25 Environmental Aspects of Drainage

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25.1 Introduction

Worldwide, the introduction of drainage systems has conserved or improved millions of hectares of land for agriculture or other purposes. The benefits of drainage (i.e. the gain in land, better quality land, or the sustainability of irrigated land use) are associated with certain disadvantages. Sometimes, the gain in one location (e.g. the creation of new agricultural land) is associated with a loss in the same area (e.g. the disappearance of an ecosystem). More commonly, however, the improvement or gain in one place leads to a burden in another place. Examples are the environmental problems created by the disposal of drainage effluent polluted with salts, nitrates, herbicides, pesticides, or harmful minor elements like selenium.

The purpose of this chapter is to assess the impact that drainage projects have on their surroundings (i.e. on the environment), and to introduce methods to assess these impacts.

This chapter, then, starts with a summary of the objectives of drainage (Section 25.2). Section 25.3 introduces three categories of environmental impacts. Sections 25.4 to 25.6 deal more extensively with the drawbacks, side-effects, or problems created by drainage inside the drained area, and upstream and downstream of it. There is growing realization that assessments of drainage needs, possibilities, and costs are incomplete if no consideration is given to the adverse effects. Section 25.7 discusses the various ways of assessing these effects through an environmental impact assessment.

25.2 Objectives of Drainage

The three main objectives of drainage in agricultural land are:
- Drainage to prevent or reduce waterlogging;
- Drainage to control salinity;
- Drainage to make new land available for agriculture.

The first two objectives are aimed at conserving or improving existing agricultural areas (vertical expansion), whereas the third objective brings new areas into cultivation (horizontal expansion).

The installation of a drainage system has two direct effects (Chapter 17):
- It reduces the amount of water stored on or in the soil;
- It introduces a flow of water through the drainage system.

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These two direct effects are usually not the main objectives of drainage. However, they trigger many indirect effects, and these are often the true reasons for drainage. The various objectives of drainage are:

- The removal of excess surface water or groundwater to achieve:
  - Better soil aeration leading to higher productivity of crop land or grassland through:
    - Deeper rooting of the crops;
    - Less restricted crop choice;
    - Fewer weeds;
    - Better use of fertilizer;
    - Less denitrification;
    - Better grass swards.
  - Drier soils leading to:
    - Better accessibility of the land;
    - Greater bearing capacity of the land;
    - Better soil workability and tilth;
    - Extension of the period in which tillage operations can take place;
    - Increased activity of micro-fauna (e.g. earthworms), which improves permeability;
    - Better soil structure, which also improves permeability;
    - Higher soil temperatures, which allows the earlier growth of crops, particularly horticultural crops, and grasses.
- Leaching for salinity control:
  - To prevent increases in soil salinity in the rootzone and thus make irrigated land use sustainable in the long term;
  - To remove salts for the introduction of salt-sensitive crops or to allow a wider range of crops;
  - To reclaim saline and/or sodic soils.
- Leaching for acidity control:
  - To prevent a build-up of acidity in the rootzone of potential acid sulphate soils;
  - To reclaim acid sulphate soils.

Besides these agricultural objectives, there may be other reasons for installing drainage systems. We could mention drainage for health, drainage to establish or improve recreational facilities, and, more rarely, to create areas for wildlife development (habitat construction). In this chapter, we shall be focusing mainly on the environmental side-effects of agricultural land drainage, mentioning the other aspects only occasionally. We also restrict ourselves to the technical issues, thereby giving no consideration to socio-economic issues.

25.3 Environmental Impacts

When we introduce a drainage system into an area, we are manipulating the environment. We can define 'the environment' as the totality of ecosystems on different scales – from local, to regional, to global. An 'ecosystem' (or natural system) is a dynamic arrangement of plants and animals with their non-living surroundings of soil, air, water, nutrients, and energy. Lakes, mangrove forests, swamps, or grasslands are ecosystems. So, too, are rice fields, polders, fish ponds, pastures, and home gardens. The latter category are modified by human activities; they are therefore called 'managed ecosystems', which are simple in comparison with the diversity of life in 'undisturbed ecosystems'.

Successful development depends on the rational use of environmental resources and on minimizing or eliminating any adverse environmental impacts by improving the planning, design, and implementation of projects. We want the land use in the area to be sustainable, which means that we want to manipulate the environment in such a way that its productivity and its fertility do not diminish with time to the detriment of human welfare.

The Commission on Ecology and Development Cooperation (CEDC 1986) distinguishes three categories of environmental impacts:
- Disturbance and/or pollution of the environment;
- Depletion and/or over-exploitation of the natural resources;
- Destruction and/or impairment of the natural ecosystem.

Disturbance

A disturbed and/or polluted environment is the least severe category of damage resulting from human interventions in natural ecosystems. Careful planning can keep the impacts on the environment within acceptable limits. Drainage is, in principle, the regulation of the water-management system. Open drains are constructed, flows in natural streams are altered, and saline drainage effluent is discharged to rivers. All these activities have an effect on the environment. These effects are difficult to predict in full, but ecological studies may provide an insight into the main environmental consequences of the planned drainage systems. And, if these systems are carefully planned, the changes in the existing ecosystems can be kept as intended. Examples are the change in habitat as a result of the introduction of drainage (Section 25.4.2) and the effect of saline seepage from drainage canals on adjacent agricultural areas (Section 25.5.4).

Depletion

The depletion or over-exploitation of natural resources is often a gradual process, which in the beginning may not appear to be severe, but in the end can have major repercussions. Especially when we realize that what happens on a small scale at field level can also take place on a large regional scale. Examples are the erosion of fertile topsoil by overland flow (Section 25.4.8) and the leaching of nutrients and organic matter (Section 25.4.9).

Destruction

The destruction and/or the impairment of a natural ecosystem is the most severe category of environmental impacts. When changes in the ecosystems are irreversible, extreme care should be taken before any activities that will produce these consequences are undertaken. Examples are the reclamation of swamps, which will result in the irreversible shrinkage of the newly reclaimed soils, or the oxidation of peat soils after the watertable has been lowered (Section 25.4.4). Another example is the acidification of potential acid sulphate soils (Section 25.4.6).

To assess the environmental impacts of the two direct effects of drainage (i.e. a lower watertable and an increase in discharge; Section 25.2), they can be categorized in predictable and unpredictable, primary and secondary, upstream and downstream of the project area, and in the project area itself.

Impact predictability, in terms of intended and unintended effects, increases when appropriate investigations are conducted prior to project execution. But surprises, often awkward ones, cannot always be prevented, particularly in the drainage of irrigated arid lands. This is clear in the following quote from the Committee on Irrigation-Induced Water Quality Problems (1989: p. 96):

> The irrigation of arid lands brings about major changes in land use and in the distribution and use of water. This in turn leads to a redistribution of salts, with unintended and sometimes unanticipated consequences. These impacts of redistribution are often minor initially, but they tend to become increasingly important over time.'

25.4 Side-Effects Inside the Project Area

25.4.1 Loss of Wetland

Wetlands are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. When wetlands are reclaimed, they lose their original function as lands harbouring particular plant and animal communities. In the past, the loss of 'useless wetlands' caused little concern. Fortunately, in recent years, people are beginning to realize that the disappearance of wetlands is not only of concern to bird-watchers and others interested in a 'natural' environment, but should be of concern to everybody.

Before drainage, the agricultural value of wetlands is generally very low. From an agricultural point of view, the loss of such poorly productive land is easily compensated for by the greater land productivity resulting from drainage. On the other hand, wetlands are usually of great value as wildlife habitats, flood-storage areas, groundwater-recharge areas, siltation basins, ecological filters, and ecological and recreational areas. The values of these functions are very difficult to estimate in monetary terms.

Whether the loss of wetland is acceptable will depend on the balance between the somewhat objectively assessable agricultural gains that result from drainage and on the subjective value which the wetland has as nature or recreation area. As the latter effects cannot be expressed in monetary terms, it is difficult to assess the costs of introducing drainage (Section 25.7). In many developing countries, which are striving to increase their agricultural production, the balance tips in favour of agricultural productivity, and in many developed countries, which can afford to treasure scarce nature areas, the balance tips towards the side of nature.

One can adopt the pragmatic attitude that, up to a certain limit, the loss of wetlands – often the only spaces not occupied by man – is acceptable provided that the reclaimed land is really productive, and if that production is necessary for food or employment and cannot be achieved by cheaper means. These conditions are seldom met in tropical peat soils, planosols, and acid sulphate soils, which, for various reasons, are difficult to reclaim and are poor in productivity, so that the positive effects of reclamation are often overshadowed by the negative effects.

The reclamation of alluvial lowlands in river deltas, which are generally more fertile than the soil types mentioned above, shows more promise, but there, too, the possible gains and losses should be equated with each other. Over the past centuries in The Netherlands, vast areas have been reclaimed from the sea or lake bottoms to be brought under agricultural production (Example 25.1). At present, however, reclamation activities have come to a standstill as a result of a combination of factors in which environmental considerations, absence of the need for more agricultural land, and high costs play a major role.

Example 25.1

The Netherlands, with a total land area of 3 400 000 ha, has a long history of land reclamation and protection against water. At present, about one-third of the country is situated below mean sea level. The endiking and subsequent reclamation of coastal salt marshes started about 1000 years ago. Since that time, some 400 000 ha of salt marshes have been reclaimed. In roughly the same period, inland peat moors and swamp forest were reclaimed by drainage, resulting in the reclamation of another 400 000 ha. From the middle of the sixteenth century, windmills made it possible to drain inland lakes; about 315 000 ha of former lakes were reclaimed in this way (Schultz 1983). On the other hand, land has been lost over the centuries by the inundation of coastal areas after dike breaches (about 570 000 ha), while the mining of peat soils has resulted in new lakes being formed (about 100 000 ha).

Since the 1960's, opposition to the loss of wetlands has gradually mounted and the reclamation of new areas has come to a standstill. Instead, in some reclaimed areas, wetlands have been created by partial drainage and the associated control of the levels of surface water and groundwater. An example is the Oostvaarders Ponds, which, through good management of soil and water over the last two decades, have become one of the richest areas of waterfowl and shorebirds, both resident and migratory, in western Europe.

25.4.2 Change of the Habitat

Improving the drainage in land that is already used for crop production or grazing may appear environmentally less damaging than converting wetlands into crop land. But, in both humid and arid regions, improved drainage can still lead to a drastic change in habitat conditions. Consequently, plant and animal life can be considerably affected (Example 25.2).

Example 25.2

In Kalimantan, Indonesia, large parts of the coastal lowlands were brought under cultivation, resulting in the acidification of the soil (as will be explained in Example 25.6). The drainage of these acid sulphate soils inevitably increases the acidity of the drainage water, which can have environmental effects both within and downstream

Table 25.1 Effect of reclamation of coastal lowlands on the fish population (after Klepper et al. 1992)

Area	Conditions	No. of fish species
Sungai Negara	Not drained , not acidified	96
Pulau Petak	Drained, acidified	29
Tabunganen	Drained, not acidified	43

of the project area. As an illustration, the number of fish species after reclamation dropped from 96 species in an undisturbed area to only 29 species in a drained, acidified area (Table 25.1). Although the decrease probably cannot be completely attributed to the reclamation practices, it is a good illustration of how human activities can affect the fauna.

25.4.3 Lower Watertable

A direct effect of a drainage system is a lower average watertable. This systematic lowering of the watertable increases agricultural production, but can also have serious side-effects on the same agricultural production (Example 25.3), and on nature conservation, forestry, and the landscape (e.g. it can cause subsidence). One way to reduce these negative side-effects would be not to keep the drainage base at the same level throughout the year, but to accept higher levels in periods that are not critical for agriculture or periods with water shortages. For example, water levels in the open drainage systems in The Netherlands are generally allowed to be higher in summer (the period with a rainfall deficit) than in winter (the period with a rainfall surplus).

Example 25.3
In The Netherlands, the average watertable in areas of rural development projects has dropped 0.35 m over the last 30 years as a result of improved drainage (Rolf 1989). This has significantly increased agricultural production, but it also has its negative impacts on the same agricultural production. During summer, the lower average watertable has increased water shortages. As a consequence, in the period from 1976 to 1985, the use of sprinkler installations for supplementary irrigation increased from 12% of the total area to 17.5% (Arnold and de Lange 1990).

25.4.4 Subsidence

A well-known effect of drainage is the subsidence of the land surface (Chapter 13). Especially the irreversible subsidence of peat soils as a result of oxidation has major repercussions on the environment. The rate of oxidation is related to the depth of the watertable and the temperature: with a high watertable and a low temperature, the oxidation rate is low. Thus, to conserve a peat layer, a high watertable should be maintained. But a high watertable implies a low bearing capacity of the land. Peat soils are therefore unsuitable for arable crops, which require a relatively deep aerated layer and a good bearing capacity to allow the use of machinery, unless one accepts a high subsidence rate and can pay for the ever-increasing pumping costs to keep the watertable deep enough.

Although most peat land was originally reclaimed to create crop land, arable agriculture on peat soils is rare nowadays in The Netherlands. Most of the peat soils are used for grassland and on a smaller scale for horticulture (flowers and vegetables). To increase the bearing capacity, farmers tend to lower the watertable, resulting in a more rapid subsidence (Example 25.4). Elsewhere (e.g. in Florida, U.S.A.), arable use, accompanied by subsidence of more than 5 cm a year, is not uncommon. In drier climates, there can be a subsequent danger of wind eroding the top of the peat soil.

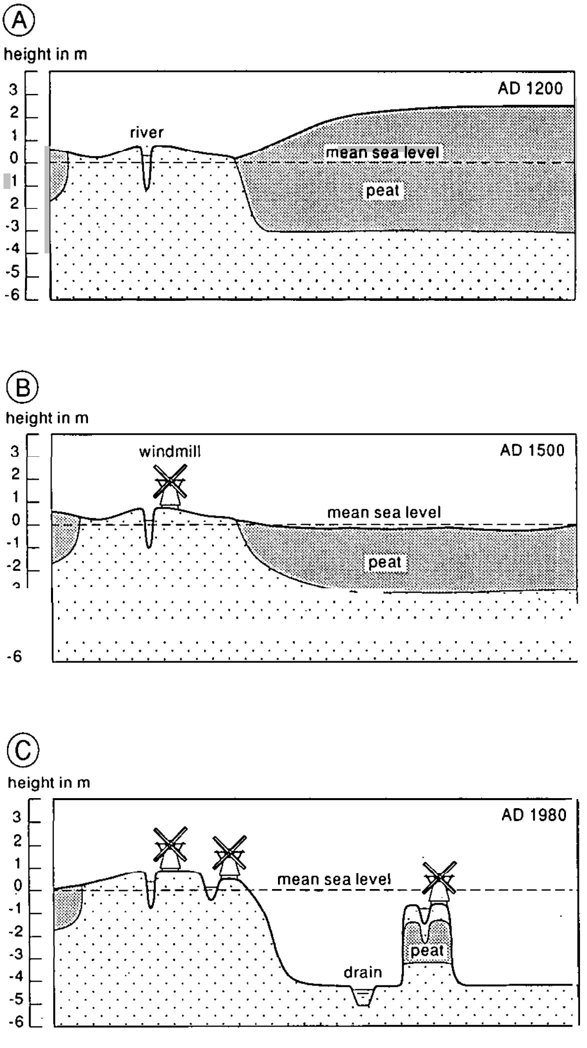

Figure 25.1 The subsidence of peat soils in the western part of The Netherlands (after De Bakker 1982):
(A) Before reclamation;
(B) After reclamation by drainage;
(C) Present situation where peat layers have disappeared because of oxidation and excavation

It should be realized, moreover, that even when a high watertable is maintained, the peat will become oxidized and, in the end, will disappear altogether.

Example 25.4
In the western parts of The Netherlands, the reclamation of the peat areas started around 1000 A.D. (Van der Molen 1982). As the areas were elevated above the river levels, drainage by gravity was easy. The water levels, which were controlled by sluices, could be maintained at a depth that allowed arable crops to be cultivated. Because of the subsidence of the peat layers, however, the drainage deteriorated and, in the fifteenth century, arable cultivation was gradually replaced by grassland. Nevertheless, the land continued to subside, and new techniques were needed to drain the areas. From the sixteenth century onwards, windmills were widely used to pump out the drainage water, thereby maintaining a good drainage base, but consequently increasing subsidence. Subsequently, the drainage base has been lowered from time to time, and nowadays, instead a few metres above mean sea level, these areas are now several metres below it (Figure 25.1).

25.4.5 Salinization

In irrigated agriculture, irrigation itself is the main source of salts (Chapter 14). About one-third of the gross area of irrigated land (270 million ha) is to some extent affected by salinity (Scott 1993). Even if the irrigation water is of good quality, it still brings in large amounts of salts (Example 25.5). In arid and semi-arid regions, irrigation can also cause secondary salinization through the capillary rise of saline groundwater. To prevent salinization, all these salts have to be removed by the drainage water. So drainage is the price one has to pay for sustainable agriculture in irrigated lands.

Sometimes, improved drainage can be an additional source of salts, as, for instance, when the lowered watertable induces saline seepage from outside the area (Section 25.4.7) or when the drainage flow brings back into solution salts from the deeper soil layers. Both effects increase the salinity of the drainage effluent, which can have environmental effects both within the project area and downstream of it.

Example 25.5
Agriculture in Egypt depends almost entirely on irrigation from the River Nile. With the year-round availability of water, two or three crops a year can be grown. Under the present cropping pattern, the quantity of irrigation water applied to a representative area in the southern part of the Nile Delta is about 1240 mm/year (Abdalla et al. 1990). Although the irrigation water is of good quality (0.3 dS/m), it brings salts into the soils at a rate of 8.0 ton/ha/year. To guarantee sustainable land use, this amount of salts has to be leached from the soil each year.

25.4.6 Acidification

Many rich coastal wetland environments are lost by the improper reclamation of soils that contain pyrite (acid sulphate soils; Chapter 3, Section 3.7.1). Subsoil layers brought into contact with the air through drainage become oxidized, leading to the formation of sulphuric acid. Triggered by drainage, the acidification of the soil can be so pronounced, with pH values dropping to below 3, that plant and animal life are seriously affected (Example 25.6).

Careful water management, in combination with agronomic measures, can help to rehabilitate abandoned areas and enable a sustainable use of the remaining areas. To prevent the pyrite from oxidizing, a high watertable has to be maintained in all cases. Other measures that can help to reduce the acidity include liming and the disposal of the acid drainage effluent.

Beside the fact that drainage of acid sulphate soils for agriculture is difficult, it can also have major negative impacts on the environment (Dent 1986):

- Loss of habitat: Acid sulphate soils are often found in coastal lowlands, which are the base of the local food chain. So the ecological impact of land drainage is not confined to the drained area;
- Loss of amenity (e.g. landscape and recreational values);
- Changes in sedimentation and erosion: Reclamation reduces the buffer functions of the area (i.e. the temporary storage of flood water; sediment and silt trap);
- Change in water chemistry: The drainage of acid sulphate soils inevitably increases the acidity of the drainage water. This may change the fauna and fish populations both within the project area and downstream of it (Example 25.2) and may make the effluent unsuitable for irrigation downstream;
- Diseases: The change from a saline or brackish water environment to a fresh water environment can increase the hazards of vector-borne diseases.

As was said at the beginning of this chapter, it is a matter of careful comparison whether the advantages of reclamation and drainage outweigh the disadvantages.

Example 25.6

The soils of Pulau Petak, an island in the delta of the Barito River in South Kalimantan, Indonesia, are mainly acid sulphate soils (AARD and LAWOO 1992). Because of the high watertable, the soils were permanently reduced so that no oxidation and subsequent acidification took place; the soils were potential acid sulphate soils. The area was covered by mangrove forest along the coast and by tidal (fresh-water) swamp forest more inland. About 150 000 ha of the 220 000 ha have been systematically reclaimed since 1920. Of the originally reclaimed area, however, 75 000 ha have been abandoned again because of the acidification as a result of drainage; the soils have become actual acid sulphate soils.

25.4.7 Seepage

A lowered watertable inside the project area can increase the seepage into the area because of the increase in hydraulic head (Chapter 9). If the seepage water is fresh, the only effects are higher drainage rates and, in some cases, a lower watertable upstream of the project area (Section 25.6). If the seepage water is brackish or saline, however, salts are brought into the area, thereby increasing the hazard of salinization (Example 25.7), which, in its turn, can also have effects downstream of the project area (Section 25.5.1).

Example 25.7
The Fordwah Eastern Sadiqia Project in the southern part of the Punjab Province of Pakistan has a serious waterlogging-and-salinity problem (Mian and van Remmen 1991). To dispose of the poor-quality drainage water, a surface drain to the Sutlej River was proposed and was partially constructed. To reach the River the drain had to cross a fresh-water zone along the river. Contamination of the fresh-water aquifer through seepage from the surface drain was likely, and public pressure stopped the project. Rather than disposing of the water to the River a new drain has been planned to an evaporation pond that will be constructed in the Cholistan Desert.

25.4.8 Erosion

Drainage can either increase or decrease erosion. A lower watertable will result in a drier top soil, which, under certain conditions, can increase wind erosion (e.g. of peat soils). On the other hand, a subsurface drainage system can reduce surface runoff and subsequently decrease erosion (Example 25.8). In sloping areas (slopes > 2%), surface drainage is closely related to erosion control. (Methods of regulating or intercepting the overland flow before it becomes an erosion hazard were discussed in Chapter 20).

Example 25.8
In the Lower Mississippi Valley, annual precipitation exceeds evapotranspiration by 500 to 1000 mm, resulting in high watertables and surface runoff. From 1981 to 1986, a drainage-runoff-erosion study was conducted in an experimental area on an alluvial (clay loam) soil (Bengtson et al. 1988). The installation of a subsurface drainage system reduced the surface runoff by 34%, although the total drainage was increased by 35%. The change from surface runoff to subsurface outflow had the following positive effects: it reduced soil loss by 30%, nitrogen loss by 20%, and phosphorus loss by 36%. Thus the subsurface drainage system had positive effects, but on the other hand it increased the total drainage outflow.

25.4.9 Leaching of Nutrients, Pesticides, and Other Elements

One of the direct effects of drainage is that it introduces a discharge through the drainage system. In this respect, water can act as a vehicle for all kinds of soluble elements that are stored in the soil. These elements (e.g. nutrients, herbicides, pesticides, organic matter, salts, and toxic trace elements) can be leached from the soil and can pollute the drainage effluent. Sometimes this is done intentionally (e.g. to leach salts in irrigated areas; Chapter 15), but it is often an unintended side-effect (Example 25.15). The effect these elements have on the environment depends, among other things, on climatological conditions, on agricultural practices (quantity and quality of the fertilizers and pesticides used), and on the type of soil. Sometimes, the effect can be positive (i.e. when the losses of nutrients can be reduced; Example 25.8), sometimes negative (i.e. when fertilizer applications are excessive; Example 25.9). If the effects are negative, preventive measures to reduce the flow of drainage water are often the only options because measures to treat this type of non-point pollution are extremely costly. An overview of the present state of knowledge about the effect of agriculture on the quality of the (ground)water is given by Bouwer and Bowman (1989).

Example 25.9
Nitrate losses through the subsurface drainage system on a farm near Bologna in northern Italy were monitored for three years (Rossi et al. 1991). A good correlation was found between the nitrate losses and the amount of water evacuated through the drainage system. The greatest nitrate losses were recorded during winter and early spring when drainage was at its highest (Figure 25.2).

The annual rate of nitrate losses of 214 kg NO/ha (50 kg N/ha) indicates a major contribution to the eutrophication (i.e. the chemical enrichment) of surface water. Because these losses were high compared with the amount of fertilizer applied (150 kg N/ha), reconsidering the farming practices (timing, rate, form, and placement of nitrogen fertilizer applications) could be a way to reduce the negative effects.

25.4.10 Health

The drainage of agricultural land can also have an effect on the living conditions in the area. Drainage for health was already practised by the ancient Greeks and Romans, who drained swamps and other stagnant water bodies to control malaria long before Ross's discovery in 1889 of the role of the mosquito in transmitting the disease. While drainage was practised with apparent success, the cause of the disease, the transmission mechanism, and the way drainage affected the transmission were not properly

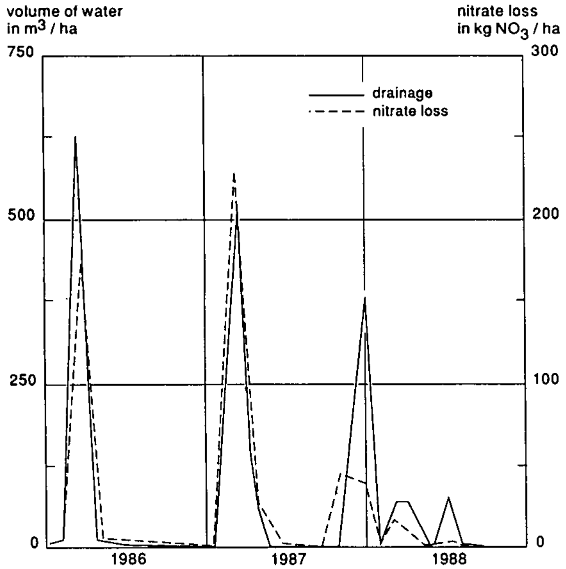

Figure 25.2 Seasonal pattern of subsurface drainage discharge and nitrate losses via subsurface drainage water (after Rossi et al. 1991)

understood: the Romans used the term *mal aria* (= bad air) to indicate a disease that they thought was caused by breathing the poisoned air from swamps and stagnant water bodies. It was only after the discovery of the role of the mosquito in the transmission of malaria that the control of this disease got a proper scientific base.

Water-related diseases are classified as follows (Birley 1989):
a) Diseases prevented by washing and bathing (e.g. skin and eye diseases and diarrhoeal diseases);
b) Diseases prevented by clean water supply and sanitation (e.g. typhoid, cholera, and hookworm);
c) Diseases acquired by water contact (e.g. schistosomiasis or bilharzia);
d) Diseases acquired from bites by water-related insects (e.g. malaria, yellow fever, and river blindness).

The diseases referred under a) and b) belong to the domain of water-supply and sanitation engineers and will not be discussed here. The activities of drainage engineers have a greater impact on the diseases listed under c) and d). These diseases are often called vector-borne diseases. The word vector refers to the organism that transmits the organism or substance which causes the disease.

Agricultural development projects, and especially irrigation projects, can have a negative impact on human health if they increase the size and number of vector habitats. Drainage can help to control vector-borne diseases by eliminating or reducing open water bodies that vectors live or breed in. In the first half of this century, colonial governments and commercial enterprises in the tropics spent a great deal of money on drainage works in an effort to prevent their administrators, labourers, and new settlers from falling victim to diseases that could signal the end of a town, rubber plantation, or an irrigation project (Snellen 1987).

Much of this experience has been lost in the second half of this century, through the sole reliance on chemical control. The increased resistance to drugs by the organisms that cause the disease, and to chemicals by the disease vectors, implies that a control strategy relying solely on chemicals cannot be sustained. Sustainable control of vector-borne diseases calls for a strategy that uses the potential of environmental measures to the full. A successful strategy incorporates three basic elements for the control of vector-borne diseases:
- Medical treatment;
- Reduction of vector-human contact;
- Reduction of vectors.

Drainage plays an important role in the last two strategies by incorporating disease-control measures into the design, construction, and operation of a drainage scheme (Example 25.10). Measures that involve drainage aim at (Oomen et al. 1990):
- Eliminating stagnant water by improving drainage, reducing seepage, etc.;
- Increasing water velocities in reservoirs, canals, and drains;
- Clearing vegetation from banks, canals, and drains.

The World Health Organization (WHO 1982) lists environmental-management measures that have proved useful in preventing and controlling malaria and schistosomiasis.