STATENS GEOTEKNISKA INSTITUT
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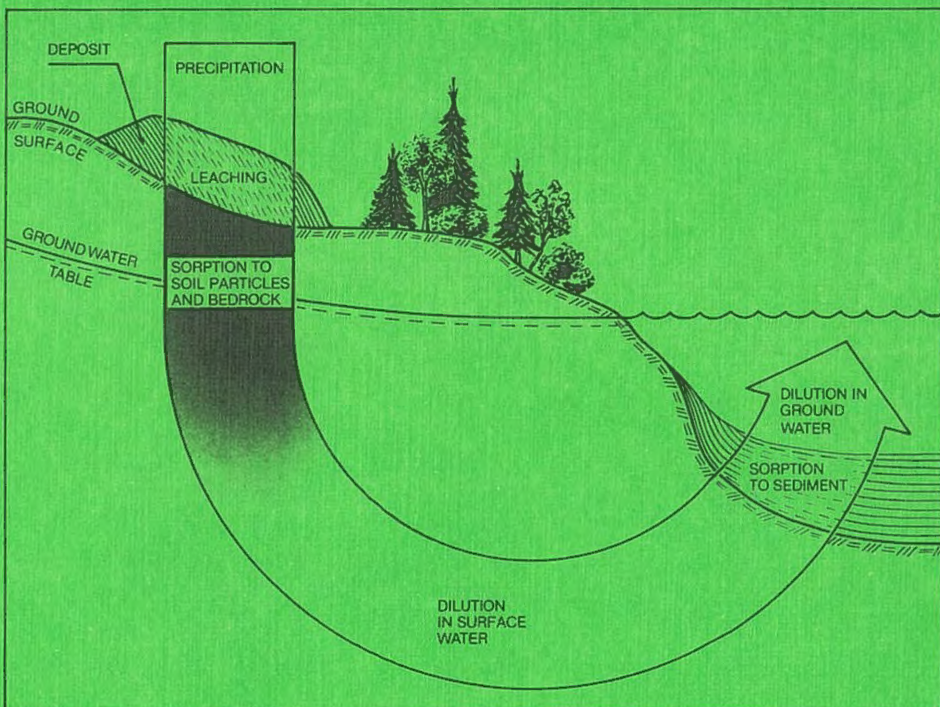
RAPPORT
REPORT **No 28 E**



Environmental control in disposal and utilization of combustion residues

TOM LUNDGREN
PÄR ELANDER

LINKÖPING 1987

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PREFACE

This document is an abridged translation from a Swedish guide for disposal of residues from combustion of coal and peat. The guide has been prepared at the Swedish Geotechnical Institute (SGI) on behalf of the Joint Committee of Power and Heating Producers on Environmental Issues (KVM), and is published in the Report series of SGI, KVM and the National Board of Environment Protection (SNV). It is to a great extent based on work performed in the Swedish Coal-Health- Environment project (Final Report in April 1983). Further results from other investigations concerning disposal of residues, e.g. the reports from the Swedish Peat-Health-Environment project, are also included in the document. The present document has been completed with a discussion regarding environmental control in utilization of the residues, while principally the appendixes and detailed advice concerning construction has been excluded compared to the Swedish guide. The appendixes comprise detailed advice and examples concerning leaching tests, calculation of disposal areas, leachate flow rate, dispersal and dilution, together with dimensioning of environmental protective measures. The parts dealing with such aspects of construction of deposits that are not of interest from an environmental point of view have also been excluded.

A reference group has followed the project and has contributed to the work with valuable suggestions for changes and additions. The members of the reference group were:

Per Almqvist	Stockholm Energi
Ragnar Hahn	Aroskraft, Västerås
Gunnar Hovsenius	Swedish State Power Board
Roland Johansson	Swedish State Power Board
Folke Larsson	National Board of Environment Protection
Birgitta Timm	National Board of Environment Protection

Further views have been added by Jan Hartlén (SGI) and Björn Södermark (SNV) and finally the guide has been under consideration by presumptive users. Drawings have been provided by Krister Hast, and typing by Gill F. de Matta. The English has been corrected by Anthony Skeat. The authors would like to express their grateful thanks to everyone who has contributed to the production of the guide.

The report represents the views of the authors, and cannot be referred to as representing the standpoint of SNV or KVM. However, SNV and KVM share in principle the views presented in the report.

Linköping in May 1987

Tom Lundgren Pär Elander

CONTENTS

1. BACKGROUND

1.1 Objective

This guide has been prepared to facilitate planning and accomplishment of disposal of residues from power and heating plants, i.e. combustion of coal and peat. It is addressed to plant owners and consultants working with investigation and design, and is directed towards the environmental aspects of disposal. The guide is mainly written in terms of disposal, but it should be stated from the beginning that the principles for environmental protection and evaluation apply to utilization of the residues as well.

The guide is written in view of Swedish conditions and legislation, but the basic principles which are described and the design and construction of measures for environmental protection are of general interest. Hence, it could be used in other countries as well, with slight modifications in view of local conditions. The original Swedish version of this report includes more detailed recommendations concerning the construction of deposits, as well as appendixes including examples of calculations of required disposal area, leachate production and dispersal of pollutants, together with conducting leaching tests.

Strictly speaking, the guide only deals with residues from combustion of coal and peat. Other residues, e.g. wood ash and residues from waste incineration, are in certain respects comparable to these. Therefore, the basic disposal principles proposed in the direction should be valid also to such residues. However, the direction ought to be used with care in the case of other residues. New types of residues which have been poorly investigated so far (for instance, residues from flue gas condensation and NO_x cleaning) are not dealt with. The extent to which the guide applies to such wastes cannot be clarified until their properties are investigated.

Co-disposal of combustion residues together with municipal waste is not treated in the guide. The reason for this is that knowledge is insufficient, primarily with regard to the way in which leaching processes are affected by mixing domestic refuse and combustion residues. Apprehension has been expressed that the solubility of trace elements is increased through formation of organic compounds, and co-disposal is consequently not recommended. However, the effects of co-disposal have not yet been classified. Regarding small plants, co-disposal is economically advantageous and it is important to supplement this guide with further investigation and recommendations concerning co-disposal. For the present, combustion residues should be tipped in a special part of the site, and at a higher level than domestic refuse if tipping on municipal deposits is considered. Another possibility of reducing the costs for small plants may be co-ordination of disposal to one and the same site for more than one plant.

1.2 Health and environmental aspects of disposal

In older times, disposal of ash was not considered to constitute any problems. The ash was proportionately coarse and could be used as a filling material e.g. in harbours and roads. Part of the ash was also used as agricultural fertilizer. Later on, as efforts were made to limit emissions to the atmosphere, other types of residues were produced which were more fine-grained and had different chemical characteristics. Awareness of the environmental risks has also drawn increased attention to water pollution by the residues.

The most immediately obvious environmental influence of disposal of the residues is **spreading of dust** and the appearance of deposits as an ugly feature of the landscape. Spreading of dust is mainly a question of health hazards, and can be mastered through adequate handling of the residues. The factor that must be considered most important to health and environment in this matter is the **release of salts and trace elements** with leachate from the deposit. The environmental hazard of a residue is determined by the amount of pollutants leached from a deposit. Also smaller amounts of heavy metals released to the environment may constitute a hazard both to environment and health. Furthermore, heavy metals can become enriched and form depots through sorption to soil particles and sediment or by uptake and accumulation in organisms. The mobility of these metals may increase in the future, e.g. due to acidification, and further contribute to the turnover of pollutants in the environment.

Typical of leachate from ash tips is the high content of salts. These are principally calcium and sulphate, but also sodium, potassium and chloride contribute high contents. These salts do not constitute any danger to human health, but may cause damage to the environment in the immediate vicinity of a tip. The salts are easily soluble and are leached relatively fast. In most cases, this means a hundred years or so.

Trace elements in the residues are not as easily soluble as the salts, but are nevertheless soluble to such an extent that the content of trace elements in the leachate is markedly elevated. An important difference in comparison with the salts is that the elevated levels remain for a very long time, several thousand years. Consequently, it is essential that the design of a disposal site regarding environmental protection measures be based on the fact that **leachate with elevated trace element content will be**

produced for a very long time. Thus, a disposal technique that involves collection and treatment of the leachate will not be appropriate.

The Environmental Protection Act requires the scale of protective measures to be assessed in terms of what is technically possible and of the cost of the measures, seen in relation to their value. It can be stated straight away that it is not feasible in practice to provide a completely waterproof, all enclosing barrier around the waste material. Instead, the basic principle that is recommended in this direction involves a limitation of the amount of leachate produced by means of appropriate siting and sealing to reduce the infiltration of water into the deposit. The following factors are significant to the measures which should apply to the individual disposal site:

- what is technically possible
- the cost of the measures
- the characteristics of the waste
- the possibilities of sorption and dilution of pollutants
- the tolerance of the site to the pollutants

The prospects for utilization of the residues in an environmentally acceptable way are frequently favourable. For instance, fly ash from pulverized coal-firing is used as a primary product in production of cement (so called modified Portland cement). Utilization of products based on fly ash (as well as fly ash mixed with FGD residues) stabilized with cement has started and is developing. Applications of these products are found in road construction, as filling material and impermeable barriers, for stabilizing environmentally hazardous waste, etc. Further development of applications of the residues, for example in production of building materials, is possible.

The possibilities for utilization are restricted in the individual case by the quality of the residues, by economic factors, such as transport cost, and by environmental factors. The demands on environmental protection required in utilization are as strict as in disposal. These demands may involve restrictions on utilization of residues, for example as a filling material, at least if the residues are not stabilized. The methods for estimating environmental impact and required measures are essentially the same in utilization as in disposal. In order to facilitate utilization of the residues, this guide has been supplemented with a conclusion regarding utilization from an environmental point of view.

1.3 Residues from combustion

Not only the fuel but also the firing method and the flue gas cleaning technique determine the type of residues that are formed. A general division of the residues can be made into the groups: bottom ashes, fly ashes and desulphurization products (FGD products).

- **Bottom ash** is a coarse-grained material discharged from the bottom of a furnace.
- **Fly ash** is the term for the fine-grained dust which is separated from the flue gas by means of a precipitator.
- **FGD (flue gas desulphurization) products** are fine-grained products, discharged from a wet scrubbing process in a slurry or from a spray dry scrubbing process as a dry powder. In both processes lime or limestone is used to absorb or bind the sulphur dioxide, and the residue consequently consists mainly of calcium sulphite (possibly calcium sulphate). Dry FGD products can also be separated together with fly ash.

Another desulphurization method is to add limestone or dolomite in the furnace. In this case, the calcium/sulphur compounds are separated together with the ash. This technique is well-established for fluidized beds, but can also be used in other types of furnace.

A further subdivision of these products can be made partly with respect to the type of fuel that is used (coal or peat) and partly with respect to the type of furnace:

- **grate firing**
- **pulverized coal firing**
- **fluidized bed firing**

This subdivision results in several types of residues slightly different in character. Properties of the residues that affect the design of a disposal site (as well as utilization) include physical as well as chemical characteristics, such as:

- salt content
- trace element content
- leaching characteristics
- content of buffering substances
- permeability to water
- capillarity
- compaction properties
- strength
- pozzolanic properties
- resistance to weathering and erosion

It is beyond the scope of this document to describe the properties of the residues in detail. Much work on this matter has already been published, in English as well as in Swedish. It should be mentioned, however, that the recommendations in this report are mainly based on the results of the Swedish Coal-Health-Environment Project and from corresponding investigations on combustion of peat.

1.4 Environmental legislation

A short introduction to the Swedish environmental legislation concerning disposal of the residues should be given, as this forms an important part of the basis on which the recommendations of this report are founded.

Both the siting and design of disposal sites are controlled by the Environmental Protection Act (SFS 1969:387) and subsequent amendments (SFS 1981:420). According to the Act, the site for the activity should be chosen in such a way that the purpose can be achieved with minimum encroachment and inconvenience at a reasonable cost. This means that the **most suitable site** for a deposit should be chosen at a reasonable distance from the plant (regarding transport costs). The suitability shall be judged with respect to encroachment upon other activities and to environmental impact. Neither should the protective measures which are required regarding the environment at a specific site be unreasonably high.

Concerning design of the deposit, it is stated that reasonable protective and precautionary measures shall be taken to prevent and rectify inconvenience, i.e. influence on the environment. The need for measures shall be judged on the basis of what is technically possible, the sensitivity of the environment, the benefit of the activity and the cost of the measures.

If it is to be feared that tipping may involve inconvenience of considerable significance, despite reasonable protective measures being taken, the activity should be permitted only if very special reasons exist. When a suitable site is found and the status of this site is investigated, it is necessary to clarify in what way technique and economy should be considered and weighed up. A general consideration, which furthermore has passed an extensive review, was published by

KHM - the Swedish Coal-Health-Environment Project (Final Report, April 1983. The Swedish State Power Board). In this investigation, protective measures are suggested that involve sealing of the disposed residues, and demands are specified concerning the extent to which the leachate flow should be limited. A general estimate concerning health and environmental impact is made, based on these demands. Furthermore, disposal principles judged to meet these demands are described. The present direction is based on the demands and on further development and specifications of the disposal principles presented by KHM. However, present knowledge concerning leaching, dispersal and environmental effects of pollutants is insufficient to set out any general limits that can be accepted from an environmental point of view. The suggested measures should therefore be considered to be minimal demands. A separate investigation and estimate should always be performed in each individual case, concerning the environmental benefit of further demands weighed against what is technically possible and economically reasonable.

The obligation to obtain permission for establishment of a deposit is set out in the Environmental Protection Act as mentioned above. The way in which concession applications are to be dealt with, and how (and by whom) permission is to be granted, is set out in the Environmental Protection Regulations (SFS 1981:574). Large plants are dealt with by the National Concession Board, while smaller installations are dealt with by the appropriate county council. Generally, the county council is the inspecting body, although these functions may by agreement be assigned to the local authorities. A summary of the procedure concerning probation of applications is shown in Figure 1.1.

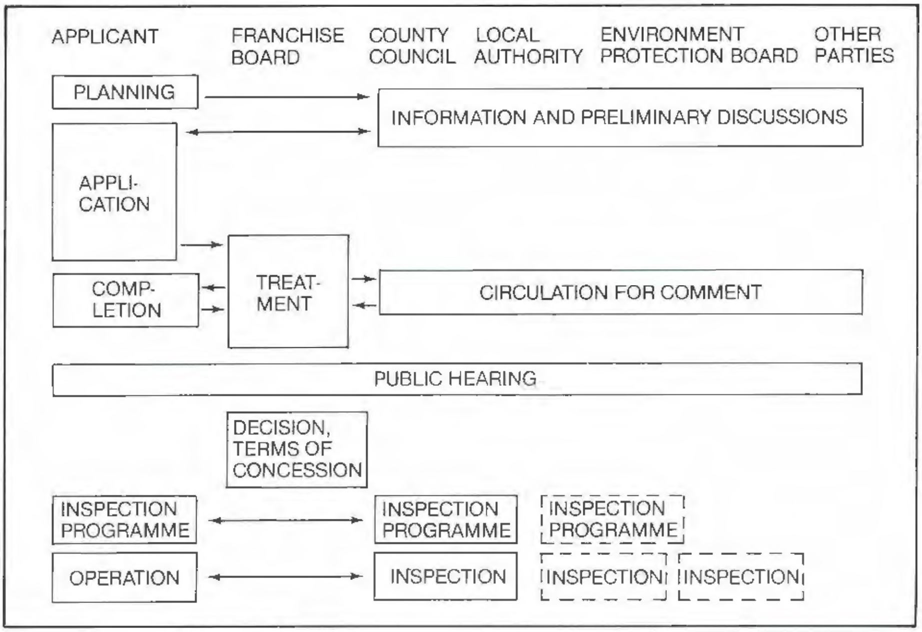

Figure 1.1 General procedure concerning probation of applications according to the Environmental Protection Act.

2. PRINCIPLES FOR ENVIRONMENTAL CONTROL IN THE DISPOSAL OF COMBUSTION RESIDUES

2.1 Deposition

We may distinguish two different methods in handling and tipping of residues, named **wet deposition** and **dry deposition.**

In Sweden, dry deposition is customary, as in disposal of municipal refuse. Dry deposition implies transport and deposition of dry or moistened residues. Residues intended for dry deposition are usually transported in open or covered vehicles. Most common are trucks or dumpers, even though rail or water transport may be used. There is a considerable risk of fine-grained, dry residues (dust) being spread during loading, transport and tipping. To counteract this, the ash is usually moistened with water (conditioned) before being loaded.

In the case of wet deposition, hydraulic transport of residues is used from the plant to a pond in which the residues settle. The transport water that is decanted contains outwashed pollutants and should be recirculated in the transport system. To obtain an appropriate distribution of residues and to simplify finishing treatment, the pond is commonly divided into smaller areas by means of temporary embankments. The pipeline outlet may also be gradually moved along the lagoon to ensure uniform distribution and quality of the filling.

The advantages of wet deposition are associated with the rational handling provided by hydraulic transport. However, hydraulic transport cannot be used if the deposit is situated far from the plant. One disadvantage is that run-off from the deposit may be obstructed due to the flat surfaces that are obtained. Damming the tipping area is expensive, and wet deposition is usually of interest only in dealing with residues from large power plants.

2.2 Environment aspects in a long-term perspective

The most important health and environmental factors that must be considered in disposal of combustion residues are **release of salts and trace elements** with percolating water to ground water and surface water. The environmental hazard depends upon the quantity of the contaminants leached from the deposit. The aim is to minimize leaching and its influence on health and environment by means of **the most appropriate siting** and **the best disposal technique** at a reasonable cost. It also has to be verified that released contaminants will be sorbed and diluted in the environment in an acceptable way.

So far, no method has been put into practice for reducing the concentrations in the leachate. The only way to minimize the quantity of contaminants leached is to **reduce the amount of leachate produced** from the deposit. Such a measure generally does not affect the concentrations in the leachate, but increases the degree of dilution in the surrounding groundwater and surface water. The processes involved in spreading of contaminants in the environment are shown in Figure 2.1.

Tipped fly ash and dry FGD products demonstrate a porosity varying between 30 and 45 %. Most of the water added to the products by conditioning will be evaporated or chemically bound to the residues due to pozzolanic reactions. Further on, these fine-grained residues show marked capillary properties and have the capacity to retain a considerable amount of water. Therefore, a long time will elapse before any leachate is released. By using adequate covering, seepage into the deposit can be reduced to 50-100 mm/year,

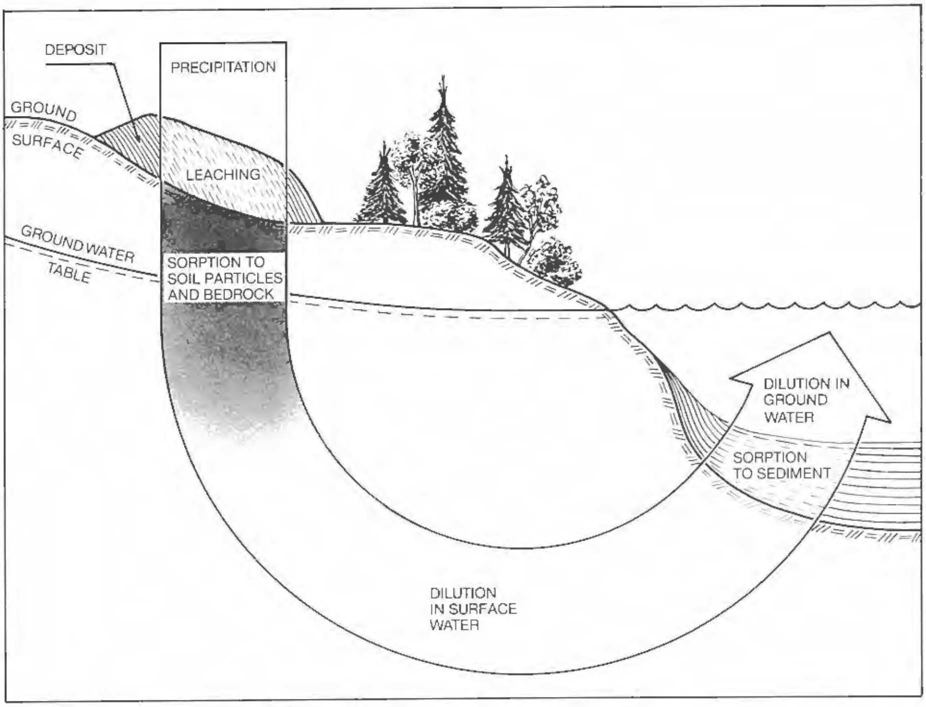

Figure 2.1 The principal mechanisms which influence dispersal of pollutants from a deposit.

resulting in delaying the leachate production a century. If no measures are applied, leachate will appear in a decade or two.

In Table 2.1, a forecast concerning the future sequence in a deposit with combustion residues is given. The forecast is valid on the assumption that measures are applied as recommended in the following sections. Apparently, chloride and sulphate contents together with pH will be particularly high in a couple of hundred years, while the content of trace elements will be enhanced in thousands of years.

Table 2.1 Time scales and mechanisms connected with leaching in a dry deposit, 10 m high. Not applicable to colliery deposits or acid ashes (KHM).

Deposit age (years)	Water situation	Leachate formation	pH situation	Leachate situation
0-2	Water is chemically bound, with exothermic reactions producing upward migration of free water.	None or very little.	pH reduction only in the surface layer as a result of carbonate formation.	Leaching from the deposit surface, primarily from exposed areas. Leachate runs off as surface water.
2-100	Unsaturated, non-stationary flow. Formation of wet fronts which move down until complete saturation conditions are established.	Probably insignificant. Capillary forces attempt to produce uniform water content and retain the water until full saturation is established.	Surface pH has fallen noticeably, but only a small amount of the buffer capacity has been utilized.	Leaching taking place, primarily in alkaline environment. Precipitation may occur close to surface of the deposit.
100-1,000	Deposit saturated, with largely stationary flow pattern in the lower parts of the tip.	Maximum leachate formation, balancing infiltration of precipitation in the deposit (50 mm/year).	Predominantly alkaline environment in the deposit, at least in the lower part.	Certain metals enter solution as ion complexes, and can reach relatively high concentrations. Relatively high salt concentrations.
1,000	Deposit saturated, with largely stationary flow pattern in the lower parts of the tip.	Maximum, possibly increasing, due to erosion of the covering layer.	pH reduction has stopped and stabilized at pH 5-8. This value may be higher in deposits with high buffer capacity.	Metal concentrations progressively decrease as pH falls to the neutral level. Moderately high salt concentrations.

During grate-firing the ash formed consists mainly of bottom ash. Bottom ash is more coarse-grained than fly ash and FGD, has minor capillary properties and is more permeable to water. The leaching process in a tip with a large proportion of bottom ash that is left without the required covering will be faster than described above. However, **leachate with an enhanced content of trace elements will be produced for a very long time.**

The impact of the completed deposit is a question mainly of enhanced content of salts and trace elements in ground and surface water. Such contamination of leachate seeping through the ground will probably be reduced through binding processes such as filtration and sorption to soil particles and bedrock. The efficiency of this purification depends to a great extent on the geological conditions. After a certain time, at a rough estimate a hundred or a few hundred years, the capacity of the binding processes may be consumed in the nearer surroundings of the deposit. This time corresponds to the period during which the leachate produced has the highest content of trace elements. The maximum content in the leachate that occurs owing to these processes during leaching of the residues will be reduced before any leachate reaches the biosphere. Knowledge concerning filtration and sorption in soil and rock is at present too limited to allow any quantitative estimations regarding the impact of the binding processes. The only mechanism likely to reduce the concentrations of trace elements in the long term perspective is dilution of leachate in ground and surface water. The extent to which the dilution proves efficient depends, among other things, on the amount of leachate produced. However, the binding processes can be expected to reduce the maximum trace element concentrations in leachate produced during the early stages of leaching.

2.3 Disposal principles

Regarding the discussion in the previous section, the following demands can be applied to a technique for use in siting and designing deposits of combustion residues:

- Limitation of leachate production.
- Durability in the long-term perspective.
- Performance independent of maintenance and regular inspection.

In view of the long-term perspective, it is obvious that disposal techniques based on leachate collection and purification are unsatisfactory. There must be no concern that a finished deposit will lead to an unacceptable impact on the environment in the future.

In the long run, **leachate production can be limited only by reducing the amount of water that reaches the deposit** from external sources. It should be possible to eliminate much of the surface and groundwater inflow through suitable siting and design of the deposit. Moreover, surface sealing of the deposit should limit infiltration by precipitation. **Appropriate siting and sealing** of the deposit to limit leachate production also creates opportunities to obtain favourable dilution of leachate.

An important factor in siting a deposit is whether it is situated in an inflow or outflow area for groundwater (see Figure 2.2). This decision has an influence on the amount of water that reaches the deposit, and the choice of measures that should be applied. Figure 2.3 shows that the effects of sealing layers and drainage layers may differ in inflow and outflow areas as far as the total quantity of

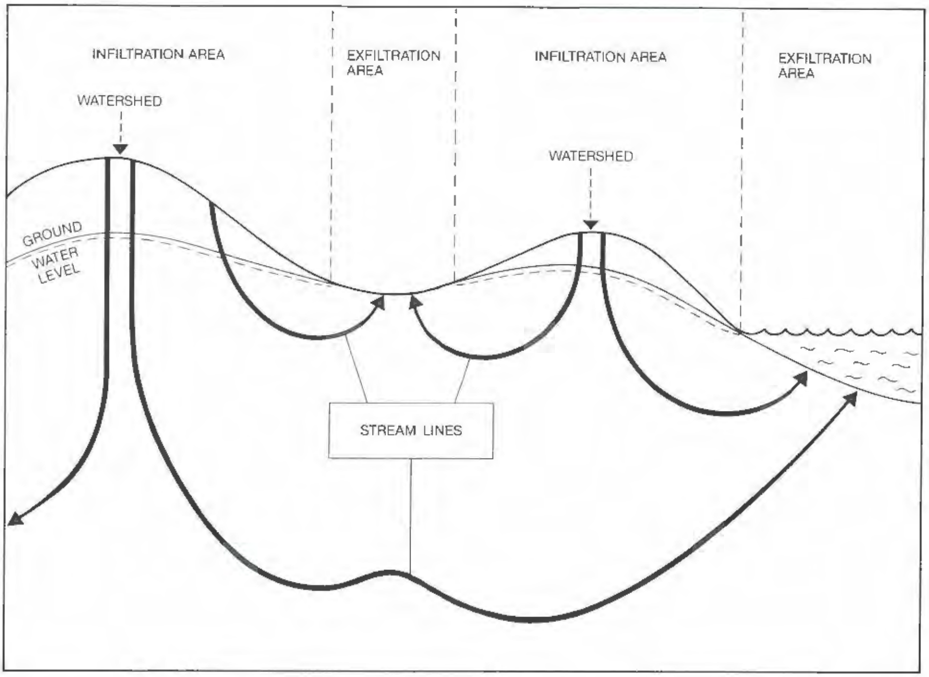

Figure 2.2 The signification of topography on ground water flow shown in principle (according to Gustavsson Y., 1972: Groundwater. From Hydrology, Studentlitteratur, Lund. In Swedish).

polluted water is concerned, as well as affecting where the water leaves the deposit. It can be seen from the drawings that **siting deposits on inflow areas is preferable** in view of the reduced quantity of leachate that is produced.

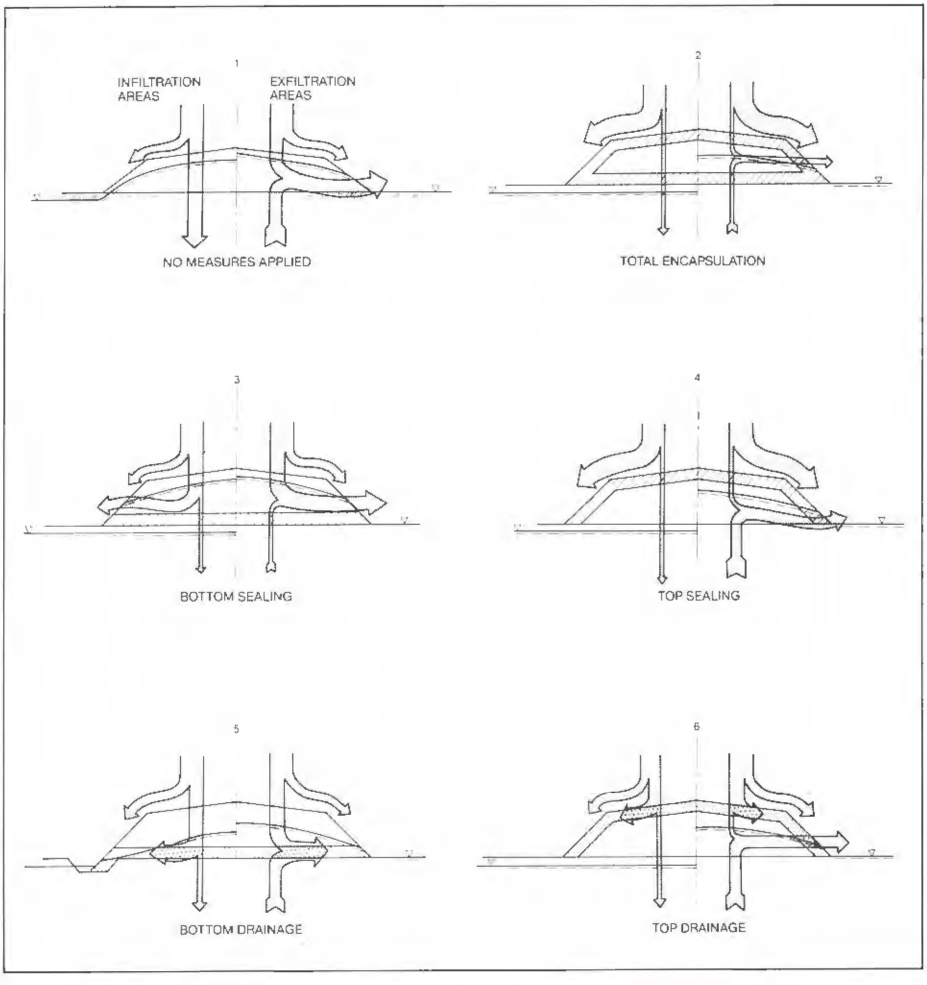

Figure 2.3 General influence on the water balance in a deposit according to the type of site and different measures. (From the Coal-Health--Environment Project, Extensive Reports supporting the Final Report, 1983).

Further advantages are gained when siting a deposit as high as possible towards the groundwater watershed:

- o Longer pathways through earth and rock for leachate, and thus greater likelihood of effective dilution and sorption of contaminants before the leachate reaches the ground surface or wells.

- o Reduced risk that wells are located in the vicinity of the deposit.

A disadvantage of siting a deposit near a groundwater watershed may be the difficulty in matching the deposit with the landscape.

A small exfiltration area close to a regional groundwater watershed can often be covered by a deposit and then transformed into an infiltration area. Such an area may be advantageous as a site. Hence, it is important to take into consideration how the water balance in an area will be affected by the origin of a deposit.

Siting close to a suitable large recipient may be advantageous in view of the rapid and effective dilution that can be obtained. Such a site should be considered only on the following conditions:

- o Limitation of leachate production as earlier stated.

- o Short pathways through earth and rock for leachate, clearly directed into the recipient and an effective water turnover in the recipient.

- o The recipient must be capable of withstanding the leachate loading.

The requirement on limiting leachate production implies that groundwater should not be able to enter the deposit. Consequently, the deposit should either be sited above the groundwater table or, for instance when filling in water areas, reach such a level that an infiltration zone is created. Dry deposition in a regional outflow area may involve high groundwater pressures and thereby difficulty in creating an infiltration zone. Siting the deposit in such an area should be considered only where there are dense clay soils. The deposit should also be provided with a bottom drainage layer to drain off penetrating ground water (Figure 2.4). High pore pressures that may reduce slope stability of the deposit are then avoided.

When siting a deposit, formations significant to groundwater recharge, for instance eskers and outwash plains, must be avoided because of their potential hazard to the drinking water supply. Usually this is the case at gravel pits. Smaller formations of this type can be exploited when it is obvious that the risk of impact on the ground water supply is small, and that dilution of the leachate is rapid and effective.

Limitation of percolating precipitation, and thereby leachate production by means of **top sealing, protective covering** and **plant growth** as seen in Figure 2.5 was suggested by the Swedish Coal-Health-Environment project. An effective sealing layer can be created out of fly ash stabilized with FGD-products, cement or lime. Surface run-off and thus the effect of the sealing layer can be improved by providing a drainage layer above the sealing layer. Finally, the deposit should be covered by soil resistant to erosion, e.g. moraine. Percolating precipitation should normally be reduced at least to 50-100 mm/year.

Vegetation growth on the finished deposit is essential. Evaporative transpiration plays a very important part in

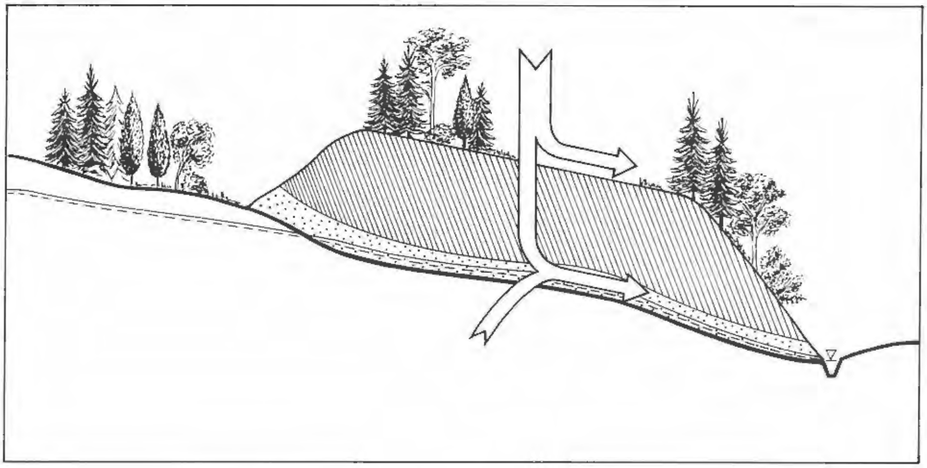

Figure 2.4 At dry deposition in an outflow area, the inflowing groundwater should be drained in a bottom layer.

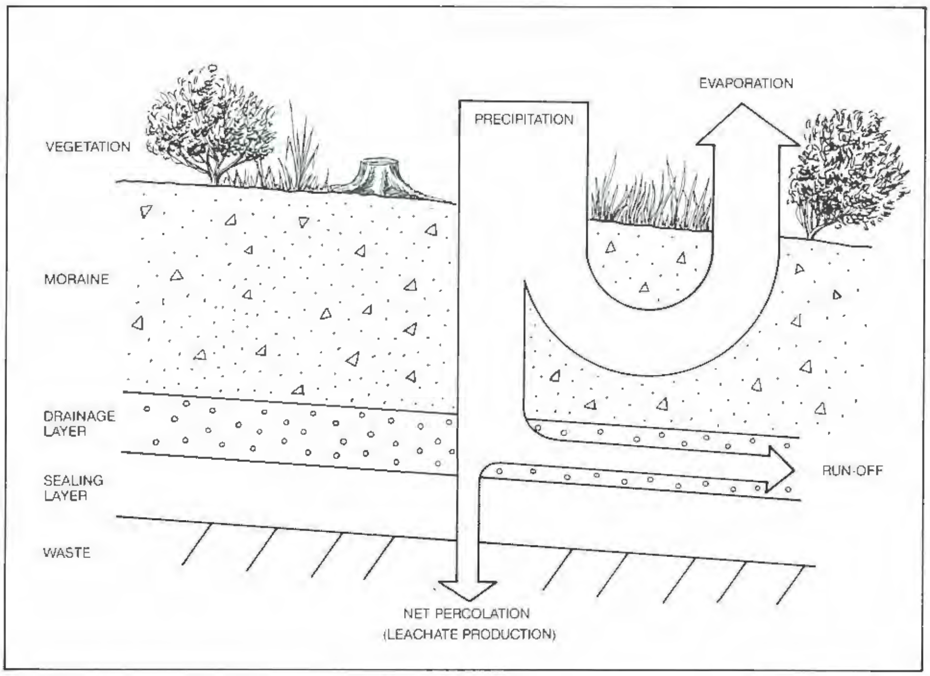

Figure 2.5 General function of the suggested cover. The drainage layer may be excluded if the sealing layer is improved correspondingly.

limiting leachate production, and is estimated to remove more than half of the yearly precipitation.

Thus, the basic disposal principles can be summarized as a limitation of the leakage of contaminants and an optimizing of the dilution through:

- o A surface sealing of the deposit in order to reduce the amount of percolating precipitation.
- o A vegetation growth on the deposit in order to promote evaporation and matching of the deposit with the landscape.
- o A siting of the deposit close to an inflow area and as close to the groundwater divide as possible,
- o or a siting close to a large, suitable recipient in which a rapid and effective dilution of leachate is obtained (Figure 2.6).
- o Possibilities to make alterations in the design of the deposit in case residues with different qualities are produced in future.

As deposition takes place above the ground water table, it is inappropriate to combine the surface sealing with a bottom sealing.

All of the water that percolates through the surface sealing forms leachate. A bottom sealing that turns out to be more impermeable than the surface sealing results only in a higher groundwater table within the deposit, and ensuing leakage of leachate at the foot (see Figure 2.3, Example 3).

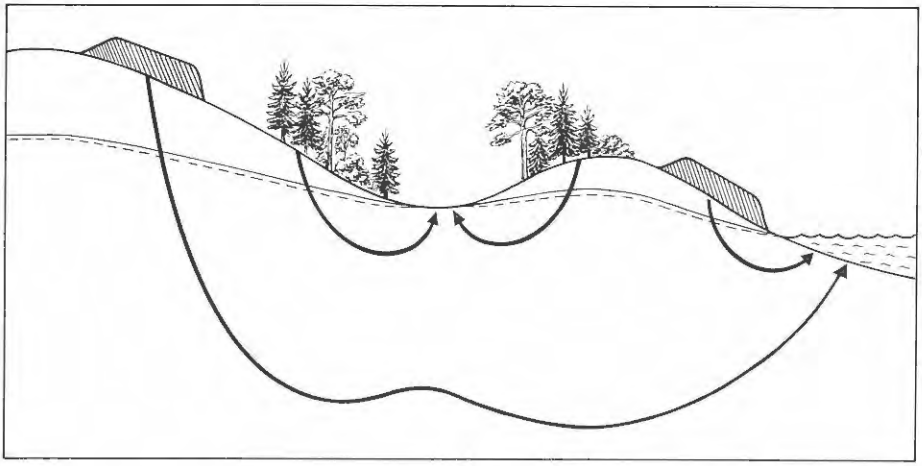

Figure 2.6 Siting close to the watershed in an inflow area results in long pathways through earth and rock for leachate and great likelihood of sorption and dilution of pollutants before the leachate reaches the ground surface or wells. The alternative is siting close to a large suitable recipient where immediate and effective dilution can be obtained.

2.4 Temporary measures during construction

Excess water which is contaminated usually arises during the construction of the deposit. In wet deposition such water is decanted as the ash settles in the lagoon. In dry deposition excess water is formed by precipitation run-off from uncovered ash surfaces. In any case, the water should be considered and treated as a leachate.

Wet deposition, including hydraulic transport, involves large quantities of relatively contaminated water. Hence, this water should be recirculated in the transport system.

In the case of dry deposition, contaminated run-off should be collected by drains and (or) ditches. Various constructions may be used, adapted to the circumstances. The water should be discharged to a surge pond. Preferably this excess water should be infiltrated into the deposit, and thereby used in dust abatement. Dry, fine-grained residues are spread by wind, so that sprinkling is necessary while tipping and in dry and windy weather also on exposed ash surfaces.

3. THE IMPACT OF DISPOSAL ON HEALTH AND ENVIRONMENT

3.1 Principles and basis of the estimate

The following health and environmental factors must be considered in disposal of combustion residues (Figure 3.1):

- o The release of salts to surface water and groundwater.
- o The release of trace elements to surface water and groundwater.
- o Radon emission from the deposit.
- o Particle emission (dust) from the deposit.
- o The impact on the surrounding landscape.
- o Limitations on further ground use.
- o Noise emission from vehicles and machines.

Spreading of dust can be prevented by fast covering of exposed ash surfaces and by appropriate measures during construction, e.g. sprinkling.

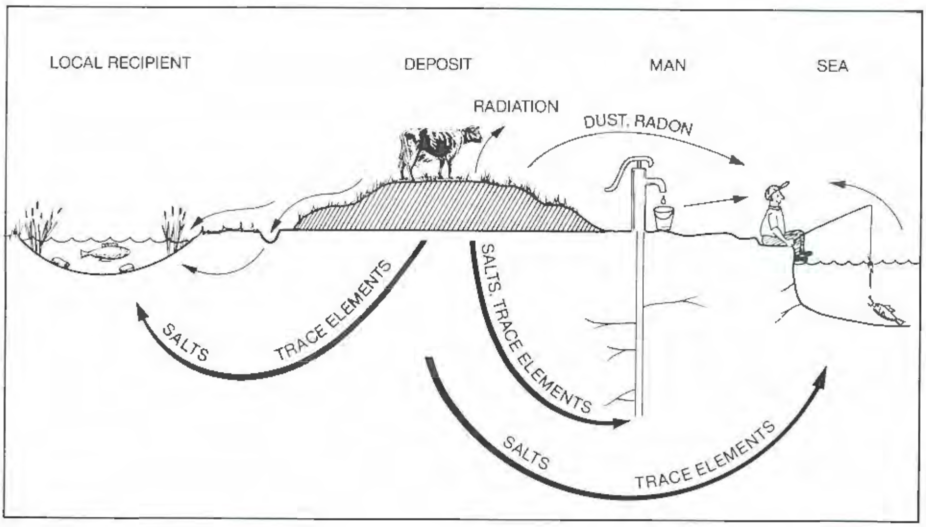

Figure 3.1 The possible effects of a deposit on human health and environment.

Risks due to radon emission are present only in disposal of certain peat ashes. Radon emission is limited by covering the deposit (provided that radon emission from the covering material is small). In the case of house construction on finished deposits which are classified as normal or high risk areas with respect to radon, the buildings shall be designed for radon protection and radon safety respectively (according to the National Swedish Board of Physical Planning and Building, Report 59, 1982).

The factors that are the hardest to master, and which may cause the most serious damage to health and environment are the release of salts and trace elements. These pollutants are leached out by and carried along with percolating precipitation and possibly penetrating groundwater and surface water. The leachate is released either to the surface water or to the groundwater. The way in which this takes place depends on the design of the deposit and on the geohydrology in the surroundings. Influence on the environment mainly applies to pollutants in surface water, while health risks are mainly associated with pollutants entering a well.

An estimate of the effect of the deposit on health and environment is based on:

- the leaching properties of the waste
- the amount of leachate produced
- the seepage paths for the leachate
- the possibilities of sorption of pollutants to soil and rock
- the dilution of the leachate
- the site of water supplies
- the limit values of pollutants in water supplies with regard to health
- the environmental susceptibility to disturbance

On this basis, an assessment can be made of the possible influence on the environment, and of the protective measures that will be required.

Starting from environmental susceptibility and present and future sites for water supplies, the risks of effects on health and environment can be estimated (Figure 3.2). This information, together with knowledge of the leaching properties of the waste and the dispersal of the substances occurring in the surroundings, determines whether the requirements on protective measures must be set higher than normal. The requirements recommended by the KHM and THM projects are considered to be the normal case. This implies mainly a reduction of leachate production to 50-100 mm/year. Even if far-reaching measures have been taken to limit leachate production, there is a considerable risk of

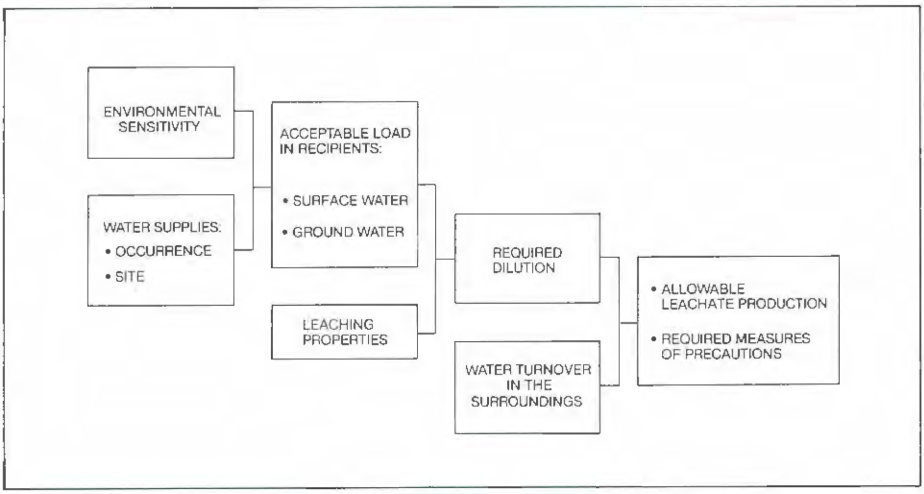

Figure 3.2 An estimate of the influence of a deposit on health and environment, together with a conclusion concerning the need for intensified protection.

enhanced levels of salts and trace elements in groundwater close to the deposit. Hence, a protective zone should be established within which no water supplies are permitted.

3.2 The leaching properties of the waste

The extent to which a waste is hazardous to the environment is dependent upon the amount of pollutants that will be released from a deposit. The chemical constitution of the waste is important to the leaching processes, but it forms an insufficient basis for an estimate of the leachate composition (pollutants and concentrations). Consequently, calculations of the environmental load due to a planned deposit have to be based on direct determinations of the leachate properties of the waste.

During the planning phase of a deposit there are of course no real leachates to analyze. An assessment of the future leachate quality must therefore be based either on laboratory leaching tests or earlier investigations and reports. The properties of common residues formed in coal and peat combustion are fairly well-known and are described in literature[1). Hence, it is not usually necessary to

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1) e.g. Waste Products from Coal Combustion - Production Character, Disposal and Utilization. Translated Extracts from the Swedish Coal-Health-Environment Project, Final Report 1983. Available from SGI.
Miljöeffekter av ved och torvförbränning. The National Swedish Environment Protection Board, PM 1708 (in Swedish).
Förbränning av torvbränslen. Swedish State Energy Board, 1985:2 (in Swedish).

include leaching tests in the investigation. The estimate may instead be based on previous experience. However, it is necessary to be convinced that the information used is valid for the current waste. In certain cases, for example in disposal of residues from divergent fuels with especially high content of pollutants or from unusual processes, leaching tests may be required. The cost of having leaching tests performed is small and is frequently justified for control and information purposes. For instance, routine tests offer a way of proving that the properties of the waste do not diverge from those stipulated in the concession.

Leaching mechanisms

The majority of conventional ashes and all desulphurization products and fluidized bed residues are **alkaline in character** to the extent that the first leachate has a pH above 7.0. The alkaline and buffer substances in the waste are also dissolved and removed, and the pH of the pore water in the deposit will gradually fall. Calculations based on laboratory tests indicate that this will take a very long time, and consequently the leachate will continue to be alkaline in character, even in the case of acid precipitation. However, in the uppermost part of the deposit one can expect a rapid fall in pH. This superficial reduction in pH is thought to be due to the carbon dioxide in the rainwater. As the carbon dioxide comes into contact with pore water with a high pH (leachate) carbonate ions are formed and removed. This formation of carbonate causes a reduction in pH. At the same time, the buffer capacity in the lower parts of the deposit increases as the dissolved carbonate is precipitated, principally as calcium carbonate (calcite). In Figure 3.3, an example is shown of calculated changes in pH with time in leachate from a coal fly ash deposit. Bottom ashes are usually less alkaline in character, so that the fall in pH takes place more rapidly in the case of tipping bottom ashes.

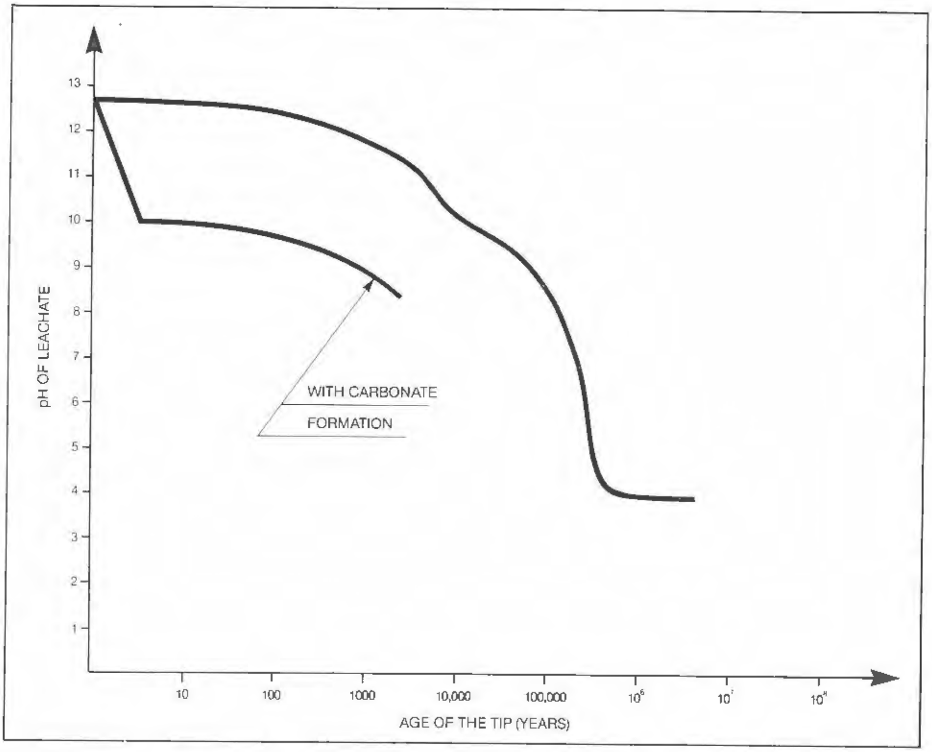

Figure 3.3 **Calculated pH change with time for a deposit mainly of coal fly ash) and the effect of carbonate formation (from Liem, H., et al, 1983: Investigation of Leaching and Weathering Processes in Coal Ashes. KHM TR 105, 1983. In Swedish).**

During its slow downward passage, the leaching water progressively dissolves components until a state of chemical equilibrium is reached. Substances already in solution may be precipitated, as the water constantly passes through zones of differing pH. As the pollutants in general are to be found in different parts of the residue - some in the form of easily-soluble particles (salt crystals), others bound in vitrified silicate matrices - and have varying solubilities under the varying conditions in the deposit, it is unlikely that they will be leached simultaneously or uniformly. In reality, leaching is a complex process which can be calculated or forecast only in general terms, not in detail. For obvious reasons, such calculations must be based on the results of various laboratory experiments, using the results of analysis of real leachate samples as yardsticks with which to compare the calculated results.

The first leachate from combustion residues contains relatively high concentrations of **dissolved salts.** These are mostly in the form of sulphates and sulphites together with borates, chlorides, hydroxides and carbonates, i.e. negative ions associated with positive ions, principally calcium, magnesium, sodium and potassium. In laboratory tests, these concentrations rapidly fall off. However, when scaled up to the size of a deposit in reality, this can be equivalent to several hundred years' leachate production. This is illustrated by a calculation of salt concentrations in leachate from peat ash as a function of time, see Figure 3.4. The calculation is based on laboratory tests in an infiltration box.

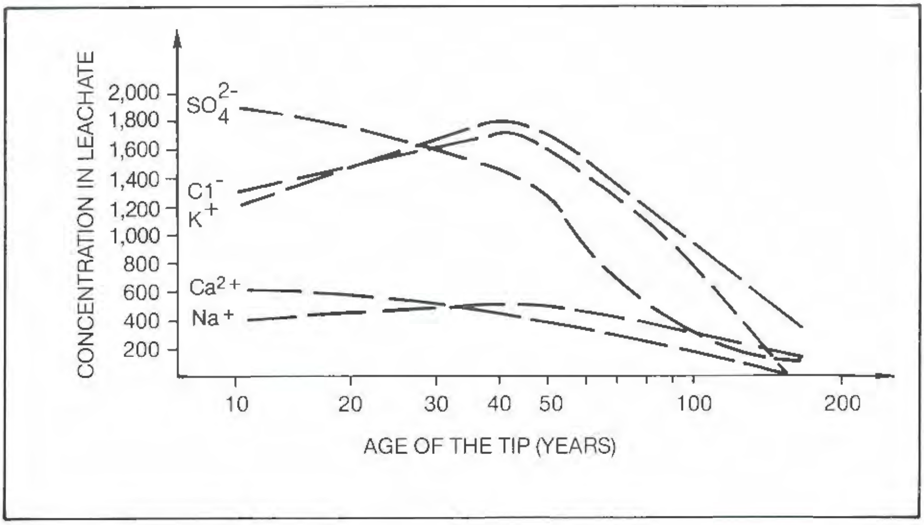

Figure 3.4 The salt concentration with time of leachate from a deposit of peat fly ash. Calculated from tests in an infiltration box (Swedish Geotechnical Institute).

The alkaline and buffer character of the ash results in slow leaching of trace elements, in spite of acid precipitation. This also leads to comparatively low concentrations of trace elements in the leachate, but at the same time it means that leaching will continue for a very long time. Easily-soluble trace elements, which for instance can be enriched towards the surfaces of ash particles, are the first to be leached. Consequently, the highest trace element concentration appears in the leachate that is first produced. As time goes on, also the less soluble trace elements are released. In consequence, trace element concentrations in the leachate will be enhanced for thousands of years. Eventually, when the pH-buffer substances in the ash are consumed, acid conditions may arise in the deposit (in the case of continued acid precipitation) which may result in an increased leaching of trace elements. Before then, at least the easily leached fraction of the elements will be leached, which compensates for increased concentrations.

Calculations based on forced leaching tests to simulate a long-term perspective show that there is no reason to expect any dramatic changes in leaching within a reasonably long range forecast (5,000 to 10,000 years). The calculations are valid on the assumption of reduced leachate production, which is essential to the time scale as the leachate flow determines at what speed the consumption of buffer substances takes place. Accordingly, measures designed to reduce leachate production can promote favourable leaching conditions in the deposit.

However, coal ashes acid in character also exist. The acidity is due to the sulphur dioxide that has been sorbed to the ash and occurs as sulphate or free SO_3. It is easily leached and the ash thereby turns neutral or alkaline in character. As long as the acid conditions in the deposit remain, leaching is more rapid and the trace element concentrations in the leachate produced will be elevated (compared to leaching in normal conditions). In such a case, washing out or chalking of the ash may be an advantageous measure to improve leachate quality. No other methods exist for improving leachate quality easily and at a reasonable cost. In such a case, it is important to determine the dependence on time and leachate flow, as well as to investigate the effect of an incorporation of alkaline ashes in the deposit. Also the need for extended measures to limit leachate production should be estimated.

Van der Sloot et al (1982) state a method of estimating the potential acidity of an ash with knowledge of the content of sulphur oxides (as SO_3), aluminium oxide, calcium oxide and magnesium oxide as shown in Figure 3.5.

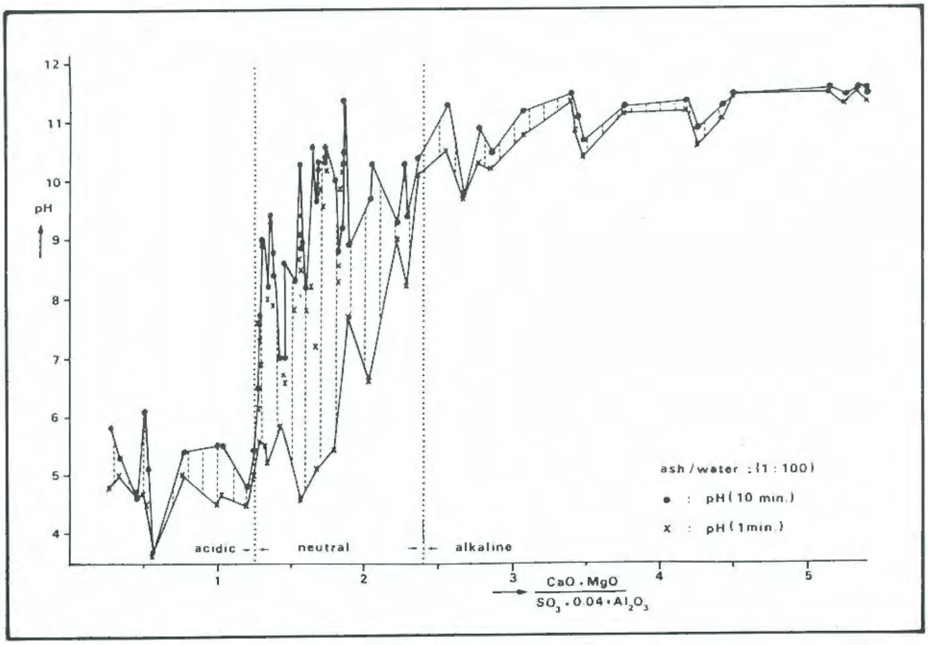

Figure 3.5 Assessment of pH in leachate from coal ash as a function of the content of CaO, MgO, SO_3 and Al_2O_3 in the ash.
An empirical relation evaluated from laboratory tests (van der Sloot, H. et al, 1982: Leaching of Trace Elements from Coal Solid Waste. Netherlands Energy Research Foundation, ECN-120).

Leachate content

The concentrations of different pollutants in leachates may vary within wide limits, partly due to the type of residue but also among different residues of the same type. This is also true for ashes produced in the same plant, so that the ash from a plant shows varying leaching properties with time. The reasons for this are varying contents of trace elements in the fuel, together with differing conditions for combustion.

Handling of fuel and residues involves a mixing of different materials and thereby a homogenization which restricts the probability that leachates with extremely high (or low) concentrations will leave the deposit. Consequently, it is unreasonable to base estimates of environmental impact and health hazards on the highest concentrations in leachate obtained from laboratory analysis. On the other hand, the use of "typical values" alone does not provide an adequate margin of safety for unfavourable conditions. Instead, an estimate of conservative mean values of leachate concentrations that can be expected from entire deposits should be a practicable method. Such estimates were made in the KHM and THM projects and are shown in Table 3.1. The estimates are based on data from laboratory tests carried out within the projects and on data from the literature, and are valid for conventional residues from coal and peat firing, including flue gas desulphurization products.

Table 3.1 Conservatively estimated mean levels of substances in leachate from a tip. The results are typical of leachate produced from residues with unfavourable leaching properties.

Elements (salts)	Symbol	Mean levels in leachate (μg/l) Coal ash (1)	Peat ash (2,3)
Aluminium	Al	5,000	<1,000
Arsenic	As	100	50
Boron	B	20,000	30
Barium	Ba	400	1,000
Beryllium	Be	10	0,1
Cadmium	Cd	20	5
Cobalt	Co	50	5
Chromium	Cr	200	100
Copper	Cu	100	100
Fluorine	F	10,000	2,000
Iron	Fe	10,000	500
Mercury	Hg	10*	0.2
Potassium	K	$5 \cdot 10^5$	$2 \cdot 10^6$
Manganese	Mn	10,000	30
Molybdenum	Mo	5,000	5,000
Sodium	Na	$1 \cdot 10^6$	$1 \cdot 10^6$
Nickel	Ni	100	30
Lead	Pb	200	100
Antimony	Sb	100	10
Selenium	Se	300	10
Thallium	Tl	50	-
Vanadium	V	300	100
Zinc	Zn	300	30
Sulphate	SO_4^{--}	$1 \cdot 10^6$	$5 \cdot 10^6$
Chloride	Cl^-	$1 \cdot 10^6$	$6 \cdot 10^6$

* Very conservatively chosen due to an estimate on a weak basis.

References:

1. The Swedish Coal-Health-Environment Project. Final Report, April 1983.
2. Combustion of peat. The National Energy Administration, Stev 1985:2. In Swedish.
3. Environmental Effects of Wood and Peat Combustion. The National Swedish Environment Protection Board, SNV PM 1708. English abstract.

3.3 Leachate production quantity

The amount of leachate that will be produced is affected by the design of the deposit, the pozzolanic properties, capillarity and permeability of the waste, as well as by climatological factors, such as precipitation quantities and evaporation conditions. In general, the rate of leachate flow will increase with time towards a maximum when stationary conditions have arisen and the deposit is more or less saturated with water. Due to capillary forces, percolating water will be retained in the waste until the water retention capacity is utilized. In calculations of leachate flow, usually only stationary conditions are considered as they cover the longest period and represent the most unfavourable case (highest rate of leachate flow).

In the long-term perspective, the leachate flow will be equal to the amount of water that infiltrates into the deposit. At a well-sited dry deposit, leachate production will be equal to the net percolation from precipitation, as shown in Chapter 2. (In the case of a deposit sited in an outflow area, flow of ground water through the deposit must be considered as well.)

In stationary conditions, the water balance in a deposit can be expressed by the equation (Figure 3.6)

$$\Delta M = P - A - E \text{ (mm/year)}$$

where: ΔM = net percolation (equal to leachate flow)
P = precipitation
A = superficial run-off
E = evaporation from ground and vegetation

This equation is valid for long periods of time (stationary conditions), and calculations are usually based on mean annual values. Unfortunately, most of the included

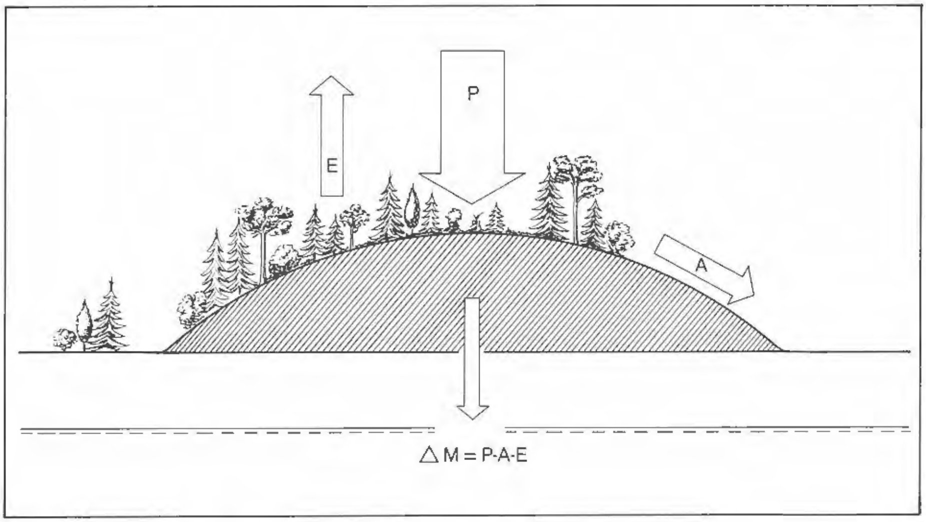

Figure 3.6 Factors affecting the water balance of a deposit.

parameters are difficult to measure, so that only rough calculations of the water balance and leachate flow can be made.

It can be seen from the equation that leachate production can be reduced through increasing evaporation and run-off. By covering the deposit as suggested above (Section 2.3, Figure 2.5), favourable conditions for run-off above the sealing layer can be obtained and at the same time evaporation is promoted by a finishing capillary soil layer. The combination of a drainage layer beneath a layer of capillary soil is helpful with respect to the capillary barrier effect. This effect arises when a capillary suction layer (e.g. of moraine) is drained from below. Infiltration of precipitation into the capillary layer produces water fronts which move downwards. However, the capillary suction effect of the capillary layer prevents water from leaving it and entering the drainage layer until the water content in the capillary layer exceeds the water content at which equilibrium prevails at free drainage (and which is close to saturation for a fine-grained moraine). Water is retained in the superficial layer and remains available for evaporation. On occasions when the capillary layer releases water, an impermeable surface beneath the drainage layer provides satisfactory run-off. However, from an economic point of view, it may prove profitable to exclude the drainage layer. In such a case, the deteriorated conditions for run-off must be compensated for through an improved sealing layer. This is possible through appropriate design when using stabilized fly ash as a sealing layer.

To ensure high evaporation, successful vegetation growth is necessary. However, it is hardly possible to maintain a vegetation which consists solely of such plants that give the highest evaporation. Instead, it is necessary to aim at a vegetation adapted to the biotope and of adequate extent and intensity. In this respect, it is usually advantageous to provide a varying flora comprising species whose growth seasons overlap one another.

By means of measures to promote evaporation, something like half of the yearly precipitation can be restored to the atmosphere (this holds for Sweden and depends to a certain extent on the local climate). The amount of water flow that is restored as superficial run-off depends on the permeability for water in the sealing layer, intensity and duration of the precipitation and also to some degree on the slope.

In calculations of the rate of leachate produced, data on precipitation and evaporation from the site projected should be used. These factors vary greatly with the siting, sometimes also over short distances and between years. As climate data from exactly the site in question are seldom available, measurements from a neighbouring climate station with a representative siting should be used. It is also essential that measurements have been collected for such a long time that precipitation and evaporation representing a "normal year" can be calculated. Long-term series of climate observations have been conducted for many places in

Sweden and are now available at SMHI (Swedish Meteorological and Hydrological Institute). Treatment of climate data is further discussed in "The Water Balance of Sweden. Annual Mean Values (1931-60) of Precipitation, Evaporation and Run-Off". (Eriksson, B., SMHI 1980, in Swedish).

To attain satisfactory sealing of the deposit, stabilized fly ash (which is to be disposed of) can be used as sealing material. Stabilization can be achieved through admixture of FGD-products and/or cement or lime to the fly ash. Usually, compaction alone is not sufficient. The permeability of the sealing layer can be adjusted through controlled stabilization efforts. Limitation of leachate production to 50-100 mm/year should be possible with reasonable efforts, which should be sufficient in most cases. This implies a highest permissible permeability for water in the sealing layer of $1 \cdot 10^{-8}$ to $2 \cdot 10^{-8}$, if this is combined with a drainage layer above. If the drainage layer is to be excluded, a reduction of the permeability to at least 10^{-9} m/s is required. This necessitates more intensive stabilization efforts, but may nevertheless be to advantage from an economic point of view.

General calculations of leachate production as a function of the permeability in the sealing layer have been carried out. These calculations hold for Swedish conditions, and are principally based on data relating to precipitation, evaporation, snow melt and groundwater formation in different regions of Sweden. Results from the calculations are presented in SGI Report No. 28 (in Swedish).

The total amount of leachate produced is influenced not only by the net percolation (calculated per area unit) but also by the total area of the deposit. It is obvious that the smaller the area a deposit occupies, the less the amount of leachate that will be produced. In this respect, high tipping heights are advantageous, as a smaller area will be required. However, it may be difficult to combine this goal with good matching of the deposit with the landscape. High deposits also exert high loads on the ground, which in some cases cause stability problems. High deposits with steep slopes may also cause trouble with slope failures, especially during the construction period.

3.4 Dispersal of pollutants

Two mechanisms come into play when leachate leaks into rock or earth, and determine the concentrations of pollutants in affected water when it reaches the biosphere or wells:

- o Binding of pollutants in earth and rock.
- o Dilution of leachate in groundwater and surface water.

The binding is a result of a number of chemical and physical processes resulting essentially in precipitation and cohesion/adsorption of trace elements to/on soil particles etc., and to diffusion of trace elements into parts of the water body where water motion is insignificant or even non-existent. These effects vary greatly due to differences in soil/rock type, chemical motion etc. Knowledge of these processes is not complete and the binding capacity is difficult to calculate and would require extensive analysis in each individual case.

However, in the long-term perspective the capacity of the soil and the rock to bind substances can be consumed a long time before leaching is finished. Moreover, the processes may be reversible if the conditions, e.g. regarding pH, should change. For these reasons, any conservative assessment of environmental and health risks of leachate in the very long-term perspective should assume only that the binding mechanisms reduce the transport speed, and are thus important only in levelling out the concentrations in time.

Accordingly, the degree of dilution, together with the concentrations in the leachate, are the only factors that are considered in calculations of the environmental load. These calculations, combined with an investigation of the sensibility to disturbances in the environment, form the basis of a judgement as to whether the specifications for protective measures (mainly required permeability of sealing layers) should be set higher than normal. Calculations of the dilution also form the basis when the protective zone for water supplies is applied around the deposit.

Dispersal of pollutants from dry deposits

As stated earlier, siting of dry deposits to infiltration areas for groundwater is advantageous in limitation of leachate production. With an appropriate top sealing of the deposit, all of the leachate that is produced will infiltrate into the underlying ground and form groundwater. In Sweden, the most common terrain in infiltration areas is broken ground with moraine interleaved by exposed bedrock. In such terrain conditions, mainly the following factors are of importance to dispersal:

- o the siting of the deposit in the drainage basin
- o the permeability to water in soil and rock
- o the occurrence of inhomogeneities in the soil (strata) and in the bedrock (fractures)
- o the leachate flow rate

In principle, there are two transport streams open to the leachate, one in the moraine above the bedrock, and one into the bedrock. Usually the permeability in the moraine is higher than the permeability in the bedrock, resulting in groundwater streams both in the moraine and in the bedrock, and leachate will be dispersed in both streams. In areas with homogeneous and poorly fractured bedrock, dispersal will take place mainly in the moraine. In certain cases, when it comes to very fractured and drained bedrocks no groundwater table is present in the moraine and all of the leachate infiltrates into the bedrock.

Moraine is a very heterogeneous soil with a pure structure that varies greatly depending on influence from washing, vegetation etc. This leads to a concentration of groundwater to streams along inhomogeneities in the moraine. Also in the bedrock the groundwater motion is concentrated and takes place along fractures and tectonic zones.

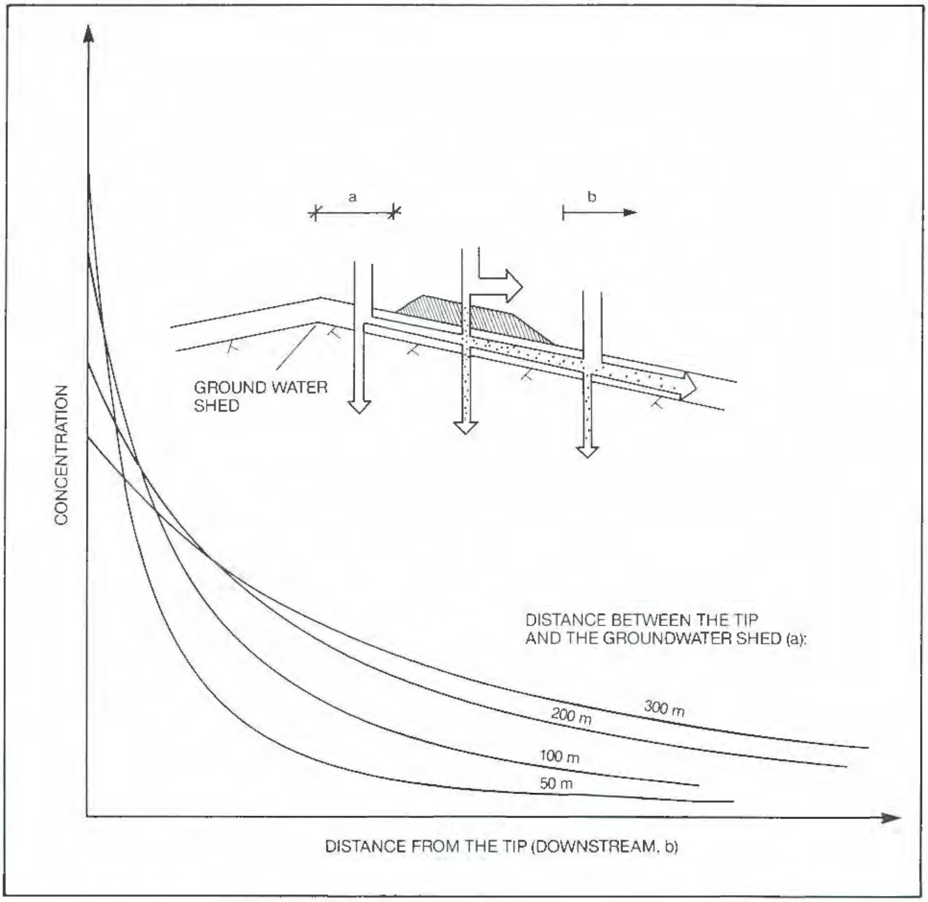

Figure 3.7 Calculated dilution of leachate in superficial groundwater shown in principle as an illustration to the signification of the siting (from KHM, Extensive Reports supporting the Final Report, 1983).

The siting of a deposit within an inflow area generally affects dilution as illustrated in Figure 3.7. The degree of dilution downstream of a deposit has been calculated as a function of the distance to the groundwater watershed. This general calculation shows that it is advantageous for the site to be as close to the groundwater watershed as possible. Indeed, there will be less dilution in close vicinity to the deposit, but the dilution will increase rapidly with the distance. Another reason for such a site is that the conditions for water supplies are considerably better further down in the drainage basin.

As the groundwater reaches an outflow area and turns into surface water further dilution takes place, the extent depending on the water turnover, which is mainly a function of the dimensions of the drainage basin. We can make a distinction between local exfiltration zones which drain smaller areas in the vicinity, and regional outflow areas which drain large areas, including smaller exfiltration zones. It is clear that dilution increases with the dimensions of the drainage basin.

Occurrence of extended, permeable strata in the soil (e.g. sand and gravel deposits) and tectonic zones in the bedrock also affects the dilution (Figures 3.8 and 3.9). Such parts usually drain larger areas and have a good water turnover. The groundwater streams are concentrated to such parts and a rapid dilution of leachate is usually obtained. Normally, larger aquifers such as these occur only in outflow areas. They are regularly used as water supplies, and it has to be proved that the dilution in such an aquifer is of such a magnitude that the elevation of trace element concentrations can be disregarded.

In a homogeneous rock mass, dilution is usually small. However, small fractures and fracture zones also occur in inflow areas, and moderate dilution may be obtained before the leachate reaches larger water bearing fracture zones in the outflow area.

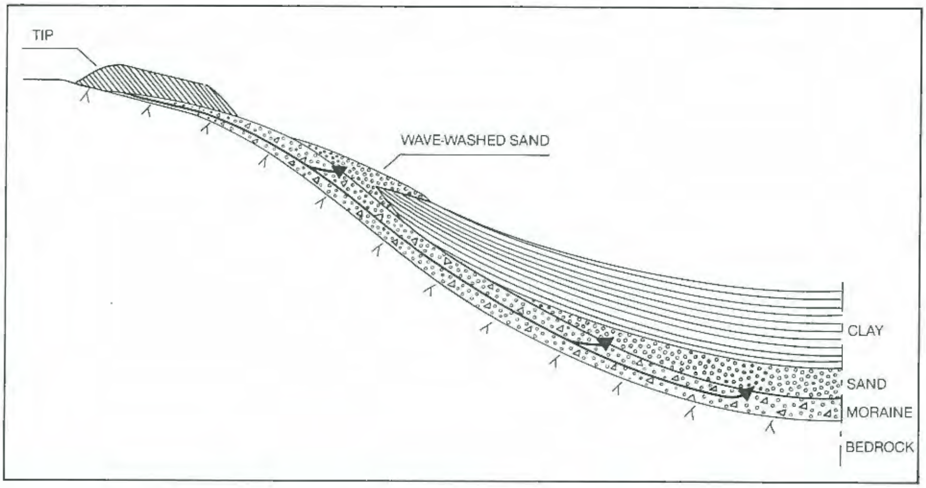

Figure 3.8 Example of dispersal of pollutants in permeable waterbearing stratas in soil.

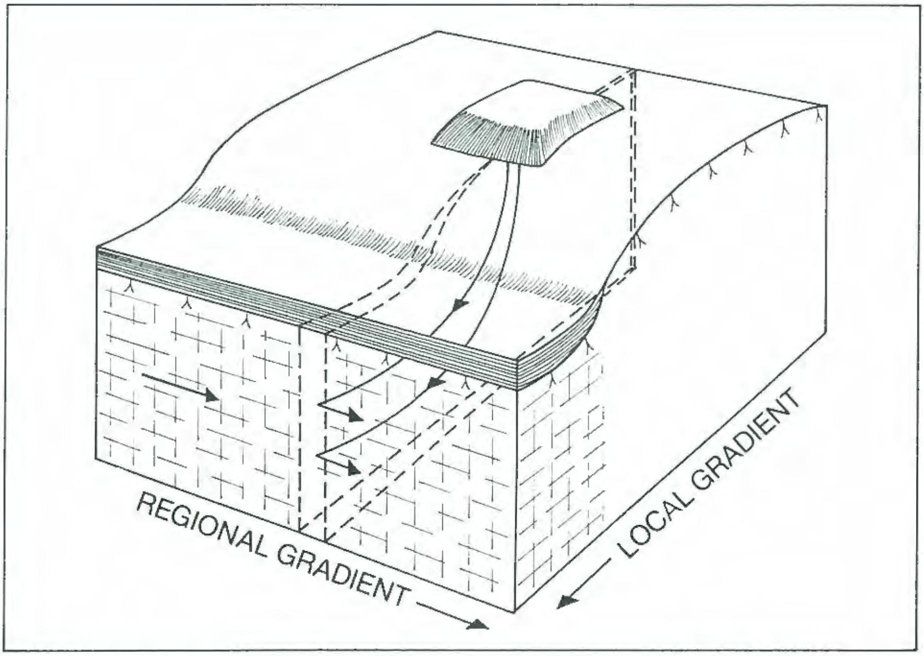

Figure 3.9 In bedrock, the groundwater flow (and transport of leachate) are concentrated to fracture and fracture zones. Discharge of leachate through small fractures in a rock mass out to a regional fracture zone of importance to water supply.

The dispersal and the dilution of the leachate vary greatly from case to case, depending on the conditions in geohydrology. It is not possible to state any general "dilution factors" and calculations must be made for each case. Water movement is a complex process and the geohydrological conditions are not entirely known. Consequently, the calculations must be based partly on assumptions and simplifications and can only be considered as approximate. More precise calculations can be carried out on computers by means of numerical models. However, the reliability of the results is dependent on careful determinations, and the models are generally expensive to use. Because of the costs, such models are at present used only in special cases. Examples showing how approximate calculations of dilution can be carried out, based on conservative assumptions concerning geohydrological conditions, are presented in SGI Report No. 28 (in Swedish).

The basic data for calculations of dilution are determined during the siting investigation. These may include:

- Mapping of drainage basins.
- Occurrence of surface water and determination of water turnover.
- Groundwater levels and groundwater flow.
- Soil stratification and soil depth.
- Nature of the bedrock, occurrence and extent of fracture zones.

Dispersal of pollutants from wet deposits

Siting of a wet deposit in or close to large recipients leads in principle to fast and effective dilution of leachate in the recipient, provided the water turnover at the deposit is adequate. Locally, the water turnover may be restricted due to creeks, natural thresholds at the bottom etc, and stagnant zones may develop. In addition, more or less permanent stratification of the water may cause stagnancy and concentration of leachate to a certain level in the recipient, with accompanying high content of trace elements.

In deep lakes, such stagnancy may develop from temperature differences. In these cases, mixing of water takes place twice a year when the temperature is nearly uniform in the water body during spring and autumn. In the sea, stagnancy develops due to differences in salt content with accompanying density stratification. Such a stratification may be fairly stable with little mixing of water as a consequence. However, an appropriate siting of the deposit at a recipient with sufficient water turnover generally results in good dilution. The degree of dilution can be calculated by means of the leachate flowrate and the water turnover in the immediate vicinity of the deposit. Knowledge concerning water flow direction, streams etc. also allows further dispersal to be estimated. Dilution is affected by diffusion as well, but the effect is marginal and can be omitted.

This fundamental discussion regarding dispersal from wet deposits can also be extended to dry deposits sited close to a large recipient. Naturally, a prerequisite is that leachate flow is unequivocally directed towards the recipient.

The basic data which are required in calculations of dispersal within a recipient are mainly:

- Rate of water turnover.
- Occurrence of local stagnant zones.
- Occurrence of stagnancy due to stable stratification.
- Occurrence of streams.
- Water flow direction.

3.5 Evaluation of environmental load

As earlier stated, the principal factors of interest to health and environment when combustion residues are to be disposed of is leaching of trace elements and salts. In view of the Swedish environmental protection law the following demands can be applied to the deposits:

- o A limited increase in salt and trace element content in groundwater and surface water may be allowed only where the hazard for disturbances in the ecological system is small.
- o The total load on the environment must be kept low enough to preserve a natural flora and fauna.
- o Damage to human health due to, for instance, spreading of dust or pollution of drinking water supplies must not occur.
- o Durability to destructive forces must be sufficient in order to meet the above demands for thousands of years.

The demands imply that an acceptable technique for limitation of leachate flow must be used and that the environmental load in particular should be analysed. The results of such an analysis of leachate, together with dispersal and dilution, have to be weighed against estimates of loads and sensitivities in water supplies and recipients. As such calculations and estimates cannot be carried out precisely but must be considered as approximate, it is important that they be based on conservative assumptions. The basis of such an estimate should include:

- An investigation of existing water supplies in the area.
- Possible sitings for future water supplies in the area.
- An estimate of the character of sensitivity in the recipients.
- Existing load on water supplies and recipients.
- Distance to buildings and other establishments.

Impact on health

Hazards to human health are at hand if the concentrations principally of trace elements in water supplies are elevated. The levels that may occur due to disposal can be estimated by means of leachate concentrations and calculated dilution. Estimated levels can be compared to aims and acceptable or recommended maximum levels. Such levels are specified in Table 3.2. A comparison between maximum levels in drinking water and the conservative mean levels in leachate as earlier stated (Table 3.1) proves that a dilution by a factor of 10 to 100 is required in most cases relating to waste from burning coal and peat.

Human exposure to the pollutants may also occur via food. Therefore the contribution to grain and livestock, for example, should be evaluated as well. There may be a risk of polluted water being used in irrigation. Knowing the amount of water used in irrigation and the area over which this water is spread out, the contribution of trace elements to the fields can be assessed. Naturally, such an assessment also has to be based on calculated trace element levels in the water supply. A general estimate of the hazards involved was carried out within the KHM-project and it was found that, with a dilution of the leachate by a factor of 100 and with normal intensity of irrigation, the additional cadmium available to plants in the ground should be less than 0.2 %.

Regarding livestock, no official limits for drinking water have been established in Sweden. According to the Governing Board of the Swedish University of Agriculture, Forestry and Veterinary Medicine, such limits should be set at least as high as the demands on drinking water for man.

Environmental impact

Environmental influence may arise when leachates reach the surface water and the biosphere. Knowledge of the sensitivity to disturbances within different biotopes is generally poor. Assessments of the influence on the environment due to leakage of leachate are consequently difficult to perform and will suffer from a great deal of uncertainty. Hence, it is of great importance to base such assessments on conservative assumptions.

Assessments can be formed in different ways. In Table 3.2, leachate levels are compared to naturally occurring background levels in Swedish watercourses, and to Canadian guidelines for protection of water organisms. If the aim is to satisfy the Canadian guidelines, a dilution by a factor of 100 (500 in the case of manganese in marine environments) must be ensured. According to the literature, these guidelines coincide for a small number of elements with levels at which toxic effects on water organisms have been observed (summarized in the Final Report from the KHM-project). Because of this, an assessment based on these guidelines will suffer from uncertainty and will leave no margin of safety. For instance, possible effects due to high levels of elements from which data is missing will be disregarded. Synergetic effects which may occur as the levels of several elements are elevated will be neglected as well. Neither will any consideration be shown to the variation in sensitivity that exists between different biotopes. Intakes affected by acidification with, for instance, effects due to elevated levels of certain heavy metals, may increase.

Disturbances in the ecological balance may arise at very low loads from pollutants. This is valid especially for substances that may accumulate in the biosphere. Because of this, long-term exposure to trace elements may cause effects at levels lower than those at which acute toxic effects have been observed. Knowledge of the hazards due to long-term exposure is poor, however, and we have no basis on which to form any judgements of limits.

Instead, a conservative assessment may be based on a comparison with natural background levels. In Table 3.2, available data on background levels in fresh water (in Sweden) and in the Baltic Sea are shown together with the conservatively estimated mean levels.

If leakage of leachate is to cause no noticeable elevation of the background levels, a dilution by a factor of 10^3-10^4 would be necessary, depending on the character of the recipient. It is seldom possible to attain such a dilution in the close vicinity of the deposit. However, the aim should be to limit the area within which groundwater and surface water will be affected by elevated levels of trace elements.

A dilution of such a magnitude that no disturbances arise is not always attainable in the close vicinity of the deposit without unreasonably far-reaching protective measures. With regard to limits for drinking water, a **protection zone** should be established within which no water supplies are allowed. The area should be adjusted in such a way that the dilution outside the area will always exceed a factor of 10-100 (depending on the leachate levels).

Table 3.2 **Comparison between pollutant levels in leachate from coal and peat ash and levels in natural water, guidelines and limit values.**

Elements	Mean levels in leachate[1]		Background levels (Sweden)		Guidelines (Canada)[4]		Limit values (Sweden)[5]
	Coal ash	Peat ash	Fresh water	The Baltic Sea	Protection of fresh water aquatic life	Minimal risk to marine aquatic life	Drinking water
Al (µg/l)	5000	<1000	10-100	0,5	100	200	150[d]
As	100	50	0,1-0,5	0,6	50	10	200(10)[c]
Cd	20	5	0,005-0,05	0,03	0,2	-	5
Co	50	5	0,05-0,5	-	-	-	-
Cr	200	100	0,1-0,5	0,1	40[a]	50[a]	50
Cu	100	100	0,2-2	0,7-0,8	5	10	50[d]
Hg	10	0,2	0,001-0,006	0,003	0,1	-	-
Mn	10000	30	2-5000	0,3	-	20	100
Mo	5000	5000	0,1-2	2,4	-	-	-
Ni	100	30	0,1-1	0,7-0,8	25	2	-
Pb	200	100	0,05-0,5	0,04-0,08	30[b]	10[b]	100
Sb	100	10	0,005-0,2	0,02-0,1	-	-	-
Se	300	10	<0,1-1	-	-	5	50
V	300	100	<0,1-0,5	0,14	-	-	-
Zn	300	30	0,5-5	1,0	30	30	1000[d]
Cl (mg/l)	1000	5000	0,4-19	-	-	-	300
SO_4	1000	6000	4-35	-	-	-	200

Notes:

a) Valency not stated. Cr^{6+} may cause damage at a level of 10 µg/l.

b) Damage reported at 5 µg/l (Litterature review in KHM, Final Report, April 1983).

c) Proposed lowering.

d) Remarkable from a technical point of view.

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3) Mean levels (Kremling, K. unpublished) estimated from:
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4. SITING OF DEPOSITS

4.1 General criteria

Careful siting of waste deposits is an important part of planning a combustion plant. This work can be relatively time-consuming, and should therefore be considered at an early stage in the project. It involves not only investigation of the suitability of potential sites, but also reaching agreement with property owners, and obtaining approval for applications under the terms of environmental legislation, and can take between 2 and 3 years. The general siting criteria are summarized in Table 4.1.

Besides the general requirements for environmental protection mentioned in sections 2.2 and 3.1, there are other factors to be considered when selecting a site:

- o Minimization of transport distance.
- o Isolation - tipping will cause disturbance for a long time.
- o Certain losses of amenity during the construction period are unavoidable (noise, dust, restricted access).
- o Physical conditions for rapid and effective dilution of leachate in the vicinity.
- o Supply of covering material.
- o Natural conditions in the vicinity can limit or exacerbate nuisance.

It is an obvious fact that the possibilities of finding a suitable site for the deposit increase with the size of the area surveyed. Naturally, the transport costs increase with the distance to the deposit. In most cases, fairly extensive investigations are needed before the most feasible site is found. For reasons of efficiency, the investigation can be divided into phases where alternatives are excluded in gradual stages and, if necessary, the search area is extended until no better alternatives can be found. Such a siting strategy, which can be used in most cases, is summarized in Figure 4.1.

Table 4.1 Summary of criteria involved in siting a deposit.

Siting criteria	Environmental criteria
o Size, necessary area	o Surface water situation
o Disposal height	o Groundwater situations
o Transport distance	o Wind conditions
o Accessibility (e.g. road standard)	o Terrestric and limnic ecology
	o Noise
o Topography	o Ground use
o Geology (e.g. type of ground and depth of soil cover)	o Natural amenities
	o Landscape value
	o Recreation
o Geotechnique (e.g. bearing capacity)	o Historical interests
o Supply of native soils for covering material	
Economic criteria	Legal criteria
o Ground costs	
o Construction costs	o Environmental legislation
o Cost for finishing off deposit	o Physical land use planning
	o Authorities' opinion
o Operating costs	o Nearby residents' opinion
o Annual cost	o Administrative responsibility
o Value of completed deposit	

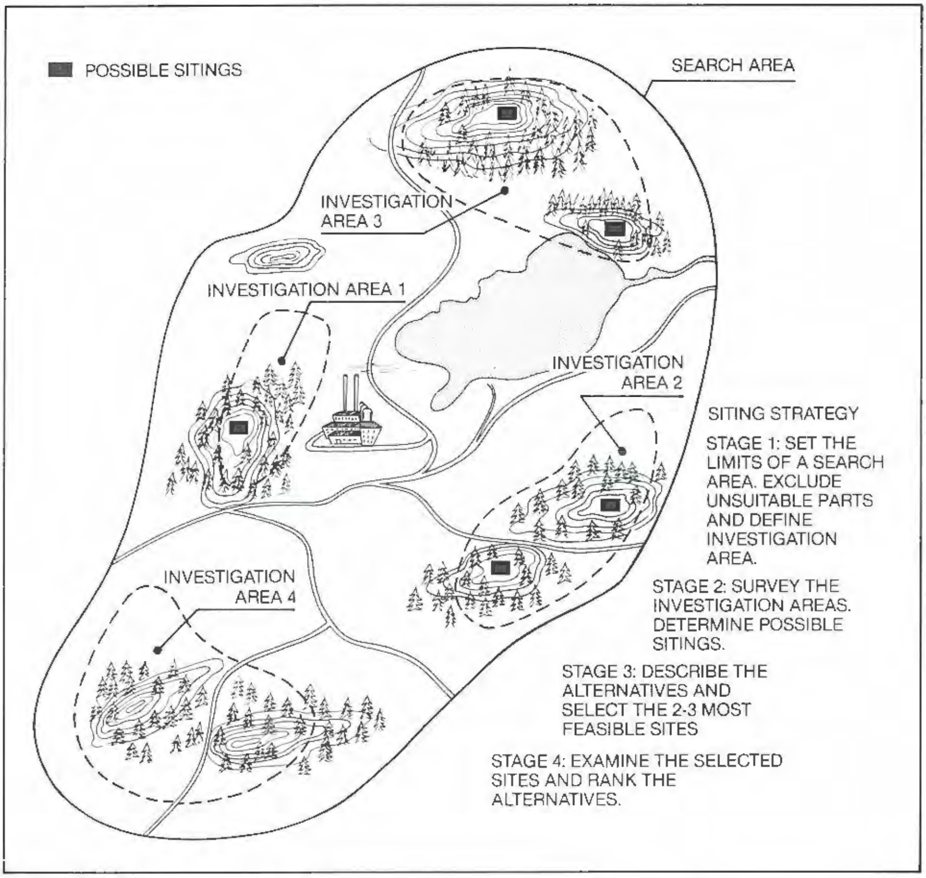

Figure 4.1 Example of a useful siting strategy.

4.2 Field investigations

The initial stages (1 and 2) are preferably based on existing sources of information such as:

- o Topographical maps.
- o Geological maps (Soil type, bedrock, hydrogeology, geomorphology, geotechnique).
- o Economic maps.
- o Land use planning.
- o Earlier investigations (e.g. concerning land and water ecology, natural amenities, historical interest).

From this basis a number of alternatives are chosen. These alternatives should satisfy the following demands:

- Sufficient area.
- Concealment.
- Normally at least 500 m from housing.
- Feasible regarding land use planning.
- Feasible regarding environment, water supply and natural resources.
- Supply of covering material.

The following field investigations should be performed in two gradual stages. The first stage (according to Figure 4.1 stage 3) involves only surveying the alternatives with the aim of limiting the complete investigations to 2 or 3 alternatives. The surveys should comprise the following conditions:

- Distribution of soil type and nature of bedrock.
- Distribution of inflow and outflow areas.
- Occurrence of fracture zones in the bedrock.
- Occurrence of water supplies and ground water aquifers.
- Distribution of species of flora and fauna.
- Possibilities for concealment, wind protection and noise limitation.
- Need for construction of roads.
- Property owners.

The alternatives remaining after the survey should be the object of extended field investigations, stage 4, with the following purposes:

- to analyse stability in the area.
- to determine the risk of settlements in the subsoil and to prescribe reinforcement measures if necessary.
- to determine the probable dispersal paths of leachates.

- o to determine the possibilities for dilution of leachate and to throw light upon the possibilities for sorption of elements to soil and rock.
- o to determine necessary demands for sealing, and extension of the protective zone.
- o to determine the need for other protective measures such as intersecting ditches.
- o to determine the need for concealment, wind protection and noise limitation.

The factors listed above are adapted to siting of dry deposits. However, it is necessary to clarify most of them also when siting wet deposits. Of further interest in the case of wet deposits are measures to determine:

- o the permeability to water in the underground.
- o the character of sediments and reproduction areas for fish.
- o (water) streams, conditions for dispersal and dilution of leachate and the hazards of environmental influence.

The purpose of investigations of areas intended for wet deposits are mainly to calculate or estimate the following factors:

- o Influence on recipient, landscape and land use.
- o Need for damming and diversion of rivers or streams into new channels.
- o Need for sealing in dams and covering.
- o Water balance.
- o Filling height.
- o Pipelines and pumping equipment.
- o Preliminary estimate of costs.

5. ENVIRONMENTAL CONTROL ASPECTS IN THE DESIGN AND CONSTRUCTION OF DEPOSITS

5.1 Environmental control during construction

During construction contaminated water will probably be produced from rainwater running off the deposit. In the case of wet deposition also water used for hydraulic transport will be polluted. Such excess water produced during construction should be considered and treated as leachate.

In the case of **wet deposition** including hydraulic transport, large quantities of contaminated water will be produced. This water will be decanted from the pond while the ash is settling. The most appropriate treatment of this water is to make it recirculate for reuse in the transport system.

In the case of **dry deposition** one important measure is to build intersecting ditches to cut off any surface water which would otherwise reach the disposal area. This water must be led past the disposal site. The second objective is to collect rainwater running off the deposit.

To prevent this water from reaching the groundwater, it must be ensured that the ground beneath the deposit is relatively impermeable, and that there is a slope from the deposit towards suitable drains. In order to prevent the formation of excessive height differences on the bottom, it is suggested that the bottom should be corrugated. The drains should be connected to a peripheral ditch system around the site in which the water will be led to a surge pond. The necessary arrangements are shown in Figure 5.1. In the case of large deposits, it is recommended (and may be necessary) to build temporary ditch systems to avoid having an excessively large run-off area.

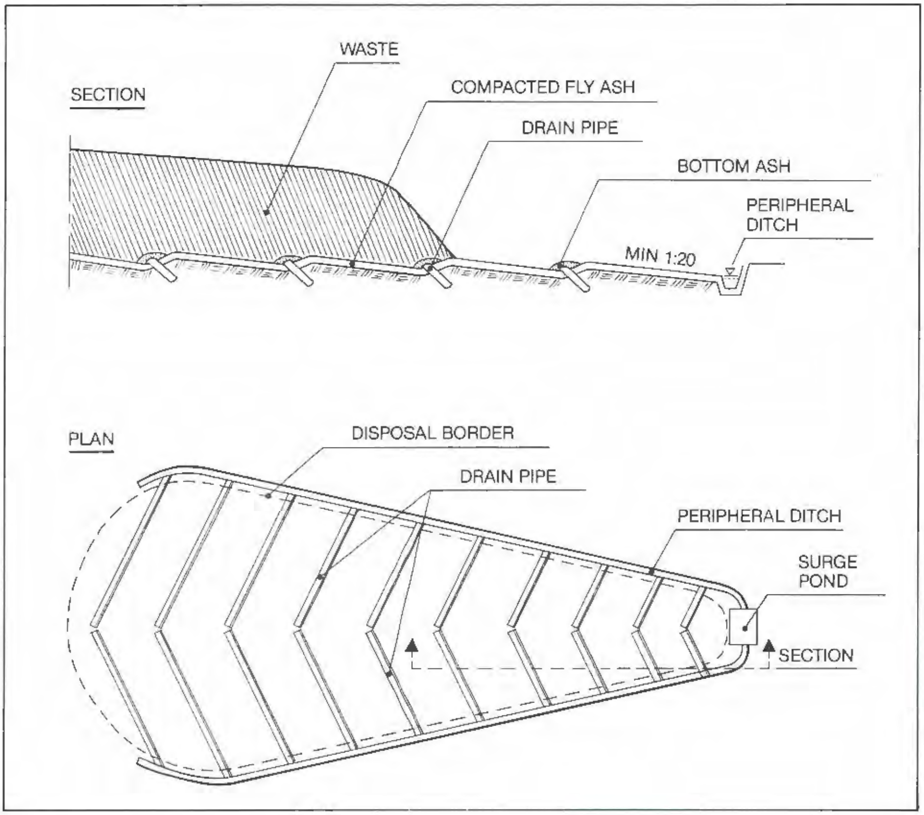

Figure 5.1 Arrangements for collection of run-off during construction.

To ensure adequate impermeability of the bottom layer, properly compacted fly ash should be sufficient. If necessary, FGD residues and cement or lime can be added to the fly ash to ensure adequate sealing. However, it is important that the permeability of this bottom sealing is higher than the permeability of the future top sealing, otherwise leakage of leachate after finishing off the deposit will take place in the toe instead of percolating to the groundwater.

The collected run-off can in most cases be infiltrated into the waste and held there by means of capillary forces during the lifetime of the deposit, i.e. until the deposit is sealed and finished off. In this way, problems associated with treatment and dispersal of contaminated water can be avoided. With this arrangement, the water can also be used to prevent dust formation. However, as the infiltration capacity of the waste is exceeded during heavy rainstorms and (at least in Sweden) during snowmelt, a surge pond is necessary.

5.2 Environmental control in the long-term perspective

As already explained in Section 2.3, the most important environmental control factor is proper sealing and finishing off of the deposit with respect to the long-term perspective.

As recommended in Section 2.3, leachate production should be restricted by means of a top sealing layer. The effect of this sealing layer may be improved by using a drainage layer above. To protect the sealing from erosion, and to permit vegetation to take root, a covering layer of, for instance, moraine is required. The drainage layer may be excluded, if the resulting impairment in run-off conditions is compensated for by an equivalent improvement of the sealing layer. The recommended covering of the deposit is shown in Figure 5.2.

The sealing layer can be built of fly ash, stabilized with FGD residues (if available) together with cement or lime. The impermeability can be improved by adjusting the amount of stabilizing agent. The normal demand in Sweden is that the leachate flowrate should be reduced to 50 mm/year, in certain cases 100 mm/year. This aim implies a highest allowed permeability of about 10^{-8} m/s if a drainage layer

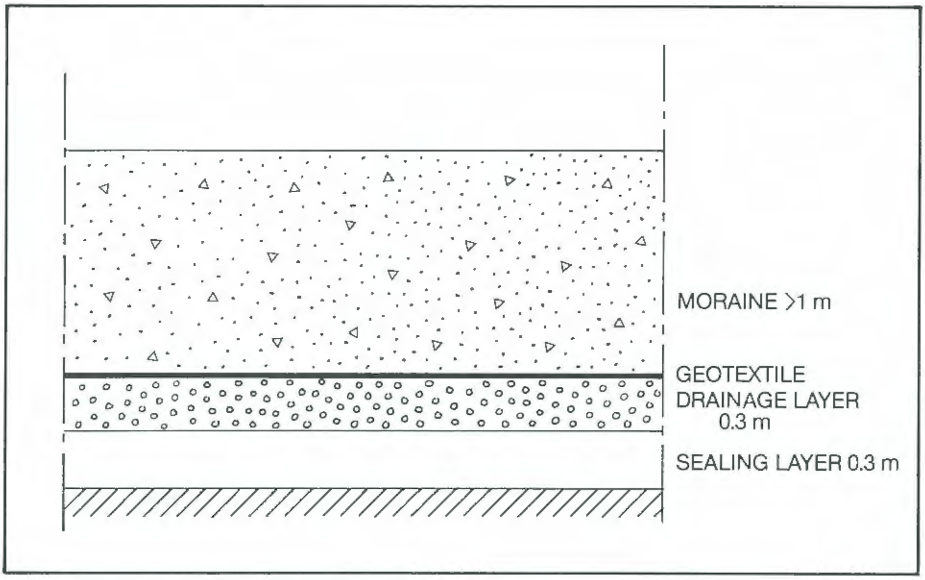

Figure 5.2 Design of the recommended covering.

is to be used, in other cases the permeability must be reduced to about 10^{-9} m/s (based on conservative calculations). The demand on impermeability depends to some extent on the Swedish climate region in which the deposit is sited.

Sealing layers consist generally of fine-grained and capillary materials and are in general sensitive to freezing (ground frost). In view of the demands for long-term durability, the sealing layer has to be either protected against frost or made durable to frost. Sealing layers durable to frost can be constructed by means of certain stabilizing agents. The specifications must be verified in each case. Protection against frost can be obtained by increasing the thickness of the soil covering to a certain extent, so that the frost never reaches the sealing layer.

If a drainage layer is to be used, this should have a thickness of at least 0.3 m and be separated from the covering layer by means of, for instance, geotextile.

The covering soil layer should have a thickness of at least 1 m to ensure the durability of the sealing layer. In addition, the covering layer should be dimensioned with respect to vegetation growth, and the species of vegetation that will occur on the deposit. The roots of certain trees can reach considerable depths and thereby penetrate the sealing layer, increasing its permeability. Such effects must be taken into account. The covering layer should consist of capillary soil resistant to erosion. Moraine, if not too coarse-grained, is a suitable soil type, common throughout Sweden. Homogeneous, coarse-grained sediments (sand and gravel) are unsuitable in view of their poor water retention capacity, which may create difficulty in plant growth and a less efficient capillary barrier effect (if a drainage layer is used). If a suitable moraine is not accessible, fine-grained sediments may be used as covering soil. Homogeneous fine-grained sediments are, however, easily affected by erosion, so that protective measures, such as rapid establishment of vegetation, are necessary.

Vegetation growth on the finished-off deposit is important not only to prevent erosion, but also as a measure to reduce leachate production by increased evaporation and to restore the landscape. As the covering layer usually consists of a meagre soil, measures such as establishing topsoil may be necessary. The species to be used should be determined by the projected land use.

The measures stated above relate to finishing off wet deposits as well as dry deposits. In the case of a wet deposit, certain adjustments of the (naturally level) upper surface in terms of slope and drainage, such as those proposed in Figure 5.3, may be necessary. Furthermore, wet deposition involves tipping in outflow areas for

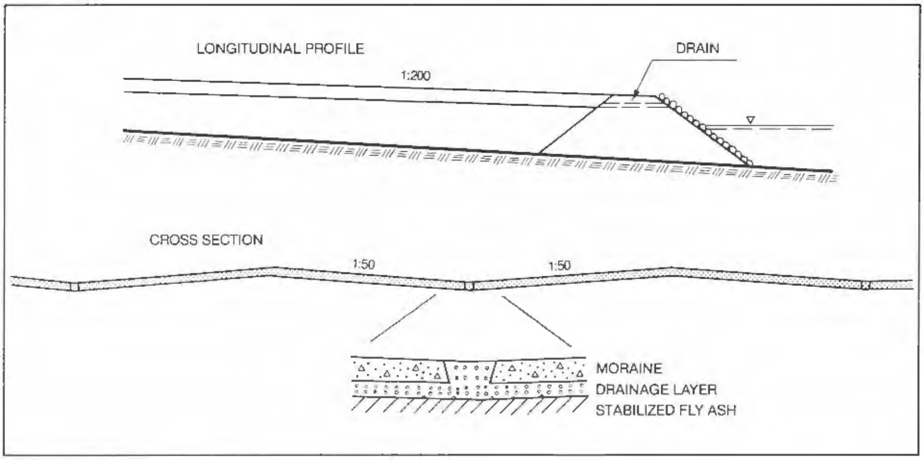

Figure 5.3 Suggested adjustments of the upper surface of a wet deposit. The measures aim at improving the conditions of run-off.

groundwater. However, in most cases it is possible to change the area into a (local) inflow zone. The prerequisites for this are that the deposit is filled to a sufficient height, and that the surface sealing and the outer dams are designed to obtain the desired water balance. The aim is, of course, to reduce the total amount of water that reaches the deposit, from groundwater as well as from precipitation. The groundwater level inside the deposit should be kept at a sufficient height to prevent groundwater inflow from outside (in stationary conditions). On the other hand, it must not be so high that the surface becomes marshy. To obtain a favourable water balance in the deposit, the permeability of the dams should be adjusted with respect to the permeability of the bottom and surface sealing. These calculations require certain investigations in the field, such as surveying naturally occurring soils in the bottom and their permeability together with hydraulic gradients.

Finishing off the deposit as described above is appropriate principally when the finished deposit is to be restored to blend with the landscape or, for instance, changed into woodland. Of course, other types of land use may come into question and, consequently, the finishing-off measures must be adjusted to the planned land use. For instance, reclaimed land (by means of wet deposition) intended for use as building land, harbour areas, industrial areas or storage areas must normally be level. It would then be necessary to reduce the infiltration of precipitation by some other means, by asphalting the surface or applying some other system of collection and disposal of surface water.

5.3 Inspection

Tipping of solid waste is permitted under certain conditions. The licensing body shall in each case indicate the specific terms and conditions for granting a permit. A most important factor is regular inspection as set out in the inspection programme proposed by the applicant and examined and confirmed by the county council (inspecting body).

As shown in Section 2.3, environmental effects from a deposit may not begin to become apparent until long after tipping has stopped. As a result, inspection programmes should be aimed firstly at details of deposit construction and secondly at operation. Inspection and approval of design and construction should concentrate particularly on measures intended to limit environmental effects:

- o Inspection of the bottom in order to estimate the need for reinforcement or excavation of unsuitable soil (applicable to wet deposition).
- o Inspection of dam construction (applicable to wet deposition).
- o Inspection of the bottom sealing and draining (applicable to dry deposition).
- o Inspection of completed ditches.
- o Spot tests on leaching of the waste.
- o Inspection of levelling of the filled deposit.
- o Inspection of the surface sealing.
- o Inspection of the surface drainage layer.
- o Inspection of the covering.
- o Inspection of vegetation growth and erosion.

The inspection of construction should include materials testing as well as inspection of the workmanship.

Inspection/approval of operation should be aimed firstly at water quality inspection. Water samples should be taken regularly both in groundwater and in surface water. All the formations that may carry pollutants from the deposit should be included in the inspection. Sampling should be started at an early stage, preferably during the site investigation, in order to obtain reference levels of the water quality. Sampling should be frequent during the years immediately after deposition has started (at least 4 times a year). The frequency can then be reduced but with regard to the character of the waste, water quality inspection should be continued for a long period also after the deposit is finished off. Usually, the water analyses may comprise only a few representative elements. These elements should be chosen in view of the following criteria:

- o Their chemical characteristics should represent other elements as well.
- o The difference between leachate levels and background levels should be large.
- o The elements should be relatively mobile.
- o Interference with other outlets should preferably not occur.
- o The analysis should be easy to carry out even at low levels.
- o Toxicity of the elements.

At inspection of water quality when tipping residues from coal and peat burning, the following analyses are frequently suitable:

- o The trace elements arsenic, cadmium, copper and molybdenum.
- o The anions sulphate and chloride.
- o Electrical conductivity and pH.

The analyses should be carried out by means of methods with such a high degree of sensitivity that the background levels can be determined. Even small elevations of the levels can then be detected, and a rapid and proper indication of any leakage of leachate will be obtained.

6. ENVIRONMENTAL CONTROL IN UTILIZATION OF COMBUSTION RESIDUES

Large quantities of combustion residues, particularly coal ashes, are well adapted to utilization. The main objects for utilization of ashes are as fill for roads and levelling work and as raw material in the cement and construction materials industries. The advantages of utilization are obvious; a waste that produces a cost in disposal is turned into a useful raw product, thereby saving natural resources such as sand and gravel deposits. Of course, environmental and health control aspects are equally important when the residues are intended to be used as when the residues are to be deposited and it may be necessary to undertake certain protective measures.

Coal fly ash is used as **raw material in cement and concrete.** Handling of dry fly ash causes inconvenience to the working environment due to spreading of dust. However, to maintain a healthy working environment it is sufficient if fly ash is handled in the same way as cement. In a long-term perspective, houses, bridges, etc. built of concrete will weather or disintegrate during demolition. The percentage of fly ash in the demolition debris will be relatively low. This debris will then be used as fill. The probable environmental impact will then be negligible, because the fly ash will be relatively well enclosed and will thus be protected against leaching of trace elements.

Combustion residues can be used to a great extent as **fill in conjunction with construction work.** Primarily bottom ashes from coal firing have been used, but also fly ash may well be used. In particular, both fly ash stabilized with cement and fly ash containing dry spraying FGD residues have a potential as construction material for ground construction work. Other combustion residues such as peat ashes and slag from waste incineration may come into use, as well as additional domains for construction use such as soil strengthening. An aspect common to these residues and to their utilization domains is that the health and environmental aspects connected with utilization can be taken into consideration essentially in the same way as in deposition of the residues. From the environmental and health point of view, fill for the construction of new harbours or levelling of large areas should be treated in the same way as the deposition of residues. The measures that will be taken to reduce leachate production must of course be adapted to the planned land use, but these measures should correspond to those relating to the deposits in terms of their effect. When the quantity of fill is limited, the demands for environmental protection measures may be less rigorous. However, the aim should be to restrict the environmental load to the same extent as if the residues were disposed of in a deposit.

Using environmental load calculations, the required environmental protection measures can be estimated. Such calculations can be performed in the same manner as the assessments of health and environmental influence from a deposit as suggested in Chapter 3. The calculations require knowledge (or conservative assumptions) of dispersal and dilution of leachate from the fill, as well as of recipients and groundwater supplies (existing and future). The leachate levels can be compared to background levels and limit values, and the contribution of trace elements to the environment can be compared to the amount emitted from other sources. On the basis of such calculations the required demands for environmental control measures at a fill can be stipulated.

STATENS GEOTEKNISKA INSTITUT
Swedish Geotechnical Institute
S-581 01 LINKÖPING
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Besöksadress: Olaus Magnus Väg 35
Postadress: 581 01 Linköping
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