PLANNING AND DESIGN OF INDUSTRIAL WASTE DISPOSALS IN VIEW OF GROUNDWATER PROTECTION

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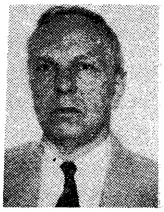


ABSTRACT

The mining and minerals treatment waste disposal in the environmentally acceptable way is a very important problem. These wastes have polluting potential due to content of leachable components which can migrate to aquifers effecting deterioration of groundwater. The paper takes as an example different types of coal wastes and methods of their examination from the viewpoint of disposal. The different types of disposal sites have been presented and their relations to protected aquifers discussed. Recommendations for planning and design of safe disposals have been proposed, as well as planning of groundwater monitoring around disposals sites. An example design of huge disposal (20 mill. m^3 of capacity) with full groundwater protection has been presented at the end.

INTRODUCTION

The disposal of different wastes becomes more and more important problem in many countries, particularly in the countries and regions highly industrialized. One of the factors which must here be taken into consideration is environmental protection. In search of most suitable waste disposal sites the abandoned surface mines, or small valleys often used. Such a solution is very often used for minerals treatment tailing and power plant ash disposal because the preparation plants and power plants are often located in the vicinity of surface mines. However, this apparently rational solutions contains often a great hazard considering that at abandoned open-pits, there is easier for waste to get into contact with groundwater, which should be often protected against pollution.

These problems are encountered sharply in Poland, and particularly at Silesia mining region. In this region , where coal production attains 150 mill. tons per year approx. 80 mill. tons of waste are produced, as well as about 15 mill. tons of ashes and slags from power plants. A portion of this waste is utilized for various purposes but 50 mill. tons of waste and about 10 mill. tons of ashes and slags require to be adequately disposed. These are tremendous masses, whose disposal requires many problems to be solved and also, among other things, the problem of groundwater protection against pollution.

Such a great scale of the problem stimulated a number of research efforts, partly carried-out within common programs with the United States Environmental Protection Agency. This research allowed to find the degree of pollution effect of the waste, i.e. what soluble` components, and in what quantify may pass from waste into the groundwater (1), as well as to provide hydrogeological criteria for the evaluation of disposal sites and recommendations for construction of safe disposals in a structure warranting groundwater protection. Also the research and practice has been done for coal waste, the results and conclusions can be extended to other kinds of mineral and industrial waste.

WASTE CLASSIFICATION AND EXAMINATION

According to observed tests, coal waste can be divided into the following sub-groups:

(i) *Dry waste* material is from quarry operations, associated with the ripping of the floor or roof, the construction of stone drifts, etc., and more rarely from dry mechanical separation. This refuse is characterized with identical mineral and chemical composition, from the sterile rocks accompanying the coal seams, and are usually coarsely grained (gross from 10 to 200 mm). The character of pollutants leached is entirely dependent upon the chemical composition of sterile rocks formations. The quantity of pollutants which may pass into solution is relatively small, because of the small surface contact with the leaching water. This is due to the effect of the rather large size of particles of this refuse and great filtration velocity of water through the material which occurs particularly in the disposal located above the groundwater table.

(ii) *Wet waste* material may be coming from washers using water or heavy fluids and from flotation processes.

The refuse from the water washers is characterized with a granulation from a silty fraction up to a diameter of 80 mm, and their chemical composition is effected by both the sterile rock and the cleaned coal. Moreover the influence on their chemical character has the composition of washing water (i.e. a highly mineralized drainage water). The wide range of grain size provides conditions for both the movement of the water through the stored material, and for large quantities of components to be leached as compared with dry refuse. Moreover some pollutants may also be washed in the form of suspension of silty fractions.

Waste material coming from washers using heavy fluids are characterized by a coarser graining than waste from water washers (i.e. grain size of 20 to 250 mm). Their chemical composition is effected by the character of the sterile rocks and cleaned coal. The chemical composition of the heavy fluids used has a substantial influence during washing. Here the components of the washing medium [illegible]e on the surfaces of refuse particles, and are first washed-out from the [illegible]. Therefore, the chemical character of this fluid should be considered from [illegible] environmental perspective. The coarser granulation of this refuse, in comparison with the preceding, does not provide conditions for the leaching of as large a quantity of [illegible]ants as for water washes because (a) of the relatively smaller contact surface of the refuse particles with the percolating water, and (b) due to the higher velocity [illegible] the rain water percolation through coarser material.

The refuse from flotation is characterized with a [illegible] fine granulation in fractions from silty to 2 mm diameter. Their chemical composition is a function of the coal characteristics, characteristics of accompanying [illegible] formations, and also the chemical substances used as flotation fluids. The [illegible] granulations of these wastes provides conditions for leaching large quantities of [illegible]nts particularly in disposal saturated with water. In case of dry disposal (e.g. a[illegible] groundwater table), a fine granulation of this refuse limits the possibility of [illegible]tration of the rain water through the stored material and may increase the [illegible] evaporation in the disposal's water balance. The composition of the fluids used in flotation process may also have substantial influence on the chemical character [illegible] leachates because some of the fluid's components may settle on the surface of gr[illegible]. The type of fluids used in flotation should therefore also be controlled for potential groundwater pollution.

Laboratory tests of wastes, with respect to their storage, should be carried out considering the conditions of storage. With reference to the above, the [illegible] chemical analyses of waste are not recommended, as this can lead to erroneous conclusions. Only a portion of the waste components can pass into leachate, and only this portion is affecting the quality of groundwater.

With sufficient time and funds, the lysimetric method of waste analyzing is recommended when conducted in columns of a 1 m diameter, and 3-4 m high. These tests may be conducted under full saturation of refuse, if storage below the groundwater table is expected or where the refuse is only temporarily impacted with rain, if disposal above the groundwater table is expected. In the first case the duration of tests has to be defined on the basis of refuse permeability. A duration of 3 to 6 months is recommended. In the second case a duration of at least one year is recommended. The water for the tests in the first case should be taken from the aquifer within which the disposal is planned. In the second case the recommendation is to expose the refuse to the natural rain. [illegible] distilled water to simulate rain is not recommended because the rains in the industrialized [illegible] are generally acidic (pH = 4-5) and containing pollutants.

To obtain fast and approximate results, leaching of the refuse can take place in 10 cm diameter columns about 1 m in height with a filtrating layer in the bottom part. In two weeks approximate results on maximum concentrations of particular components passing to groundwater in optimal conditions can be obtained, and the amount of leachable pollutants per one tone (or m^3) of stored wastes. In interpretation of these results caution is recommended where solubility may be impacted by increased time.

It is recommended that lysimetric tests be performed for planning before commencing storage, and short tests be performed during operations to determine variability of the stored.

In order to plan and design the disposal site, the chemical analyses of leachates should analyze all components and elements to estimate which could be harmful to groundwater quality. The chemical analyses of leachates, obtained in the laboratory process of the stored refuse, may comprise only those elements and compounds which were found harmful during the basic examination. This shortened procedure may be used if the coal and sterile material has approximately uniform characteristics. The analyses of the leachate should determine all related physical-chemical parameters, as one cannot judge beforehand which may be harmful.

Analyses for planning should be completed with a high degree of accuracy to determine not only the potential threat from a given toxic component in groundwater, but also the secondary impact from organisms of plants or animals using these waters. This secondary concentration may be sometimes more harmful.

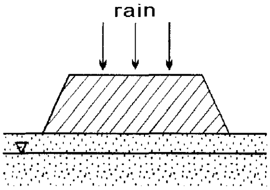
SITE CLASSIFICATION

Classification and evaluation of sites for the storage of waste for groundwater protection, should consider the following criteria:

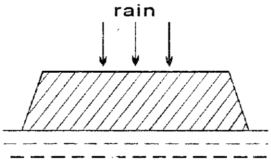
I. The hydrogeological criteria based on reciprocal spatial relations of the disposal and the threatened aquifer is discussed in the following classifications:

A. <u>Over-terrain disposals</u>.

1. On permeable ground

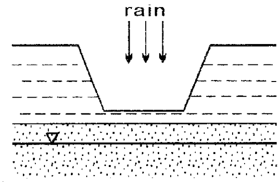


2. On non-permeable ground

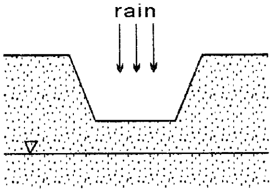


B. "Dry" disposal sites (below terrain level but above the groundwater table exposed to rain precipitation).

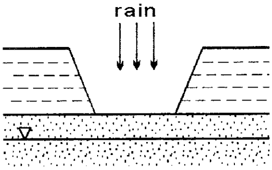
1. Within the impermeable layer (i.e. clay pit)



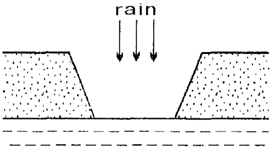
2. Within the permeable layer (i.e. sand pit)



3. Within the unsaturated permeable layer and underlined with unsaturated permeable layer (i.e. clay pit)

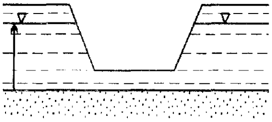


4. Within the unsaturated permeable layer and underlined with impermeable layer (i.e. sand pit)

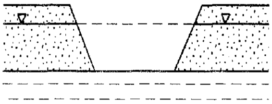


C. <u>"Wet" disposal sites</u> (below terrain level and below the groundwater table).

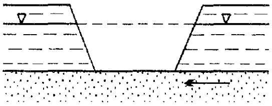
1. Within the impermeable layer underlined with confined aquifer



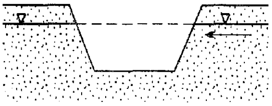
2. Within the permeable layer underlined with impermeable layer



3. Within the impermeable layer directly underlined with confined aquifer

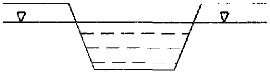


4. Within the permeable layer

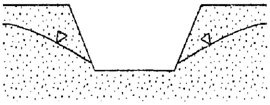


The disposals mentioned in pt. C, 2, 3 and 4 could be:

a) Wastes completely saturated



b) Dry by existing (from the period of open-pit excavation) draining arrangements, i.e., ditches, pumping stations - refuse is stored in dry pit and then is saturated with water



In the first of these two cases, the pollutants pass into water much faster. In the second, there is a much slower rate although the sum of leached out compounds in an extended period will be more or less similar.

II. The hydrogeological criteria based on the relationship between the disposal and aquifer permeability.

A. Disposals with the permeability lower than the surrounding aquifer (mostly disposals of floating refuse).

B. Disposals with permeability higher than the aquifer or a majority of disposals.

C. Disposals with permeability similar to the surrounding aquifer.

III. Criteria for a protected area is recommended to distinguish disposals when:

A. The entire aquifer must be protected.

B. A determined part of the aquifer must be protected or the particular water intakes.

IV. Criteria for positioning the disposal and the protected area:

A. Protected area is situated in the threatened zone posed by groundwater being in direct contact with the disposal (downstream of groundwater).

B. Protected area is situated in the indirect influence zone where pollutants may appear either as very diluted or as a result of dispersion.

C. Protected area is situated within the same aquifer, but outside the hydrodynamic or dispersional influence of disposal (e.g., upstream of groundwater flow).

V. Distinguishing criteria for the degree of groundwater protection:

1st degree - total protection, when the groundwater quality cannot be changed at all,

2nd degree - partial protection, when permissible values cannot be exceeded or water must be protected against increases of determined components (i.e., Cl, SO_4, heavy metals) only

3rd degree - when a given aquifer is not subject to special protection.

PLANNING AND DESIGNING FOR DISPOSAL

Planning .the storage of waste in an open-pit should be preceded by:

- knowledge of the waste characteristics including leachability based on tests described above and the quantity planned for storage over a given time,
- detailed investigation of the hydrogeological conditions of the site and
- required spatial and qualitative protection of the aquifer.

The survey of hydrogeological conditions should include:

- spatial parameters of the aquifer in contact with the disposal (thickness, spreading and hydraulic relations with others),
- permeability and specific yield,

- distribution of a hydrodynamic network of the groundwater hydrostatic heads,
- the original groundwaters' chemical characteristics,
- lithology of aquifer,
- the site slopes and bottom considering permeability,
- climatological conditions, especially the amounts and rainfall distribution.

Parameters of permeability should be determined usings standard field tests (e.g., pumping tests, or water forcing especially in the zone of aeration) or laboratory tests (in filtration columns, and sieve analyses).

Reconstruction of the hydrodynamic net should be performed on the base of surveys of the groundwater table in bore holes, or where possible with use of remote sensing geophysical methods. The thermistor or tracer methods are not recommended for large sites and non-point pollution, since they are less adequate than in the case of particular wells. The mathematical model verification of the hydrodynamic network is recommended since there are better possibilities to adjust to real conditions. The recognition of the hydrodynamic net of the region is one of the most important elements of determination of the disposal's eventual influence on groundwater and should be made with the greatest accuracy. The proper reconstruction of hydrodynamic net and good knowledge of permeability gives possibility of high accuracy of forecasts.

The use of aerial photography is strongly recommended to define the lineaments to delineate potential groundwater carrying pollutants. The pollutants are not transported through the whole section of the aquifer, but through the flumes which could be located only with use of remote sensing methods.

The chemical characteristics of water of a considered aquifer should be determined by analyses of groundwater. Sampling should be done from the points specified based on the previously described investigations at 2-3 month intervals (at least one year prior to storage). This is necessary to determine seasonal or other factors such as influence from an urbanized area.

Knowledge of lithology of the aquifer formations, is necessary for the evaluation of absorption and ion exchange, that can take place between the polluted water and the rock (soil) skeleton.

The requirements of aquifer protection should take into account current and future plans for water use since disposal impacts may exist for several years.

After collecting appropriate data, it is possible to forecast the influence of waste disposal in an open-pit on a selected part of the aquifer, or on the entire aquifer under consideration. Such a forecast may be of qualitative or quantitative character, both in respect to time and the degree of deterioration of the groundwater quality. The forecast may be prepared either using computer methods, or a descriptive computation method. One should realize that there are no all purpose programs which would afford a formulation of all phenomena, in a three dimensional system from the aspect of time and considering different behavior of various ions. The problem is more difficult as the phenomena occurring in the unsaturated zone. One can make approximate forecasts enabling improved decision making. It is possible to obtain more accurate results when the forecasts concerns one pollutant only, e.g., chlorides, or molybdenum, as opposed to polluting components.

The forecast and its conclusions should be followed by recommendations concerning the method of disposal and eventual prevention as needed.

When considering the relationship between the planned disposal site and the protected part of the aquifer the following applies:

- if the protected part of the aquifer is situated upstream of the groundwater flow, a 20-meter protection zone should suffice, since the dispersion influence will not exceed this limit,

- if the protected part of the aquifer is situated in the zone of indirect influence of the disposal, then such disposal can be planned without a protection where the 2nd degree protection requirement applies. However, this is not acceptable when the 1st degree of protection is required,

- if the protected part of aquifer is located in the zone of direct influence of the disposal, i.e. downstream, then this disposal planning cannot be considered without providing protection, unless an appropriate model will indicate that this is permissible.

PLANING MONITORING WELLS AND THE CONTROL PERFORMANCES

Monitoring of the disposal influence on the groundwater quality can be performed through sampling and analyzing water from monitoring wells, or shallow probes, and from natural springs, where possible.

Dependent upon local geological conditions and on requirements of the scope of inspection, there can be 1-3 monitoring pipes arranged in the some boreholes to sample different aquifers or for sampling the different levels of the same aquifer. When more than one pipe is installed within a drilled well, total insulation is required.

When necessary (e.g. in case of aquifers of great thickness) to determine the contents of pollutants in vertical zones, then a single pipe monitoring well suffices for the zonal sampling. This should be used only when high precision is not required.

When disposal is totally insulated from the aquifer, the monitoring should only determine the disposal's isolation. Wells should by spaced along its circumference. The wells' distance from the disposal verge should be not more than 20 m upstream 30 m in the intermediate zone and 50 m downstream in the groundwater. The spacings between the wells should be denser downstream, looser in the intermediate zone and looser upstream. The respective numerical values can be e.g. a ratio of 1:3:5. Locating particular wells should be based on the analysis of effected sealing and on the hydrodynamic water heads' distribution.

Location of monitoring wells, where disposal will impact groundwater quality, should consider:

- the hydrodynamic water heads' network,
- the spatial structure of the aquifer and its transmissivity,
- the existence of flumes (lineaments) confirmed by remote sensing,
- the reciprocal spatial relationship of the disposal and the protected zone.

When the entire aquifer is to be investigated only a few wells may be located in the zone of indirect influence of disposal. Where the disposal is impacting downstream groundwater, the consecutive wells should be placed at distances gradually increasing i.e.:

1st	well	50	to	100 m	from the edge of disposal site,
2nd	well	100	to	300 m	from the edge of disposal site,
3rd	well	400	to	700 m	from the edge of disposal site,
4th	well	800	to	1500 m	from the edge of disposal site.

The wells in this direction should be located along the lines of a stream with the greatest hydraulic dipping or along the flumes (lineaments). The lines of monitoring wells (one to four) should be placed within an area encompassed by streams that could come in contact with the disposal. When controlling a specific part of the aquifer, the monitoring wells should be located along one or two lines between the disposal and the protected part. The lines should be located on the basis of hydrodynamic criteria or along the lineaments if any.

Distances between the wells can be similar as on the previous example.

The monitoring wells should be drilled with a method, avoiding colmatation of the zone near the well giving entirely erroneous conclusions. This results in groundwater flowing around the less permeable zone around the well, hindering the exchange of water between the well and the surrounding aquifer. The recommended filter diameter is 4 or 6 inches.

During drilling, the lithological log of all layers should be determined accurately. Levelling of the stabilized groundwater table, and tests to determine the permeability and the specific yield of all tested aquifers should be executed.

The water sampling from monitoring wells should be conducted after removal from the well approximately 1-3 fold volume of waters. Additional removal of water from the well can change the natural flow, whereas not removing the water may cause the sampled water to be in extended contact with air or with the well casing. For the investigations of the unsaturated zone, and for the compacted rock material characterized by very fine pores, one may use (only in the course of drillings) soil or rock material samples taken for centrifuging to obtain micro-samples of water.

The water sampling connected with measurements of the water table position should be carried out with frequency:

- Dry Type disposals, once a month (above groundwater table),
- Wet Type disposals, every 3 months (below groundwater table).

For Dry Type disposals, full analyses (about 40 designations) of groundwater should be made every 3 months and remaining monthly analyses may be shortened (about 15-18 designations specified on the basis of preliminary analysis).

Due to the frequency (particularly in developed regions) of significant fluctuations of groundwater quality be various activities (e.g. fertilization, dust emission e.t.c), it is essential to posses reference data, which can be:

- a minimum one year cycle of the groundwater's analyses made prior to storage for the entire aquifer or,

- when considering one part of the aquifer, using references from groundwater analyses from a part of the aquifer that does not undergo the influence of the disposal (groundwater upstream).

The results of groundwater tests should be periodically (minimum once a year) tabulated and discussed, to draw conclusions and to propose appropriate recommendations.

AN EXAMPLE OF DISPOSAL

Basing on the experience gained from many years' research and experience, a task has been assigned to design a safe disposal site for ashes from a coal-fired power plant and coal waste within the area where rich and good quality aquifers to be protected were situated. The disposal site should be located in the mines-out part of a huge sand pit. The surface area of disposal is 190 ha, capacity of disposal 20 mill. m^3, storage 2 mill. m^3/year with hydraulic method of disposal in the closed water cycle.

The hydrogeological conditions are illustrated in the figure no. 1. There are encountered here three locally isolated but regionally connected aquifers.

I. The upper aquifer 10-20 m thick is constituted by the Quaternary sands with a transmissivity of about $T = 500\ m^2/d$, which are subject to mining in places to the floor and there and here, its portion has been left at the sand pit in the bottom; within this aquifer, shallow public water wells (individual) are situated;

II. The intermediate aquifer is a thin layer of Tertiary sands with a transmissivity $T = 150\ m^2/d$ without any more importance;

III. The lower aquifer is very abundant, and of high quality, Tertiary groundwater reservoir with a transmissivity $T = 1200\ m^2/d$, which is now being exploited for supply of nearby city and in the future, is planned be a drinking water reserve for the whole region.

In these conditions, the ash and coal waste disposal was decided to be built as leakproof. Owing to the precise drillings (100 m * 100 m), it was found that underlying layer of clays is of a continuous nature, and it is practically impermeable ($T = 3*10^{-4}$ m/d).

So, the slopes of open-pit were designed to be sealed by covering with a clayey carpet, 1-2 m - thick, plied by a double PVC film and in the subsoil, by providing a vertical leakproof screen, 1 m thick and 2-20 m - deep, filled with a bonded clay mixture and fitted with a bonded clay mixture and fitted with a packing piece made of PVC film. Between active part of the sand pit and disposal area, a dividing dam was provided by making an embankment with leakproof core wall connected with the vertical screen as above.
When storage is over the disposal surface will be shaped to ensure high rate of surface run-off, the covered with clay and revegetated.

Thus, a completely leakproof basin was achieved to provide a full protection of groundwater, both at the present - day time and for the remote future, which was a requirement of the environmental authorities.

Now anotherone disposal of coal desulfurisation wastes is being designed in similar hydrogeological conditions with groundwater protection.

CONCLUSIONS

Seven years research programme enabled to get information about methodology of wastes examination, about their polluting potential, about migration of pollutants into aquifers and within aquifers. This enabled to develop the guidelines of this type of wastes disposal planning and design with full protection of environment.

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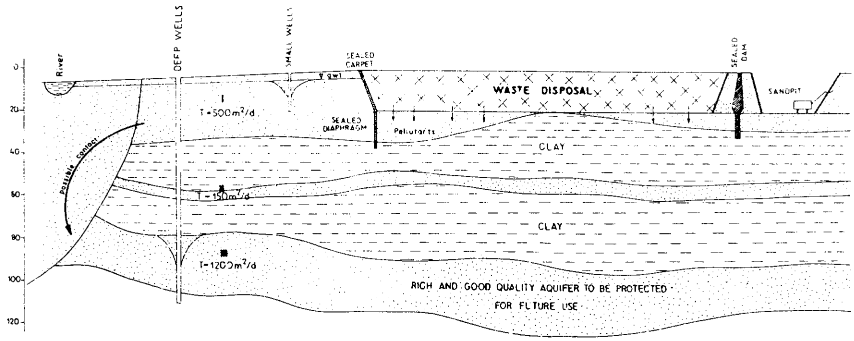

FIG. 1. SAFE FLY ASH AND COAL WASTE DISPOSAL IN LARGE SAND-PIT

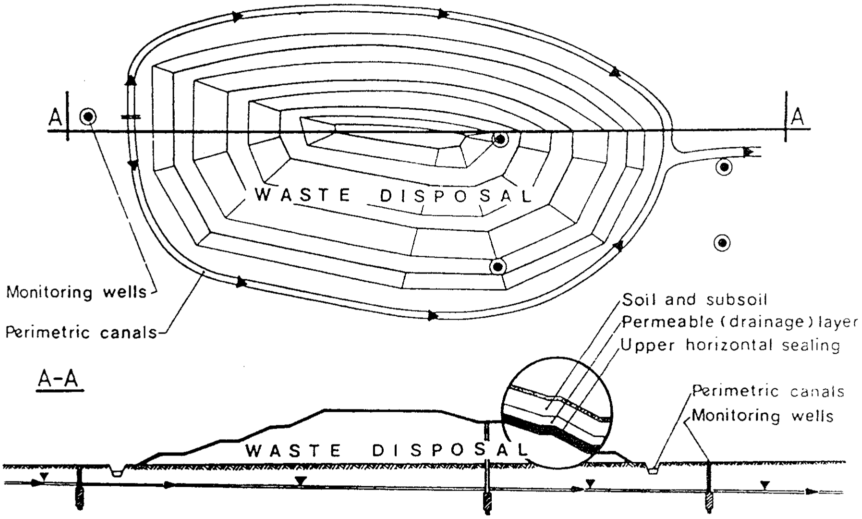

FIG. 2. GROUNDWATER PROTECTION -
DISPOSAL ABOVE GROUNDWATER TABLE

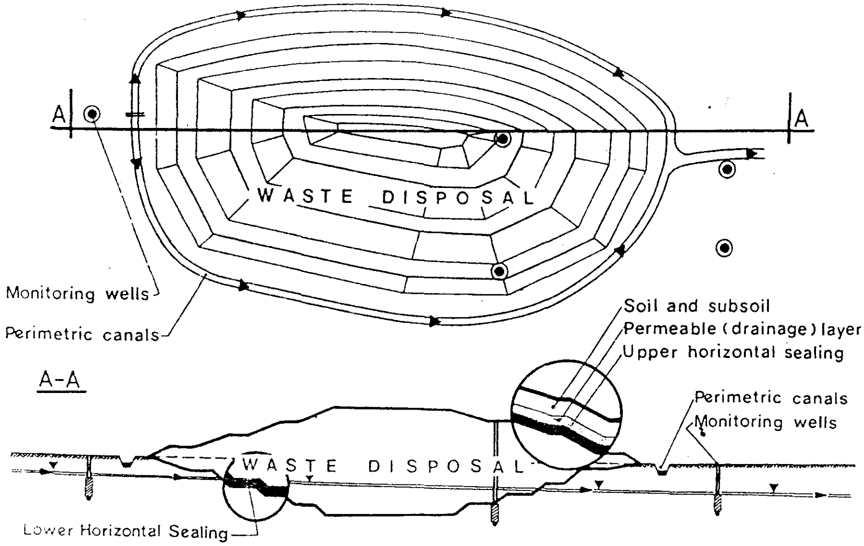

FIG. 3. GROUNDWATER PROTECTION -
DISPOSAL BELOW GROUNDWATER TABLE

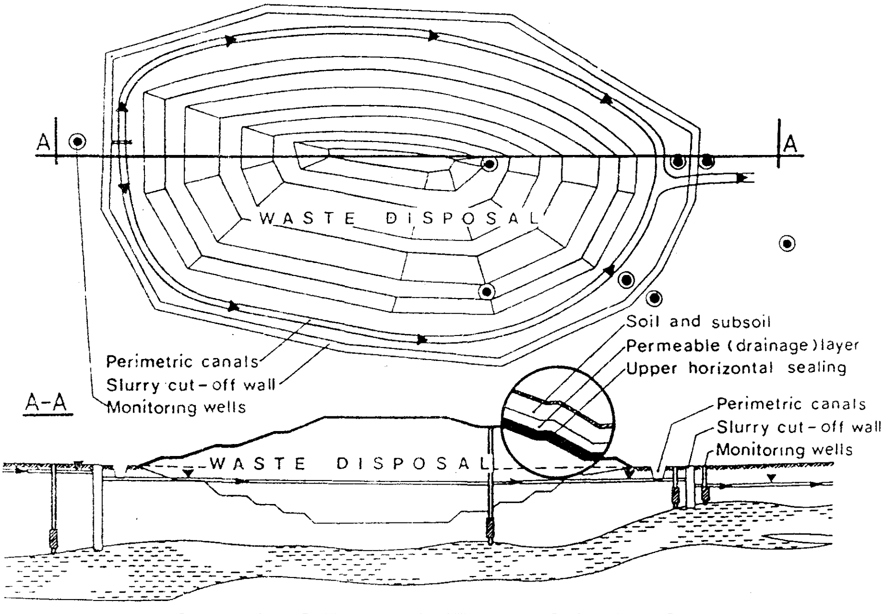

FIG. 4. GROUNDWATER PROTECTION -
DISPOSAL BELOW GROUNDWATER TABLE