UNEP Environmental Management Guidelines, No. 8

ENVIRONMENTAL GUIDELINES FOR

The restoration and rehabilitation of land and soils after mining activities

UNITED NATIONS ENVIRONMENT PROGRAMME

THE RESTORATION AND REHABILITATION OF LAND AND SOILS AFTER MINING ACTIVITIES

Environmental Management Guidelines

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THE RESTORATION AND REHABILITATION OF LAND AND SOILS AFTER MINING ACTIVITIES

Prepared by UNEP in consultation with
FAO, UNESCO, ISSS and other UN
specialized agencies

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FOREWORD

It has been our concern, shared by other bodies and agencies within and outside the UN family, that development projects and programmes should take due account of basic environmental parameters and constraints. It is, indeed, clear that broad-based sustained development is not feasible, especially in the long-term perspective, without sound environmental assessment at the inception.

To assist in disseminating widely the knowledge which has been accumulated on several aspects of environmental management, UNEP has initiated a series of publications called UNEP Environmental Management Guidelines. Six such guidelines were published in 1982. The next three publications in the series deal with soil and land issues, one of the most critical resource bases for sustained development. They result from the close co-operative undertakings with FAO (Food and Agriculture Organization), UNESCO (United Nations Educational, Scientific and Cultural Organization) and ISSS (International Soil Science Society), fortified by a series of meetings of high-level experts and reviewers.

As in the case of the earlier publications, the guidelines for remedial or preventive measures which have been presented in these studies are meant to be illustrative rather than exhaustive in character. They are not substitutes for local experience, foresight and prudence, which are the only sure shields to assured national environmental management policies.

I sincerely hope that the present set of guidelines will meet practical needs, particularly in developing countries. Additional sectors will be examined and further guidelines prepared in collaboration with the United Nations specialized agencies, UNDP and other multilateral and bilateral development financing institutions, taking fully into consideration comments and advice which we expect to receive regarding the current guidelines series.

Mostafa K. Tolba
Executive Director

PREFACE

These "Guidelines for the restoration and rehabilitation of land and soils after mining activities" result from a co-operative activity of UNEP and the Research Institute on Environmental Development, Warsaw, of the Government of the Polish People's Republic, under FP 1106-76-02. They aim at assisting Governments of UN member countries to deal at the national level with technical, institutional and legislative policies essential for land and soil restoration and rehabilitation after mining activities, an important source of loss of productive soil cover. They are the second in a set of three guidelines on soil and land issues, following the guidelines that explore various facets of an integrated national soils policy.

We acknowledge with gratitude the contributions received from the experts meetings on the subject in Katowice 1976 and Warsaw 1980, from the director and his staff of the Research Institute of Environmental Development, Warsaw, Polish People's Republic, and from FAO and the UN Department of Economic and Social Affairs.

Within UNEP, Mr. I.P. Garbouchev, Senior Programme Officer (Soils), had the major brunt of assembling the papers and acting in liaison with the specialized agencies of the United Nations. Several experts and consultants, acting in their personal capacities, have reviewed various stages of these guidelines and gratitude is expressed for their assistance.

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Director
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INTRODUCTION

These are general guidelines for the protection and reclamation of mining areas. They are applicable irrespective of global location and prevalent socio-economic relations. They cover:

- the forms of environmental degradation caused by open cast and underground mining as well as by mineral processing;
- recommendations for reclamation of soils disturbed by mining;
- guidelines for investigating and documenting geological, hydrological, soil, vegetation, meteorological, economic and social conditions;
- the need to create technical and social conditions conducive to reclamation;
- planning and designing of reclamation efforts;
- legal, administrative and financial aspects of reclamation;
- training of specialized personnel.

These guidelines are directed to *government administration at various levels, mining companies, environmental protection services, social and political organizations as well as research bodies acting in the field of environment protection and rational management of environmental resources.*

Mining supplies raw materials necessary for the survival and socio-economic development of nations. Mining is only feasible, however, on areas with sufficient mineral deposits. Hence there are frequent confrontations between mining and traditional forms of land use. It happens often in the areas of agriculture and foresty as well as urban habitat and industry. Extraction of natural resources is unavoidable but all means of preventing environment degradation and for restoration of soils and vegetation should be used on the areas disturbed by mining.

If national legislation does not require use of reclamation measures, it should be subject to verification on the basis of positive experience of other countries.

If techno-economic conditions at the time of mining do not allow full extraction of raw materials, dumps containing small quantities of minerals should be formed and reclaimed in order to recover the remaining resources at a later date using improved technology.

Selective storage of the overburden, ores and processing wastes can be properly carried out following a thorough examination of geological conditions and other related techno-economic aspects of the site.

A survey should also be used to determine the possibilities of selective soil removal and storage for soil restoration at each mining site.

LAND DEGRADATION EFFECTED BY MINING

Mining changes the geological structure, relief, water relations, local climate, landscape and disturbs the soil and destroys vegetation as well. Direct disturbance occurs relatively quickly; however, the zone of influence outside the direct mining area is also considerable.

Direct degradation occurs on old mine workings, on overburden and waste dumps and on sites used for building development associated with mining where soils and vegetation have been destroyed.

Indirect degradation occurs on areas of subsidence pits and adjacent to:

- old mine workings;
- overburden and waste dumps;
- mine building and processing works where detrimental changes in soil structure, relief, water relations, chemical properties, soil and vegetation, atmospheric purity, local climate and human and animal health are observed.

Surface mining

This kind of deposit exploitation destroys soil and vegetation and disturbs areas where ore deposits, waste dumps and mine buildings and processing works are situated. Drainage of deposits may lead to aridity surrounding lands. The workings are mostly dry, sometimes partly flooded. In case of rocky minerals and shallow deposits or complete lack of overburden a substantial difficulty appears in shaping the soil and vegetation.

The reclamation of mine lands, during exploitation, requires adequate quantities of soil of suitable quality for shaping relief and stabilizing the site.

The use of shot fire techniques causes "pollution" of an area with rock splinters and as well destroys the geological structure and constitutes a danger to people and fauna. Appropriate danger zones should be defined around such areas.

Open pit mining (open cut mining)

Direct changes in the geological structure, relief and water relations are much more evident here than in the case of surface mining. Here, huge masses of soil are first removed to external dumps, and then later the spoil is moved to internal dumps around the site in further exploitation. As a result of overburden movement beyond the pit, extensive final workings develop and these mostly become flooded. External dumps cover vast areas, thus conflict in the land-use sphere with agriculture and forestry.

Older rock formations stored at dumps are highly resistant to weathering and might contain components toxic to vegetation. The post-extraction workings are especially difficult for re-use because of their depth, steepness of slopes, rockiness of soil, water erosion, flooding, etc.

Indirect degradation results mainly from the drainage of water from aquifers in surrounding areas. Loss of water occurs quickly in wells, with the result that surrounding populations must be provided with an alternative source of water and water must be used with economy in remote areas. Swamps and fish ponds dry out, water in springs and streams disappears and meadows and pastures with shallow groundwater levels dry out.

The magnitude of deleterious impact of the open cut mine pit depends on the geological structures, hydrological features, depth and area of the pit, and existing soil, vegetation and climatic conditions. In extreme cases the area affected varies from several hundred to several thousand square kilometres.

High external dumps considerably disturb water, soil and vegetation in their activity. The magnitude of this deleterious impact depends mainly on the carrying capacity of soil, technical parameters of a dump adjusted to the relief and the way of its exploitation and reclamation.

The end of deposit exploitation shall initiate the restoration of underground waters, land soil, and vegetation and ecological and economic functions as well.

Underground mining

Direct changes of underground mining areas are caused by extraction and processing plants as well as waste dumps and tailings. The biggest disturbance of relief, water relations, ecological and economic conditions appears in subsidence pits which are a feature of some underground workings.

Vertical and horizontal movement of rocks to the extent of some dozen metres can occur and cause flooding or drainage of soil. This substantially diminishes the land-use value, eventually making the affected area completely unfit for reclamation. Soil subsidence poses dangers for all sorts of buildings and surface and underground installations.

Mineral processing

Mineral processing plants are always accompanied by waste dumps and tailings dams. The direct and indirect forms of land degradation which result from solid waste dumps are discussed above.

Liquid wastes are stored in tailings dams which require building of sedimentation ponds. Storage of liquid processing wastes often causes changes in water relations and salination and may be responsible for flooding of agricultural toxic metals or with chemical residues used in processing mine ore. Especially noxious and dangerous are overfull sedimentation ponds, the deleterious influence of which is intensified by hydrostatic pressure; they directly threaten the environment with the hazard of wall failure.

Sludge is hard to reclaim because of difficulties involved in drainage combined with the usual high content of salt and other substances toxic to vegetation and its tendency towards cementation.

CLASSIFICATION OF TERRAIN AFTER MINING ACTIVITIES REQUIRING RECLAMATION

This classification is presented in the table. It comprises:

- the ways of extraction of minerals;
- the forms of land degradation associated with mining;
- forms of post-mining workings and wastes dumps;
- requirements to the land and soils reclamation and rehabilitation;
- water relations.

OBJECTIVES IN RECLAMATION OF AREAS DEGRADED BY MINING ACTIVITIES

The main goal of reclamation is to return affected areas as near as possible to their economic and ecological value. It does not aim to return them to the original state.

Shallow workings, when filled with water, may be adapted for fish breeding; deeper ones may be used for recreation as well as for water detention reservoirs. Very deep workings with steep slopes may be used as water detention structures only.

Such water-orientated reclamation of mined and subsidence pits is particularly desirable near industrial and urban developments. Rock dumps and tailings dams as well as dry workings and subsidence pits may also be reclaimed for agriculture and forestry. Such areas are rarely used for industrial and recreational building and housing estates.

The agricultural development of reclaimed land requires proper shaping of the land to develop acceptable relief and soil water relations, restoration of the soil, productivity, strengthening of slopes, building of road networks, etc.

Forestry is planned more on lands and soils which are poor in nutrients and highly permeable. On toxic and thermally active soils agriculture should be preferred since placing 100 to 150 cm of fertile soil material allows revegetation by grasses and crops but not by trees.

Some mined areas may also be reclaimed for housing estates, sporting grounds, urban green areas, etc.

Where repeated extraction operations are envisaged or an area is to be reworked, mining restoration cannot proceed to the fullest degree due to investment of capital, temporary reclamation methods and so on.

PRELIMINARY INVESTIGATIONS

Mapping

Mapping is used to delineate areas of direct and indirect environmental degradation.

Geodetic mapping should consider the relief and location of surface, underground, natural and artificial features. Use of remote sensing for planning as well as for inventory is recommended.

The scale of maps should depend on the area of the land involved and the type of mining activity. For general planning, scales from 1:5,000 to 1:25,000 are recommended; for detailed planning scales of 1:5,000 and below. Contour intervals should depict the topographic relief. It is recommended that contour intervals 5 plus 1m. be used. Where earthworks are envisaged it may be necessary to use 0.5 plus 0.25 m intervals with supplementary measurements/cross-sections, etc.

Apart from the above general maps, it may be necessary to prepare special maps.

Geological investigations

These investigations should cover all strata which may influence reclamation, particularly:

- overburden formations including soil, with the area of extended open-cast extraction;
- soil formations with surface foreseen under overburden and wastes dumps within the direct degradation zone;
- gangue layers and lenses within the ore deposit;
- actual mineral ore together with gangue inserts;
- in the case of open cast mining, the layers for surface formation at intervals of 1-15 m.

Samples are collected from drill cores and bore-holes for all different lithological layers.

Field and laboratory experiments of soil should create a basis for:

- estimating the likely toxicity of a formation (compare with section on treatment of infertile and toxic materials, below);
- an estimation of the basic nutrient requirements for vegetation,
- an inventory of material usable for land reclamation;
- an inventory of material usable for soil restoration (recultivation).

Geological information should show the physical structure of formations that are fit and unfit for use in reclamation as well as form a basis for determining the amounts and quality of waste material together with the forecast of the likely result of weathering on dumps and tailings.

Geological research should also define geomechanical properties of formations for use in calculating the stability of dumps and to assess the possibility of use of the reclaimed land for building purposes.

Hydrological investigations

Hydrological information should include details of total surface area of rivers, lakes, etc., and the extent of underground waters, details of rainfall infiltration ratės and chemical properties. Prediction of quantitative and qualitative changes in surface and underground waters should be prepared for given conditions of exploitation and dumping of overburden and wastes.

For areas subject to direct and indirect degradation the following studies should be carried out: filtration parameters, directions and rate of flow of underground waters, elements of balance underground and surface waters.

The prediction also covers the range of:

– depression of ground waters as a result of drainage of aquifers;
– flooding of lands caused by dumps and tailings;
– pollution of surface and underground waters.

Assessment of the impact of hydrological changes on agriculture and forestry as well as other forms of land use is an important objective of these investigations.

Meteorological and climatological investigations

In order to plan reclamation it is essential to collect data on climate (including local microclimate) from the records of meteorological stations. Standard data like temperature, insolation, evaporation, cloudiness, air humidity, wind distribution and intensity have to be collected for a long-term period. If there are no data available for a specific area one should refer to reliable standard data prepared by the World Meteorological Organization. It is necessary to define whether the mining operations might induce changes in existing microclimate, e.g. influence on lakes, forests, special plantations, etc.

Soil survey

Soil surveys provide details of the characteristics of the different types of soils in the area, detailed descriptions and laboratory analyses of representative soil profiles, soil capability data, and an assessment of the availability of topsoil and subsoil layers fit for use in reclamation. Within the indirect degradation zone it is necessary to determine all physical and water soil properties required.

Mapping is performed as described in that section above. Here special attention should be given to the quality and quantity of soil material available and needed for soil restoration and rehabilitation.

Collection of biodata

The following aspects should be considered when describing the vegetation: list of planned species, character of ecosystems and land use. The results of research should be presented on maps as in the section above.

Special attention should be paid to concentrations of protected plants or plants forming habitats for protected fauna. One should also analyse the indirect impacts of causing an over-population by harmful fauna or species containing toxic substances.

For such an inventory a considerable amount of manpower with appropriate expertise is needed. In the absence of this trained manpower students and school children may be employed after proper training.

Land use and infrastructure inventory

An inventory of land use (i.e. arable lands, meadows, pastures, forests, waters, housing estates, industrial areas, barren land, etc.) should be carried out. The value of specific soils should be defined for the areas affected by direct and indirect degradation.

The effects on surface and underground structures should be evaluated so that an estimate can be made of the losses likely to be caused by mining.

Description of mining operations

Excavation methods should be described taking into consideration types of machines and equipment used for extraction, transportation and dumping of overburden and gangue interlayers. Also the methods of mineral processing should be defined including the kind, the amount of flocculants, coagulants, etc., eventually used, along with details of methods of their utilization and waste disposal.

For newly established mines and processing plants and other areas planned for exploitation, the likely operation time-table should be given as well as details of subsidiary equipment, dumps, tailings, etc. Also given should be forecasts of pit development and effects of the scatter of rock splinters and the noxiousness of noise and vibrations.

For existing mining projects the following aspects should be investigated:

- method of land use before commencement of mining activities with an evaluation of the land and a schedule of its use for mining and industrial purposes;
- kind and scale of land changes;
- methods of deposit exploitation, transportation, dumping of overburden and waste, and waste processing and disposal;
- methods of neutralization, deconcentration or selective dumping of radioactive and toxic material to be used;
- data on drainage methods and existing facilities, size of the eventual extraction pit and its impact on land management, flooding and subsidence;
- data on disturbance of the surface and buildings as well as civil engineering projects on subsidence areas and details of preventive measures taken;
- kind, size and state of building and civil engineering projects as well as their function after termination of activity, eventual justification for their dismantling, etc.

Sociological studies

Sociological studies should cover size of population, property aspects, social, religious, political and economic aspects of the region subject to mining investment as well as forecasts of changes effected by mining and consequent reclamation. The aim of the study is to prepare the local population and authorities for changes in the environment and their habit of life. This study should be carried out earlier in developing countries with ancient habits and traditions which may be disturbed by proposed measures. The scope of the study should be adapted to the scale of the planned environment changes.

COMPATABILITY OF RECLAMATION REQUIREMENTS AND MINING OPERATIONS

Reclamation requirements are very important at all stages of mining activity, i.e. planning, designing, construction, exploitation of single mines and mining complexes.

Social aspects

Demographic, political and economic conditions should be considered when locating mines and determining the processes of reclamation.

Attention should be paid to property ownership, cultural objects, etc.

Land-use planning

Dumps, store places, tailings dams, machine assembly grounds, processing plants, administrative and service centres should be located on the areas with lowest value for agriculture, forestry and other land uses. Dumps and tailings should if possible be located in abandoned mine workings in subsidence pits where runoff does not occur and on other waste lands. Highly productive farming and forest lands, sanctuaries, national parks, cultural monuments, etc., ought to be protected.

Adaptation of mining methods and techniques

The mining methods and processing techniques to be used should be thoroughly evaluated to ensure that they have minimal environmental impact and that the affected areas can be reclaimed.

The techniques of mining and mineral processing and overburden and waste-dumping should be such as to minimize degradation of adjacent farming and forest lands.

Mining, transport and dumping machines should be used to shape workings and dumps into geometrical forms favourable to reclamation with minimal input of additional earth works.

Dumps of potentially flammable material should be built so that the danger of self-ignition is eliminated.

Toxic materials should be neutralized before dumping and the subsoil should be specially prepared in order to protect underground waters and the environment generally against pollution. Neutralizers should not impede reclamation. Waste dumping in water reservoirs may be allowed provided the water be protected against noxious substances. Here local regulations may be very rigorous.

Waste dumping should be carried out so that the material can be used in future if required as secondary raw materials. Overburden stripping techniques and techniques for removing gangue interlayers should allow for separation of the different materials including soil for reclamation and for selective transportation and dumping of the different materials. Dump drainage should be designed in order to protect surface waters from pollution by substances suspended or dissolved in mine waters. Maximum use of mine waters should be made for reclamation, irrigation and other economic purposes where the water is suitable.

Conical dumping is pointless in view of the instability of slopes and reclamation constraints.

PLANNING OF RECLAMATION OPERATIONS

Preliminary planning

Reclamation should be planned concurrently with the plan of overall mining activity. The preliminary aim is to define reclamation techniques to be used for chosen areas (compare section 4) to define the method of approach to the problem and to organize financing of reclamation operations. Reclamation should be based on reseach result derived from the investigations referred to in the Preliminary Investigations section. The preliminary plan also determines the scope of further investigations required for detailed planning of reclamation.

Preliminary reclamation plans should be discussed and agreement reached with local authorities, institutions and persons directly concerned and especially with users of respective areas.

Detailed planning

A detailed plan refers to particular aspects or periods (1-2 years) defined in the preliminary plans and includes detailed data relating to individual aspects which have been investigated according to the Preliminary Investigations section.

The basic elements of the plan are as follows:

- definition of acceptable reclamation techniques and the scope of reclamation operations at particular development periods;
- quantitative and qualitative studies of soils and other topsoil layers needing protection, assessment of means of winning those

layers, transportation of the material and its location in final or temporary dumps;
- storing fertile soil in such a way as to minimize its depreciation in value for reclamation;
- methods of shaping slopes and top-layers of dumps and tailings damps as well as the slopes of mined areas;
- techno-biological strengthening of slopes of workings and dumps;
- methods of soil restoration on reclaimed lands;
- methods of regulating water relations within dumps, workings and the indirect degradation zones;
- ways of and the time schedule for filling the workings with water, forecast of water properties, ways of preventing water pollution;
- programme of building, modernization or reconstruction of access roads;
- programme of building of other facilities to allow the use of reclaimed lands;
- methods of introduction of pioneer vegetation and selection of species, forecast of their influence;
- ways of rehabilitation of soils of storage areas after the topsoil is used;
- ways of reclamation of overburden and wastes dumps;
- calculation of operations costs and estimation of reclamation effectiveness;
- funding reclamation costs;
- examination of ways of transformation, sale and distribution of reclaimed lands to future users;
- recommendations for users of reclaimed lands;
- schedule of reclamation operations.

RECOMMENDATIONS FOR RECLAMATION

Surface mining

Stockpiling of topsoil, subsoil and valuable portions of overburden

Valuable portions of soil necessary for reclamation can be obtained through:
- removal of topsoil and peat from land planned for mining and other forms of technical development;

— removal of subsoil fit for future restoration at a mined site or for restoration at adjacent areas.

Some overburden layers are very useful for land and soil restoration.

These layers should be stored on top of dumps or used to cover toxic wastes dumps.

The basic mining methods used should create prerequisites for selective excavation and deposition of valuable overburden layers. Hydraulic methods of extraction do not allow selective extraction of valuable soil layers, so special technology should be introduced for land and soil rehabilitation.

In the long run, storing of topsoil and peat for future reclamation requires their protection against degradation and, in the case of peat, against fire as well.

Shaping of dumps and workings

When forming dumps it is necessary to observe the following points:

— use non-productive sites, toxic and rubble formations deep inside the dump;
— appropriately seal off toxic and radioactive dumps at the base in order to protect surface and ground waters against pollution;
— protect potentially flammable dumps against arson or self-ignition.

Top layers of dumps and the batters of exhausted mine workings should be shaped so that the slope permits gravitational drainage of water while at the same time providing protection against water erosion (the minimal slope of batters should be 1 per cent on dumps and 0.05 per cent on natural ground). Because of the danger of erosion and land slip it is necessary to adequately shape the batters of dumps and workings.

Shaping of particular batters should be based on stability calculations taking into account geotechnical and water conditions. However the steepness of slopes should not exceed 40 per cent in case of monolithic and rubble formation and 30 per cent in the case of sandy and fine-grained ones. Where agricultural use is to be made of the batters the slope should not exceed 15 per cent. Batters higher than 10 m should have benches every 6-10 m vertical interval. These should be parallel to contour lines with a slope of 5-10 per cent towards the dump. The objective of those benches is to intercept rainwater and the material eroded from the slopes. In high rainfall areas the vertical interval between benches should be smaller and the benches themselves wider (e.g. 6-10 m). Around the perimeter of the upper edge of the top layer of the dump it is necessary to build a ridge 5-6 m wide and 0.5 m high with slope towards the centre of the dump (or construct drainage ditches) to intercept the flow of surface water down the batters. At the foot of the batter one should form silt traps to intercept the material eroded by water before revegetation is established.

The degree of slope of the batters of workings for flooding should be such as ensure their permanent stability both during the filling of workings and later during the use of the water reservoir. An adequate grade on underwater slopes is about 5 per cent in loose material. If during the mining activity permeable layers are encountered which will possibly reduce the use value of water stored in the working, proper precautions should be taken during shaping of the mine batters to isolate these layers and prevent loss of water through them.

During hydraulic and underwater exploitation the underwater batter must also be stable.

Covering the surface of dumps, fills, workings and slopes with protective soil layers

The thickness of the covering topsoil layer depends on the properties of the soil used in reclamation and the projected land use after reclamation. The biologically active layer of reclaimed soil should at least be 80-120 cm thick for farming lands and 120-200 cm thick for trees.

When the reclaimed ground is toxic and cannot be neutralized it should then be covered with a layer of soil. If the ground is not toxic but infertile, reclamation for forest purposes does not require placing such a thick layer as mentioned above. However, for agricultural purposes it is advisable to develop a soil rich in nutrients and with a high water-holding capacity.

Topsoil can be placed in 25-40 cm thick layers on well-levelled and stabilized ground surfaces.

When drainage of surfaces covered with fertile soil is necessary, drainage facilities (ditches) should be constructed in such a way that the toxic layers remain fully covered. It would be more favourable to construct drainage structures in fertile layers (for clean waters) or toxic layers (for polluted waters).

Water management

Water management of reclaimed land consists most of:
- draining of excess rainwater with a system of ditches and drains;
- increasing water retention through improvement of the physical and water soil properties;
- introduction of erosion control measures to limit surface flows;
- regulating of ground-water level on land where flow has been impeded by dumps across valleys and watercourses;
- control of waste runoff combined with eventual treatment;
- restoration of watercourses following mining operations;
- purification of surface and underground waters where they have been in contact with toxic soils and are to be introduced into surface watercourses or ground waters;
- construction of proper entry points for waters used to fill mined site areas (workings, subsidence pits) and for regeneration of waters in drained areas.

Introduction of particular water management for clean and polluted waters is needed.

Road construction

On areas being reclaimed it is necessary to:
- reconstruct main roads destroyed or cut temporarily during mining operations and repair roads destroyed by mining and ore transport operations;
- construct access roads to link reclaimed lands and the existing road network.

Filling of old workings

Workings may be filled with waste from other mines, ashes and other wastes, which will be harmless in an underground environment.

These workings are often used for storing municipal waste but in such cases their potential for pollution of ground water should be considered. Sealing the bottom with neutralizing chemicals or mixtures of different wastes may prevent such problems.

Where abandoned mines are used for water storage the supply may come from underground or from the surface. Shallow reservoirs (to 5 m water depth) filled with non-toxic oligotropic flow water are useful for fish and recreation. Deep reservoirs can be used for collecting water for industrial and community purposes. The mine base and batters require proper treatment where toxic materials outcrop to prevent water contamination from these layers.

In order to control the water inflow and runoff it is necessary to use relevant protective materials. The batter surfaces, especially those near and above water level, require protection from wave action.

Treatment of infertile and toxic materials

The following soils, among others, may be regarded as toxic. Those with:

a) excess acid reaction (pH in KC below 4.5);
b) excess alkaline reaction (pH over 8.0);
c) salinity—caused by water-soluble sodium chlorides, sodium or magnesium sulphates—over 1 g/dm^3 of soil expressed in NaCl;
d) sulphates (in absence of $CaCO_3$ in soils), i.e., the content of native sulphur or sulphides is higher than:
- 0.01 per cent in loose sands,
- 0.03 per cent in clayey sands and sandstones,
- 0.08 per cent in clay, silt and clay slates.

If $CaCO_3$ appears in soils, the above given values rise by 0.1 per cent per each 0.5 per cent of $CaCO_3$. In the case of organic substances, those values should be reduced so that, e.g. 2 per cent of those substances reduces the sulphur value by 50 per cent; the given values are expressed in pure sulphur;

e) hydrolytic acidity is higher than:
- 1 mval/100 g in loose sands,
- 2 mval/100 g in clayey sands,
- 4 mval/100 g in clay and silt;

f) — water-soluble boron content is higher than:
- 5 ppm in sand formations,
- 10 ppm in clay and silt;

g) content of toxic trace elements (Cu, Pb, As, Zn, Mg, Se, Sr, Cd, Co, Mo, etc.) is at least twofold higher than maximal values in adjacent non-degraded arable or forest soils;
h) the content of colloidal silt (fractions below 0.002 mm) is higher than 40 per cent;

i) aeration may cause thermal build up or self-ignition;
j) ionizing radiation is twice that in non-degraded adjacent arable or forest soils;
k) pollutants exceed admissible pollution standards for potable, industrial, irrigation and fish water—according to the standards for water reservoirs and local conditions.

Material which is toxic to vegetation should be neutralized (or isolated where there is a lack of fertile soil), i.e. deleterious substances should be neutralized or decomposed. Material with excess acidity should be neutralized by using alkaline substances (e.g ashes, basic communal and industrial wastes, lime). Alkaline materials should be fertilized with acid substances (acid peat, reeds, tree leaves and conifer needles, coppers, aluminium sulphate, gypsum, phosphoric acid) to achieve a suitable soil pH level. Water soluble salts may be removed by leaching and cultivation of salt-tolerant and salt-absorbing plants. Radioactivity may be neutralized by use of boron compounds.

Infertile material with low water- and mineral-holding capacity may be improved through use of silt and humus, while cemented or very clayey soils may be improved by adding sand and humus.

Stimulating biological activity

Newly shaped and topsoiled areas should be protected against water and wind erosion through immediate establishment of vegetation cover.

On areas reclaimed for agriculture, soil-building and deep-rooting vegetation should be established to initiate the soil-improving process. In selecting vegetation to improve soil productivity it is necessary to consider soil properties and microclimate conditions. In the first years of cultivation soil-forming plants should be used, but in later years crops should be chosen on the basis of economic considerations.

In a temperate humid climate the following plants may be regarded as pioneer species: grasses and small-seed legumes; meliot *(Melitotus albus)*; alfalfa *(Medicago sativa, M. falcata, M. media)*; annual lupin *(Lupinus lutens, L. angustifolius, L. albus)*; perennial lupin *(Lupinus poliphyllus)*, bird's-foot trefoil *(Lotus corniculatus)*, sainfoin *(Onobrychis viciaefolia)*, health-hen *(Coronilla varia)*, as well as other fodder plants.

On lands to be reclaimed as forests where there is insufficient soil available it is necessary to plant species of trees and shrubs which are tolerant of a wide range of conditions: grey and black alder (*Alnus incana* and *A. glutinosa)*, willow *(Populus nigra, P. alba, P. tremula)*, oleaster *(Eleagnus angustifolia)*, seabuckthorn *(Hippophae rhamnoides)*, tamarisk *(Tamarix gallica)*, birch *(Betula* sp. or *B. verrucosa)*. The decision on whether or not to plant pioneer types of trees and shrubs or those of economic importance depends on soil properties and methods of soil restoration. Often pioneer types will be used on sloping areas.

Where careful restoration of soil has been carried out using organic and mineral fertilizers and attention has been paid to soil water-holding capacity the range of cultivable plants, trees and bushes that can be used is wide and there is less effect from the infertile or possibly toxic fill material.

Agriculture and forestry

Until sufficient soil fertility has been achieved agricultural production must be subsidized from reclamation funds.

Proper selection of plan species and crop production techniques is very important in achieving success in reclamation, especially in the preliminary stages. Mineral fertilizer rates for crops should be much higher than on normal soils under similar natural and economic conditions. The quality of plant and animal products from reclaimed soils should be checked, especially those produced on soils containing excess amounts of heavy metals and radionucleides.

Other land uses

Depending on local conditions and available technology, abandoned mines areas may be used as recreation and sporting grounds, for community and industrial waste dumping grounds, etc.

Open pit mining

Deep workings as usually cannot be filled during mining activities. They may be used for storing other wastes, but care should be taken to ensure that contamination to underground and surface waters does not occur.

In order to prevent access to deep workings which cannot be reclaimed for agriculture and other purposes it is recommended that trees and bushes be planted on benches and accessible slopes. Lower parts of slopes and roads should be protected against stone slides (during weathering and washing through precipitation waters) by building fences, belts of bushes along the slopes, etc. Upper edges of steep slopes should be planted with thorn bushes or fenced to prevent accidents.

Underground mining

Shaping of waste dumps

Wastes from mining and mineral processing should be analysed to establish their chemical content and physical properties (see Geological Investigations section). It is necessary to define changes in properties of dumped material as a result of weathering and erosion. It is especially important to determine the contents of toxic, radioactive and combustible susbtances.

It is necessary then, after taking due regard of the concentration of such substances, to design proper techniques for dumping waste, sealing the dump bottom, locating most toxic products deep in the dump, diluting pollutants, deacidifying, etc. Sealing may be done with shields of foil, silt, ash and lime with some water-glass as well as through strong compaction of the bottom to prevent infiltration and to achieve a filtration factor of ca. 10^{-6} cm/sec. Sealing should also provide protection against ground-water entry by upthrust.

Sealing of the bottom and upper layers should protect surface and underground waters from a contact with toxic substances or from infiltration of polluted waters. Dumping of wastes into the water favours spread of pollutants whereas dumping on a dry, resistant and compact base provides the best protection. Note should also be taken of the methods outlined in the Surface Mining section.

Before decisions are taken on methods of dump reclamation it is necessary to consider possibilities of economic use of the waste material, thereby avoiding the need to establish dumps.

Control of salinity

Water-soluble salt may be produced by weathering of rock in dumps and then leaching by rainwater. These salts may then cause problems with establishing vegetation or may pollute surface or ground water. Factors that affect the weathering and leaching include stability of dumps, sealing and drainage of the base of the dump and the state of compaction or dumped material.

To enable vegetation establishment on the top layers and slopes of dumps it is necessary to desalt upper layers (e.g. through leaching or conversion of easy hydrolizing salts into sparingly soluble ones) as well as to prevent infiltration of saline waters. It might be useful to leach the dump layer with water and then evaporate the saline water in a tailing dam built especially for this purpose.

Control of thermal activity in dumps

Mining wastes that have a high contents of coal (up to 40 per cent) or pyrites (up to 8 per cent) may be subject to thermal processes. Heavy compaction of a dump during its construction (in its respective layers) minimizes the likelihood of combustion of wastes. Compaction reduces the amount of air in the centre of the dump, thus reducing the likelihood of ignition as well as improving stability. Dump layers should be compacted to a filtration factor of $10^{-5}-10^{-6}$ cm/sec.

Control of current weathering

In order to control weathering and leaching of wastes in water it is useful to drain the upper layer of a dump (the depth depends on frost penetration, the type of established vegetation and reclamation techniques and varies between 1.2 m to 2.0 m). Polluted waters are then drained into tailings dams where evaporation and settling take place.

Treatment of infertile and toxic material

Soil restoration and cultivation of plants are handled as in the Surface Mining section.

Selection of plant species

Species and varieties of plants should be selected to suit local soil conditions as well as the purposes of reclamation (see Surface Mining section).

Control of subsidence

In order to reduce the likelihood of subsidence it is recommended that the empty spaces left after mining be filled with materials supplied from outside (sand or other suitable wastes).

Subsidence pits can be filled with water provided there is a waterproof layer between the surface and the base of extracted mineral.

If there is a possibility of drainage of water from subsidence pits by gravitation, it is necessary to construct an adequate network of drains and drain ditches. Larger depressions may be used for dumps, in which case the pits are filled up to the level of adjacent areas.

Tailing ponds

Avoidance of tailing ponds

Tailing ponds for toxic and heavy-metal-containing materials are especially detrimental to the environment. Every effort should be made to avoid storage of liquid waste.

Shape of tailing ponds

Tailing ponds should be designed so that there is a minimal risk of failure and consequent damage to adjacent areas. Tailing ponds of sites high above sea level are particularly dangerous since water seepage can occur through walls and the base and water can be released if the structure overflows or the walls are breached. Tailing ponds should be built with an adequate spillway and drainage system. In case of toxic or radioactive substances it is necessary to ensure proper sealing of the bottom and the walls and to take precautions to purify and neutralize drainage waters.

Treatment of tailing ponds for reclamation

The surface of a tailing pond should be stable and accessible. This situation can be achieved through drainage, coagulation, revegetation, (e.g. cultivation of hyacinth, reed, eucalyptus, etc.). Dry surfaces may be covered with productive soil and utilized appropriately.

Selection of plants

According to the properties of the reclaimed soil and the methods and aims of reclamation either pioneer plants or final species should be cultivated. Biological reclamation, without proper shaping and use of an outside layer of topsoil, requires many years of cultivating pioneer plants (mainly grasses and legumes).

Social impact

All reclamation schemes should be assessed from the social impact point of view. Also environmental control should be carried out to monitor the possible changes which might occur.

LEGISLATION

Environmental protection and, *inter alia*, reclamation of land degradation by mining should be regulated by law in all countries. Such legislation should encourage integration of industrial growth and environmental protection (including reclamation).

In the formulation of acts of parliaments, national and local aspects as well as already existing international conventions and other related acts and agreements should be taken into account.

ADMINISTRATION AND SUPERVISION

The enforcement of appropriate legislation, along with the introduction of the recommendations presented in these guidelines, requires suitable administrative organization. Administrative, supervisory and executive services should ensure that reclamation requirements are observed at all stages of programming, designing and implementation of mining projects.

Reclamation projects should be designed by properly trained staff and should be accepted by local administrative authorities before implementation. Control of implementation of a project in pursuance of the plan accepted by local authorities should be placed in the hands of competent bodies. The offices which will be entrusted with the control of reclamation will depend on the administrative structure of a given country. A system of government control may be necessary to ensure that reclamation is carried out.

EDUCATIONAL AND PROFESSIONAL TRAINING

Planning and implementation of reclamation programmes require specially trained personnel. Education and training should take place at three levels: basic (higher) level, secondary level and technical level. The trained staff is essential for planning, designing and managing of reclamation as well as for review and control of reclamation projects.

In addition a suitable extension programme is needed through the mass media to promote awareness of reclamation problems in the society throughout the country.

There should be an awareness of the administrative and technical problems associated with reclamation amongst geologists; hydrogeologists; miners; geodesists; town planners; technologists; those concerned with water, soil, flora, fauna; farmers; foresters; and those concerned with air pollution control. This can be achieved through the introduction of relevant disciplines into educational programmes of technical secondary schools, universities and post-graduate studies institutions.

FINANCING

When planning mining investment it is essential to allow funds for reclamation. These might be funds deposited by an enterprise in a separate controlled bank account. They might accrue *inter alia* from taxation of each extracted mineral unit or product and might be transferred to the proper authority for reclamation purposes if a suitable reclamation programme is not implemented by the mining company.

It is desirable to create a strong executive body for supervising the observance of the quantity, quality and rate of completion of reclamation works. Such a body should be equipped with adequate financial resources.

Table. **Classification of mining areas requiring reclamation**

Type of degradation	Form of degradation	Land as soil factor	Relative height/ depth	Water relation
Direct	external dump	toxic	high	dry
		infertile	medium	humid
		rubble	low	
		potentially good	sloping	
		good		
	internal dump	toxic	high	dry
		infertile	medium	humid
		rubble	low	flooded
		potentially good	below gravitation drainage	
		good		
	abandoned mines	toxic		
		infertile	shallow	dry
		rubble	medium deep	humid
		potentially good		flooded
		good		
		flooded		
	top soil dumps	potentially good	medium	dry
		good	low	humid
	technical building			
Indirect (zone)	protection belts	soil	non-levelled	dry
		toxic	levelled	humid
		potentially good		
		good		
	extraction pits	soil	dry	
		infertile	humid	
		potentially good		
		good		
	subsidence pits	soil	gravitation drainage	humid
		potentially good		

		good flooded	possible limited	flooded
Indirect	technical building	soil infertile rubble potentially good good		dry humid
	other forms	soil infertile rubble potentially good good		dry humid flooded
Ground mining	technical building	soil infertile rubble potentially good good		dry
	dump	toxic rubble potentially good reaction: acid neutral alkaline thermal action: active non-active burning	high medium low central near mines	dry humid
Indrect (zone)	technical building	soil potentially good good	dry humid	
	protection belts	soil toxic infertile rubble potentially good good	dry humid	

	subsidence pits and uplifts	soil potentially good good	dry humid flooded	
	depression pit	soil potentially good good	dry humid	
Indirect (strip)		as in open cut mining		
Direct	technical building	as in under-ground mining	high	
	solid wastes dumps	as in under-ground mining	low sloping	
	tailing ponds	as in under-ground mining dumps and easy drainage heavy drainable	high low underlevel	wet flooded
Indirect (zone)	protection belts flooding	as in open cut mining		

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