites et des virus

L'élimination des parasites est totale ainsi que celle des virus (Tableau III).

TABLEAU II

Résultats globaux de la décontamination obtenue par infiltration contrôlée à Ben Sergao

	Coliformes fécaux		Streptocoques fécaux	
	Bassin de 3 m de sable	Bassin de 2 m de sable	Bassin de 3 m de sable	Bassin de 2 m de sable
entrée (Ulog)	6,92	6,77	6,01	6,30
sortie (Ulog)	3,88	4,88	3,13	3,79
abattement moyen (Ulog)	3,05	1,89	5,76	2,51

TABLEAU III

Elimination des parasites et des virus par infiltration contrôlée à Ben Sergao

	Parasites	Virus
Effluent brut	4010 oeufs helminthes/l	Virus poliomyélitique
Effluent décanté	840 oeufs helminthes/l: * 670 Nématodes/l * 170 Cestodes/l * 0 Trématodes/l	-
Effluent après infiltration	aucun parasite	aucun virus observé

Nota: l'aménagement pilote de Ben Sergao est une réalisation de la Coopération Maroco-Française, dans le cadre du programme des Collectivites locales; il a été mis en oeuvre par la Direction des Collectivités Locales du Ministère de l'Intérieur du Maroc.

- Abattement des Coliformes Fécaux en Fonction du Temps de Séjour

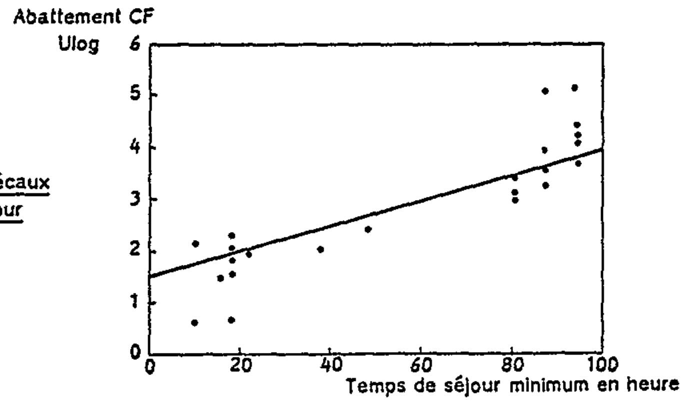
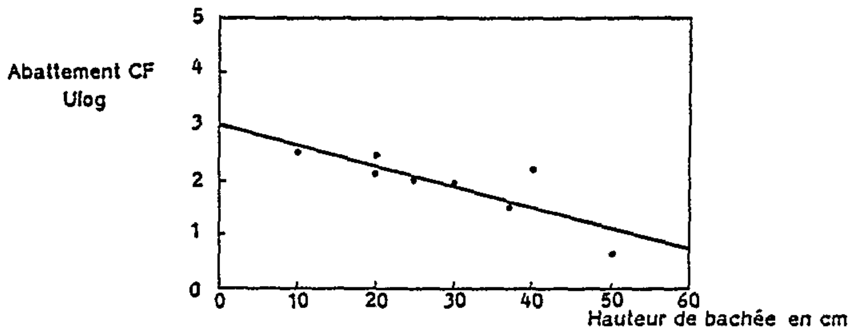


Fig. 14



- Abattement des Coliformes Fécaux en Fonction de la Hauteur de Bachée Unitaire (2m de sable)

Fig. 15

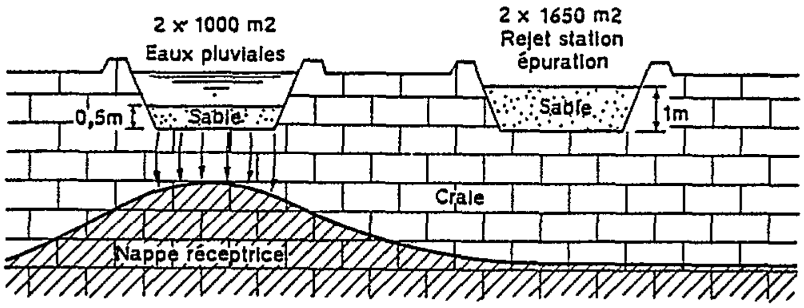
5.6 Flesselles (Somme, France)

Site: plateau crayeux, absence de cours d'eau.

Objectifs: supprimer la stagnation des rejets de la station d'épuration et protéger la nappe de la craie contre la pollution bactérienne.

Principe: épuration terminale du rejet de la station d'épuration des eaux usées domestiques ainsi que des eaux pluviales par infiltration contrôlée dans des bassins à sable rapporté sur la craie (Fig. 16).

Dispositif: eaux pluviales: décantation (4200 m^3) puis infiltration dans 2 bassins de 1000 m^2 chacun. Eaux usées: épuration terminale dans 2 bassins d'inflitration de 1650 m^2 chacun. Capacité 2200 éq-hab. (Fig. 17 et 18). Le sable rapporté est du sable dunaire.



Coupe Schématique de l'Aménagement de Flesselles

Fig. 16.

Résultats: Les eaux usées sont infiltrées à des vitesses variant de 0,2 à 0,4 m/j, les eaux pluviales à des vitesses de l'ordre de 1 m/j. L'élimination des germes est faible du fait de la faible épaisseur (0,5 ou 1 m) du sable et de l'apport continu des effluents. En effet l'abattement des germes est fonction de la nature du sable (sable fin à granulométrie très serrée), de son épaisseur et du mode d'apport de l'eau. A Flesselles, pour améliorer la décontamination, il faudrait au minimum 3 m de sable dunaire et un bassin de stockage temporaire qui permettrait un apport d'eau séquentiel sur les bassins. L'apport par "bâchées" permet d'utiliser toute la surface des bassins et d'obtenir dans le massif sableux un écoulement de type piston qui favorise la réoxygénation par convection.

Entretien: ratissage périodique du fond des bassins après vidange totale et séchage (Fig. 19)

-Flesselles

Mise en Place du Sable Filtrant sur le Substratum de la Craie

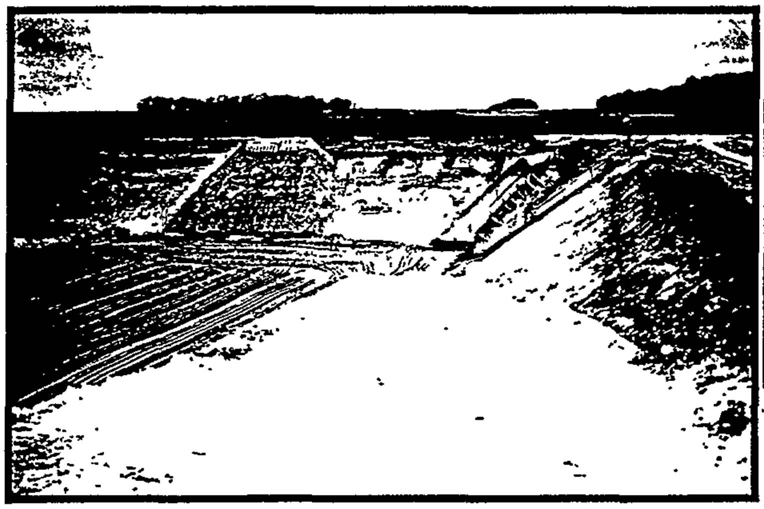


Fig. 17

. Flesselles

Bassin d'Infiltration
des Eaux Pluviales
après une Pluie

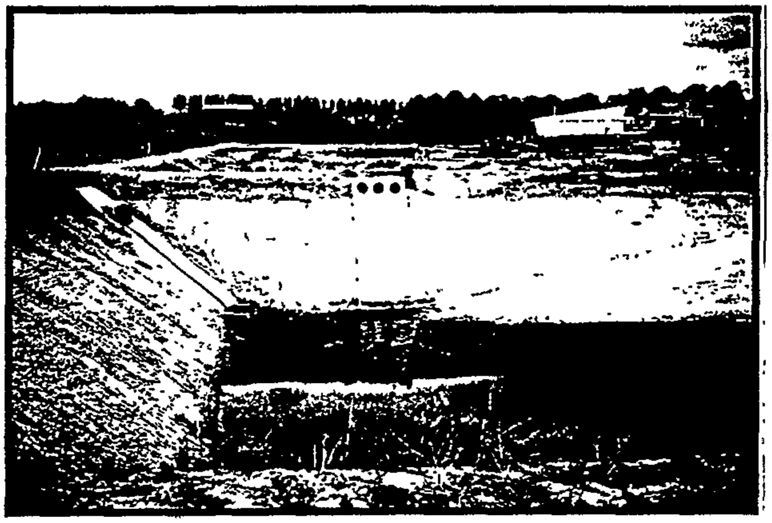


Fig. 18

- Flesselles

Nettoyage des Bassins

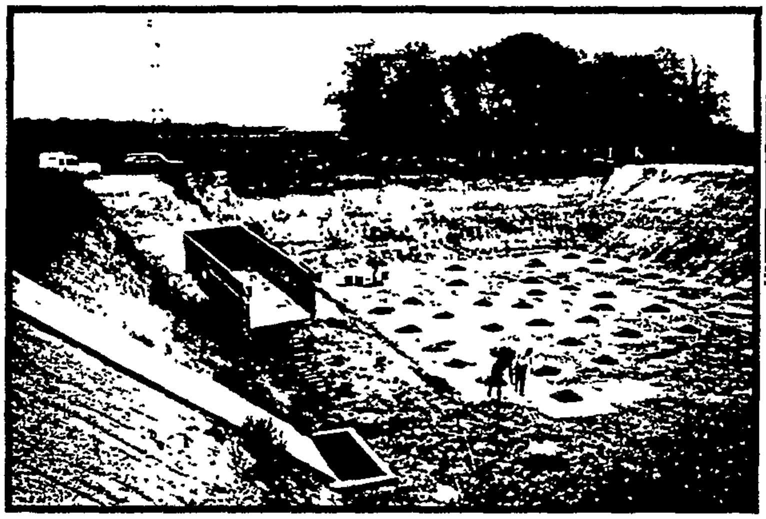


Fig. 19

RE-USE OF TREATED SEWAGE EFFLUENT IN THE ISLAND OF MALTA

By

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1. INTRODUCTION

The Maltese islands are made up of two islands: Malta and Gozo. Malta is the larger island with an area of approximately 300 sq. km and a population of 330,000. Malta is one of the most densely populated countries in the world. The climate is semi-arid with long, hot and dry summers and cold winters during which there are short, heavy downpours. The mean annual rainfall is 568 mm, of which only an estimated 25% infiltrates to augment underground water supplies.

Over the years Malta has experienced water shortage problems, a situation reflected in local laws. An old regulation, for example, stipulates that every house should have an underground cistern of adequate capacity for rain-water collection. Another prohibits the use of first-class water for the purpose of irrigation. All along, therefore, Malta has been trying to solve the problem of water shortage in its own way and with its limited resources.

As far back as 1884, Lord Chadwick suggested that sewage should be used for irrigation, thereby saving first-class water for domestic use. In 1952, Morris repeated the same suggestion, but recommended that, due to particular local conditions, irrigation with raw sewage should not be carried out.

There are no permanent surface water streams or lakes on the island, but up to about 25 years ago, underground resources were adequate to meet the local water demand. A rapid rise in water demand has occurred over the last 25 years, due to various factors, including the slow but steady increase in population (including the increase in tourist population), the increase in standards of living and industrialization. Over-exploitation of local aquifers led to a gradual salinity increase. During the sixties, the World Health Organization, as executing agency on behalf of the United Nations Development Programme, carried out a study on the local water supply and wastes. Among the recommendations which followed this study was sewage treatment for the purpose of re-use in irrigation and aquifer recharge. In 1978, the Swedish consulting firm VBB carried out a pre-investment study on an Integrated Liquid and Solid Wastes Reclamation Project.

As a follow-up to these studies and recommendations, a sewage treatment plant was commissioned in 1983 in the locality known as Sant Antnin and since then it has been producing water for irrigation.

2. THE SANT ANTNIN SEWAGE TREATMENT AND IRRIGATION PROJECT

Of the total area of 13,000 ha under cultivation in Malta, only about 4% is under irrigation; the rest may be described as dry or semi-irrigated land, which depends more or less upon rain which falls during the period September to April.

Prior to the installation of the Sant Antnin Sewage Treatment Plant (SASTP), irrigated land was supplied with water obtained from privately-owned wells, usually tapping a perched aquifer to the northwest of the island. The SASTP was designed to augment the irrigated area in Malta by 600 ha and this in the southeast region which has traditionally been under dryland cultivation. Moreover, the groundwater resources in the region are not of high quality, so that there is no risk of groundwater pollution.

The design capacity of the SASTP is 12,000 m^3 per day, equivalent to just under 50% of local sewage production. Sewers draining the inland parts of Malta (100,000 p.e.) converge to a central pumping station from where the sewage is pumped to the SASTP. The raw sewage is strong, having a BOD5 of 500 mg/l and a Total Kjeldahl Nitrogen of 75 mg/l. This reflects the relatively low per capita water consumption of the community. Levels of heavy metals and other toxic elements are as expected of a typical domestic sewage.

Figures 1 and 2 show a block diagram and plan of the installation, respectively. The sewage flow admitted to the plant is adjusted on a monthly basis in such a way that the flow meets the predicted agricultural demand. The sewage is subjected to preliminary and primary treatment[then follows biological treatment by the Activated Sludge Technique, where virtually complete carbonaceous and nitrogenous oxidation are achieved in the same plug-flow reactor. Finally, the water is subjected to rapid sand filtration and disinfection by chlorine gas. Unrestricted irrigation is practised in the area, so that the reclaimed water has to reach adequate health standards. Fecal coliform levels of less than 100 per 100 ml in 80% of the samples are achieved by maintaining a trace of free chlorine in the final effluent. Table I shows mean analytical data. The effluent is

Table I

Sant Antnin Sewage Treatment Plant Laboratory
Mean Routine Analytical Results - 1986
(based on samples taken during period March - November)

Analytical Parameter	S/S*1	SE	SFE	FE
pH	7.4	7.1		7.2
Turbidity		12.5	2.8 (77%)*2	3.1
E.C., microS/cm	4097	3744		4033
Suspended Solids, mg/l	205	25 (88%)	4 (84%)	
Chloride, mg Cl/l		1002		
Ammoniacal N, mg/l	74	0.4 (100%)		
Nitrate N, mg/l		47		
C.O.D., mg/l	472	55 (88%)	36 (35%)	
E.O.D., mg/l	251	10 (96%)	6.7 (33%)	
Alkalinity, mg $CaCO_3$/l		198		
M.B.A.S., mg LAS/l		0.06		0.07
Boron, mg B/l		1.0	1.0	
Fecal Coliforms /100ml		10^5	10^5	1
Fecal Strepts / 100ml		10^4	10^4	2

*1 S/S - Settled Sewage (Primary Effluent)
SE - Secondary Effluent
SFE - Sand Filtered Effluent
FE - Final Effluent

*2 Values in parenthesis refer to the % reduction from preceding stage.

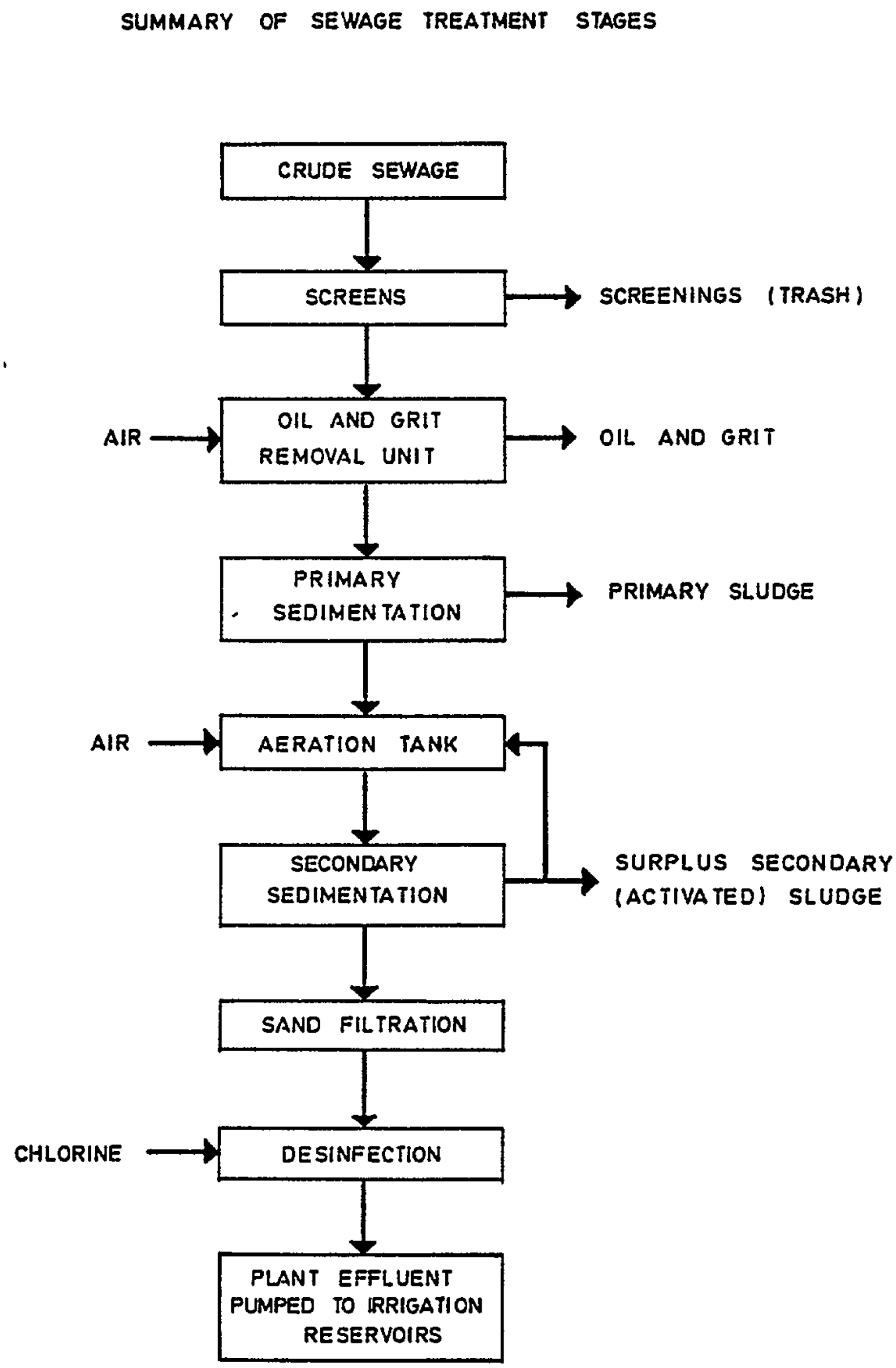

Fig. 1 Summary of Sewage Treatment Stages

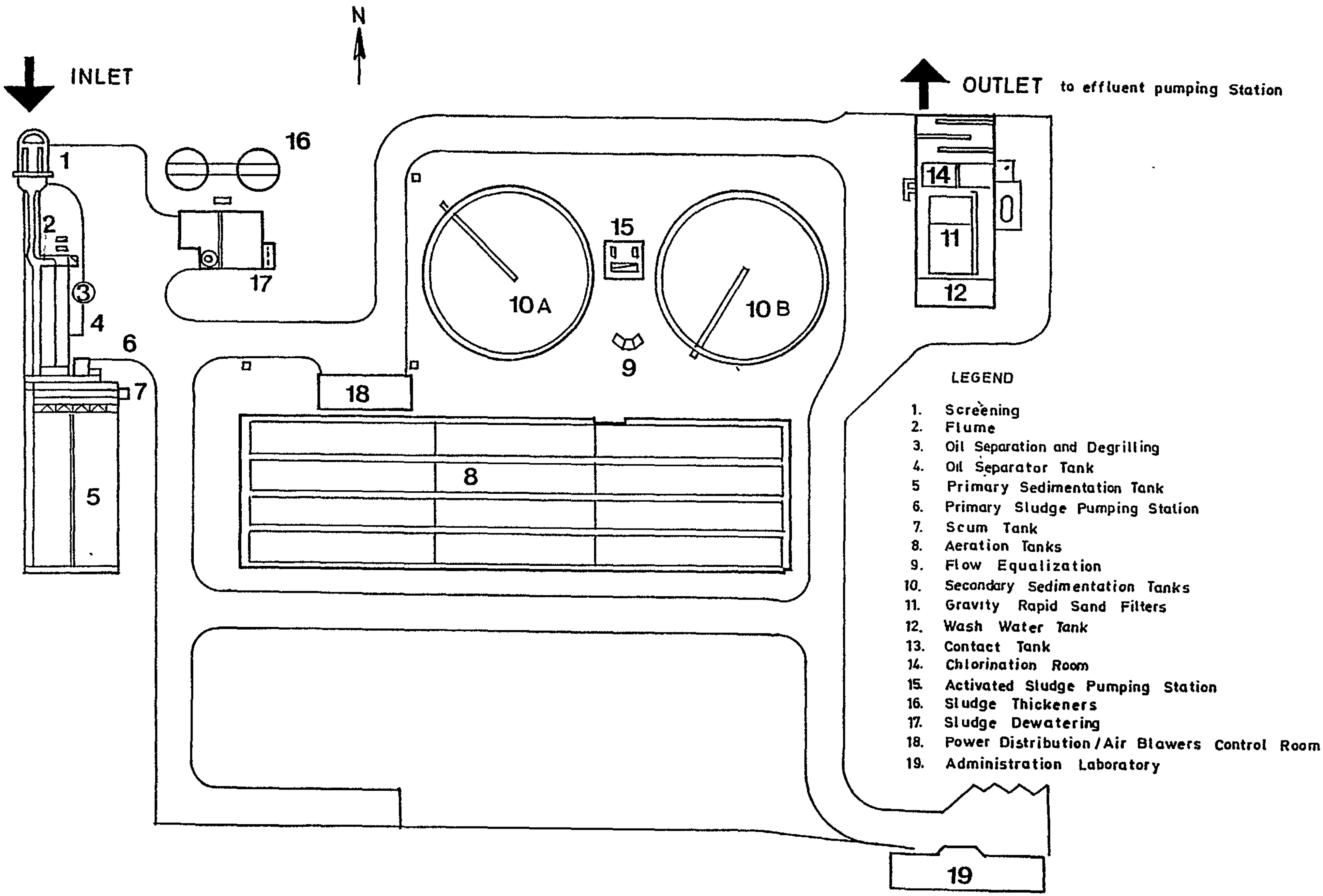

Fig. 2 Treatment Plant Installation

pumped to 5 irrigation reservoirs situated on high ground which together provide a total capacity equivalent to a 24 h supply.

Activated sludge plants are easily upset by wrong biomass management, sewage feed quality and flow fluctuations, and insufficient aeration capacities. Periods of biological instability invariably result in a deterioration of effluent quality. The plant may take several weeks to recover. In order to limit the occurrence of such situations it is necessary to have the operation of the plant always under control. There is not much sophisticated equipment at the SASTP, which has resulted in a significant load of manual and routine operations including sampling and analysis in an on-site laboratory fully equipped to carry out all routine analysis, including microbiological tests.

Although officers from the Department of Agriculture assist local farmers by discussing problems and giving advice, agricultural management was entirely in the hands of the local farmers. During 1986, 290 farmers in the area benefited from the project. Furrow irrigation was practised, but spray irrigation was also used. The main crops cultivated in the region were potatoes, tomatoes, broad and runner beans, vegetable marrow, green pepper, turnips, cabbages, cauliflower, lettuce, strawberries and clover.

The capital cost for the project was 16 million US$, of which 1.4 million US$ were the foreign component, comprising designs and machinery supplied by the Italian firm Breda.

A total of 859,000 m^3 of reclaimed water was pumped to irrigation during 1986, and this during the period March to November. Fig. 3 shows water pumped to irrigation month by month during 1986. The cost of this water amounted to 1.1 US$ per m^3. Approximately 50% of this cost was due to annual repayments on capital investment, while the rest went on salaries, power, chemicals, fuel, maintenance and water distribution costs. An annual nominal fee of 100 US$ per ha of irrigable land was charged. The revenue collected was a mere 4% of effluent cost. Financial aspects apart, however, the project has created a number of not easily quantifiable benefits, viz. an increase in agricultural production, creation of new job opportunities and last but not least, the reduction of pollution which otherwise would have resulted following the disposal of sewage into the Mediterranean Sea.

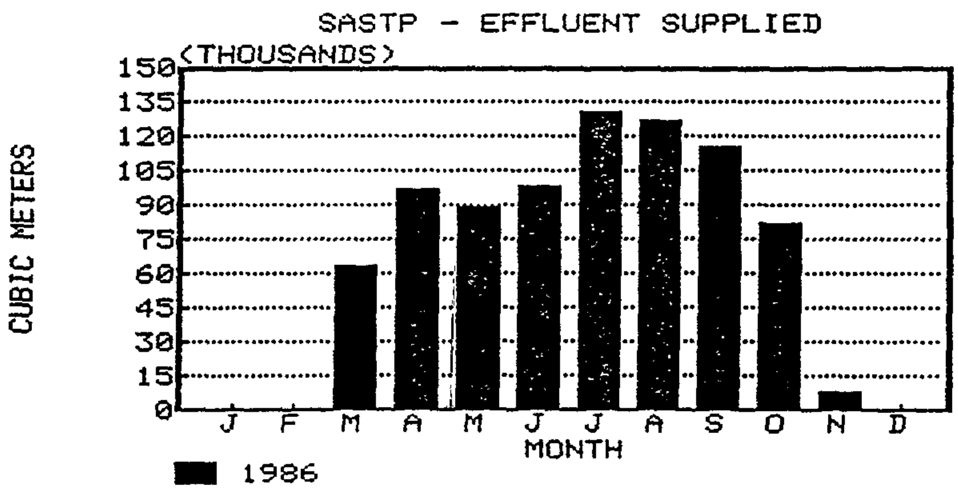

Fig. 3 SASTP - Effluent Supplied

2. PROBLEMS ENCOUNTERED

Many difficulties have been encountered since 1983 when the plant started operations.

Fig. 6 shows the increase in water demand since the start of operations. Nevertheless, water demand never went beyond half plant design capacity, because of the original 600 ha earmarked for irrigation, only 300 ha were under irrigation in 1986. The other 300 ha either still required to be connected to the irrigation network or required reclamation before they could be cultivated.

Effluent salinity is rather high, reflecting the high sodium and chloride ion levels in the domestic supply. Strictly speaking, the effluent must be considered as a water of marginal quality, needing special agricultural management techniques. In spite of this, however, no special techniques have been adopted. Figs. 5 and 6 show the results of soil salinity monitoring. Soil samples are taken before and after the irrigation season. Apparently, salts accumulate in the soil as a result of irrigation, to be washed down again during the winter months. Also, rather surprisingly, some crops which are generally considered as sensitive to salinity have been cultivated successfully. These included strawberries and runner beans. This is undoubtedly related to the permeable nature of the local calcareous soil and goes to show that salinity standards for water intended for irrigation may be misleading if taken without regard to the local soil properties.

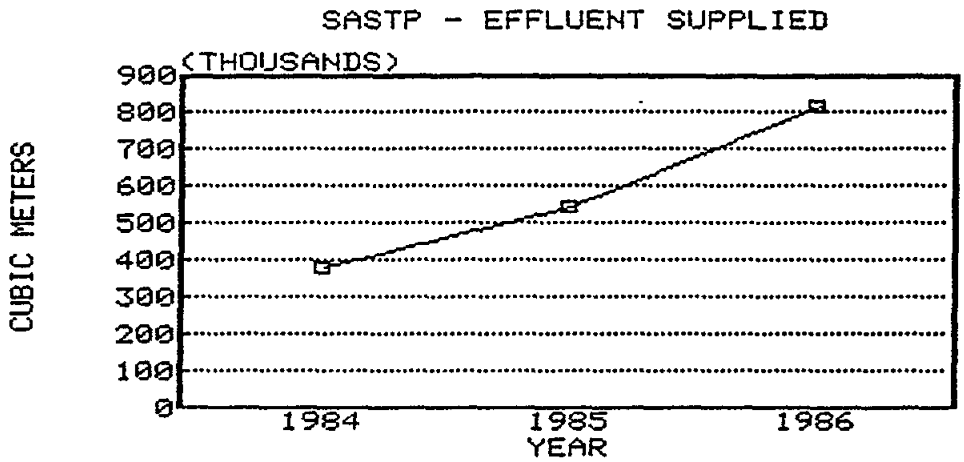

Fig. 4 SASTP - Effluent Supplied

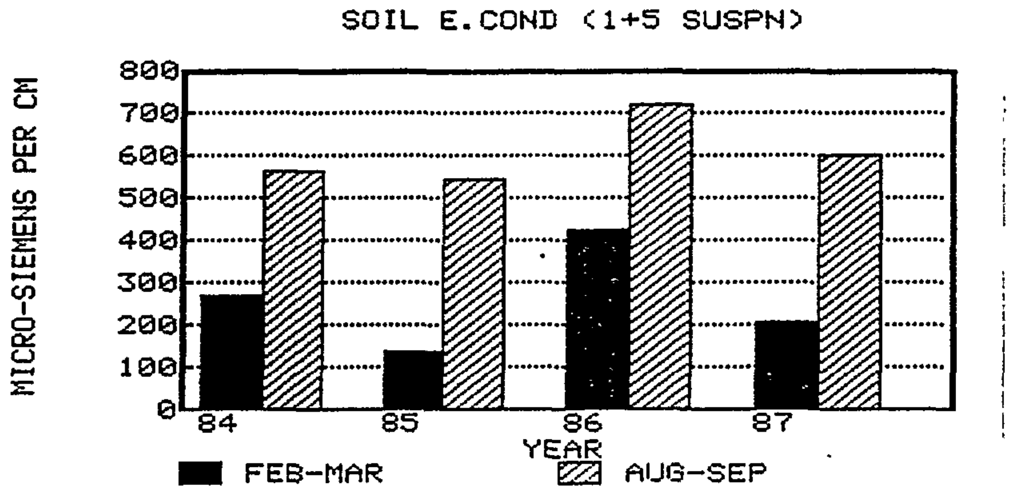

Fig. 5 SOIL E. COND (1+5 SUSPN)

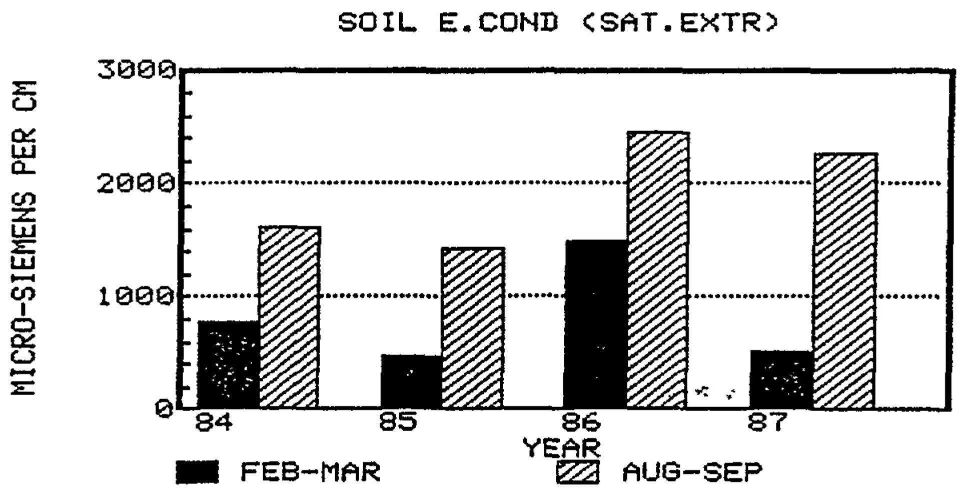

Fig. 6 SOIL E. COND (SAT. EXTR)

It is felt that the substitution of vegetable crops with more water-responsive industrial crops should be more carefully considered. Cultivation of fodder crops, for instance, besides reducing further the health risks, would help to cut down on the importation of fodder. This would require considerable mechanisation. In this respect, the fragmentation of the land would certainly pose problems.

3. CONCLUSION

Unlike many countries in which sewage treatment is taken for granted, Malta has had its first experience of sewage treatment and re-use with the coming into operation of the SASTP in 1983. To the majority of the population, sewage has been something to be got rid of as quickly as possible. It is understandable, therefore, that to a certain extent, this attitude still exists[for example, it is not uncommon to encounter a certain diffidence in its re-use. This attitude will be changed first of all by maintaining a high standard in the finished product and also by maintaining good public relations.

From this point of view, the Sant Antnin Project has undoubtedly been a success. Proof of this comes from the number of government waste re-use projects, the feasibility of which is being studied. These include·

(i) the extension of the existing irrigation network to cover the whole southeast of the island[

(ii) the setting up of a sewage treatment plant for effluent re-use to the north of Malta[

(iii) the setting up of a similar plant in the island of Gozo[

(iv) the setting up of a Solid Wastes Recycling Plant where sewage sludge from SASTP and municipal solid wastes are co-composted for use in agriculture. This project is in the tender evaluation stage and is due for implementation in 1988.

(v) use of sewage reclaimed for aquifer recharge.

TREATMENT AND USE OF SEWAGE EFFLUENT FOR IRRIGATION AND OTHER PURPOSES IN SYRIA

By

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1. INTRODUCTION

From 1980 statistics, about 80% of the urban population in Syria had a domestic water supply net system and about 70% of those had a combined sewage system (industrial, house sewage and storm water flow) exploiting the existing overflow on the same net system.

In rural areas the figures for water supply are 55%, sewage water about 30%, and as for the case of this network system (water supply - sewage water), it can be said that it is in good condition.

In future trends predictions for the year 2000, drinking water and sewage water net system projections reach 98% and 95% in the urban regions, and 95% and 90% in the rural regions.

It has been estimated by Syrian statisticians that water consumption was between 80-200 litres per person daily in 1980 and will be between 175-250 litres per person daily in 2000 for urban areas. In rural areas in 1980, it was between 50-100 litres per person daily and is expected to reach 150 litres in 2000.

Water resources to meet the needs of domestic water in Syria consist of springs, wells, lakes and rivers. According to the specifications of raw water, there are different methods for drinking water treatment as in European systems whereas this treatment aims at reaching the drinking water standard of WHO. Recent data in Syria (ratios and consumption, water supply treatment plants) show levels comparable with European conditions.

In contrast, in the field of sewage water treatment it can be seen that treatment ratios in Syria (cities and villages) are almost zero, except for some small treatment units for some industrial and tourism plants; the largest is a treatment unit which functions only in the summer of the 'Rumal Lahbeya' (Golden Sands Beach) residential site which comprises villas (chalets) for projected population of 12,000, which has been developed by a private company, the Tourist and Vacation Cooperative of Homs, with financial assistance from the government. The first phase, for a population of 7.000, including a sewage treatment plant, is now complete.

The treatment plant, built (at an estimated cost of LS 4 million) by the French firm SOAF comprises the following stages: (i) balancing tank; (ii) screens; (iii) grease and sand removal; (iv) biological treatment by activated sludge in two tanks; (v) clarification (with recirculation of activated sludge); and (vi) chlorination with sodium hypochlorite to a residual of 0.3-0.5 mg/litre. The effluent is discharged into the mouth of a small river away from the bathing area.

Sludge from the clarifier is concentrated in a thickener and then goes to sludge drying beds but can be alternatively processed in a pressure filter, the liquid being returned to the clarifier and the sludge being collected by truck for disposal.

This treatment plant is in service for only two months in the summer during which period which the effluent treated water pours into the sea, but cannot be considered as an applied model for re-using the effluent treated water in irrigation, and should not be regarded as a typical Syrian experience in this sector.

The report dealt only with the basic elements of re-use of wastewater in irrigation. The use of this effluent for other purposes is not carried out, because sewage water is discharged directly into rivers, lakes or the sea. Consequently, the water from these resources (except the sea) is used mainly for irrigation.

Industrial plants use either neighbouring well water or the public water supply.

As the author has mentioned in earlier reports, sewage water from cities or villages pours into water resources such as the Mediterranean Sea, rivers, lakes and untreated water is used for irrigation purposes.

Up to the present, some studies have been carried out by American, and English companies for major Syrian cities (e.g. Damascus, Aleppo, Lattakia, Homs, Hama) but up until now for technical and financial reasons nothing has been put into operation.

What is presented here are the results of studies and research undertaken by the author, considering the local environmental conditions in Syria.

2. WATER-BORNE DISEASES IN RELATION TO THE USE OF SEWAGE WATER FOR IRRIGATION IN SYRIA

Owing to the shortage of freshwater and since market gardening in urban areas provides a livelihood for large sections of the population, irrigation and recycling of wastewater is essential. This is carried out with polluted sewage water. Fig. 1 shows a typical situation of the cycle of sewage water for irrigation in Damascus the illness cycle that accompanies it in Syria. In order to prove this illness cycle, the author was able to find a correlation between the frequency of contagious diseases such as cholera and typhus, and the use of sewage water or polluted river water in irrigation (Fig. 2). This confirms the necessity for sewage water treatment, especially to reduce microbial pollutants.

As polluted water (from rivers, lakes, etc.) is used mainly during the summer for irrigating raw vegetables, in which the concentration of pollutants is maximum, all sewage water must be treated in an advanced way so as to ensure hygienic requirements for irrigation water. Ways to achieve these objectives are found in the following sections.

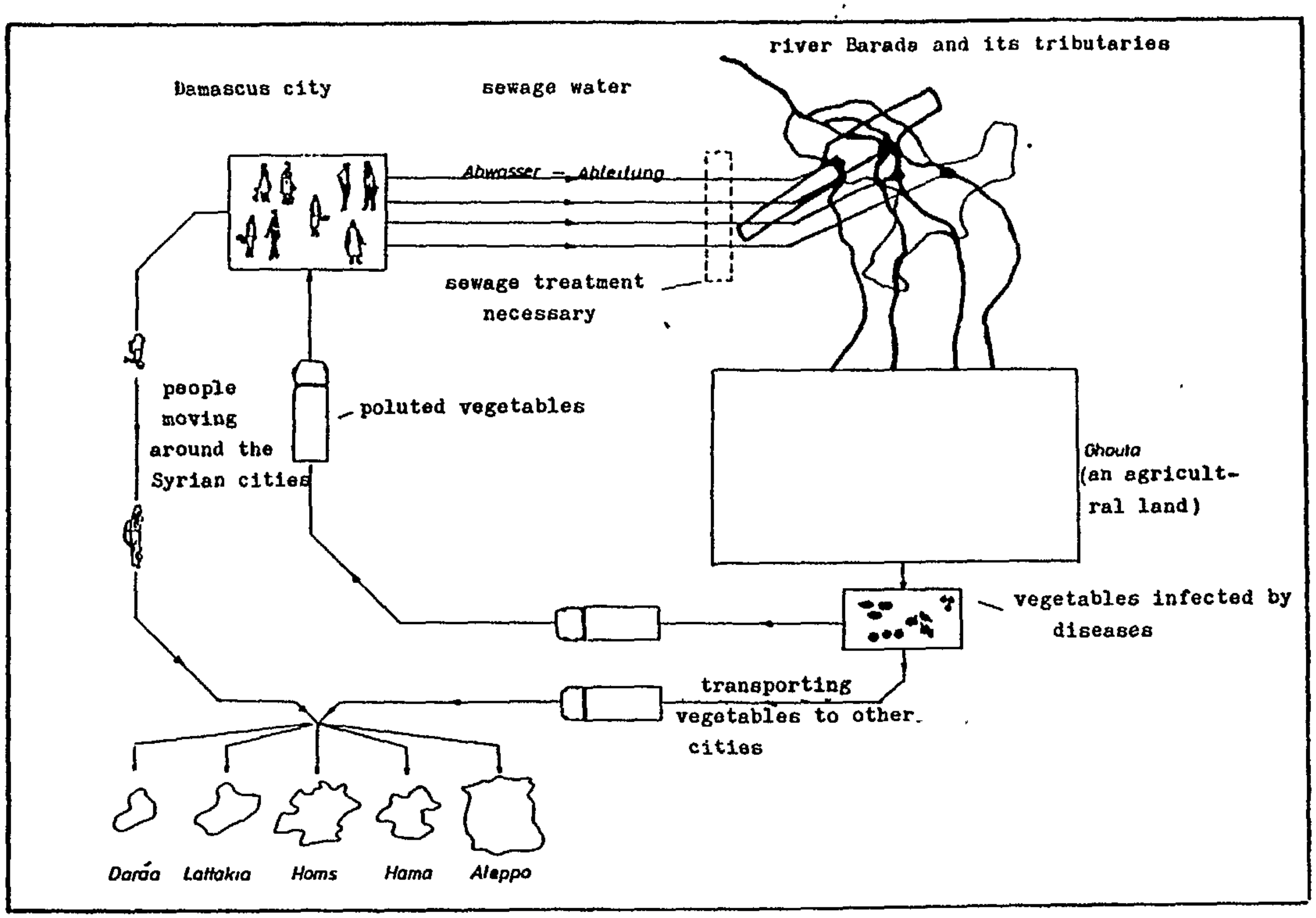

Fig. 1 The illness cycle as a result of sewage water irrigation

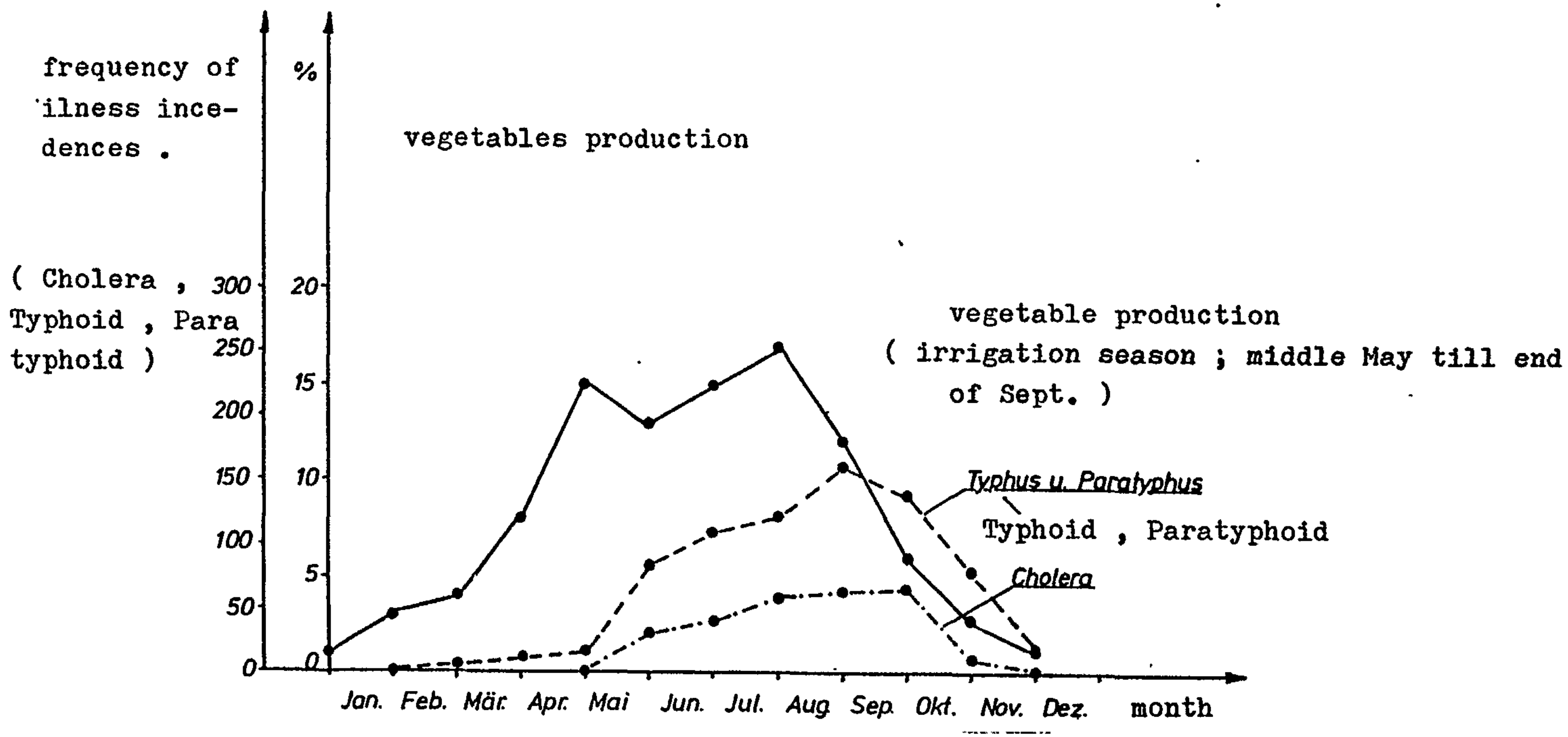

Fig. 2 Vegetable irrigation with sewage water and the amount of yearly illnesses in Syria

3. THE BASIC METHODS OF TREATMENT

In sanitary engineering science, there are different accepted treatment methods used for specific goals, which have been adopted worldwide. If a new treatment system for sanitary sewage water in Syria is to be set up, first we must calculate the efficiency and economy of the treatment in addition to its requirements as part of the classical treatment method, which we can discuss, in order to have an active system to lessen the danger of pollutants in health and environment and to use their relative values more economically (for instance, the values related to mechanical treatment as comparative values).

Table I summarizes the results of different treatments of sewage water and their costs in respect of the decreasing degree of organic pollution (BOD_5).

Table I
Comparison between the costs and benefits in various kinds of treatment (according to the BOD_5)

Kind of treatment	Decreasing the Organic pollutants BOD_5 in %	Remaining BOD_5 in effluent water (mg/l)*	Relative efficiency of treatment	Relative annual costs in relation to mechanical treatment
Mechanical	30	210	1.0	1.0
Biological without nitrification	95	15	3.2	2.40**
Biological with nitrification	95	15	3.2	2.80***

* Taking into consideration that the amount of average concentration of (BOD_5) in raw sewage water is 300 mg/l.

** According to the sources (references) the relative costs for building is limited to the second amount.

*** The additional costs provided that the nitrogen compounds (nitrification, denitrification) decrease.

In the case of the mechanical-biological treatment (Table I), the improvement in the result of the treatment as far as the third level corresponds to the costs until factor (2.2) and this proportion is calculated because it is known that the proportional yearly costs for mechanical treatment only, gives factor (1) as a comparative operator.

In addition, the biological-mechanical treatment systems for sanitary disposal water have recently gained experience and high technical knowledge. Besides flexibility, it has a high degree of safety.

The biological-mechanical treatment is not totally adequate for antiseptics.

There are three major methods for disinfection (antiseptics):

i) antisepsis with chlorine
ii) antisepsis with ozone
iii) antisepsis by the use of chemical coagulation (e.g. by use of fine lime).

Antisepsis by chlorine may be achieved either for sewage water that has been treated mechanically only, or for sewage water that has been treated biologically. Using chlorine to antisepticize water that has been treated mechanically demands a high consumption of the chlorine substance, forming a high proportion of CL organic compound.

These are biologically indigestible compounds and near-poisonous. In general, certain problems occur through transporting and storing chlorine, especially in work places.

According to Imhoff, sterilizing sewage water (mechanical and biological treatment), by decreasing the rate of bacteria to 98-99%, demands the usage of CL·2 Grams/M3 sewage water.

In the case of raw sewage water, the fall off of bacteria to 90-95% demands the use of 20 CL grams for each M3 sewage water.

In addition ,CL does not play more than a subservient role in decreasing the rate of the organic pollution (BOD_5), apart from the fact that it is difficult to treat raw sewage water with chlorine, compared with the same treatment for sewage water which has already been treated biologically.

The use of a compound physico-chemical treating system instead of biological treatment with added chlorine, also makes it possible to achieve antisepsis of sewage water without chlorine.

According to the kind of compound-treating system, the relative costs range between 104-211%. The physico-chemical treating system followed by chloring, is relatively expensive. Antisepsis by means of ozone may be used for sewage water treated mechanically-biologically.

This is because water treated by other incomplete methods needs large amounts of high-priced ozone. In reality, by using ozone there are no concomitant dangers except that it needs a permanent source of energy to produce ozone.

Antisepsis with ozone has the following advantages:

i) no leavings or chemical sludges are formed
ii) there is no need to modify the treated water as for example in the case of chemical coagulation with lime
iii) reaching a progressive sterilization for treated water, that is besides cutting off the activity of bacteria, ozone too cuts off the activity of viruses and thus ozone is better than chlorine
iv) the poisonous effect of sewage water treated with ozone is very low compared with other methods
v) removing pollutants from treated sewage water and improving the qualities of purifying water.

In spite of the great advantages of the treating system for sewage water with ozone, it is still rather an expensive system.

Antisepsis of sewage water with chemical coagulation, e.g. by the use of lime, may be achieved right from the second stage following the mechanical-biological treatment. Fundamentally, treatment by lime in the high field for 'pH' with the value pH | 11.5 (HL=high lime process), achieves near-perfect sterilization and the alkali sludge formed should afterwards be useful in agriculture without further modification.

It seems that the re-use of lime by means of burning the gathered lime compounds and modifying the burning gas, will be possible in future. By recycling the lime, the nutrients (nitrogen-phosphorus) may be kept for plants for manure purposes, and thus avoid loss. Phosphorus remains through the re-use operation (recycling) of the lime. What is lost must be restored with fresh lime. The settled lime may be used to fertilize the agrarian lands while the nitrogen compounds mostly remain in the treated water.

In Fig. 3, we can see the typical planning exhibit for a mechanical-biological treatment plant with the following treatment by chemical coagulation with lime and its re-use.

A treating system by coagulation achieves perfect disinfection and its cost is clearly higher than the cost of disinfection methods by the use of ozone and chlorine. The direct chemical coagulation operation by lime through two successive periods without a biological treatment period, is considered cheaper than any other method but it does not bring about compete sterilization. The other chemical physical treatment methods do not remove enough dissolved organic subjects (BOD_5). That is because the substances removed from sewage water do not amount to more than 10%.

Generally, the above-mentioned considerations lead us to the following conclusion.

The best treatment method for sanitary sewage water in Syria, which allows for subsequent agricultural use is the biological-mechanical treatment system, followed by the disinfection system with the use of ozone. The problem of supplying such systems with enough financial resources (energy needed is included) can be considered as overcome. The same is true for ozone. The amount of power for the disinfection of sewage water for agricultural use in Syrian towns in the inner and drought-prone areas, and with all its population of 6 million can be estimated as follows in Table II.

Table II

The necessary electrical power for various dosages of ozone for a biological-mechanical treatment plant treating sewage water from 6,000,000 personsor (equivalent person) nearly 1.2 (Hectometre)^3 of sewage water daily

Ozon (O_3) consumption "mg/l"	Electrical Power "Megawatt"
1	1.5
5	7.5
10	15
20	30
40	60

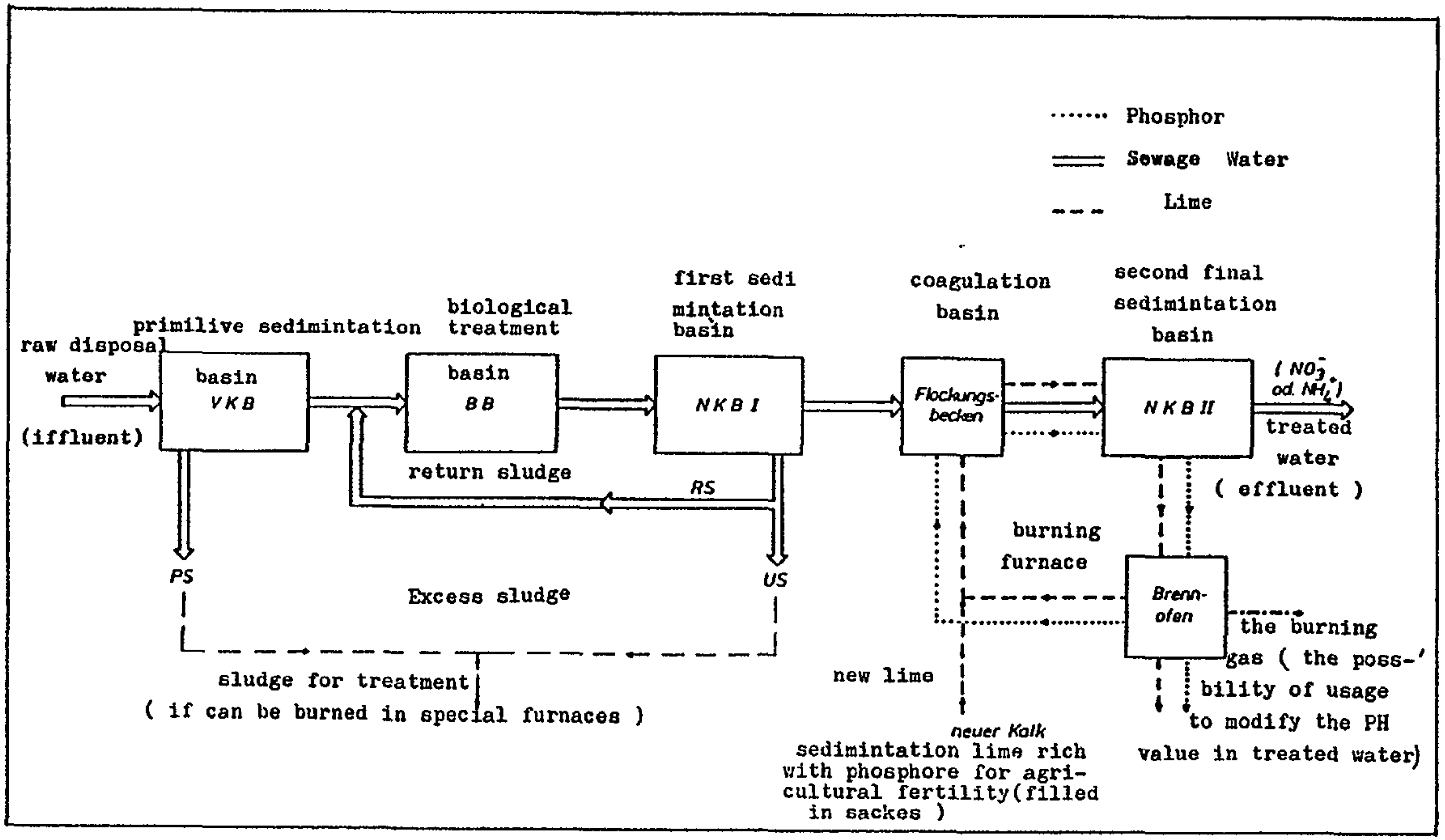

Fig. 3 A typical scheme for a biological-mechanical treatment plant and a following treatment by lime coagulation and recycling of lime

Thus we can come to a decision as to the correct treatment that will ensure, taking into account Syria's circumstances, the protection of the water supply on the one hand and the complete disinfection of sewage water in order to exploit it in agricultural use in irrigation, on the other hand.

Protection of the water supply necessitates a decrease in the nitrogen compounds of sewage water that is discharged into it. This decrease can be achieved by biological treatment at a fairly low cost.

For thinly populated areas in Syria (villages) where cheap land is found, we can suggest treatment methods of sewage in these regions for its re-use in irrigation, such as installation of a non-technical system, e.g. oxidation ponds. By installing 5-7 oxidation ponds, with the retention time for each of five days, put consecutively as follows:

anaerobic ponds
facultative ponds
maturation ponds.

This treatment lowers microbial pollution to the rate of 100 coliform per 100 ml effluent water. This water becomes suitable for irrigation. This kind of treatment by ponds has various advantages related to expense, maintenance, skilled personnel, operation, construction and experience.

4. EVALUATION MODEL TO DEFINE THE PURPOSE OF SEWAGE WATER TREATMENT

In order to estimate the financial cost of the treatment system in connection with the utility of sewage water after purification, the following major three criteria only are of concern:

a) the costs of sewage water treatment;

b) the security degree of the treatment system in relation to the damage that may occur to the usufructuaries;

c) environment protection as opposed to environment pollution.

These main criteria subsume other criteria. The results of this estimation are summarized in Table III.

Table III

Evaluation table showing link between type of sewage water treatment and the criteria of cost, environmental influences and work security

Criterion	Deposition of treated water in water source (river, sea)	Plants irrigation	Water filtration	Recycling of sewage water treatment in drinking water
Costs	4	3.5	2	1.4
Environmental Effects	1	2-3 I-M 2.5	3	4
Work Security	4	2-3 I-M 2.5	2	1
Whole Relative Consequence	9	7.5-9.5 I-M 8.5	7	6.4

Notes Related to Table III

1. The assessment was done in a way that the influence of the single criterion had been estimated to be between 1-4 for single usage of treated sewage water and degree 4 was defined for the necessary influence, which degree 1 was defined for direct passive influence.
2. The same importance was given to the different criteria because the controllers of the other usage purposes may get partly different levels of care according to the person who assesses and has an important point of view in this assessment. If we want to be more accurate, the costs controllers and environmental influences may vary according to the environment and location where the owner of this assessment lives.
3. The cost was evaluated according to the consequences of Fig. 4 where it is shown in a simple form. Degree 4 was considered as a degree for estimating the biological and mechanical treatment cost as the lowest level of the requirements for sewage water treatment. so the assessment values for advanced treatment systems can be calculated, by relating ratio (4) to the relative treatment cost according to Fig. 4.
4. The evaluation of work security was done on the basis of calculating hygienic dangers on the usufructuary of the treated water in purification plants out of order or not working properly, e.g. in the agricultural usage condition, work security is linked to the types of irrigated plants. Where there is a defect of the purification plant which is used to irrigate vegetables, this leads to the use of polluted water for irrigation resulting in damage to health.
5. The environmental effects define the harmful passive influences that are able to affect soil, air and water and by a progressive treatment for sewage water in order to be used for drinking, the influence of these water will be at all harmless for environment, so it is estimated with degree 4.
6. From our study of the whole assessment degrees in Table III, for kinds of single usage, we found that the requirements of the qualitative use treatment (plants irrigation and pouring treated water in the water source got nearly the same estimation).

This means that the mechanical-biological treatment of sewage water together with the additional disinfection (part or whole) and considering the criteria (cost, work security, harmful environmental influences), these things as a whole, are nearly equal in importance to the mechanical-biological treatment by itself. If we want to re-use treated sewage water for agricultural purposes, there will be an additional cost but this cost will be low compared with the positive value of the re-use of treated water in the areas of environment protection and work security (Table III).

Depending on the limited results according to the calculated model, it will be useful too to consider the necessity of evaluating sewage water for agricultural purposes in Syrian inner cities such as Aleppo, Homs, Hama, the desert and drought-prone areas such as Damascus, Sweda, Dair Alzour and Tadmor (Fig. 5).

In contrast, there is sufficient fresh water in the coastal area to be used for agricultural purposes. In this case, sewage water will be directed almost to the water source (river or sea) after treatment, and the type of treatment for sewage water will be determined at that stage.

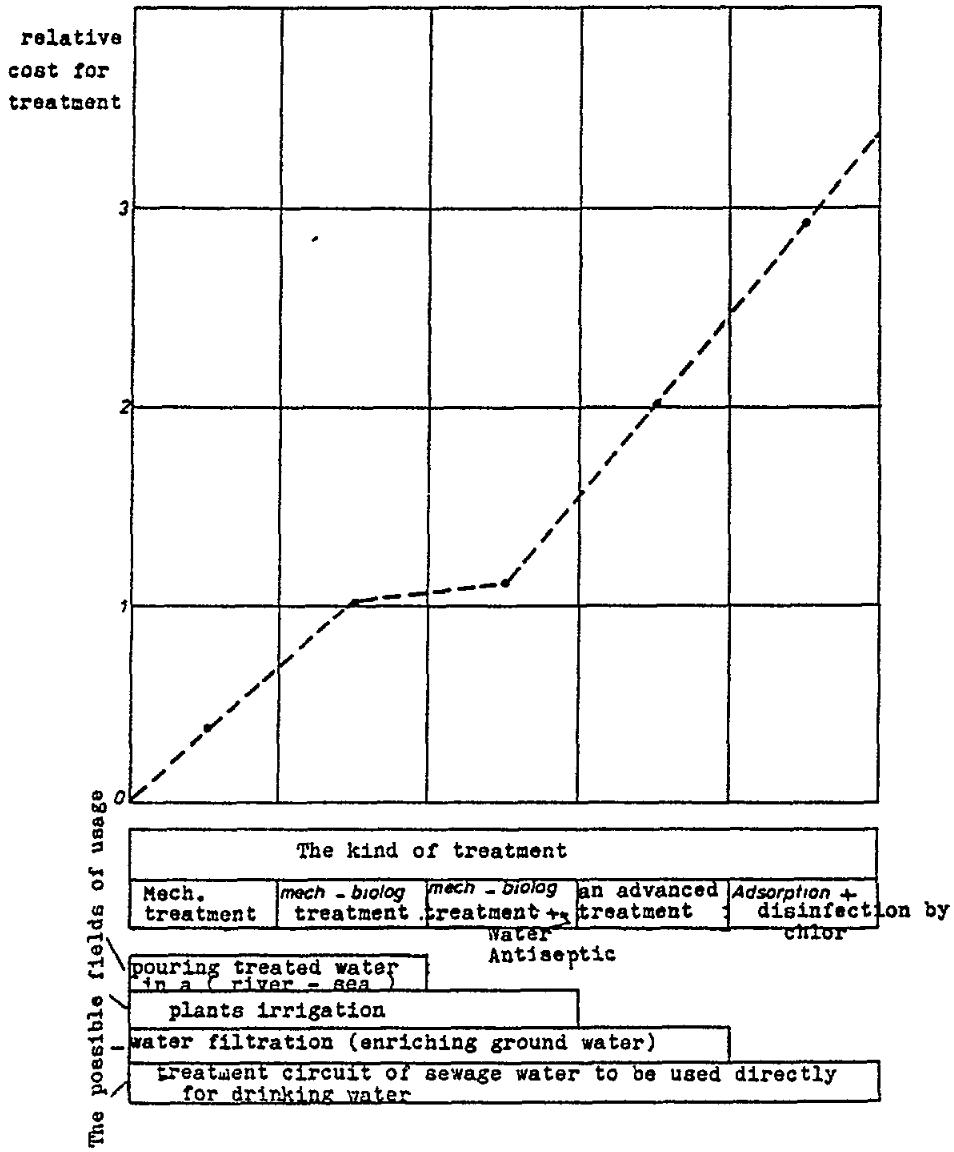

Fig. 4 The relative cost for sewage water treatment in relation to the kind of treatment according to the purpose of the usage.

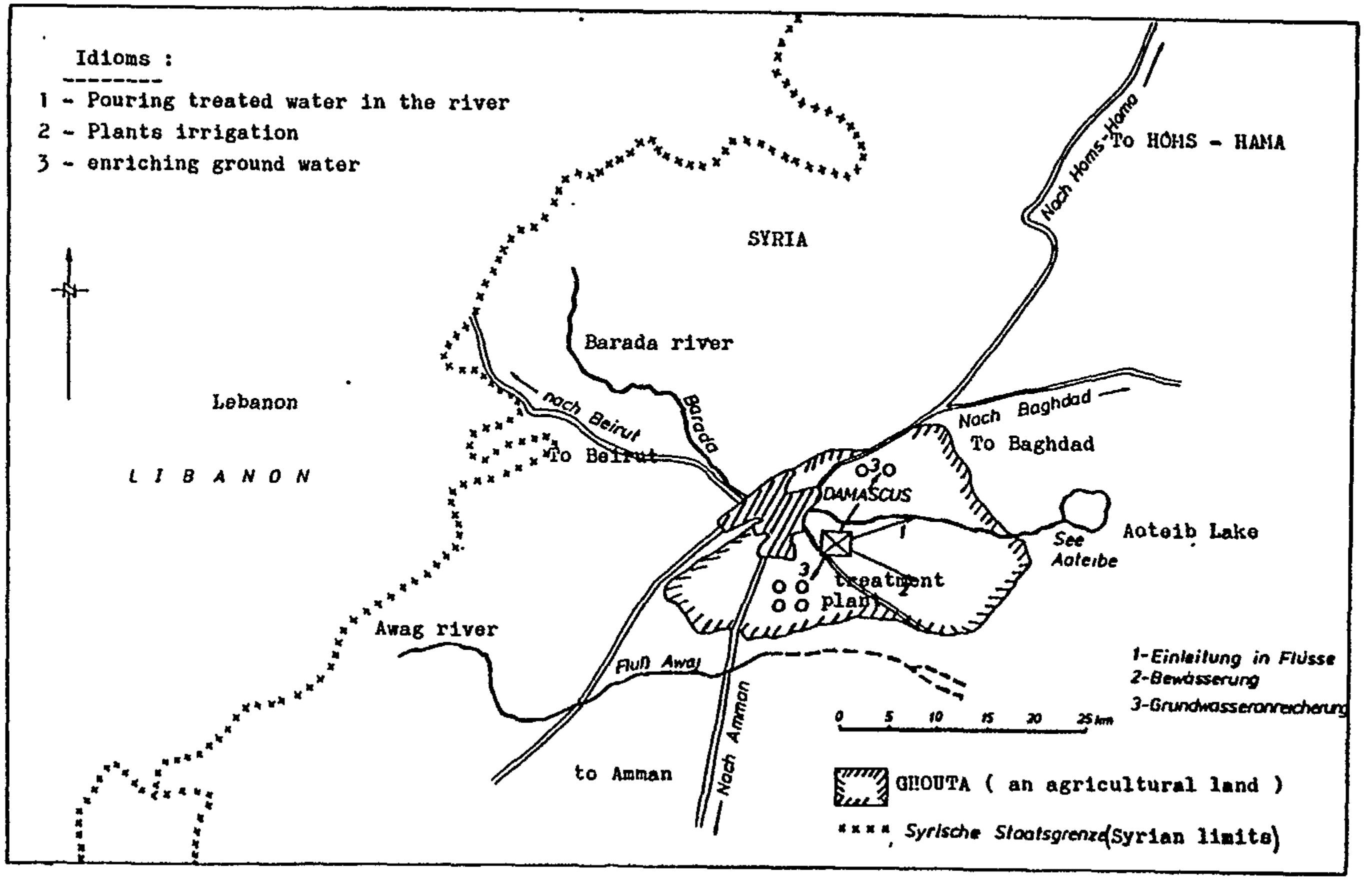

Fig. 5 The uses of treated sewage water (Damascus as a case study)

5. RAIN FLOW POLLUTION IN COMBINED SEWER SYSTEM IN LATTAKIA AND ITS TREATMENT

All the sewer networks in Syrian cities are combined systems and the amount of rain flow in them consists of between 20-200 times more in dry weather flow according to the climatic location of the city.

Until recently, Environmental Sanitary Engineering Science has been restricted to the area of the protection of water sources from urban pollutants. It, therefore, has focused on the treatment of dry weather flow. But research and recent American and European studies have shown the importance of rainwater flow treatment in sanitary sewers and combined systems as well.

Dry weather flow contains organic and microbial pollutants but storm weather flow contains higher ratios of these pollutants.

According to the measurements which took place in Busnau (Stuttgart), the following ratios were defined (Table IV) between pollutant load in dry weather flow and storm weather flow of the first shock of rain water.

Table IV

Average Ratio of Pollution load in the storm and dry weather flow in the first shock

Average ratio of pollution load resulting from storm weather flow to pollution load resulting from dry weather flow in combined sewers (RWA/TWA)			Time after start of rain water flow (minute)
Coliform Bacteria	Total number of micro-organisms	Organic Pollution (BOD_5)	
33	100	13	0 - 12

The figures in the table show that the large amount of pollutants in water sources is due to storm weather flow. This is how the initial flow of pollutants in storm weather flows exerts a negative effect on hygiene.

It is clear that the effects of storm weather flow exceed those of dry weather flow by at least 13 times in the case of organic pollution (BOD_5) and reaches 100 in the case of total micro-organisms.

The qualitative relationship among the various pollutants in rain weather flow is shown in Fig. 6 which explains the rainflow studied in the first period (from the beginning of storm weather flow, about 50% of the total flows).

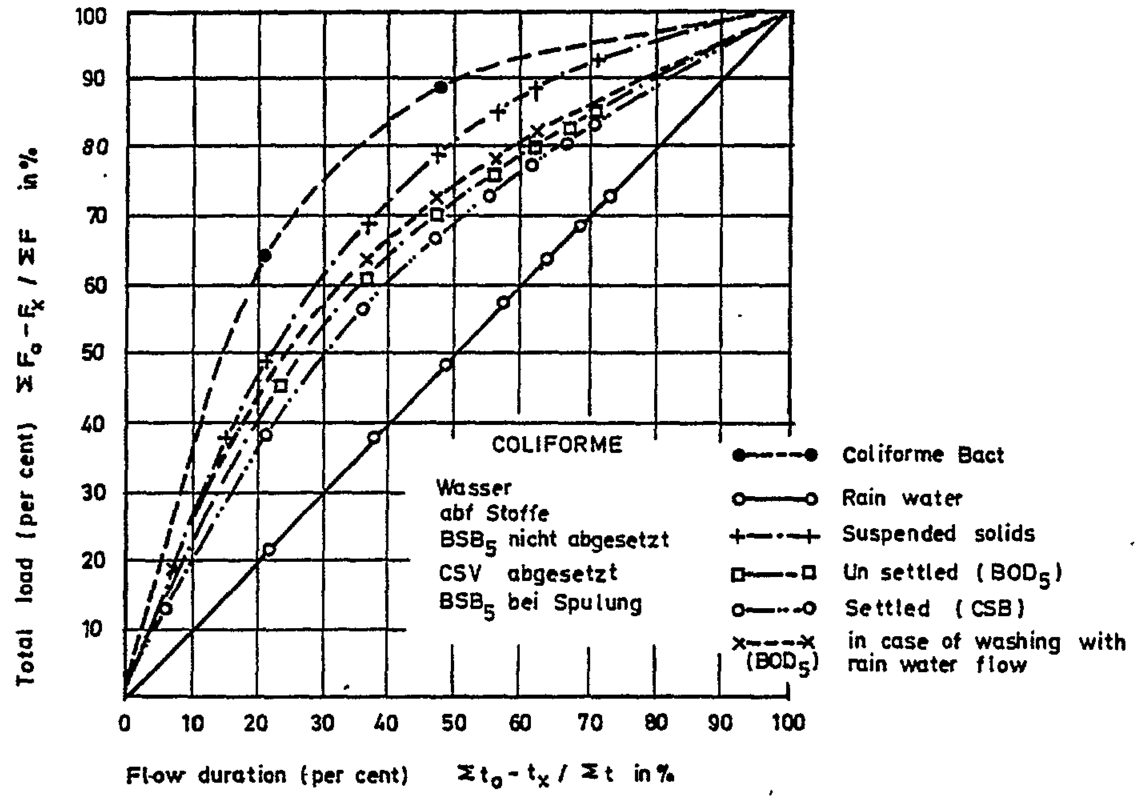

Fig. 6 Time distribution of loads in the city of Stuttgart - Busnau (1.16)

All this shows the extent of very high pollution (organic and microbial, and settleable solids) of the storm water flows taking place in the first retention period of rainfall in a combined sewage system. This stresses the importance of treatment of stormwater flow by means of rain overflow tank systems, especially as far as the first shock of rainfall or flow and the protection of water sources and public health is concerned. Therefore, water sources for irrigation purposes in Syria will become safer.

In an earlier published study (Awad, 1983), the author has formulated, on the basis of the measurements done in Busnau/Stuttgart and Pullach/Munich and related experience, mathematical formulae and simulation models for rainfall and flows in Latakia city, for a period of 13 years.

The end result was presented in curves for Lattakia and other German cities (Fig. 7). These curves allow us to calculate the necessary volume of storm overflow tank in relation to the protection of water resources from organic and microbial pollutants.

This type of provision can be recommended for other coastal Mediterranean cities.

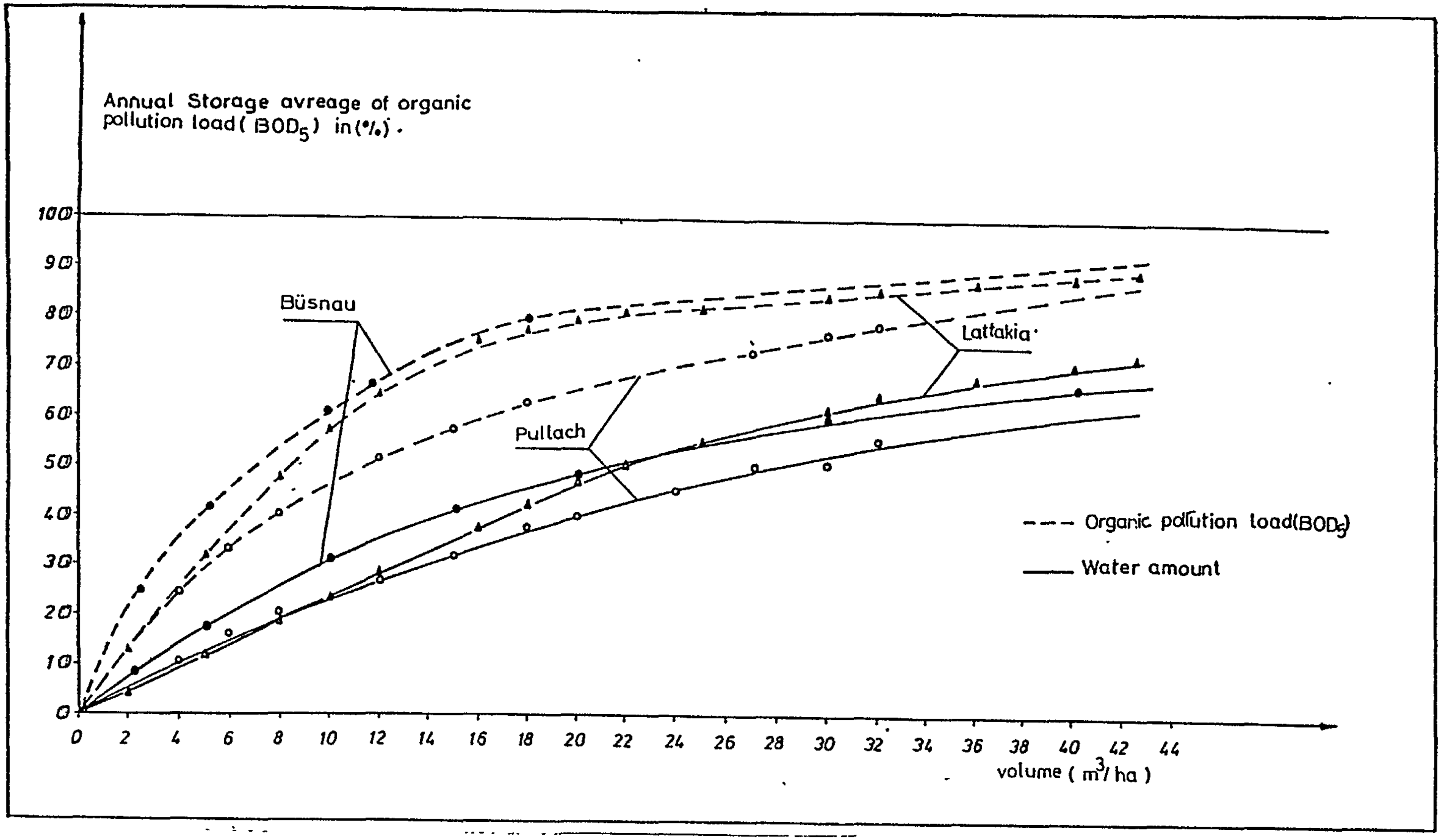

Fig. 7 Organic pollution load (BOD_5) stored annually in overflow tanks within a combined sewer system. Comparison of German cities (Stuttgart-Munich). Their values were measured in a laboratory with mathematical patterns of Lattakia city.

6. SPECIAL SUGGESTIONS FOR SANITARY SEWAGE WATER TREATMENT IN THE COASTAL CITY OF LATTAKIA

6.1 The Present Situation

The city of Lattakia (population 300,000, estimated to reach 500,000 by the year 2000), has at present, an extensive network of combined sewer systems, most of which work by free gravity discharging into different points on the Mediterranean (Fig. 8).

At present, there is no treatment for sewage water, as a result of which the environment in the touristic regions north and south of the city is damaged. It is thus necessary to put forward a plan to ensure the disposal of sanitary sewage water in the city of Lattakia (disposal-treatment).

6.2 Sanitary Sewage Water Treatment

After studying the urban and topographic data, the following locations were chosen for the installation of sanitary sewage units·

north	1- El-Jouar 2- El-Merouj
south	3- El-Aedine 4- El-Baasa

After the detailed study of sewage water problems in the city of Lattakia concerning sewage water treatment related to the site of the treatment unit and type of effluent usage, the evaluation of the chosen locations from the environmental and urban point of view, a general sanitary concept has been put forward for the city of Lattakia till the year 2000 (Fig. 8).

6.3 The Recommended Plan (Fig. 8)

6.3.1

Alternative means of collecting, treating and disposing or re-using wastewater in the Lattakia area have been identified and evaluated in preceding studies published by the author who is now with the Ministry for Environmental Affairs. The required facilities comprise essentially four items, namely sewerage, storm drainage and treatment, sewage treatment and effluent disposal.

6.3.2 Summary of plan

6.3.2.1

The recommended sewerage system is based on the existing network and is a mixture of both combined and separate systems.

6.3.2.2

The basic concept is that all sewage will either be pumped or will gravitate to the Damsarkho Pumping Station which will have a peak flow capacity of 2246 l/s by 2000 AD. The foul sewage will be discharged to the treatment tanks situated at Jouar. The year 2000 connection to the treatment works will be a twin 1000 mm diameter pipe, 5.25 km long.

The stormwater treatment concept is recommended for the Lattakia areas in order to reduce investment in large sewers and for better hygienic conditions.

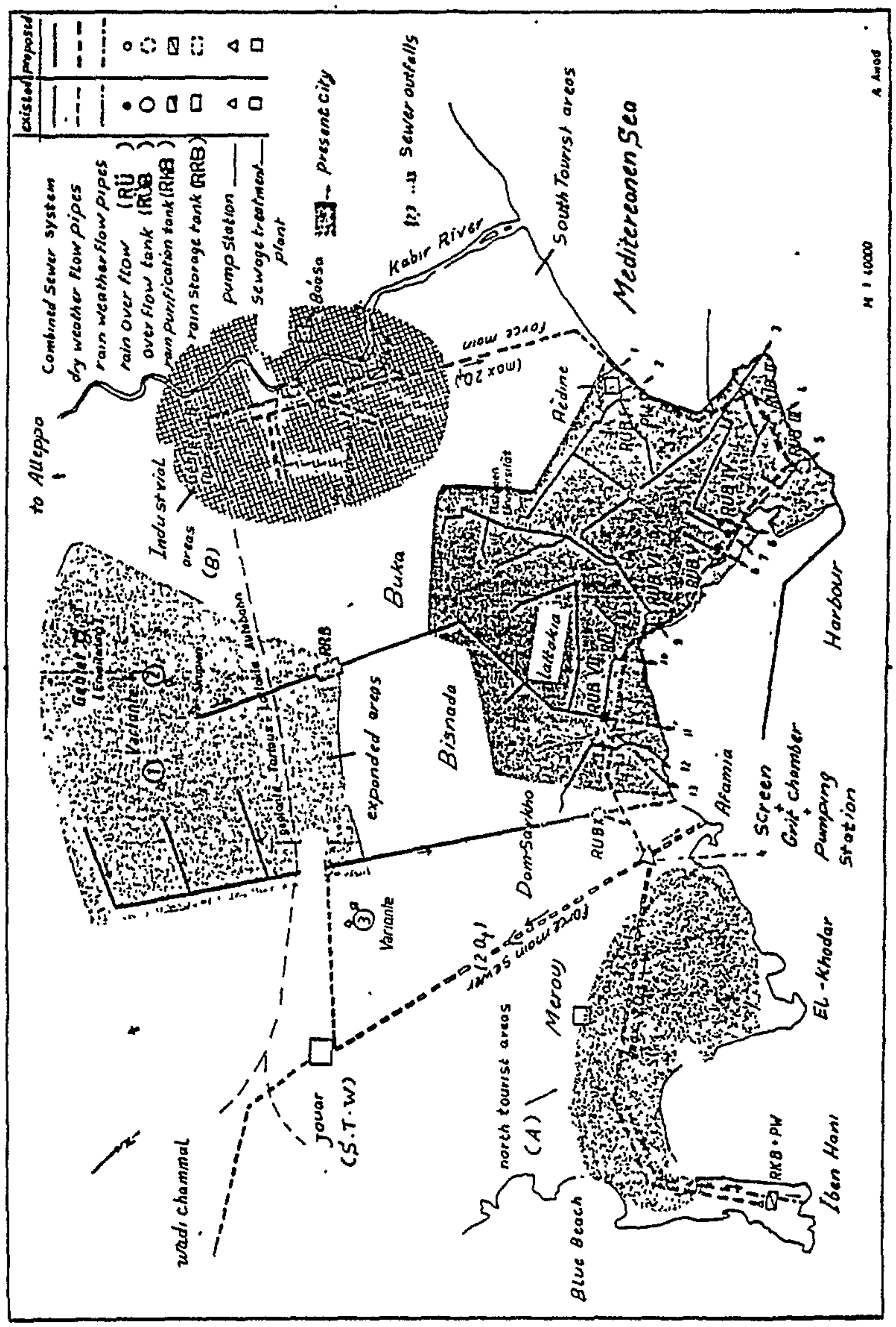

Fig. 8 General sanitary plan for the city of Lattakia

6.3.2.3
There has been noticeable cooperation between the sanitary project and rain flow treatment. The touristic region (A) in the north and the industrial region (B) situated along the river Kabir Al-Shimali each have a separate sewer system. The rest of the city has a combined sewers system, divided into seven parts, at the end of which there is an overflow tank for treating rain water flow.

6.3.2.4
The expansion area (C) of the city of Lattakia will have three solutions as shown in Fig. 8. All of the wastewater generated in Lattakia will be treated in one treatment at Jouar, and will comprise preliminary units consisting of mechanically raked screens and removal of grit and other inorganic material, followed by secondary treatment in activated sludge tanks or aerated lagoons. The lagoons will consist of complete-mix basins followed by partial-mix basins. The latter will function or be mechanically aerated. There will be facultative lagoons where sludge accumulation will take place. The total area required for a treatment system to deal with the year 2000 peak flow of about 200,000 Ms/d from 500,000 people will be about 60 ha.

By the aerated lagoons system the inherent advantages are a minimal sludge disposal problem, ease of operation and built-in flexibility for conversion to more sophisticated extended aeration or activated sludge systems if necessary at a later date.

6.3.2.5
The effluent will be disposed of to the Wadi Channel to the north of the Jouar treatment works site. Almost 5 km of 1200 to 1500 mm diameter gravity land outfall will be required. The Wadi Channel will serve as a future irrigation drain. If the flow in the receiving channel were to be used for irrigation of vegetables, it would be advisable to upgrade the treatment system by the provision of maturation ponds and disinfection.

7. RECOMMENDATIONS

Sewage treatment plants are relatively expensive installations whose operation, monitoring and maintenance require trained specialist staff. Otherwise, they cannot achieve their cleansing objective and keep the plant in good condition over many years.

Even in the case of simple uncomplicated cleansing processes such as ponds it has been shown that they, too, can product the desired effect only where trained personnel are available. This requirement is all the more important in the case of highly technical plant. The training of specialist personnel takes a long time, and it is accordingly important to carry it out in good time, before the treatment plants are complete. This entails first providing the necessary training establishments. Accordingly, the following course is recommended for the training of the necessary personnel in Syria.

Since there are as yet no treatment plants in Syria's coastal region, one model of each type of treatment plant (activation and ponds) should be established. It is suggested that first a sophisticated technical plant should be constructed either in Damascus or in the coastal town of Lattakia, for the following reasons.

Hygienic conditions there require urgent measures for the protection of water resources; owing to shortage of space, only this type of plant is possible there as it does not take up a great deal of space. Furthermore, Damascus and Lattakia also have a university and a college of technology, so that this model plant could serve at the same time for research and training purposes. Students can then undergo further practical training in the plant. For this reason, a low-technology model plant should also be constructed near Damascus (suburb) or Lattakia, so as to provide opportunities for gaining practical experience with this type of installation and in order to draw comparisons with the high-technology plant. The model plants should be planned and constructed by firms in co-operation with the chief planner. At the same time, the regional authorities should also be brought in at this stage, so that later they can, at least partially, themselves take over responsibility for planning and operation. Otherwise these plants should be manned by trained personnel from industry (skilled workers and/or master craftsmen), who should be able within a short time to run the plant independently under the direction of a qualified plant manager. The latter should also undergo training abroad, whilst the remaining supervisory staff should gain several months' experience abroad, e.g. in neighbouring countries.

Treatment plants would be built in the remaining regional centres and in rural areas along the same lines as the model plant in Damascus or Lattakia. An important aspect is the retention of a uniform system, i.e. the same operational system and mechanical equipment. Only in this way can uniform training and reliable operation be guaranteed.

Having regard to financing difficulties, the provision of plants in other coastal towns (regional centres) may be effected as follows:

i) the treatment plants should be built in central points according to water management requirements, each individual plant being complete, including the cleansing systems;

ii) the personnel would be trained as and when these plants are established, either at the model plants in Damascus or Lattakia or at plants in other Arab-speaking countries (Tunisia);

iii) training would be provided primarily in both the low and high technology plants in Damascus or Lattakia, whilst the training abroad is regarded as supplementary.

The organisation of various types of plant is described in another report (1C) according to type and size.

Other recommendations most appropriate for local conditions in Syria.

1. As regards the hygienic benefit to the population, (lack or shortage of fresh water-recycling of wastewater for irrigation is general) complete treatment plants should be installed in all cases. This cannot be achieved merely by installing a screen and sand trap. These plants must consist of mechanical-biological treatment stage followed by advanced treatment for disinfecting purposes. This can be achieved through the methods described above.

2. If stage-by-stage development is necessary for economic reasons, this should be managed in such a way that complete plants are erected at central points throughout the country.

   Building up the system by stages has certain financial advantages but it is also more effective in achieving the desired hygienic results.

3. In contrast to Europe, additional trained staff are required to carry out bacteriological tests. This could also be handled by personnel already available (e.g. water supply or health officials).

4. It is necessary to adapt a uniform training and reliability in operation which means the choice of a uniform system (same construction and same mechanical equipment).

5. It is extremely important to treat the rain flow water by using overflow tanks. This ensures the protection of water resources from pollutants and, in addition the effluent water will be safer for irrigation purposes.

6. An accurate and continuous monitoring programme is essential to efficient system operations. Data accumulated form a comprehensive monitoring programme will provide a measure of system efficiency and also enable problem areas to be defined so that corrective measures can be undertaken rapidly.

7. There is a need for data on sewage flow, BOD and SS collected on a regular basis. A monitoring station should be established in every city where treatment of sewage water will be taking place and a monitoring programme established, preferably on a weekly basis.

8. Investigations should also be carried out to control oil discharges and other compounds to the sewers from industrial premises, in order to prevent the untreated sewage from contaminating the beaches.

9. There is a need for accurate cost records to be defined for the current sewerage operations. At present, the actual costs for operating the facilities and the final costs of constructing new facilities are not adequately documented. There is as a result no firm basis for developing localised cost estimates, and data from other locations must be used or data developed on some other basis, both of which may not be strictly applicable to local conditions. Keeping accurate records of capital and operation and maintenance costs and having them available for management and engineering is necessary for efficient planning and operation.

   It is recommended that the wastewater management scheme be financed as far as possible from a surcharge on the water bill.

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9. WORKS CONSULTED DURING THE STUDY AND PREPARATION OF THE REPORT

1A. Awad, A., (1983)[Probleme der Abwasserbehandlung Syrischer Städte, Institut f. Siedlungswasserwitrschaft, Wassergüte-und Abfallwirtschaft, Universitat Stuttgart.

1B. Awad, A., (1985)[The Protection and Planning of the Mediterranean Basin· "The role and competence of the State and regional and local authorities", Conference of the regions of the Mediterranean Basin, Marseilles.

1C. Awad, A., (1986)[National report "Solid and liquid collection and disposal in the S.A.R.", PAP - 7/ME/(2444) Rev. 1, Split, Yugoslavia.

2. Berg, Gerald et al., (1968)· Removal of poliovirus 1· from secondary effluent by lime flocculation and rapid sand filtration, Journal American Water Works Association, Vol. 60, No. 2, Feb.

3. Bernhoff, R., (1974)· Die Rolle von Kalk Dolomit bei der Reinigung hauslicher Abwasser, Auszug aus einem Referat von der 3. International Kalktagung in Berlin am 9. and 10.

4. Bischofberger, W., (1975)· Leistung und Kosten der Abwasserreinigungsverfahren, Gewässerschutz-Wasser-Abwasser, H. 19.

5. Bischofberger, W., (1978)· Entwicklungstendenzen beim Gewässerschutz und in der Abwassertechnik, Berichte aus wassergütewirtschaft und Gesundheitsingenieurwesen, Heft Nr. 22, TU, München.

6. Black A. Pexal, (1971)· Recovery of calcium and Magnesium Values, Journal American Water Works Association, Vol. 63, No. 10.

7. Culp, R.L., Culp, G.L., (1971)[Advanced wastewater treatment von Environmental Engineering, Ser., New York, N.Y.

8. Dean, Robert B., and Smith, James E. Jr., (1974)· Disposal and recycling of wastewater sludges containing Lime, 3rd International Lime Conference, Berlin, Germany.

9. Doyle, Charles, R., (1967)· Effectiveness of high pH for destruction of pathogens in raw sludge filter cake, Journal WPCF, Vol. 39, No. 8, Washington.

10. Environment Protection Agency and Engineering Science Ing. Arcadia, California (1977)· Process design manual for land treatment of municipal wastewater, technology transfer publication EPA 625/1-77-008, U.S.A.

11. EPP, C., (1975)· Virologische Untersuchungen and der Ozonanlage der Firma Demag auf dem Abwasserversuchsfeld Gro Elappen, Münchner Beitrage zur Abwasserfischerei-und Flußbiologie, Bd. 26 R. Olderbourg Verlag, München.

12. Hays, B.D., (1977)· Potential for parasitic disease transmission with land application of sewage plant effluent and sludge, Water Research, II 583 - 95.

13. Katzenelson, E., Kletter, B. and Shuval, H.I., (1974)· Inactivation kinetics of viruses and bacteria in water by use of Ozone, Journ. Amer. Water Works Assoc. 66, 725-729.

14. Knoll, K.H., (1965)· Hygienische Mikrobiologie in· Kumpf-Maas-Straub Hanbuch der Müll-und Abfallbeseitigung, KZ 5112, Erich Schmidt-Verlag, Berlin - Bielefeld, München.

15. Krauth, Kh., Staab, K.F., (1982)· Erfahrungen mit der Denitrifikation auf dem Klärwerk des AZV Biet, Bas 57. Siedlungswasserwirtschaftliche Kolloquim am 8./9.3 in Stuttgart.

16. Krauth, Kh., (1979)· Der Abfluss und die Verschmutzung des Abflüsses in Mischwasserkanalisation bei Regen, Stuttgarter Berichte zur Siedlungswasserwritschaft 45 und 66.

17. Mara, D.D., (1975)· Proposed design for oxidation ponds in hot climates. Journal of the Environmental Engineering Division, American Society of Civil Engineering 101 (EE2) 296-300.

18. Mayer, H., (1979)· Untersuchungen zur weitgehenden Reinigung biologisch gereinigten Abwassers. Die praktische Anwendung der Abwasserfiltration und ihre bedeutung in der Abwassertechnologie, Gewässerschutz, Wasser, Abwasser (35) Dissertation TH Aachen.

19. Meyer, H., (1975)· Praktische Anwendug der Weitgergehenden Abwasserreinigung unter besonderer berucksichtigung der Kosten, institut fur Siedlungswasserwirtschaft RWTH Aachen, Vortrag vom Europaischen Abwassersymposium EAS 1975, gehalten in München.

20. Morrison, S.M., Martin, K.L., (1973)· Lime disinfection of sewage bacteria at low temperature, International symposium on Research and treatment of wastewater in cold climates, Saskatoon, Saskatchewan, Canada, August 24, Colorado State University, Fort Collins.

21. Nebel, C., Gottschling, R.D., Unangst, P.C., O'Neill, H.J. und Zintel, G.V., (1976)· Ozone provides alternative for secondary effluent disinfection, Part 3, Water Sewage Works 123, 6, 81-83.

22. Neis, U., Bender, A., (1981)· Abwasserhygienisierung, die Wirkung des Fällung-und Flockungsprozesses im Vergleich zur Chlorung, Institut fur Siedlungswasserwirtschaft, Universitat Karlsruhe.

23. Nubaum, G., (1976)· Einige Bemerkungen zur Regenwasserbehandlung in Kanalnetz.

24. ATV-Landesgruppentagung 1974, Heilbronn ATV-Berichte No. 28.

25. Orth, H., Prigge, M., (1980)· Abwasserbehandlung in der Region kano in Nigeria, wasserwirtschaft (70), Heft 12.

26. Overath, H., Prigge, M., (1980)· Möglichkeiten und Grenzen des Einsatzes von kalk in der Abwasserreinigung, Berichte aus wassergütewirtschaft und Gesundheitsingenieurwesen, Institut fut bauingenieurwesen TH München, Nr. 22.

27. Pavoni, J.L., Tittlebaum, M.E., Spencer, H.T., Fleishmann, M., (1972)· Virus removal from wastewater using ozone, Water Sewage Works, 12, 59- 67.

28. Rosen, M.H., (1979)· State of the art of ozonation for Commercial Applications in the U.S., AIChE 86th National Meeting, Houston, Texas, April 1-5.

29. Ruck, W., (1982)· Einfluss von Ozon auf die Flockbarkeit von organischen Wasserinhaltsstoffen in mach. - biologisch gereinigten abwassern, Unveröffentlichte Dissertation am Institut fur Siedlungswasserbau, Abwasser und Abfalltechnik, Universitat Stuttgart.

30. Scherb, K., (1974)· Ozonnandlung, ATV-Fortbildungskurs II/B. in Essen unveroffentlochtes Manuskript.

31. Sebastian, F.P., (1974)· Purified wastewater, The Untapped water resource, Journal WPCF 46, No. 2.1.239.

32. Siegel, B., (1977)· Ozone Disinfection of secondary effluent PCI Ozone Corporation, West Caldwell, New Jersey.

33. Strauch, D., (1980)· Mikrobiologgische Untersuchungen zur Hygienisierung von Klarschlamm 1. - 8. Mitteilung, senderdruck aus der Zeitschrift "gWF" - Wasser/Abwasser 121.

34. Thon, L., (1979)· Weitergehenden Abwasserreinigung mit Ozon und anschlieβender Eisenflockung, Untersuchung mit dem Ablauf der mechanischen und biologischen Klaranlage einer Papierfabrik. Diplomarbeit im institut fur Siedlungswasserbau, Wassergute und Abfallwirtschaft, Universitat Stuttgart.

35. Veldermann, Alecander B., Case report of the Dakar-Tunis and Alexandria Masterplan Studies, Coastal Pollution Control, WHO course, Volume II, Denmark, 1976.

36. Ward, R.W. and De Graeve, G.M., (1978)· Residual Toxicity of several Disinfectants in Domestic and Industrial Wastewaters. Journal Water Pollution Control, Feb. 50 2703-2722.

EXPERIENCE ALGERIENNE EN MATIERE DE TRAITEMENT ET DE REUTILISATION DES EAUX USEES DES EFFLUENTS URBAINS POUR L'IRRIGATION ET POUR D'AUTRES FINS

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RESUME

L'accroissement des besoins en eau aidant, l'on sera de plus en plus amené à prendre en compte la réutilisation des eaux usées dans tout système de planification des ressources en eau, qu'il soit régional ou national, particulièrement dans les pays arides et semi-arides. Les stations d'épuration doivent à l'avenir viser un double objectif: diminution de la pollution et valorisation des eaux épurées et des boues. Pour répondre aux derniers critères recommandés pour une réutilisation des eaux usées, des choix judicieux de procédé s'imposent. C'est dans ce cadre que nous présentons dans ce rapport le système d'épuration des eaux de la Ville d'Annaba et le schéma de réutilisation des effluents traités.

1. INTRODUCTION

1.1 Intérêt de la réutilisation pour l'Algérie

Au cours de ces dernières années, le développement économique et social de l'Algérie a été marqué par une forte croissance de l'urbanisation et un intense développement industriel tant au niveau des grandes agglomérations qu'à celui des villes moyennes. Ces deux phénomènes ont nécessité la mise en oeuvre à travers les différents plans de développement d'importants programmes d'investissements en matière de mobilisation des ressources en eau et d'assainissement.

Ces investissements se sont traduits par une augmentation importante des volumes distribués pour les besoins d'alimentation en eau potable et industrielle.

Les volumes de rejets d'eau usée sont estimés comme suit:

1979 : 350 Mm^3

1985 : 660 Mm^3

2010: 1,5 Milliard de m^3

Compte tenu de l'accroissement des besoins en eau et du potentiel en ressource en eau actuel, le développement de la réutilisation des eaux usées prendra une part importante dans les systèmes de planification et de gestion des eaux.

A l'heure actuelle les avantages qu'offre la réutilisation des eaux usées ne sont plus à démontrer particulièrement dans les pays arides et semi-arides. Dans certaines de ces régions les ressources en eau suffisent à peine à couvrir les besoins en eau potable.

Cependant si les avantages sont nombreux, tels que l'optimisation de la gestion des ressources en eau, le recyclage des fertilisants, l'augmentation de la production agricole, il ne faut pas oublier les inconvénients. Le plus grave est celui lié aux risques pour la santé humaine: la transmission à l'homme des germes pathogènes, des métaux lourds et d'autres produits chimiques toxiques que contiennent les eaux usées.

1.2 Les risques sanitaires

Une étude réalisée par la Banque mondiale (1986) sur plusieurs cas en pays developpés et en voie de développement a montré que la réutilisation d'eaux usées brutes ou partiellement traitées a été la cause des maladies suivantes:

i) chez les consommateurs de légumes crus ou de salade: ascaridiose, trichocéphalose, choléra, amibiase;

ii) chez les consommateurs de viande bovine insuffisamment cuite le taenia (la viande provenant de bétail pâturant sur des prés irrigués avec les eaux usées);

iii) chez les travailleurs d'exploitation agricoles irriguées par eaux usées: les mêmes maladies, plus l'ankylostomiase;

iv) chez les populations résidant à proximité de telles installations agricoles notamment celles utilisant le mode d'irrigation par aspersion.

1.3 <u>Les normes de réutilisation et leur évolution dans le temps</u>

Prenant en considération l'utilisation de plus en plus importante des eaux usées plus ou moins traitées, l'OMS au début des années 1970 a réuni des comités d'experts autour de cette question.

Les normes sanitaires étaient alors très strictes.

<u>1968</u> Californie: moins de 23 coliformes totaux/100 ml pour l'irrigation des terrains de golf, des parcs publics, des pâturages pour le bétail laitier; moins de 2,2 coliformes totaux/100 ml, pour l'irrigation directe des cultures vivrières. Il s'agissait de normes trop contraignantes, car même les moyens technologiques de l'époque ne pouvaient atteindre ces niveaux de traitement.

<u>1973</u> Les travaux d'un groupe d'experts de l'OMS ont abouti aux conclusions que "l'irrigation non limitée des cultures ferait courir peu de risques à la santé si l'on utilisait des effluents d'une qualité bactériologique de 100 coliformes/100 ml".

<u>1985</u> La réunion d'épidémiologistes tenue à Engelbert propose de nouvelles normes:

Irrigation sans restriction

- moins de 1000 coliformes fécaux/100 ml
- moins de 1 oeuf viable de nématode par litre

Nous constatons une nette évolution depuis les normes de 1968.

1.4 Traitement

A travers les études menées pendant les dernières années concernant la réutilisation des eaux usées, ont été dégagés les nouveaux critères à prendre en compte pour une telle utilisation:

i) élimination au maximum des helminthes intestinaux

ii) réduction effective des éléments pathogènes (bactéries, virus)

iii) effluent clair inodore.

Il est montré par ailleurs que le système de traitement par les étangs de stabilisation convient le mieux pour répondre aux trois critères. Généralement bien conçu et bien exploité, ce système de traitement peut éliminer totalement les oeufs d'helminthes, réduire à 99,999% les bactéries entériques et à 99% les virus entériques.

C'est dans ce cadre que nous présentons à la suite du présent rapport le système d'épuration des eaux usées de la ville d'Annaba par les étangs de stabilisation et un schéma de réutilisation de ces eaux.

2. PRESENTATION DE LA REGION D'ANNABA

2.1 Besoins en eau

L'essor socio-économique de la région d'Annaba a engendré depuis plus d'une décennie, un accroissement des besoins en eau (Fig. 1), dépassant largement les réserves exploitées.

Actuellement, l'AEP, l'agriculture et l'industrie consomment au total un volume annuel d'environs 123 Mm^3, provenant du barrage de la Bounamousse (95 Mm^3), de la nappe profonde des graviers d'Annaba (8 Mm^3) et du massif dunaire de Bouteldja (20 Mm^3).

L'ensemble des secteurs socio-économiques accuse actuellement un déficit en eau de l'ordre de 80 Mm^3/an. Ce déficit sera resorbé en totalité par la mise en exploitation du complexe d'adduction en eau du système de Mexenna (145 Mm^3) (Fig 2).

Le secteur industriel consomme à lui seul plus du tiers du volume annuel des réserves mobilisées, soit 50 Mm^3.

2.2 Le climat

Le climat de la région d'Annaba, est du type méditérannéen à variations saisonnières marquées: été chaud et sec, hiver doux et humide.

Les pluies annuelles ou intérannuelles de la région sont très irrégulières et leur régime s'étale entre deux saisons distinctes, l'une sèche (mai-octobre), l'autre humide (novembre-avril).

La moyenne des pluies (sur 40 ans) est de 703 mm/an avec d'importantes variations, de 345 mm (année la plus sèche) à 1015 mm (année la plus humide).

Les températures montrent également d'importantes variations, avec un maximum absolu de 46,4° C et un minimum absolu de 0,8° C.

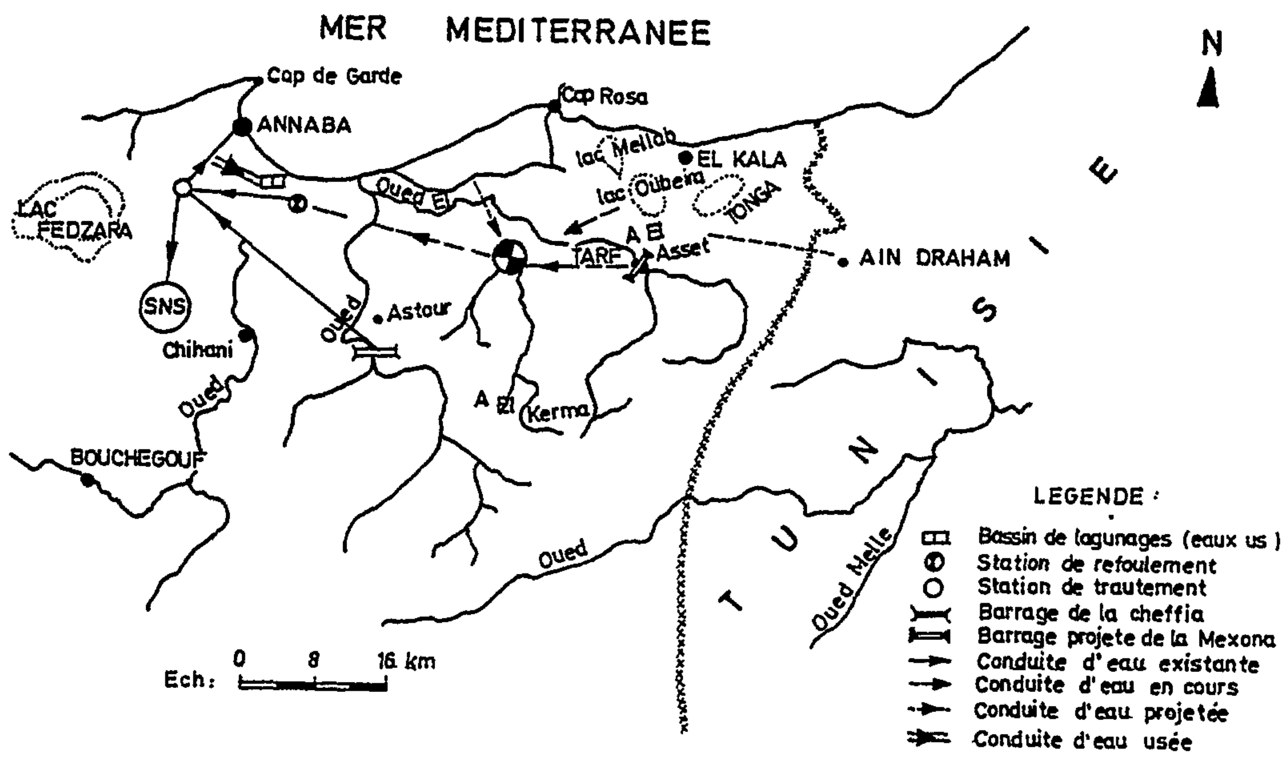
La moyenne annuelle de l'evapo-transpiration est 1123 mm.

2.3 Les étangs de stabilisation de la ville d'Annaba

2.3.1 Les solutions envisagées

La ville d'Annaba connaît actuellement une extension assez forte et l'étude de l'alimentation en eau de la ville montre que cette extension conduit à une fourniture d'eau potable relativement élevée.

Les eaux usées sont actuellement rejetées sur le rivage marin et dans la petite darse du port. Dans un souci d'hygiène et de salubrité, il a été décidé d'épurer les eaux usées avant rejet dans le milieu naturel. Plusieurs solutions étaient possibles:


MER MEDITERRANEE
N
Cap de Garde
ANNABA
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TONGA
LAC FEDZARA
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TARF
A El Asset
AIN DRAHAM
SNS
Astour
Chihani
Oued
A El Kerma
BOUCHEGOUF
Oued
Oued Mellé
TUNISIE
Ech:
0 8 16 km
LEGENDE :
Bassin de lagunages (eaux us)
Station de refoulement
Station de trautement
Barrage de la cheffia
Barrage projete de la Mexona
Conduite d'eau existante
Conduite d'eau en cours
Conduite d'eau projetée
Conduite d'eau usée

Fig. 1

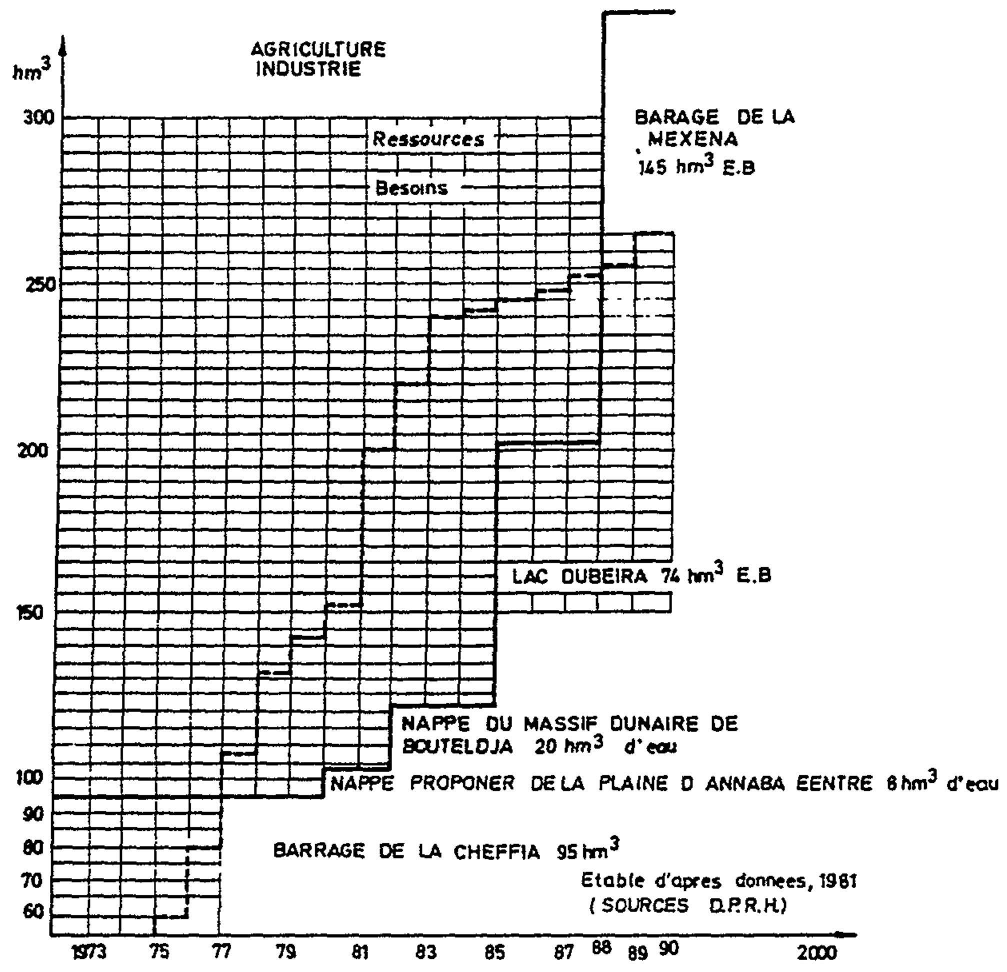

hm³
AGRICULTURE
INDUSTRIE
Ressources
Besoins
BARAGE DE LA MEXENA 145 hm³ E.B
LAC OUBEIRA 74 hm³ E.B
NAPPE DU MASSIF DUNAIRE DE BOUTELDJA 20 hm³ d'eau
NAPPE PROPONER DE LA PLAINE D ANNABA EENTRE 8 hm³ d'eau
BARRAGE DE LA CHEFFIA 95 hm³
Etable d'apres donnees, 1981
(SOURCES D.P.R.H.)
300
250
200
150
100
90
80
70
60
1973
75
77
79
81
83
85
87
88
89
90
2000

Fig. 2

i) rejet en mer par une conduite sous-marine, mais l'anse d'Annaba peut faire craindre la présence de courants défavorables rabattant les eaux usées vers la rivage (à noter que le rejet en mer nécessite en tout état de cause une épuration préalable);

ii) construction d'une station d'épuration biologique.

L'expérience montre que très peu de ces stations fonctionnent correctement pour de multiples raisons, dont l'une est la pénurie de techniciens hautement qualifiés capables de contrôler efficacement la marche correcte de l'installation. D'autre part, dans une étude sur l'optimisation des installations d'épuration des eaux usées et la comparaison des solutions, la SONADE démontre que le coût d'une station d'épuration biologique est de 2 à 3 fois supérieur à celui des étangs de stabilisation.

2.3.2 Construction des étangs de stabilisation

Des terrains étant disponibles à une distance raisonnable d'Annaba, le choix s'est alors porté sur les étangs de stabilisation. Deux sites furent reconnus:

i) le premier dans le marais de M'khadda à proximité de l'embouchure de la Maffragh, à une distance de 22 km de la ville;

ii) le second à la surface des salines d'Annaba englobant une bande de terrain située au nord-ouest de ces dernières, celui-ci à une distance de 7 km de la ville.

Compte-tenu du coût respectif de la conduite de refoulement (diamètre 1.250 mm) et des frais d'exploitation, le terrain des salines fut retenu. Par ailleurs, celui-ci offrait d'autres avantages:

a) Le terrain des salines est plat. Il convient parfaitement à la création des bassins horizontaux. Sous la couche d'argile décomposée par le sol, le substrat est composé d'argile jaune peu perméable.

b) L'eau épurée pourra être réutilisée pour les besoins industriels d'El-Hadjar et du printemps à l'automne pour l'irrigation d'un périmètre agricole proche de la station. L'eau épurée sera de bonne qualité chimique et bénéficiera d'une dépollution bactérienne exceptionnelle. Le rendement des étangs de stabilisation est de 99,999% de dépollution des microbes pathogènes alors qu'à l'aval de stations d'épuration biologique on retrouve normalement une charge de 10^4/litre de germes tests de contamination.

2.4 Processus d'épuration en étangs de stabilisation

La destruction des matières polluantes s'effectuant par des processus purement naturels, la technique d'épuration par lagunage est plus extensive et plus lente que les procédés d'activation utilisés dans les stations d'épuration classiques qui sont beaucoup plus compactes.

Le cas le plus général est celui des installations mixtes, dites de "stabilisation", où s'établissent des conditions anaérobies dans une partie du milieu liquide, surtout en profondeur, le reste fonctionnant en milieu aérobie.

Dans les étangs de stabilisation, la destruction des matières organiques s'opère grâce à une association biologique extrêmement large et non pas exclusivement par des bactéries, comme dans le cas de l'épuration classique par boues activées.

Un des avantages considérables de l'étang de stabilisation par rapport à une station d'épuration conventionnelle réside dans la destruction presque complète des bactéries. Toutes les études entreprises à l'échelle mondiale sont unanimes à constater le puissant effet bactéricide de cette technique.

2.5 Domaine d'application

L'épuration par des processus naturels convient particulièrement bien aux agglomérations ou collectivités de petite et moyenne importance, lesquelles ont constitué jusqu'à présent son principal champ d'application, bien que des installations comprenant des étangs d'une superficie totale de plusieurs centaines d'hectares aient pu être réalisées dans le monde (Melbourne).

Le procédé est spécialement intéressant pour les petites collectivités disposant de peu de moyens, tout comme dans les zones touristiques où la population peut s'accroître dans des proportions très importantes.

De plus, contrairement aux stations d'épuration conventionnelles qui nécessitent un entretien suivi par un personnel qualifié, la surveillance d'un étang de stabilisation ne nécessite qu'un minimum de contrôle que peut assurer dans le cas de petites collectivités un ouvrier non spécialisé. Ce minimum de contrôle est néanmoins indispensable au fonctionnement correct de l'installation.

Enfin pour une collectivité disposant de terrains d'étendue suffisante et dont les effluents sont rejetés dans un milieu naturel nécessitant une protection particulièrement poussée sur le plan sanitaire, la mise en oeuvre de la technique du lagunage est pleinement justifiée étant donné la pérennité du traitement et son efficacité sur le plan de la réduction des pollutions organiques et surtout de l'élimination des pollutions bactériennes.

En résumé, et si l'on compare une station d'épuration conventionnelle à un étang de stabilisation, ce dernier, lorsqu'il existe une disponibilité de terrains, présente certains avantages comme la simplicité de mise en oeuvre, un minimum de contrôle et d'entretien, ce qui réduit de façon considérable les frais de fonctionnement, et la fiabilité du traitement tant du point de vue de la réduction des charges organiques que de celui de l'élimination de la pollution bactérienne. Ce dernier point est fondamental car il est très difficile et onéreux d'éliminer les germes sur des effluents traités en station classique. En outre, un dispositif de stérilisation nécessite une surveillance très étroite, qui rend son efficacité très aléatoire dans le cas de petites collectivités. En outre, cette solution offre la possibilité de supporter sans dommages pendant plusieurs semaines des surcharges très importantes.

3. LES EAUX USEES DE LA VILLE D'ANNABA

3.1 Analyse des eaux usées

3.1.1 Analyses chimiques

Les analyses pratiquées sur échantillons font apparaître les résultats suivants:

Ca	(en mg/e).	62
Mg	"	45
Na	"	252
K	"	35
So_4	"	127
PH	"	7,6
Amonium	"	3,89
Phosphates	"	12

Ces résultats sont normaux et n'appellent pas de commentaires.

3.1.2 Analyses bactériologiques

Coliformes totaux	:	$1,4 \times 10^9$/litre
Colibacilles	:	$1,1 \times 10^9$/litre
Streptocoques	:	$1,1 \times 10^9$/litre

3.2. Le système d'assainissement de la ville d'Annaba

C'est un dispositif multiple qui fonctionne sur l'ensemble ou presque du réseau d'assainissement des eaux usées et pluviales de la ville d'Annaba, exception faite du centre ville où il est unitaire.

Evacuées par ces réseaux, les eaux usées seront en totalité relevées et refoulées vers les étangs de stabilisation par un réseau de stations de pompage réparties dans le tissu de la ville.

3.3 Caractéristiques des étangs de stabilisation de la ville d'Annaba

Le site de la station occupe une superficie de 160 ha et est localisé à l'endroit dit "les salines" situé à 7 km à l'Est de la ville d'Annaba.

Les données de base qui ont permis de dimensionner les différents étangs sont les suivants:

	ETE	HIVER
- Volume journalier admis dans l'installation	65.700 m^3	66.790 m^3
- charge organique journalière entrante	18.250 kg	18.885 kg
- concentration en DBO5 des eaux brutes	278 mg/l	282 mg/l
- concentration en DBO5 des eaux épurées	10 mg/l	30 mg/l
- rendement global d'épuration	96 %	90 %

L'ensemble du système (Fig. 3) est constitué de 13 bassins formant trois séries de quatre bassins chacun avec un treizième pour l'homogénéisation qui constitue l'exutoire des eaux épurées.

La répartition des superficies par nature de bassin est la suivante:

<u>Bassins anaérobies</u> : profondeur - 2 m

1ère série	8 ha 32
2e série	8 ha 32
3e série	8 ha 32

<u>Bassins aérobies</u> : profondeur - 1,50 m

1ère série	16 ha 2
2e série	16 ha 2
3e série	16 ha 2

<u>Bassins de maturation</u> :	profondeur - 1,20 m
1ère série	17 ha 98
2e série	17 ha 99
3e série	17 ha 99
<u>Bassins de polissage</u>:	Profondeur - 0,90 m
1ère série	8 ha 82
2e série	8 ha 82
3e série	8 ha 82

En outre, il existe un bassin d'homogénéisation où se regroupent les effluents traités des 3 séries. La superficie de ce bassin est de 6 ha, ce qui permettra un temps de séjour supplémentaire et un point de rejet unique de l'effluent.

La surface totale d'emprise des bassins est de 160 ha.

Pour les rendements des étangs de stabilisation, les degrés de satisfaction attendus en été à la sortie des bassins sont les suivants:

- bassin aérobie 20 mg/l
- bassin de maturation 12 mg/l
- bassin de polissage 10 mg/l.

Les durées de séjour prévues sont les suivantes:

- bassin anaérobie 2 J
- bassin aérobie 10 J 33
- bassin de dématuration 9 J 23
- bassin de polissage 3 J 44

ce qui donne une durée de séjour totale de 25 jours.

Les autres ouvrages à l'amont sont les suivants:

- bassin de tranquillisation et de dissipation d'énergie
- dégraisseur
- venturi pour la mesure des débits
- ouvrage d'equi-répartition de l'effluent
- regards de répartition dans les 3 bassins.

3.4 Principe de fonctionnement

3.4.1 Description

Le système est donc basé sur 3 séries de bassins identiques; chaque série comporte le même nombre de bassins et les bassins aérobies de maturation et de polissage ont tous la même superficie dans la catégorie concernée.

Les eaux usées cheminent donc du bassin anaérobie où elles subissent une forte dégradation des matières organiques vers les bassins aérobies. Ce processus se poursuit dans les bassins aérobies et de maturation où s'amorce également la dépollution bactérienne.

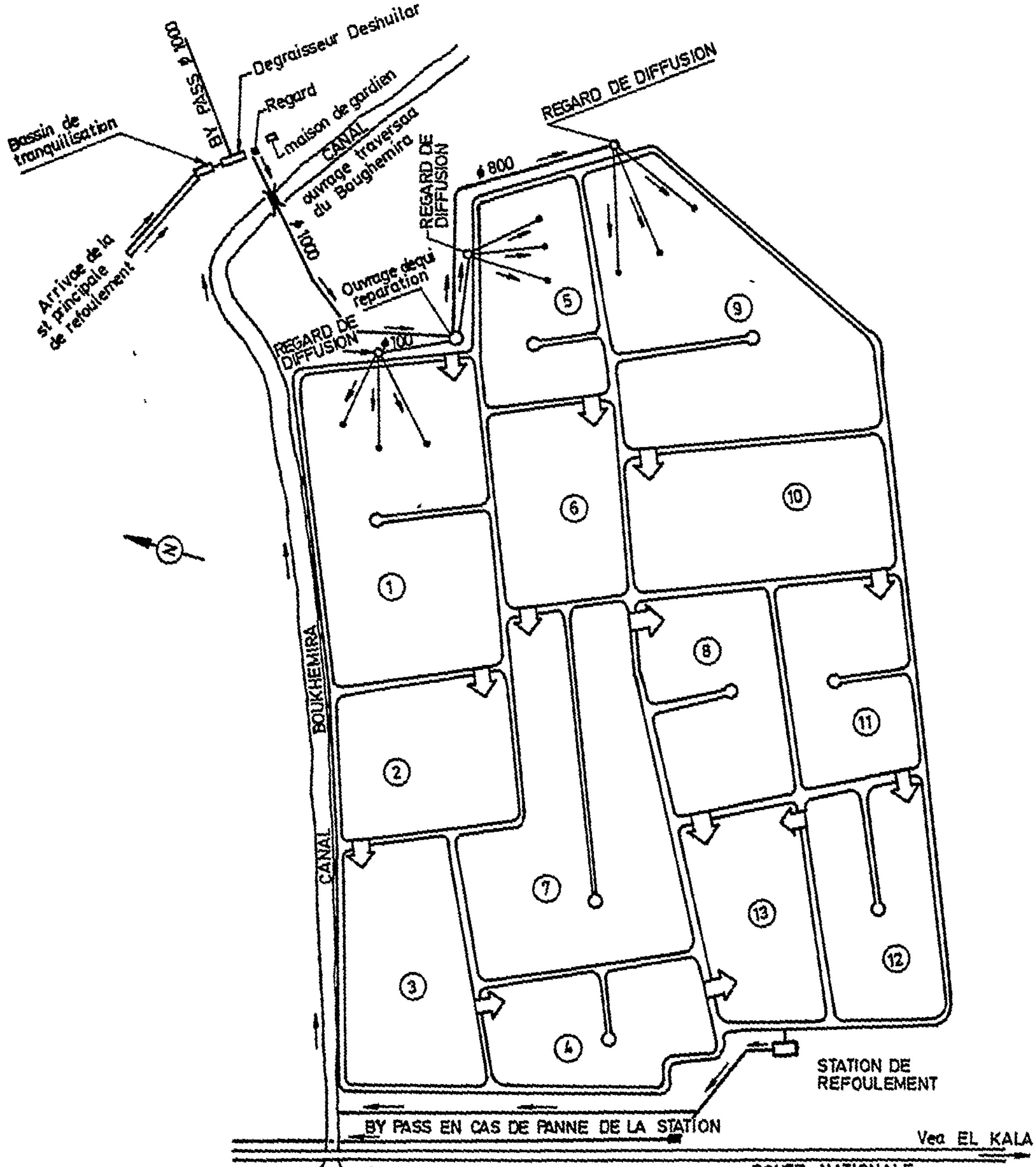
La diminution des germes de contamination est surtout sensible dans les bassins de polissage ou l'action solaire et l'oxygène naissant provenant de la photosynthèse algale sont favorisés par une faible profondeur des bassins (0,90 m).

Les eaux épurées des 3 séries déversent dans un bassin d'homogénéisation où le temps de contact d'une journée améliore encore la qualité de l'effluent. De ce bassin, les eaux épurées sont évacuées par siphonnage vers le canal à ciel ouvert.

3.4.2 Situation actuelle de la station d'épuration

Toutes les infrastructures (bassin, digues, ouvrages à l'amont des étangs) sont en cours de réalisation.

La mise en service aura lieu cette année grâce à l'achèvement des travaux d'équipement de la station de relevage principale (700 l/s) située dans le réseau d'assainissement de la ville d'Annaba.



SERIE I BASSINS 1 2 3 4
SERIE II BASSINS 5 6 7 8
SERIE III BASSINS 9 10 11 12
13ème BASSIN D'HOMOGENEISATION

4. Schéma de réutilisation des eaux de la station d'épuration

4.1 Réutilisation des eaux traitées pour l'agriculture

La station d'épuration ainsi conçue vise un double objectif:

i) épuration des eaux usées entraînant une diminution importante de la pollution des eaux de la zone côtière;

ii) valorisation des eaux épurées.

S'agissant du second objectif, il est à retenir pour deux raisons principales. Les effluents traités sont pour leur majeure partie de provenance domestique et se prêtent donc en principe à l'irrigation. Des terres agricoles aptes à l'irrigation sont disponibles dans un rayon économiquement intéressant. On peut irriguer jusqu'à 2000 ha à partir des eaux traitées.

Deux voies sont envisagées, l'expérimentation et la réutilisation directe. En matière d'expérimentation un protocole interviendra sur une parcelle de 7,5 ha dégagée par les services de l'agriculture et située en face du 13 ème bassin.

Pour une utilisation directe, il y a lieu de respecter rigoureusement deux conditions:

a) les qualités bactériologiques, liées à la présence de certains germes pathogènes qu'il faudra au préalable identifier et dénombrer pour évaluer les risques de contamination. Dans cette hypothèse, l'on sera amené à opter pour un choix cultural adapté qui tout en permettant la réutilisation des eaux usées assurerait une meilleure production agricole;

b) la qualité physico-chimique: on s'attend à ce que l'eau usée au contact des bassins acquiert une salinité importante. Cela tient au fait qu'il existait des marais salants dans l'aire occupée par les bassins de lagunage.

La nappe phréatique est fortement influencée par cette ancienne mine de sel. L'eau d'un puits situé dans cette zone titrait jusqu'à 5 g/l de sels.

Pour résoudre ce problème, on devra par le jeu de remplissages et vidanges répétés de l'ensemble des bassins du système ramener le taux de concentration en sel à un niveau convenable, compte tenu de la nature pédologique des sols de la plaine d'Annaba. Aux stades suivants, on envisagerait d'autres actions complémentaires, telles que l'isolement des bassins de la nappe phréatique par des films polyethylénés judicieusement selectionnés, à défaut par le rabattement du niveau de la nappe phréatique.

4.2 Réutilisation des eaux pour l'industrie

Le tissu industriel, dans la Wilaya d'Annaba, est constitué essentiellement d'unités de production de l'acier et de ses dérivés, d'engrais phosphatés et de quelques autres unités agro-alimentaires: lait, tomate, piments, etc.

Dans une première étape, on ne s'intéressera qu'aux possibilités de réutiliser les eaux usées traitées pour les systèmes de refroidissement du complexe sédérurgique d'El-Hadjar. Il s'agirait plutôt d'une expérimentation de laboratoire visant:

- la connaissance des facteurs limitant l'utilisation des eaux usées à des fins industrielles;

- la détermination des moyens technologiques à investir pour atteindre la qualité physico-chimique requise pour une telle situation; à ce stade apparaît la nécessité de compléter ces aspects de la question par une étude de rentabilité économique des procédés technologiques à employer pour valoriser efficacement le m^3 d'eau réutilisé dans les circuits de refroidissement.

4.3 Réutilisation des eaux usées épurées dans la recharge artificielle des acquifères côtiers

Cette question ne sera abordée dans une première étape qu'à titre expérimental par les essais de laboratoire, dont le but serait d'établir au mieux la dynamique de certains composants chimiques ou bactériologiques présents dans les eaux, après épuration.

5. CONCLUSION

Dans les zones méditérranéennes, et notamment celles qui accusent des tensions en matière de ressources en eau, la réutilisation des eaux usées constitue probablement le meilleur moyen d'atténuer les conflits entre les demandes urbaines et les demandes agricoles. De ce fait elle constitue un potentiel de ressources en eau intéressant à mettre à la disposition des planificateurs de gestion des eaux.

Les nombres guides ont évolué nettement et d'une façon favorable à la REU au fur et à mesure que cette question a été abordée. La hiérarchie des pathogènes est reconsidérée. De ce fait l'épuration par les systèmes d'étangs de stabilisation apparaît comme intéressante dans la mesure où elle répond le mieux aux nouveaux critères demandés pour une réutilisation des eaux usées pour l'agriculture, en plus de sa simplicité de mise en oeuvre et du minimum de contrôle et d'entretien qui réduit de façon considérable les frais de fonctionnement.

REFERENCES BIBLIOGRAPHIQUES

- OMS - 1973. La réutilisation des effluents: méthodes de traitement des eaux usées et mesures de protection sanitaire. Rapport d'une réunion d'experts.

- OMS - 1981. Health aspects of treated sewage re-use; report on a WHO seminar, Algiers 1-5 June 1980.

- SONADE - 1975. Etude d'avant projet d'épuration des eaux usées domestiques par la technique de lagunage.

- NAFAA - 1985. Nappes aquifères superposées en région côtière hydrodynamique et hydrochimique (Aquifères de Annaba La Fafrag Nord Est Algérien).

- Séminaire maghrebin sur la réutilisation des eaux usées après traitement en agriculture. Tunis 23-26 avril 1986.

  1. Mme TRAD-RAIS et H. Saillet. Etude de la contamination bactérienne de la nappe du sol et des cultures par l'apport des eaux usées traitées et de boues résiduaires.

  2. A. Bouraidi. Effet de l'irrigation avec les eaux usées traitées et de l'application des boues résiduaires sur le rendement des agrumes.

  3. B. Lassouad. L'utilisation des eaux usées épurées en agriculture.

  4. M. Jemli. Réutilisation des eaux usées en Tunisie.

  5. A.L. Khrouf, N. Kamoun. Traitement des eaux usées en Tunisie.

  6. T. Egger. Expériences concernant l'utilisation agricole des eaux en RFA. Exemple de l'association d'utilisation des eaux usées à BRUNSWICK.

7. P. BOUTIN. Problématique de la réutilisation agricole des eaux résiduaires.

8. A. PROST. Les risques infectueux liés à la réutilisation d'eaux usées.

9. A. FAYAS. Utilisation des eaux usées en agriculture à Majorques.

- Pollutec 1982. Conférences techniques internationales.
Recyclage et traitement avancé des eaux usées.

    - M. AUSSOLEIL. La réutilisation des eaux usées comme élément de planification des eaux.

    - SHUVAL H. 1986. Wastewater Irrigation in Developing countries. Health Effects and Technical Solutions. World Bank Technical paper number 51.

- Séminaire sur les problèmes de santé posés par la réutilisation des effluents traités.

1. Dr. TAKASHI Asano, Robert Chivelli. Réutilisation des eaux usées pour la recharge des eaux souterraines et l'irrigation agricole.

2. A.C. CHANG et A.L. Page. Aspects chimiques de la réutilisation des effluents pour l'irrigation et la recharge des aquifères.

3. EDWARD S. Kempa. Traitement nécessaire avant réutilisation industrielle des eaux usées.

4. A. VAN HAUTE, Précautions sanitaires et traitements requis dans le cas de réutilisation industrielle et d'épandage d'eaux usées.

5. EBBA. Lund. Problèmes de santé liés à la réutilisation des effluents, trois notes.

   I. Bactéries

   II. Virus

   III. Protozoaires et helminthes

6. Réemploi des effluents traités pour l'alimentation des aquifères et l'irrigation.

IZMIR MUNICIPAL WASTEWATER TREATMENT AND RECLAIMED WATER CHARACTERISTICS

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1. INTRODUCTION

Izmir is one of the most important commercial and industrial centres of Turkey. The city of Izmir, an urban centre with 2 million inhabitants, extends right round the east end of the bay of Izmir from Semikler to Yenikale, and consists of the central Izmir and Karsiyaka regions. The existing sewer system serves Karsiyaka, Bayrakli and the central Izmir area. Most of the sewer system discharges directly to the bay through outfalls located along the shoreline. Sewers serving the areas adjacent to Melez creek discharge directly to the creek. The shoreline areas are between Karsiyaka and Bayrakli and between the Bayrakli and Mersinli industrial areas. Industries in these areas discharge through their own sewers either directly or indirectly via creeks crossing the area. The waste discharges are totally untreated and finally find their way through 98 disposal points and creeks into the bay.

The city is a commercial, industrial and touristic centre as well as an important international port with a harbour in the inner bay. Izmir is an important port of entry for raw materials and products imported into Turkey, and also has the largest export facilities for regional products.

Most industries are situated right on the coastline, for reasons of topography, transportation, industrial and cooling water supply and drainage. Only three alternative sides are possibly subject to industrial development. These are Gaziemir, Bornova and Buyuk Cigli. The availability of water has resulted in the rapid development of industry in the Bornova plain. Industries discharge their wastes and contribute significantly to the present water pollution of the streams and of Izmir bay.

Izmir, one of the fastest-growing cities in Turkey, according to the 1985 census results, has a 4.4% share of the total national population. This fast increase has caused problems with energy distribution, water supplies, communication, transportation and housing which is insufficient for the city residents. In particular, the disposal of waste materials (for example wastewater and solid wastes) is an important problem for Izmir city. The system is very primitive, discharging into the bay which is the internationally acknowledged symbol of the city of Izmir, and which is being destroyed aesthetically, touristically, recreationally and economically. Parts of the bay are being increasingly exposed to various pollutant loads and the bay is becoming a turbid, foul-smelling and shallow salty swamp. In addition to aesthetic problems, the present situation poses the risk of serious health hazards for the city population of more than two million inhabitants.

These problems can only be resolved by collecting the domestic and industrial wastewaters in Izmir, and subjecting them to treatment techniques, so that the city will have a better environmental quality and cleaner sea water in future years.

GENERAL DESCRIPTION OF THE POLLUTION OF IZMIR BAY

Izmir bay, especially the inner bay as shown in Fig. 1, is a receiving medium with limited capacity for dilution and dispersion of pollutants. In the inner bay, the collection of sludge at several creek mouths and the high concentration of organic substances have caused unpleasant odours as well as a disagreeable appearance for the city. As a result, the port area has undergone severe environmental deterioration.

Izmir bay's pollutant sources can be categorised in two groups: the point pollutant sources and the non-point pollutant sources. The point pollutant group, which contains domestic and industrial wastewater can be controlled by good planning which comprises both domestic and industrial wastewater management. Pollution in the bay is predominantly caused by the domestic and industrial wastewaters of the city. Polluted loads discharged are constantly increasing and thus enlarging the polluted area as can be seen from Fig. 2 (D.E.U., 1985). It is predicted that over the next 30 years, population, wastewater flow rates, organic pollution, suspended solids, nitrogen, phosphorus, heavy metals and toxic material loads will be about three times as much as their present values as summarized in Tables I to VII (D.E.U., 1985).

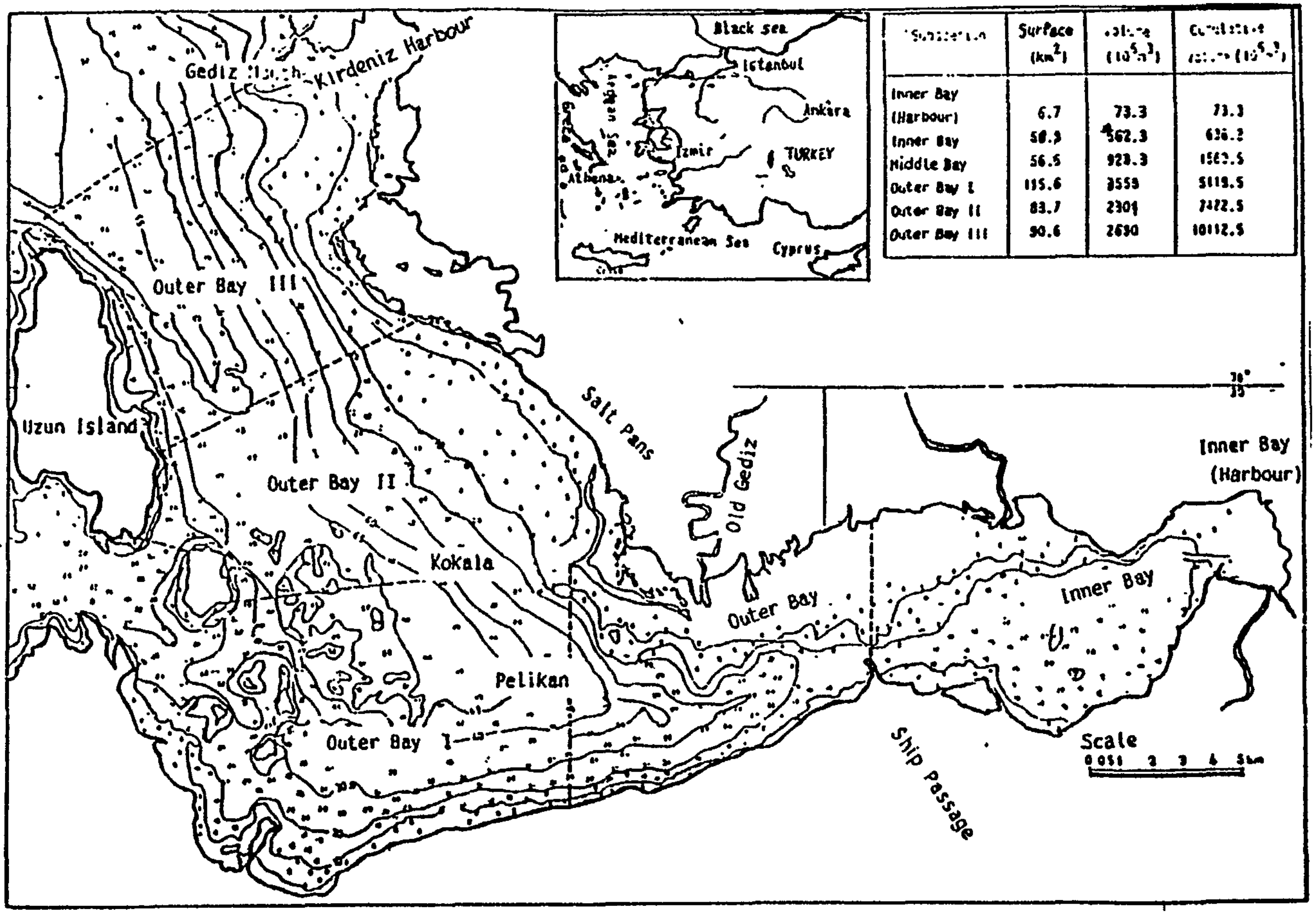
Other secondary sources of pollution in the bay are overland flow caused by precipitation, agricultural drainage, wastewater drainage from port activities, waste loads carried to the bay by streams and rivers. These non-point sources located all around the bay are not easy to control but in the long run their management and control will be necessary and can be achieved by means of good forward planning.

The general rates of discharged pollutants into the bay are as follows:

- 50% domestic and industrial wastewaters
- 15% pollution originating from the streets and roads as a result of rain washing
- 10% pollutants carried by the rivers
- 10% agricultural pollution (over fertilization and some insecticides)
- 8% erosion of soil
- 4% pollution originating from ship traffic
- 3% uncontrolled pollution

The domestic and industrial wastewaters discharged into the bay contain the following pollutants: organic substances, suspended solids, pathogenic micro-organisms and viruses, nutrient (nitrogen and phosphorus) and heavy metals.

Organic substances discharged into the bay have caused the depletion of dissolved oxygen in water by creating an anoxic condition and a bad smell, a typical indicator of anaerobic processes, is given off. Furthermore, in the inner bay areas very low oxygen concentrations have led to the disappearance of most of the marine life.



[illegible]	Surface (km^2)	[illegible] ($10^5 m^3$)	[illegible] ($10^5 m^3$)
Inner Bay (Harbour)	6.7	73.3	73.3
Inner Bay	58.3	562.3	636.2
Middle Bay	56.5	923.3	1562.5
Outer Bay I	115.6	3559	5119.5
Outer Bay II	83.7	2304	7422.5
Outer Bay III	90.6	2690	10112.5

Fig. 1 Physical characteristics and bathymetry of Izmir Bay

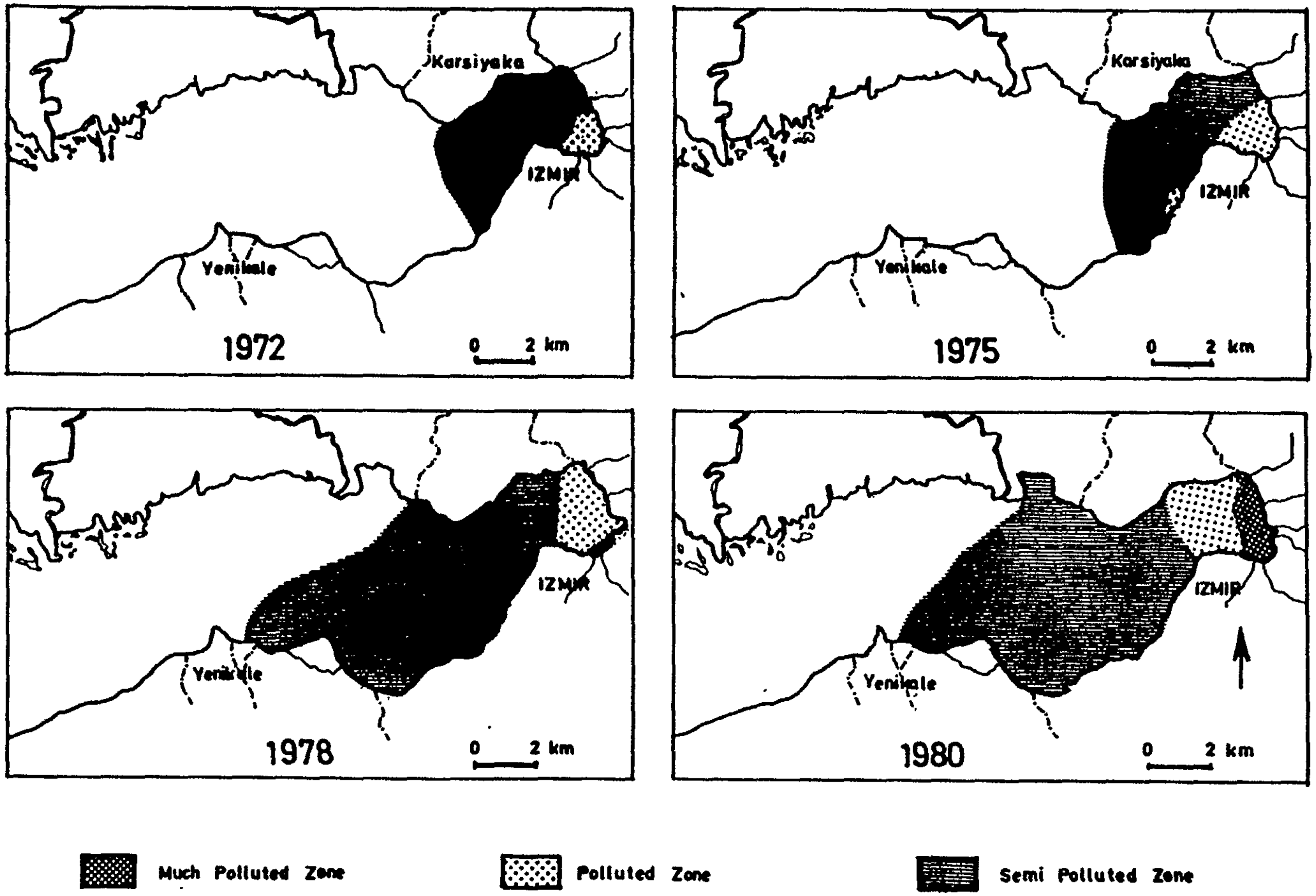


Fig. 2 Expansion of the zone of pollution in Izmir Bay (Kocatas, 1981)

Table I

Prediction of urban population in Izmir Metropolitan Area

Years	Population
1985	1,595,660
1995	2,163,600
2005	2,689,750
2010	2,997,400
2015	3,267,000

Table II

Prediction of domestic and industrial wastewater flow rates originating from the Izmir Metropolitan Area

Years	Domestic wastewater discharge (m^3/d)	Industrial wastewater discharge (m^3/d)	Total wastewater discharge (m^3/d)
1985	245,000	93,000	338,000
1995	420,000	118,000	538,000
2005	628,000	143,000	771,000
2010	752,000	155,000	907,000
2015	898,000	168,000	1,066,000

Table III

Prediction of BOD loads

Years	Domestic BOD_5 load (kg/d)	Industrial BOD_5 load (kg/d)	Total BOD_5 load (kg/d)
1985	112,000	102,000	214,000
1995	173,000	130,000	303,000
2005	242,000	157,000	399,000
2010	283,000	170,000	453,000
2015	310,000	185,000	495,000

Table IV

Prediction of suspended solids loads

Years	Domestic SS load (kg/d)	Industrial SS load (kg/d)	Total SS load (kg/d)
1985	117,000	49,000	166,000
1995	184,000	62,000	246,000
2005	255,000	75,000	330,000
2010	298,000	81,000	379,000
2015	327,000	88,000	415,000

Table V

Prediction of nitrogen loads (as N)

Years	Domestic Nitrogen (kg/d)	Industrial Nitrogen (kg/d)	Total Nitrogen (kg/d)
1985	6,125	2,325	8,450
1995	10,500	2,950	13,450
2005	15,700	3,575	19,275
2010	18,800	3,875	22,675
2015	22,500	4,200	26,700

Table VI

Prediction of phosphorus loads (as P)

Years Phosphorus	Domestic Phosphorus (kg/d)	Industrial Phosphorus (kg/d)	Total (kg/d)
1985	1,960	140	2,100
1995	3,360	180	3,540
2005	5,020	215	5,240
2010	6,016	234	6,250
2015	7,184	252	7,440

Table VII

Estimates of heavy metal loads

Parameter	Pollution load (kg/d)
Chromium	7,500
Lead	7
Cadmium	0.7
Zinc	16
Copper	3
Mercury	11
Cyanide	58

Suspended solids continually deposited at discharge points have caused the gradual filling up of the inner bay area. Also the organic matter in the suspended solids and the settled dead marine organisms have given rise to anaerobic decomposition in the sediment causing depletion of the oxygen and creating bad smells. Both the suspended matter and the growing micro-organisms increase the turbidity of the water, which limits transparency and thus impedes the photosynthetic activity providing oxygen for the water column.

Pathogenic micro-organisms and viruses in surface waters and the bay threaten severe health hazards for the city of Izmir. Thus, the use of the Izmir bay area for fishing, recreation and tourism has been largely limited by the presence of these organisms which may cause a variety of diseases.

In addition to organic loads, stimulation of algal biomass production by photosynthesis occurs in Izmir Bay, a phenomenon mainly leading to eutrophication, which is enhanced by nutrients such as nitrogen and phosphorus contained in wastewaters.

Industrial wastes have been and with few exceptions are being discharged into the bay without any previous treatment causing waste loads of heavy metals and toxic substances. These substances settle and accumulate in the sediment and are incorporated into the food cycle there in significant concentrations in marine vertebrates and fish. As a result, biomagnification can occur in human beings in respect of heavy metals. The heavy metals and toxic substances which mainly pollute the bay are chromium, lead, mercury and cyanide. Among these, chromium from the tanning industries has the largest share in the waste load input and it is believed that the concentrations of the rest of the heavy metals in the bay have not yet reached disturbing levels.

3. PRESENT INDUSTRIES IN IZMIR

The industrial situation is in process of changing from processing agricultural products to manufacturing goods. The older industries are the tanneries, raisin and tobacco processing and olive oil production plants. More recent industries are dairy products, wrapping materials, truck and tractor parts, an iron and steel mill, detergent and soap products, cement, several canning factories and distilleries.

These industries all produce a large amount of heavily polluted effluents per unit of production which are discharged either directly or through canals of wastewater to the sea. Some of them have treatment units for their effluents, for instance, a paint factory, a vegetal oil factory, and a tannery factory.

Most industries in the Bornova area discharge large amounts of organic matter, suspended solids and floatables content effluents into a nearby ditch, draining into the Manda creek which runs through agricultural areas before finding its way into the bay (Fig. 3).

The tanneries, mostly located to the south of Izmir, have been obliged to construct collective treatment plants in the city to treat their own wastewaters.

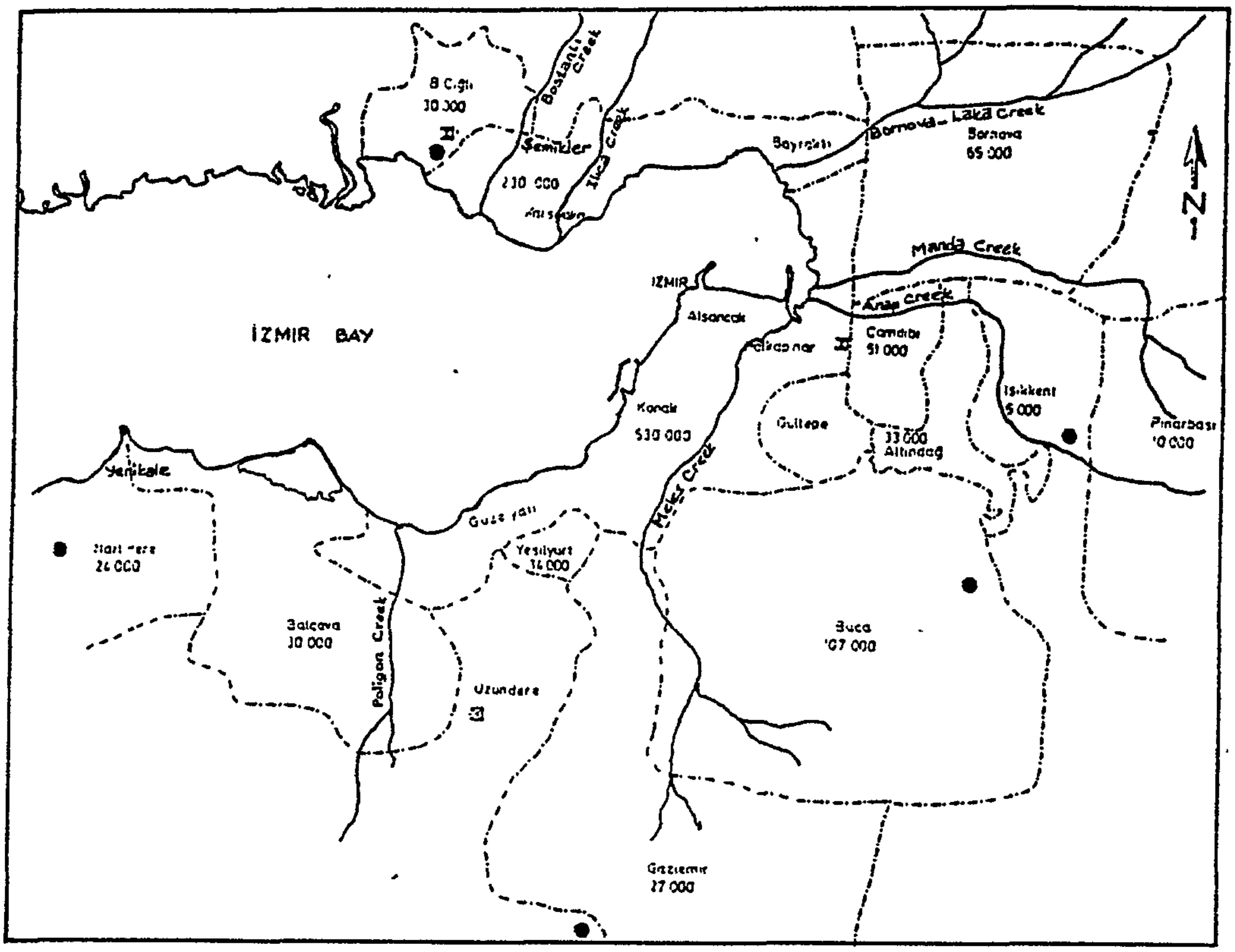


Fig. 3 Regions of Izmir city

4. POLLUTION PREVENTIVE LEGISLATION

Turkish Environmental Law 2872 (1983) sets out a principle of "Polluters pay", effective in the prevention and alleviation of pollution. Based on this law, a bay law related to the industrial wastewaters management for the city of Izmir is to be prepared. The main thinking behind this regulation is that pretreatment for industrial wastewater must satisfy certain discharge criteria. If any parameter has a value higher than that indicated in the by-law, that industry/industrial plant will be forced to set up a pretreatment plant for these parameters, after which they will be allowed to discharge their wastewater to the sewerage system.

5. MUNICIPAL WASTEWATER COLLECTION AND TREATMENT FOR THE CITY OF IZMIR

Three projects have been already been prepared on municipal wasterwater collection and treatment in the city of Izmir· the "Izmir Sewerage Project[Master Plan and Feasibility Project" (Camp, Harris-Mesara, 1971), the "Izmir Sewerage Project Master Plan and Feasibility Report")Su-Yapi, Holfelder, 1981) and the "Izmir Wastewater Treatment Plant Feasibility Study" (Dokuz Eylül Univ., 1985). In all of those projects, the collection, treatment and disposal of the domestic and industrial wastewaters in Izmir have been dealt with in great detail and the necessary public health engineering measures have been developed.

The total amount of wastewater produced in the city of Izmir during 1985 was about 341,000 m^3/day (3,950 l/sec) and it is predicted to reach about 1,066,000 m^3/day (12,340 l/sec) by 2015. The possibility of re-using such large amounts of water should be carefully considered in the choice of suitable methods of treatment and disposal, especially for a city like Izmir with semi-arid climate and a scarcity of water.

5.1 Wastewater Collection

The Izmir sewer system, the main parts of which are under construction, consists of a 49 km long main track encircling the bay and its subsidiary collection works amounting to 90 km and an extensive network of tertiary sewers. The construction of the main canal was started in 1983 and this is presently being continued in three sections. Wastewater collected by means of this sewerage system will be conducted to the north of the bay near Cigli to be treated in the treatment plant there. The main rationale of the sewerage project is to eliminate direct and indirect discharge of wastewaters to the inner bay where mixing and dilution potentials are quite low. In fact, the inner bay area has no capacity to assimilate wastewaters which have undergone even advanced treatment. Therefore, the idea of constructing small local treatment plants instead of a main one on the outskirts of the city, will still not provide an adequate solution for the prevention of pollution in the inner bay (Fig. 4).

5.2 Wastewater Treatment

A stabilization pond system, therefore, is a better resolution of Izmir's problem than the other alternatives. This system consists of mechanical screens, a grit chamber and three ponds. This combination has been found to be the most appropriate method of treatment for domestic wastewaters and pretreated industrial wastewaters (Fig. 5). In this alternative, the wastewater is held in anaerobic ponds, facultative ponds and maturation ponds with a detention period of 4, 16-18 and 5-6 days respectively. In the anaerobic and facultative ponds, organic substances (BOD) and suspended solids (SS) are removed. During the 5-day detention period in the maturation pond, efficient coliform removal is achieved by means of solar radiation or photoxidation and antibacterial substances produced from algae.

This system is the most economical with respect to both initial investment and operating costs, compared with all other possible alternatives. Furthermore, stabilization pond systems are ideal processes for a city like Izmir which has a sub-tropic climate and depletion of pathogenic micro-organisms can be realized making use of natural processes. Thus by keeping the wastewater in shallow ponds for a few weeks, very efficient pathogen removal occurs as well as BOD and SS removal during summer. The efficiency of removal is so high that no fecal coliforms will be present in the effluent during the summer. The efficiency of in-plant pathogen removal during the winter season might however drop considerably. The dilution capacity and bacterial die-off rates provided by a marine outfall system still to be designed will make up for this loss of efficiency and it will be possible to meet the recreational standard of 1,000 FC/100ml during the winter period also. However, since the bay is not used for recreational purposes during the winter time, the application of this recreational standard contains an additional safety factor.

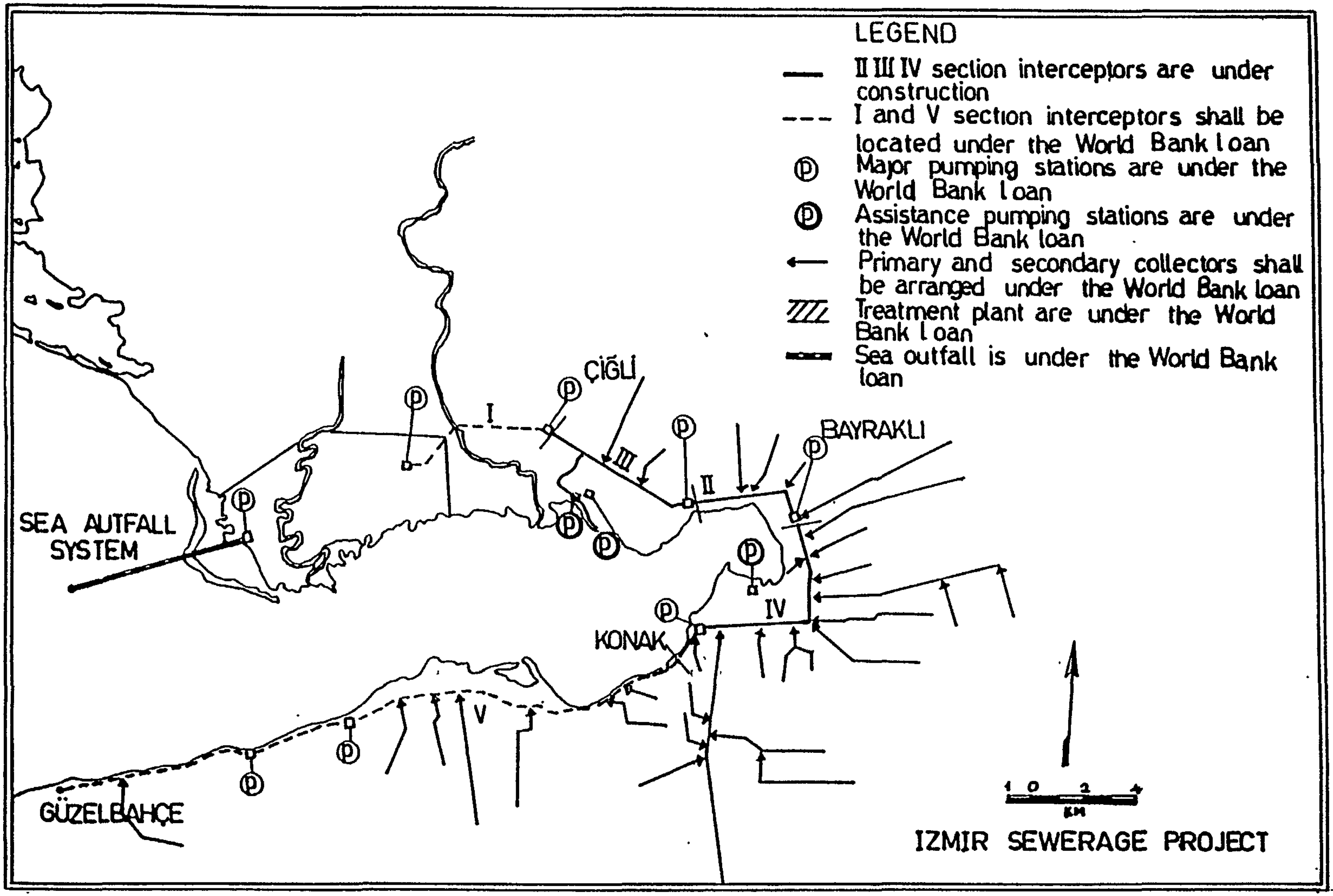


Fig. 4 Izmir Sewerage Project

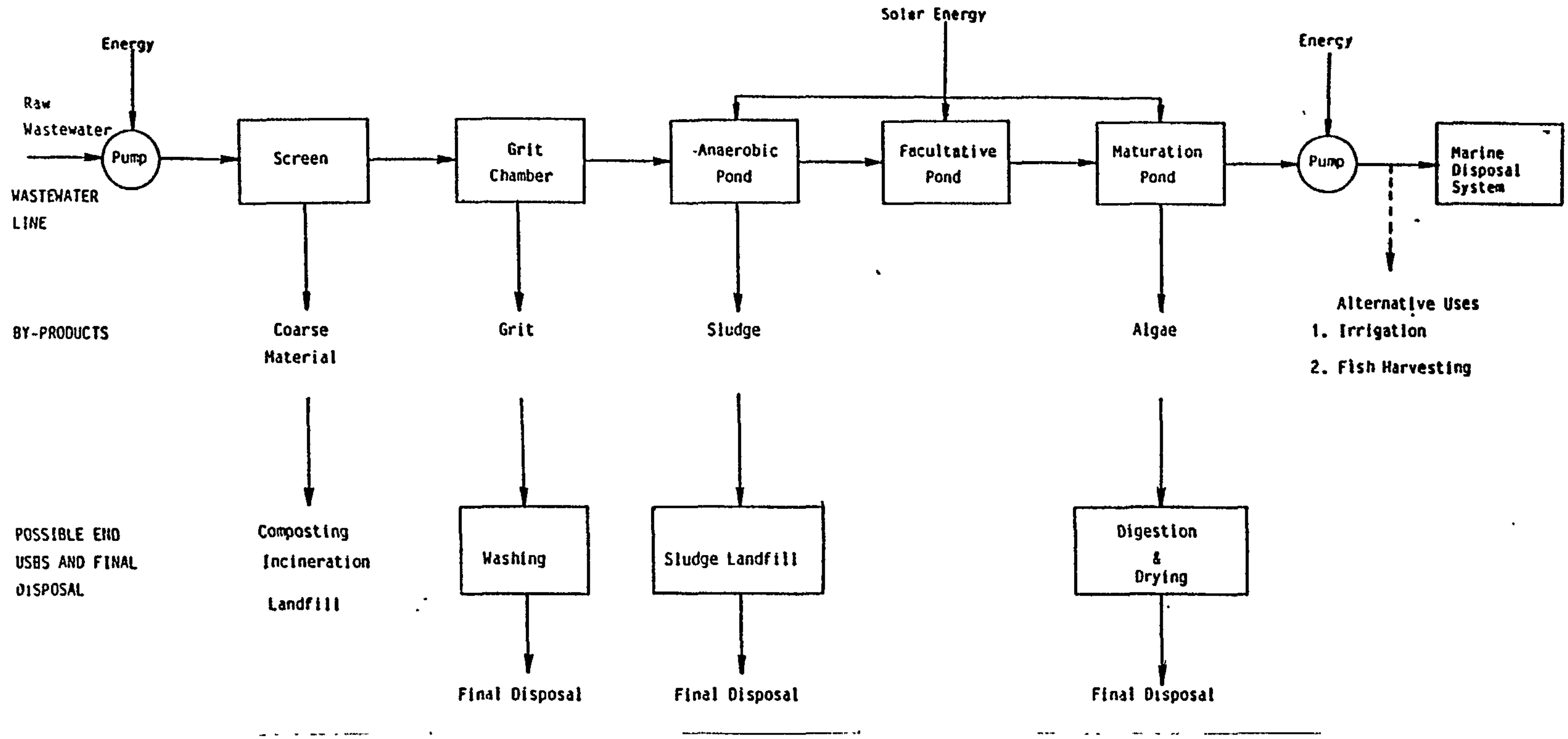


Fig. 5 Flow Chart of the Izmir Wastewater Treatment Plant Stabilization Ponds

In stabilization pond systems, nitrogen and phosphorus can be removed to a greater degree (50-90% nitrogen, 65-70% phosphorus) by algal harvesting and consequently eutrophication in the receiving media can be controlled more effectively. Algae to be harvested will have a potential economic value.

Nevertheless, stabilization ponds do present some disadvantages for the city, among these foul smells which may be produced by anaerobic units, and mosquito problems. But it has been definitely established that well-maintained and properly operated stabilization ponds do not incur more odour and insect problems than other well-operated treatment systems.

The main disadvantage of the stabilization pond system is that it requires large areas of land located close to the city. It is well established that given the availability of such areas, natural treatment systems in cities with warm climates like Izmir have numerous advantages. The area required for the stabilization pond system for the year 2015 is roughly 2,000 ha. Fortunately for Izmir, there is land available in Cigli with an area of 3,100 ha which is topographically convenient and ideally located for the construction of stabilization ponds (Fig. 6). A large part of this area is publicly owned, and is not convenient for agricultural purposes because drainage is not possible and it cannot be used for the construction of buildings because of its low soil-bearing capacity. Stabilization pond systems do not require heavy concrete structures and can be built using earth dikes.

In stabilization pond systems, however, sludge accumulates at the bottom of the anaerobic parts and is well digested within a few years. This sludge can subsequently be dried and removed by alternatively separating the ponds from the systems. This sludge is of great value as a raw material due to its nitrogen, phosphorus and organic matter content. Its heavy metal content will also be low because the raw wastewater influent will not have a high concentration of heavy metals. Because they will be treated in the pretreatment system at the source of wastewater (for example, in the polluting factory) these sludges can be used as fertilizer, can be composted together with solid wastes or can be processed and used as fuels.

The stabilization pond system proposed has great potential for efficient treatment. The treated wastewater can be used for irrigation and industrial purposes. It is also possible to utilize part of the treated wastewater for cooling and industrial purposes in the developing "Organized Industrial District (AOSB)" in the Cigli region. Further treatment may be required for some specific industries, however.

In the stabilization pond system, both project and construction are made possible by World Bank financial support. The trends project is finished and a private company is presently preparing the application project. This will be finished by the end of 1988 and construction will begin in 1989. The system will be operational in 1992.

5.3 The Criteria for Stabilization Pond based on Legal Framework

In respect of treatment criteria, standards of municipal wastewater in treatment system in Izmir city have been studied for two years in the Prime Ministry General Directorate of Environment and Dokuz Eylül University of Izmir. Now the criteria for the municipal wastewater have been prepared, the draft has been finalized and this study will be approved in the near future.

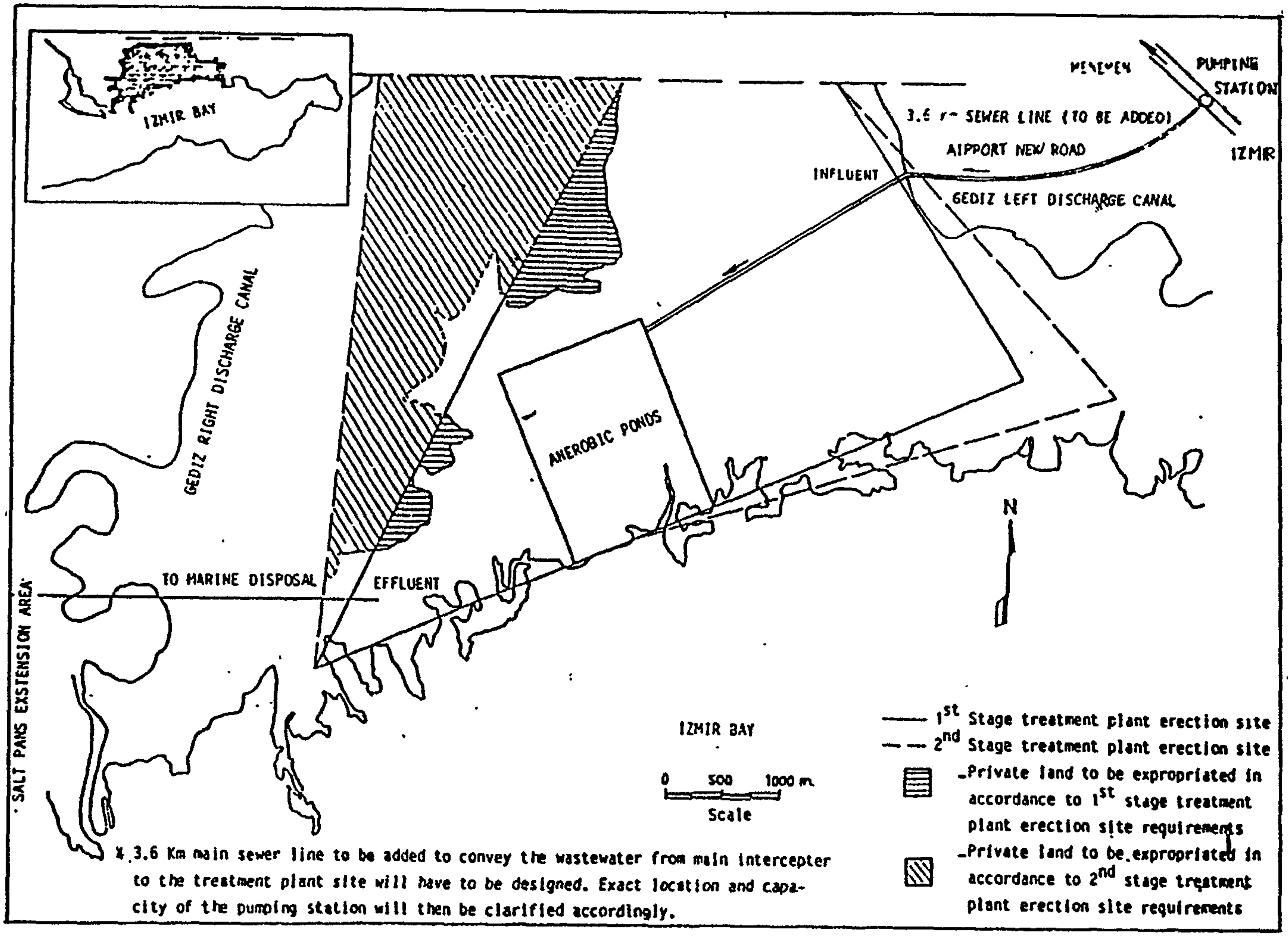


Fig. 6 Location of stabilization pond system and land requirement

When the municipal wastewater is treated in the stabilization ponds, they will have the characteristics shown below (Table VIII).

Table VIII

Wastewater characteristics for Municipalities (Population over 10,000) with a raw BOD load in excess of 600 kg/day

Parameter	Composite sample of 2 hour	Composite sample of 24 hour
BOD (mg/l)	50	45
COD (mg/l)	140	100
SS (mg/l)	45	30
pH	6-9	6-9

5.4 Financial Aspects

The cost of the above-mentioned project in 1986 was as follows·

Collectors and secondary sewers	103,000,000,000 TL
Treatment plant and outfall	43,000,000,000 TL
Engineering services	4,700,000,000 TL
TOTAL	150,700,000,000 TL

6. CONCLUSION

It is believed that with the realization of this project environmental problems in Izmir will be considerably reduced.

7. REFERENCES

1. Camp, Harris Mesara, "Izmir Projesi, Kanalizasyon Master Plan ve Fizibilite Raporu", Izmir, 1971.

2. Dokuz Eylül Univercity, Faculty of Engineering and Architecture "Izmir Wastewater Treatment Plant Feasibility Study", 1985.

3. Kocatas, A., "Izmir Körfezinde pollusyonun Bazi Fizikokimyasal ve Biyolojik Etkilerinin Mevsimsel ve Yillara Bagli Degisimleri", (Profesörlük Teze), Izmir Ege /ni. Fen Fakültesi, 1981.

4. Su-Yapi, Holferder, "Izmir Kanalizasyon Projesi Ana Plan ve Olabilirlik Raporu", Ankara, 1981.

RE-USE OF TREATED WASTEWATER POSSIBLE APPLICATIONS IN YUGOSLAVIA

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1. ABSTRACT

The paper presents the Yugoslav interest and attitude towards the application of treated wastewater for irrigation and other purposes. The re-use of treated wastewater has not been carried out so far, but its application is being planned mainly as an accompanying activity together with the protection of water resources and the sea, or possibly for saving drinking water on the islands and in the isolated coastal areas. The reasons for and characteristics of this approach are presented and dealt with, as well as the necessary preliminary activities related to the implementation of the wastewater re-use in the coastal regions of Yugoslavia.

2. INTRODUCTION

The need to re-use treated wastewater appears to exist only in the coastal area of Yugoslavia. The coastal belt of Yugoslavia is more than 4,000 km long, and the distance between its farthest points is 750 km, which shows the high degree of development of the coast.

In Yugoslavia, there are over 1,000 islands, mostly unpopulated. In the coastal belt and on the islands there are about 1,000,000 inhabitants, most of whom live in some large towns on the coast, while the rest live in a great number of small settlements (Fig. 1). In this area, there is significant economic activity. Industry is mainly concentrated in the vicinity of large towns (Split, Rijeka, Zadar, Sibenik) and only a small part of this industry is located in the small towns and settlements. Agriculture is poorly developed, primarily due to unfavourable soil conditions (mainly rocks) and unsuitable hydrologic conditions and the shortage of water in summer. Therefore, agriculture is well developed only around the estuaries of the rivers on the coast.

Tourism is certainly the most important activity of this area and it is continually developing. Tourism is more significant in small towns, whereas large towns are mostly transit centres. This tourism is of a typically seasonal type with peaks in July and August, while its intensity decreases in winter. There are more than 6,000,000 tourists in this area annually.

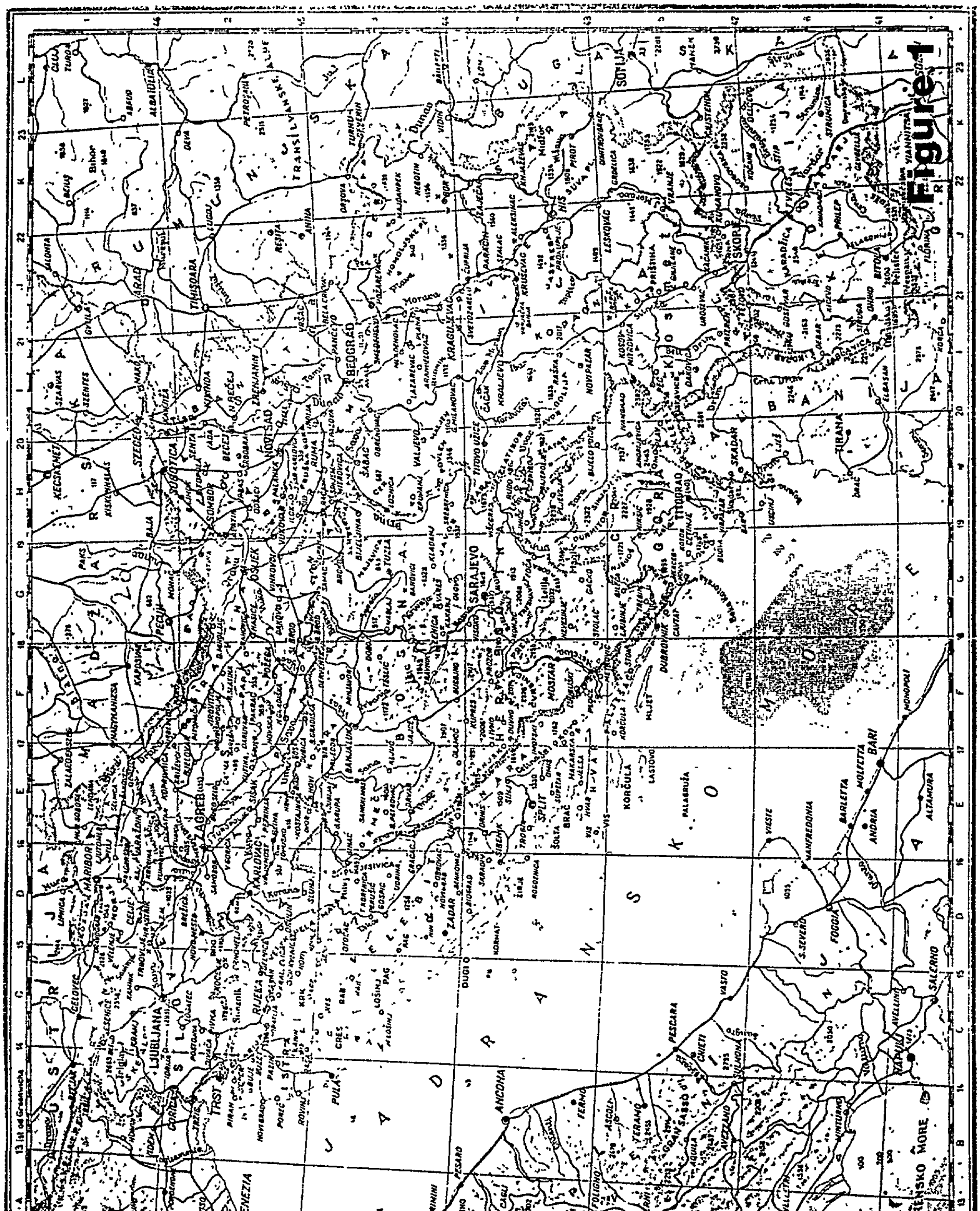

BEOGRAD
SARAJEVO
ZAGREB
LJUBLJANA
NOVI SAD
TIRANA
BARI
ANCONA
1:4,000,000

Figure 1

The Adriatic coast is characterized by a typically Mediterranean climate, with cold and wet winters and dry and warm summers (Fig. 2). Starting from the east to the west along the coast the regions become more humid and colder. From the geological standpoint, this area is a typical karst terrain, with rocks and mountains without any large valleys and flat areas. Such topological, climatological and geological conditions caused the formation of the respective water resources, so that there is a lack of water in these areas. This is particularly true for the islands, which are characterized only by an unstable lense of fresh water under the islands. The specific features of these areas are karst springs and sub- marine springs with characteristic significant oscillations in capacities. Some of these springs have a considerable capacity, like Jadro (min 5 m^3/s), Ombla (6 m^3/s), Rjecina (3 m^3/s). The catchment areas of these springs include the immediate hinterland and the regions further inland. The characteristic feature of these springs is that they have been formed and are located in typically karst regions, and are mainly of an overflow type (Fig. 3). Several large rivers flow into the Adriatic Sea in the coastal area, such as the Zrmanja, Krka, Cetina. These rivers are recharged in the continental part of the country.

Large towns are the highest consumers of water, throughout the whole year continuously. Most small towns are high consumers only during the summer, so that they are characterized by high oscillations in consumption primarily due to the periods of seasonal peaks in tourism. Agriculture is not a significant consumer of water, due to lack of water and also because the soil is not rich nor easily available.

3. WATER SUPPLY - PRESENT STATE

The problem of water supply in this area has been solved in various ways. Large centres are supplied by water from the regional water supply systems which use water from streamflows or water-rich karst springs. Small towns mainly use the local sources or are connected with the regional systems.

One of the local sources is rain harvesting. Most of the coastal settlements have solved the problem of water supply successfully. The situation on the islands is more complex. Large islands, located near the coast, are connected by submarine pipelines to the regional systems on the coast. Small islands and the islands located farther off shore use local sources, rain harvesting and water tankers supplementing supply during the summer. Although the situation is neither easy nor simple, the supply of the islands with potable fresh water is still satisfactory. The greatest problem is oscillations in the consumption during the summer months, when the local sources lack water or completely dry up. In addition to the problem of water quantity, another problem has lately become acute, i.e. the pollution of water, which thus eliminates some of the sources in the area, so that they are no longer sufficient.

A similar situation applies in industry. Industry is located in large towns or in the vicinity of significant water resources, so that there are no problems of water supply.

The situation is more complex with regard to agriculture. The mild Mediterranean climate makes possible an intensive growth of various plants, such as Mediterranean fruit, if sufficient quantities of water can be ensured.

Unfortunately, in the summer months there is a shortage of water on the islands and in isolated areas, so that even the water supply is inadequate, and agricultural activities are limited to small lots around the houses.

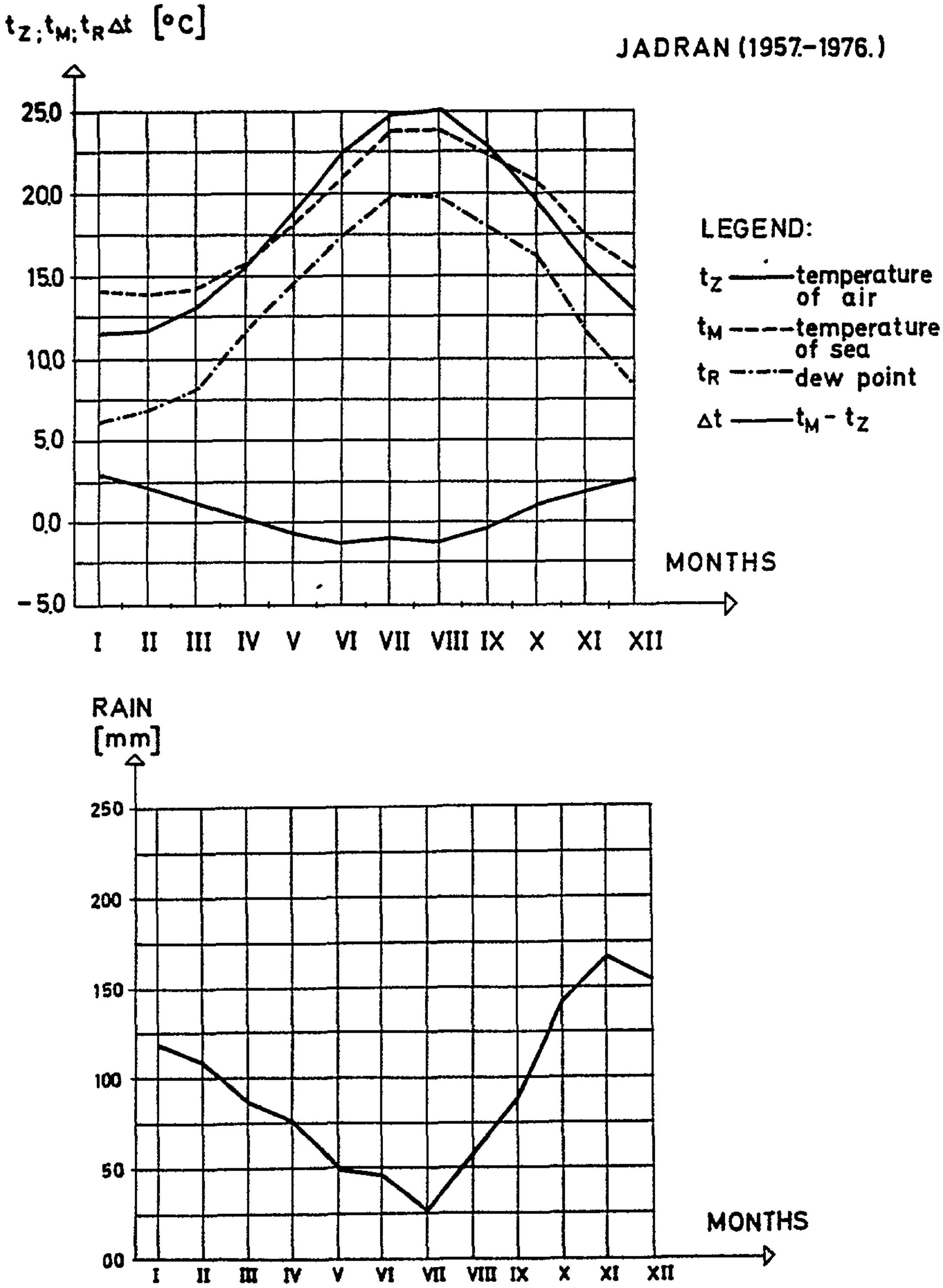
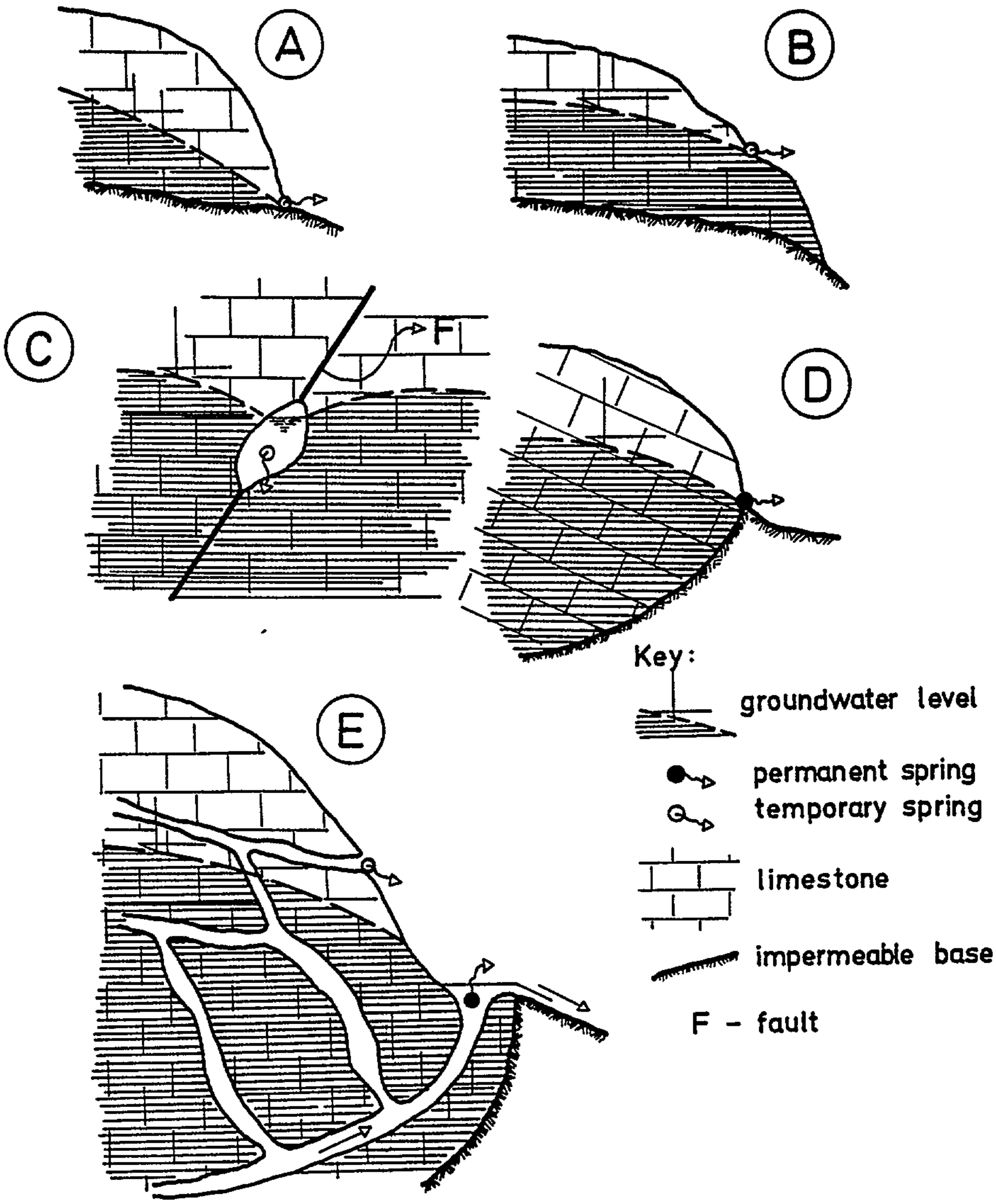


Fig. 2



(A) and (B) two types of bedding springs; (C) spring emerging from fractures; (D) overflow types of springs; (E) ascending spring.

Fig. 3 Classification of karst springs according to geologic and tectonic conditions (according to Bonacci, 1987)

The existence of a large market (tourism) and the problems related to the import of Mediterranean fruit, make agriculture an important factor in this area, so that plans are currently being made to try to solve the problem of water supply for agriculture. One of the alternatives to be considered is the re-use of the wastewater, especially on the islands and in isolated coastal areas.

4. RE-USE IN YUGOSLAVIA (STATE-OF-ART)

The re-use of wastewater for agriculture or some other purposes has not been carried out so far in Yugoslavia. However, this statement applies only to the directly organised re-use of wastewater and not to re-use through polluted water resources.

The reasons why re-use has not been so far carried out are numerous and can be summed up as follows: the activities on the islands and in the coastal area did not have significant economic importance as to require the application of this non-conventional source of water for agricultural production and other purposes. However, the development of tourism and the resulting increased consumption, high costs of water supply and food supply, and the increasing demand for the purification of the wastewater, make the re-use of wastewater acceptable for the irrigation of agricultural areas and landscape. Accordingly, certain initiatives have been undertaken in order to analyze all the aspects of this problem. Another reason that has made re-use an important subject to be considered by the water authorities and others, is the uncontrolled application of re-use in certain regions. Some islands and coastal areas use, for irrigation purposes, the groundwater which is mixed with wastewater flowing out of the septic tanks. The same applies to small islands which have the lense of fresh water floating above the sea water. This water has been used for irrigation for a long time, but today this problem is becoming more acute since the consumption of water on the islands has increased and there are great quantities of wastewater which freely, without control, flow underground and thus make the groundwater quality questionable and dangerous for use for irrigation.

5. PLANNING AND POSSIBILITIES FOR RE-USE

According to the analyses undertaken, it has been established that it is difficult to carry out the re-use in the situation as it is in Yugoslavia, since: i) there is little interest in this type of water supply; ii) geological, hydrological and topographical characteristics of the area are not favourable; iii) there is not enough experience and knowledge to solve these problems. It has also been found out that re-use can be carried out in certain small coastal areas only but with different objectives. Thus, there is no possibility for the development of re-use of great capacity; only small plants could be installed.

According to the specific features of this area: future demands, development trends, plans for the protection of water resources, the carrying out of re-use in the coastal area and on the islands is planned in the following situations:

i) when the polluted groundwater has already been used for irrigation (areas which have solved the water supply from other sources);

ii) when the groundwater in karst areas used for the water supply should be protected;

iii) when the coastal sea in the closed bays and basins should be protected from eutrophication or where wastewater is treated with high efficiency (secondary treatment);

iv) when water for irrigation or water supply should be provided from such sources.

The facts stated above show that the re-use of treated wastewater as an additional source of fresh water, is not of primary importance for this area. This source of fresh water is significant and justifiable only if it simultaneously solves some other problems (groundwater protection, protection of the sea and others).

5.1 Improvement of the present use of the polluted groundwater

As already stated, some types of re-use of the polluted groundwater are already being carried out, in certain locations, most frequently on small islands (Fig. 4). In the summer months, it is re-use in the real sense of the word, since the groundwater is renewed exclusively by the wastewater from the septic tanks. The local population, as well as the water authorities, are certainly aware of this situation. Therefore, local inhabitants use this water only for irrigation, as there are no other sources for this purpose during the summer months. However, the local population is not quite conscious of the problems and threats resulting from this type of irrigation. Consequently, the water authorities are considering this problem in order to improve the existing application. The geological characteristics of the area (karst, cracked rocks) are such that they make possible fast sinking of the water underground with minimum purification on its way. Therefore, the only possibility is the use of the purified water directly from the surface retentions. The construction of such surface retentions, indispensable for improving water quality, and for the balancing of demand and supply, is not easy in these rocky terrains. The optimal solution is the retention of the type - plastic lined pond.

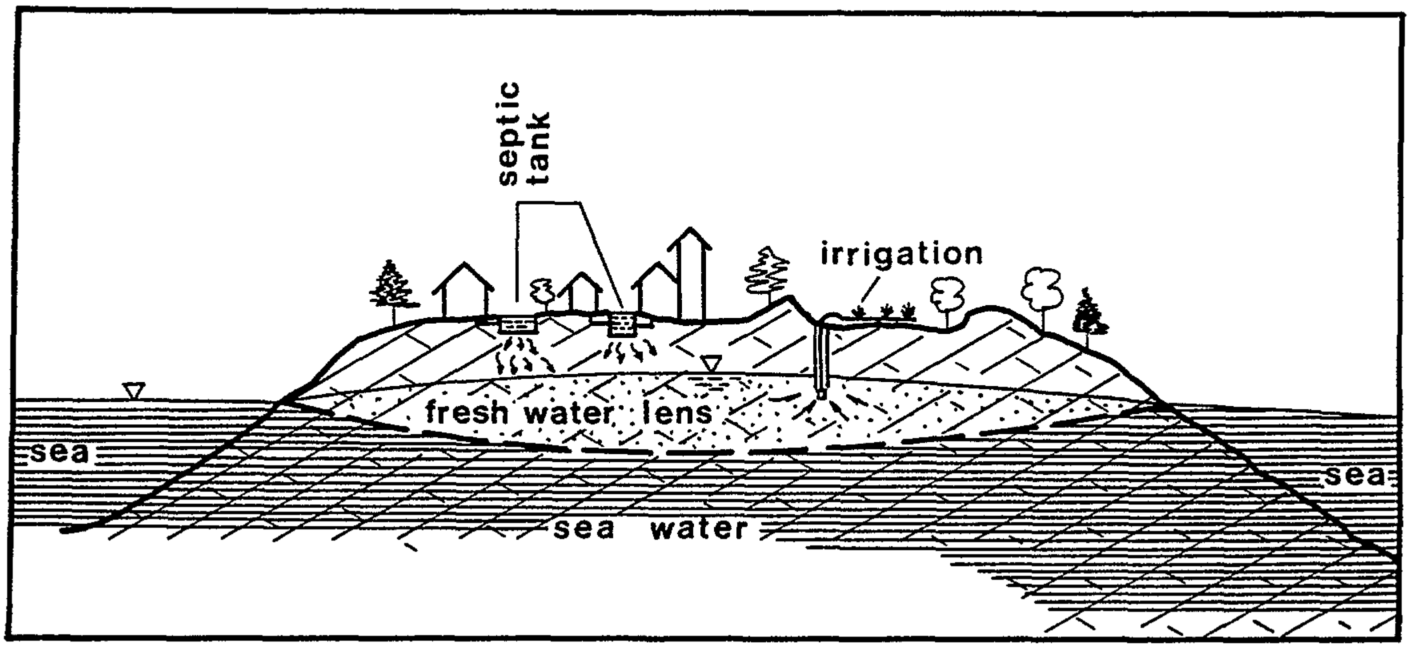


Fig. 4 Re-use practice on the small island

On the other hand, the treatment of wastewater in this area will not present a great problem since the wastewater is typically domestic water of standard quality. The greatest problem is the high oscillations in the inflow of wastewater.

Starting from these characteristics, it has been concluded that the present consumers of the polluted groundwater should build retentions along with the respective plants. Past examinations of this water have shown that, in most cases, the water should be kept in the retentions only in order to reduce the bacteria to the required standards, and to improve the quality of water in respect of the other characteristics. Consequently, septic tanks would be quite sufficient as pre-treatment. However, it is questionable whether it is justified to use the underground aquifer as retention for these purposes due to the following reasons·

a) whether it is harmful to pollute the groundwater, even if small quantities are considered[

b) whether the groundwater losses are too great and hence dangerous for the pollution of the coastal sea.

Generally speaking, these questions are not easily answered, and this problem should be solved from one case to another in accordance with the local characteristics.

5.2 Re-use as the protection of groundwater in karst

The hinterland represents the area of recharge for the great coastal sources (springs, rivers) used for drinking water. These regions are large and are located in a typical karst area. In order to protect this water all the settlements in this area should have the wastewater treatment with a high degree of purification. The reasons for this have been already mentioned (karst, low auto-purification capacity of the underground soil). The settlements are scattered and small, so that the construction of a sophisticated regional treatment plant could not be justified. Therefore, it is recommended that simple processes should be used, e.g. lagunas, being simple and efficient plants, so that the treated water is retained in the plastic lined ponds and used for irrigation. Applying this solution (Fig. 5), the inflow of the purified water into the underground will be prevented, and simultaneously the water will be used efficiently, since these areas lack water for irrigation, particularly in the summer months.

Those regions situated just beyond the coastal belt are characterized by exceptionally warm and dry summers and cold winters. Consequently the vegetation of this region is poor and the terrain rocky. However, these areas include small karst poljes suitable for the intensive development of agriculture. Water has always been the limiting factor. Other forms of groundwater protection are expensive and uncertain; hence the suggested solution is considered suitable for this area (cheap construction, easy maintenance, not too much energy, no demand for skilled personnel, efficiency in the elimination of bacteria, agricultural production).

5.3 Re-use as the protection of the sea

The coastal belt of the Adriatic sea in Yugoslavia is exceptionally well-developed, and there are numerous bays and straits of various sizes. Since these bays are well protected, they have, since ancient times, been suitable for the location of settlements. Nowadays, however, the controlled and uncontrolled sources (point and non-point) of pollution have

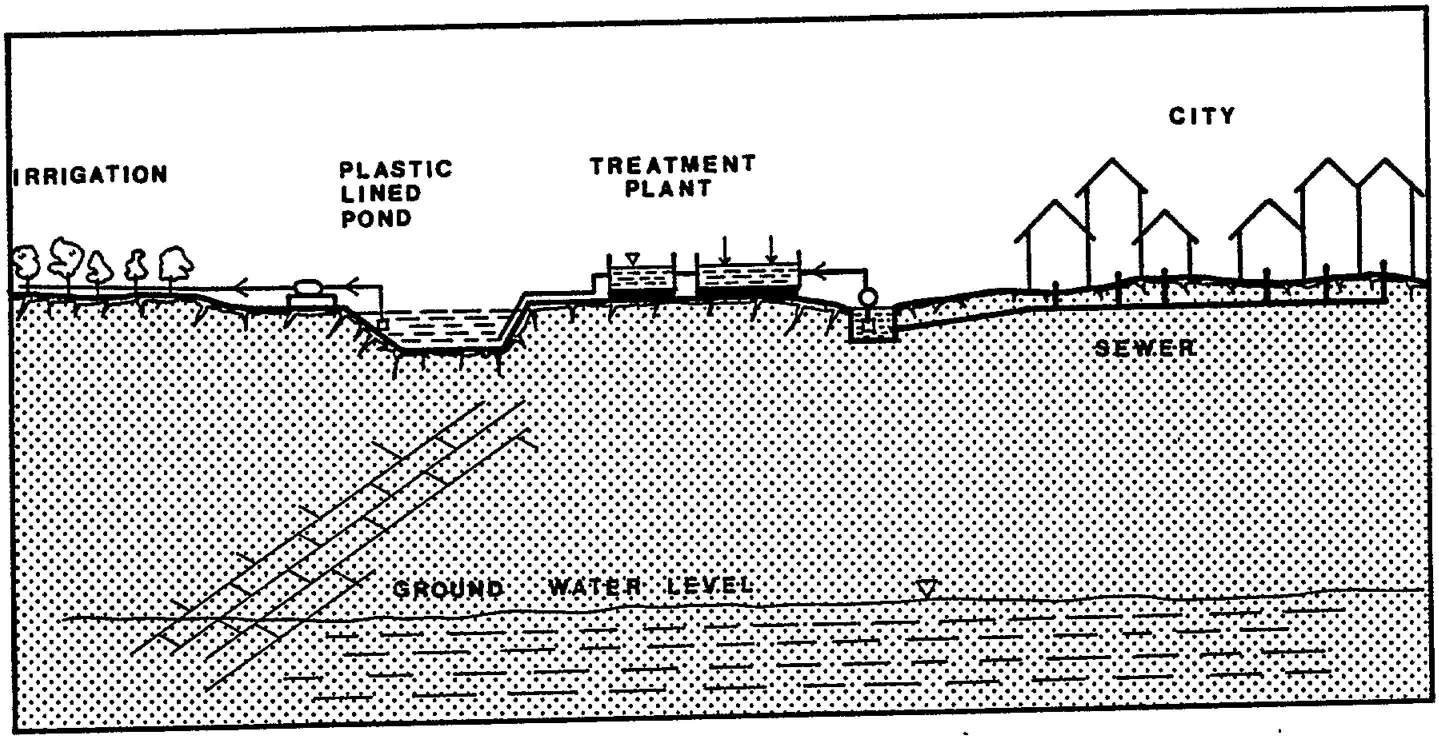
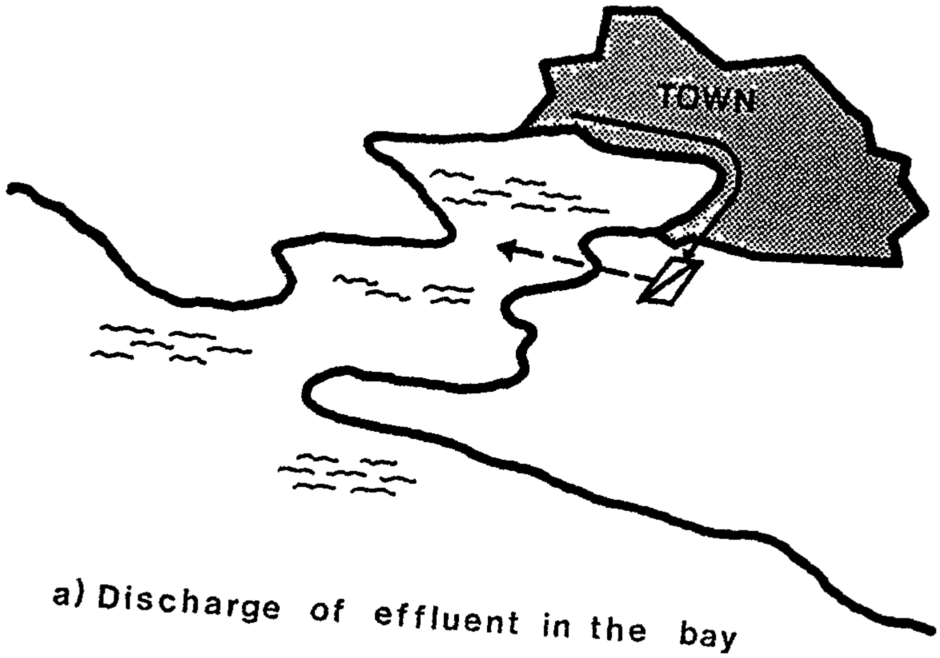
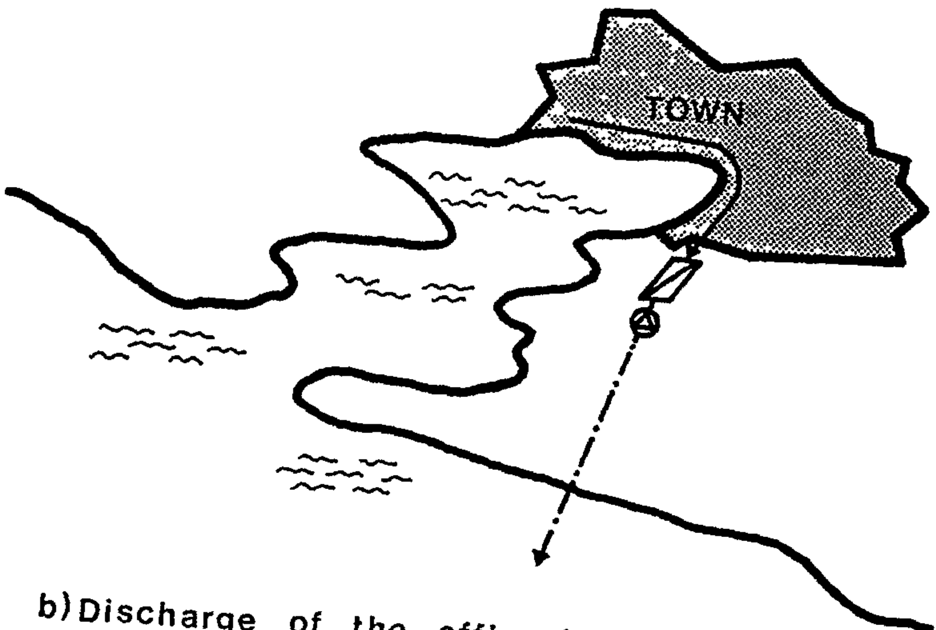


Fig. 5 Re-use scheme in the case of groundwater protection

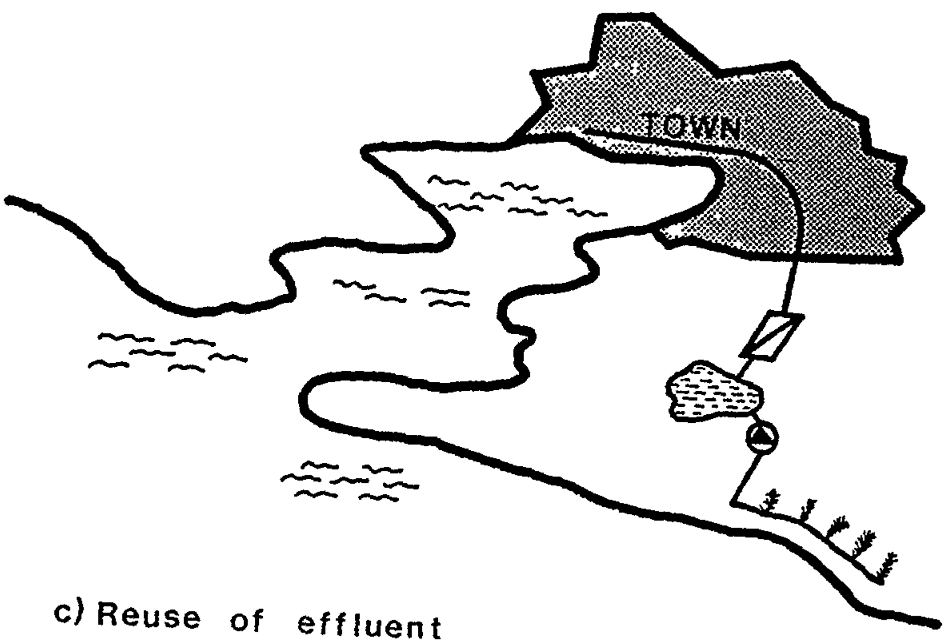
polluted and degraded the sea in these bays in some places to a state of eutrophication. The main cause of the high degree of pollution is the insufficient exchange of the sea water in the bay with the clean, open sea, so that the nutrient salts are stored to build up in the sea. In order to solve this problem it is necessary to treat the wastewater, and sometimes the storm runoff, to a degree which will prevent eutrophication; this implies the construction of plants of high efficiency, or pumping the wastewater several kilometres outside the bay and releasing it into the open sea. If the water is efficiently treated, its release into the sea can be justified; whether there are economical and environmental reasons for it when the areas by the sea have not sufficient quantities of water for irrigation and for other purposes. This release is even more questionable considering the expense of the operation. Thus, when the water is pumped out of the bay, with the previous treatment of a lower degree, it is necessary to analyze the economic and environmental aspects of this solution as compared with the application of re-use wastewater for some local needs. Accordingly, bearing in mind the great demand for water in this area, and the necessity to protect the sea, the application of re-use is considered to be an efficient and environmentally justified solution, particularly for areas on the islands since the cost of bringing water there is extremely high. In the present situation, when the disposal of the wastewater is effected by long submarine outfalls with the respective mechanical treatment, this method is not very attractive for other areas. However, such disposal of wastewater cannot continue indefinitely. The application of a treatment of higher degree will make re-use of wastewater more acceptable (Fig. 6).



a) Discharge of effluent in the bay



b) Discharge of the effluent in the open sea



c) Reuse of effluent

figure 6

5.4 Re-use as the procedure for providing water for irrigation and water supply

The carrying out of re-use exclusively for irrigation purposes takes place in Yugoslavia only for the islands distant from the coast and for the isolated coastal areas without water. In the future it will probably be used only for the islands since the construction of regional coastal water supply systems has been planned.

The coastal areas and those islands connected to the regional water supply systems, can store water from the regional system during the winter, when the consumption is lower and thus they can provide sufficient quantities for irrigation, but it is questionable whether it is economically justifiable to use water for this purpose. If the regional systems cannot satisfy all the demands on their capacity, then the carrying out of re-use for irrigation of agricultural areas and landscape can be fully justified, particularly as a measure for saving water from available resources, and for the development of agriculture. This is not the case at present, but it does not mean it will not happen, primarily on the islands.

6. CONCLUSION

From the facts stated above, it can be concluded that re-use of wastewater has not been carried out in Yugoslavia. However, increasing demands for water in the areas short of water will probably lead to the application of this method, as a measure for reducing the consumption of drinking water. Re-use to satisfy the demands of agriculture exclusively, is not likely to occur in the near future, but it will have application in combination with other purposes, such as groundwater and sea protection. Re-use of this type can be justified in the present situation, and therefore certain efforts are being made to bring this about.

Yugoslavia is very interested in improving its knowledge in this field and in exchanging experiences in this field, hence all the activities, including the activities carried out by PAP/RAC are very helpful. We are conscious of all the problems and dilemmas in the application of this source of fresh water, and therefore, are trying to prepare the necessary technical and legislative measures.

VALORISATION DES EAUX USEES PAR L'IRRIGATION EN FORET MEDITERRANEENNE

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1. INTRODUCTION

Deux des questions les plus difficiles auxquelles sont confrontées les collectivités locales en région méditerranéenne sont la prévention des incendies de forêt et l'élimination des eaux usées.

L'idée très séduisante *a priori*, de les résoudre simultanément en irriguant la forêt avec les eaux usées avait été émise depuis plusieurs années. L'installation expérimentale de Cogolin est la première tentative faite, en France, pour vérifier la possibilité de sa mise en oeuvre opérationnelle.

2. DESCRIPTION DE L'INSTALLATION

Le site retenu est situé sur la commune de Cogolin, dans le Var, à proximité du Golfe de Saint-Tropez. Le substrat géologique est un micaschiste du massif des Maures, la pente (5 à 40%) et la profondeur du sol (20 à 50 cm) sont assez variables. La végétation a été très marquée par l'action de l'homme, et notamment par les incendies anciens: bouquets de chênes-lièges et de pins maritimes (dépérissant à cause du Matsucoccus), disséminés au milieu d'un maquis à bruyère arborescente et cistes bien développé. Elle est donc très inflammable et combustible et constitue un milieu bien représentatif de la Provence cristalline.

Les eaux utilisées pour l'irrigation sont les effluents de la station de Cogolin qui ont subi un traitement par boues activées en aération prolongée et une double filtration par tamis de 180 à 120 microns successivement.

La qualité de cet effluent est caractérisée par un pH légèrement basique proche de la neutralité, une minéralisation et une charge en matières en suspension assez faibles, une DCO à teneur moyenne de 46 mg/l, une prédominance de l'azote ammoniacal parmi les différentes formes de l'azote minéral et une charge bactériologique aux valeurs classiques pour les différents germes.

L'effluent utilisé constitue donc une eau d'irrigation de qualité convenable ne devant pas entraîner de problèmes majeurs pour les espèces.

L'ensemble du site a fait l'objet d'un débroussaillement préalable à la mise en place du dispositif.

L'irrigation a porté sur deux types d'arbres:

- les arbres de la forêt autochtone composée de chênes-lièges, de chênes verts et pubescents, de pins maritimes et de quelques rares fruitiers;

- des plants introduits, au nombre de 1.600 environ, appartenant à 14 essences feuillues (merisier, érable sycomore, ailante, aulne de Corse, micocoulier, platane d'Orient, robinier, saule blanc, sophora, peuplier blanc, chêne-liège et 3 espèces d'eucalyptus: dalrympleana, gunnii et macarthuri) et 2 essences résineuses (pin pignon, cyprès vert). Ces plants ont été installés en deux étapes, en 1982 et 1983 avec quelques regarnis en 1984.

Deux méthodes d'irrigation ont été utilisées (Figure 1):

- l'aspersion sur les deux secteurs I et II (12 asperseurs sur chacun, à l'écartement 12 x 18 mètres) qui porte sur 0,8 ha environ;

- la "micro-irrigation" (localisée) sur les secteurs A, B, C, et D, selon un procédé mis au point par la Compagnie du Bas-Rhône-Languedoc, qui porte sur 1,7 ha environ.

La dose a été d'une fois l'ETP (évapo-transpiration potentielle) en aspersion et a varié entre 0,5 et 2 fois l'ETP en micro-irrigation.

Au début de la seconde campagne d'irrigation, en 1984, deux zones "témoins" ont été implantées; la première campagne portait en effet sur l'ensemble du dispositif pour assurer la reprise des plants installés dont la plupart appartiennent à des essences hygrophiles.

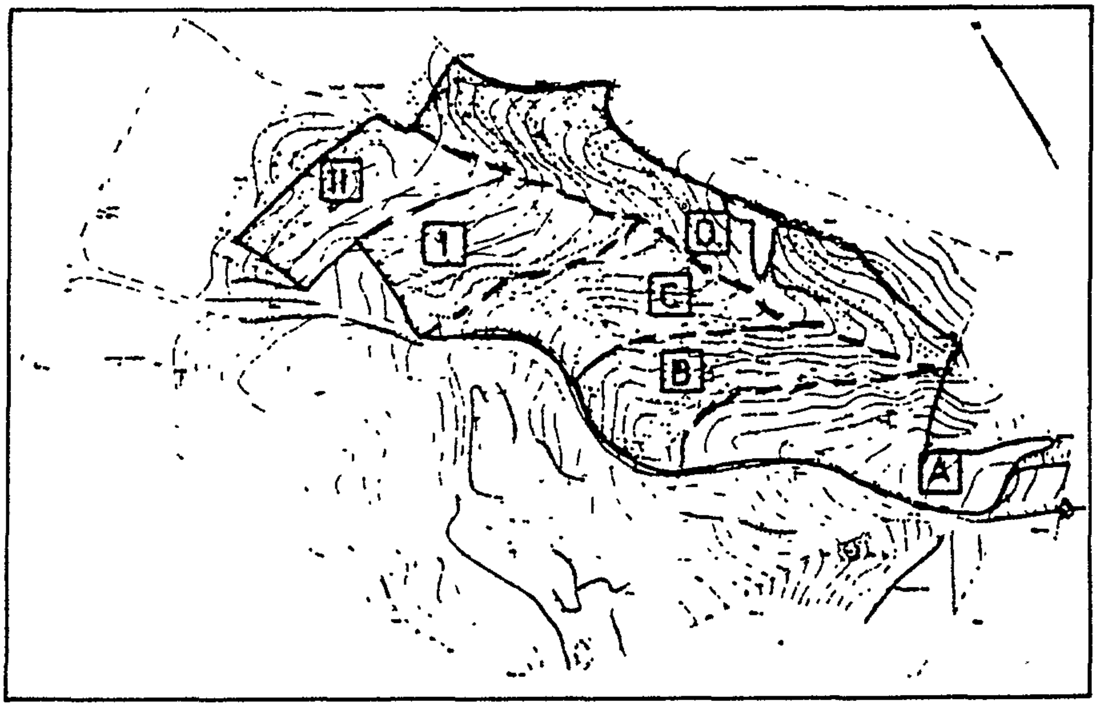


Figure 1: Terrain expérimental - différentes parcelles

3. RESULTATS

Au bout de trois saisons estivales de fonctionnement, l'installation donne toujours satisfaction. Les problèmes de colmatage que l'on redoutait a priori, notamment en micro-irrigation, ne se sont pas posés avec acuité. Néanmoins, il est nécessaire de prendre des précautions très soigneuses lors de l'arrêt hivernal de l'installation: chloration, rinçage et vidange.

- La réaction de tous les végétaux a été très positive, là où les arbres en place formaient les bouquets pré-existants, le couvert s'est fermé et s'est assombri, entravant la reprise de la broussaille du sous-bois. L'effet "pare-feu-arboré" a donc été renforcé. Là où les arbres en place sont clairsemés ou absents, la broussaille ainsi que les rejets de chênes, ont, eux aussi, vigoureusement profité de l'irrigation, surtout en aspersion. La micro-irrigation, privilégiant les arbres plantés, a moins profité à la broussaille.

Les plants irrigués pendant trois ans ont tous beaucoup mieux poussé que les plants témoins qui n'avaient été irrigués que la première année pour faciliter la reprise. La figure 2 indique les croissances toutes espèces confondues, en pourcentage de la hauteur initiale, mesurée mois par mois au cours de l'été 1984. La figure 3 indique les croissances de quelques espèces, année par année.

Deux observations sont à faire.

a) La micro-irrigation donne de bien meilleurs résultats que l'aspersion. L'interprétation de ce fait est que la micro-irrigation favorise surtout les plants, alors que l'aspersion profite aussi à la broussaille qui concurrence les plants;

n) les essences qui réagissent le plus favorablement à l'irrigation sont, en règle générale, les essences les plus hygrophiles, les moins longévives, et celles dont la croissance est la plus rapide, comme, par exemple, le robinier et le saule et, dans une moindre mesure, l'aulne de Corse, le platane, le micocoulier et l'ailante.

Des mesures d'inflammabilité ont été réalisées pendant tout l'été selon la méthode INRA (épiradiateur). Elles ont montré une très forte diminution de l'inflammabilité, à cause de la turgescence constante des végétaux. Toutefois, l'importance de la biomasse de broussaille (surtout en aspersion) laisse subsister un risque d'incendie qui serait important si on ne procédait pas à un débroussaillage annuel. A l'occasion de celui-ci on peut également assurer la maintenance du dispositif. Ce débroussaillage doit être poursuivi jusqu'à ce que le couvert des arbres soit fermé.

L'étude de la qualité des eaux de percolation et de ruissellement, réalisée par la S.C.P., a montré que les eaux de percolation, en toutes saisons, et les eaux de rúissellement en hiver et au printemps n'étaient pas affectées par l'apport d'eaux usées. Par contre, les eaux de ruissellement après les premières pluies orageuses de fin d'été et d'automne ont une charge d'autant plus proche de celle de l'effluent de la station que l'épisode pluvieux est important et qu'il suit de près la période d'irrigation. Cette charge accrue n'a cependant qu'un impact polluant réduit puisqu'elle intervient au moment où le régime hydrique permet une meilleure dilution. La qualité des eaux s'améliore ensuite progressivement.

La suivi de l'évolution physico-chimique des sols montre une amélioration sensible: augmentation du pH, de la capacité totale d'échange et de la teneur en phosphore total; diminution des teneurs en carbone et azote.

Au point de vue bactériologique, la concentration bactérienne dans les sols augmente parallèlement à la dose d'irrigation. On n'a pas retrouvé de germes pathogènes dans les sols et le phénomène d'accumulation de la charge polluante d'une saison d'irrigation à l'autre ne se produit pas. On n'a pas trouvé non plus de contamination bactérienne dans les aérosols au-dessus des parcelles avoisinant les zones en aspersion.

Bien qu'aucunes observations quantitatives n'aient pu les concerner, les mauvaises odeurs ne sont que légèrement perceptibles lors de l'irrigation par aspersion, qui n'intervient que la nuit; elles sont d'autre part absentes des zones où la micro-irrigation est pratiquée.

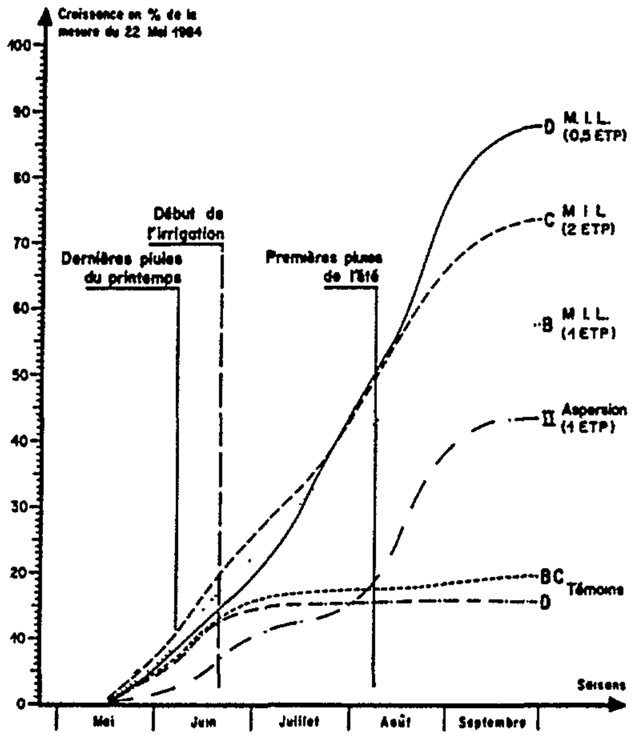
S'agissant d'une installation expérimentale, on n'a pas jugé les coûts assez significatifs pour réaliser une étude économique.

4. CONCLUSIONS

L'irrigation de la forêt méditerranéenne avec des eaux usées peut contribuer à la résolution de deux graves problèmes, en diminuant la pollution des eaux douces ou marines due aux effluents de station d'épuration (problème particulièrement aigu en été où coïncident maximum de population et étiage des cours d'eaux), et en favorisant la croissance rapide d'arbres pré-existants ou plantés: ceux-ci atteignent plus rapidement le stade où leur couvert est suffisamment élevé et sombre pour constituer un pare-feu arboré non combustible.

La technique la plus recommandable est celle de la micro-irrigation (localisée), moyennant le respect de certaines précautions: filtration de l'effluent, chloration périodique, vidange soigneuse, en hiver, débroussaillage jusqu'à ce que le couvert des arbres soit fermé.

Après le succès de cette installation pilote, il serait très souhaitable d'entreprendre des réalisations en vraie grandeur, surtout si, après avoir démontré les possibilités d'irrigation avec des eaux déjà traitées, on arrive - et le projet est déjà lancé par la D.D.A.F. du Var - à obtenir des résultats aussi positifs avec les eaux brutes dégrillées et filtrées. On pourrait alors proposer aux collectivités préoccupées des pointes de débit estivales qui "débordent" leurs stations d'épuration, d'écrêter ces pointes en les envoyant directement valoriser les forêts environnantes, économisant ainsi la construction d'une nouvelle station.



N.B.: M.I. = Micro-Irrigation (localisée). Les zones A (M.I.L) et I (aspersion) ne sont pas prises en compte ici.

Figure 2: Evolution de la croissance des arbres au cours de la saison d'expérimentation (toutes essences confondues)

Années	0=82	1=83	2=84	3=85
Parcelles	Doses d'irrigation			
T	0	1 ETP	0	0
B	0	0,5 ETP	1 ETP	0,5 ETP
C	0	2 ETP	2 ETP	1 ETP
D	0	1 ETP	0,5 ETP	0,5 ETP

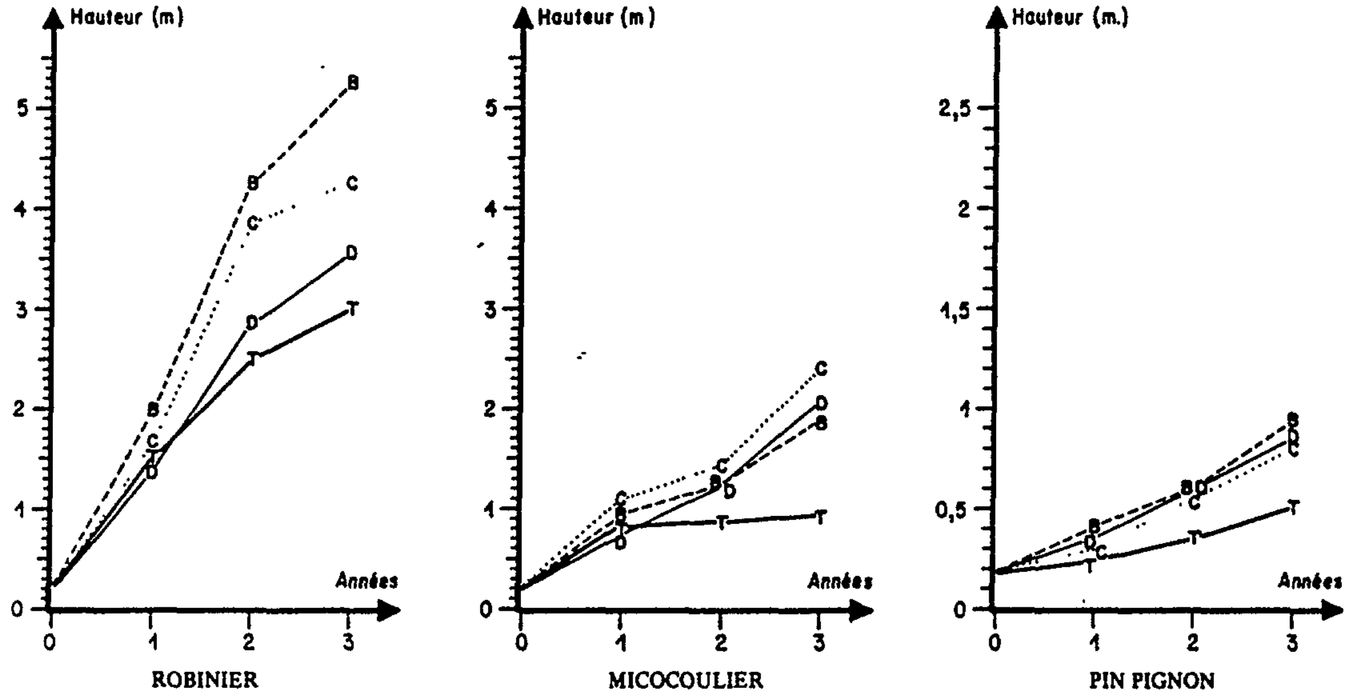


Figure 3: Croissance de quelques essences

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