GENERAL CASE STUDIES OF DRAINAGE METODS AND SYSTEMS IN AGRICULTURAL LAND

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INTRODUCTION

When thorough studies have revealed that:

- A significant drainage problem is present, i.e. water levels are too high and/or proper leaching of the soils cannot take place
- Land use adjustment is not feasible, for example switching to rice crops and range lands
- Drainage is physically applicable and necessary, flooding from rivers, seas and lakes is absent or rare, a suitable outlet is available
- Drainage is socially feasible and local technology is available
- Environmental and other negative side effects are limited and/or curable

it will be necessary to determine a cost effective type of drainage method and system.

The following conditions are amongst the most decisive to influence the choice:

- Rainfall, irrigation
- Geo-morphology
- Soils
- Land use
- Agro-socio-economics

The rainfall/irrigation conditions can be roughly classified according to climatic zones as:

- Humid temperate zones with regular monthly rainfall
- Humid tropical zones with dry periods of less than 3 months
- Semi humid tropical zones with dry periods of more than 4 months
- Irrigated arid and semi arid zones

The most important geo-morphologic conditions can be broadly characterised as:

- Coastal plains
- Coastal and inland river delta's
- Inland river plains and large river valleys
- Upland small valleys
- Upland alluvial fans
- Upland plains and depressions

The influential soil conditions can be roughly divided in:

- Saline soils, i.e. soils with excessive levels of sodium chloride leading to high values of electric conductivity, ECe > 8
  (These soils occur mainly in irrigated arid and semi arid areas or otherwise in coastal lowlands)
- Alkaline soils, i.e. soils with excessive levels of sodium carbonates leading to high pH values (pH>9)
  (These soils occur in areas with sediments originating from specific types of rock as for example in central Europe and Northern India)
- Acid sulphate soils, i.e. soils with excessive levels of iron sulphides leading to low pH values (pH<4), mostly associated with marine environments and especially mangrove vegetations
- Heavy soils, i.e. soils with a clay content higher than 40 % prevalent in deltaic areas or inland plains
- Organic soils (peat soils) formed by the vegetation in swamps
- Normal soils, i.e. soils that do not come in any of the above categories.

The most relevant land use and cropping conditions can be roughly discerned into:

- Natural wetlands maintaining bio diversity and/or providing the opportunity to collect natural products or to develop eco-tourism
- Moisture requiring cropping systems including paddy fields, pastures, cane lands, some palm tree crops
- Most other agricultural crops

The agro-socio-economic conditions that play a role are:

- Whether it concerns large estates and farms, producing for commercial purposes, or small subsistence farms
- Whether there is a strong or weak social organization (water boards)
- Whether drainage technology is widely available or scarce

In practice, only some combinations of climatic, soil and land use groups occur. For example, organic soils and acid sulphate soils are not found in arid and semi arid regions. Alkaline soils occur mainly in regions with cool winters and hot warm summers and not along the coast. Saline soils are found only in arid and semi arid regions or along the coast. Rice crops and sugar cane are not found in temperate climatic zones.

Therefore, we will base the discussion on cost effectiveness of drainage systems on a number of selected combinations represented in 12 case studies:

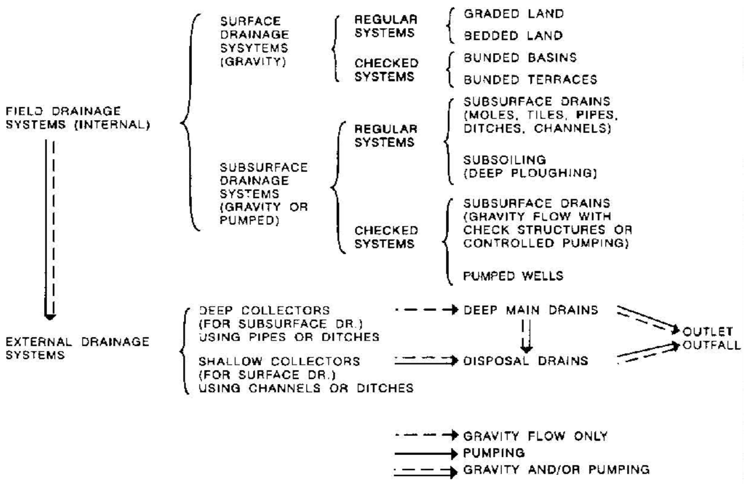

Figure: A classification of types of agricultural land drainage systems.

One may also want to consult the article on Cautious and Restrained Drainage that can be downloaded from the Reports & Cases page of this web site.

1. Historic drainage in The Netherlands with open drains

(Temperate humid zone)

1a. Deltaic regions with peat land

About one third of the agricultural land in The Netherlands consists of peat soils formed by the decay of plants and organic materials in the marshes and swamps. The water table in such soils originally is shallow and must be maintained shallow otherwise the organic material decomposes, the soil shrinks and the land subsides. Under the climatic and soil conditions the primary land use option is grassland for cattle and sheep grazing and fodder. This explains why dairy cattle and cheese making developed strongly.

The agricultural practice required some form of control of the water table. In winter, with little evaporation, submergence of the land must be avoided while in summer the water table should not descend too deeply.

The control is required for better grass growth, to give dry feet to the animals, to prevent the topsoil from damage by the cattle hoofs, and to be able to cut the grass for winter hay as fodder.

Already a millennium ago, people started to protect the land from flooding erecting protective bunds (dikes). Bunded lands, however, have no drainage outlet. Therefore they excavated open ditches with a spacing of about 10 m and a depth of 0.5 to 0.6 m that were connected to a sluice through which the water was discharged into the river when the land became soaked and the river level was sufficiently low. The sluices used to have a gate that opened only when the water level in the agricultural land was high and in the river low. During dry periods in summer, water was allowed to enter the drainage ditches through some other means. Otherwise the gate remained closed.

The gravity outlets did not provide an optimal water control during wet periods when the river levels were high because the drainage outlet failed. Slowly, all kinds of windmills were developed to lift the water. Later, engines and pumps replaced the windmills.

The combination of diked land with drainage system and controlled outlet is called a polder.

Initially, the agriculture functioned at subsistence level, i.e. the dairy produce was mainly for home consumption or sold at the local market. Presently, the agriculture is commercial. Still, at present, the open ditches are still maintained. As the water table is shallow and the storage facility for water is small, the drains need a high discharge capacity to cope with the drainage flow in rainy periods and to permit the entrance of water into the soil in dry periods. Pipe drains are not recommended. The standard pipe drains would not have enough drainage capacity in rainy periods and the infiltration of water from the pipes into the soil in dry periods is limited. Larger pipe drains would be too costly. Also, the installation of pipe drains under shallow water table conditions would be cumbersome. Further, the pipe drains provide no means to separate the grasslands for good grazing management and to give drinking water to the animals.

Questions box 1a

1a.1 - What are the adverse effects of performing deep drainage in peat land?
1a.2 - Why is it recommended to use moisture resistant crops in peat land?
1a.3 - What are the advantages of open drains in peat land compared to pipe drains?
1a.4 - Why do environmentalists have objections against drainage of peat land?

1b. Coastal and river plains, clay soils with cambered bedding systems for arable crops

Clay soils in The Netherlands are usually not heavy in the sense that they contain a clay fraction higher than 50%. Of old they were used as arable land growing grain and tuber crops and vegetables. The clay soils of the river plains were also used for fruit trees and orchards.

The clay soils have developed by deposition from rivers or the sea under wet conditions. Only the topsoil was exposed to occasional drying in summer. Thus, the topsoil could develop a clear structure. The subsoil, till about

1m depth, was permanently wet, had little structure, and was slowly permeable for water. At still greater depth most clay soils are underlain by lighter textured and sandier soils with a better hydraulic conductivity.

Traditionally, the clay soils used as arable land were equipped with a surface drainage system consisting of camber beds with a width of about 10m separated by open ditches. The beds were formed by ploughing the soil from the ditches towards the centres so that each year the height of the beddings increased until, during rainy periods, the water that could not infiltrate into the soil would run off over the surface of the bed slopes towards the ditches. The outlet conditions are similar to those described in 1a.

When in the last century farm mechanisation and commercialisation set in, the bedding systems were felt a hindrance. Therefore tile drainage was introduced, as discussed in 2.

The orchards did not have bedding systems but simply shallow open drains. As the land under the trees is not ploughed for seedbed preparation the surface is irregular enough to have natural pathways for the water to flow overland to the ditches. In summer, the trees evaporate more water than arable crops so that the water table in that season is comparatively deeper. In winter, the trees are dormant, the leaves have been thrown off, and there is some tolerance to water logging.

Questions box 1b

1b.1 - Why were the heavy soils in arable land in the Netherlands originally drained by surface drainage rather than by subsurface drainage systems? 1b.2 - Why did the surface drainage system consist of beddings and not of basins or graded land? 1b.3 – Why did orchards not have bedding systems?

1c. River plains, loamy soils for arable crops

Loamy soils were mainly used for arable cropping. They were mainly found on the natural levees in the delta. The levees have sandy subsoil and usually had better hydraulic conductivity than the clay soils.

The loam soils were not equipped with a surface drainage system as were the clay soils, but with a subsurface drainage system consisting of open drains. The drains were deeper than those in the peat lands (say 1 m deep) and the average water level in the drains, especially in winter, was also established deeper. This was only possible because the elevations were higher so that the outlet situation was more favourable.

When in the last century farm mechanisation and commercialisation set in, the open drains were felt a hindrance. Therefore tile drainage was introduced, as discussed in 2.

Questions box 1c

1c.1 - Why is the drainage situation in the loamy soils relatively favourable? 1c.2 - Why were loamy soils drained by subsurface instead of surface drainage systems?

2. Later pipe drainage developments in The Netherlands

Early last century, tiles drains, baked from clay, were applied to alleviate some of the problems mentioned in 1. Firstly, the drains were laid in hand dug trenches. All soils in the Netherlands, including the clay soils, contain enough sand silt to cause drain blocking once they entered the drains. Therefore, all drains were covered or surrounded by peat litter.

The main reason of the introduction of clay pipes was to create larger parcels. Commercialisation en enlargement of the farms made this enterprise economically feasible.

The clay pipes were also placed in the field ditches of the surface drainage systems of the poorly structured alluvial clay soils (1b). It appeared that the surface drainage, and consequently the topsoil drying in summer, had produced enough structure improvement to increase the infiltration of rainwater into the soil so that the surface runoff decreased in the course of the time while the subsurface drainage increased. The better permeability of the underground contributed to this. After the 1950's the bedding systems were gradually removed.

In newly established polders in the originally shallow sea, the above experiences were advantageously used to develop a reclamation system of the initially undeveloped, supersaturated, clay soils. First shallow ditches were dug at short spacing (say 5 m.), together with reclamation crops like reeds and colza, and later pipe drains spaced at some 20m replaced the surface drainage. Thus the clay soils underwent a ripening process whereby the oxygenation, soil structure, and permeability improved. Finally it was found that the hydraulic conductivity of the first m. of soils became so large, more than 10 m/day, that the pipe drains could be spaced more widely.

The choice of putting eventually pipe drainage systems in the new polders instead of open drainage ditches was, like in the "old land", founded on the wish to create large uninterrupted parcels for mechanised cultivation. The new farms would be commercial, mechanised, and have sizes of 40 ha and more. As the drain lines would be about 200 m. long one could create parcels with a width of 400 m and a length of at least 1 km. This also reduced the maintenance cost of the open drains, though the pipe drains are not devoid of maintenance requirements.

Initially, tile drains were installed manually in machine excavated trenches. Later, drainage machines that excavated the soil with a digging chain and had a chute by which the pipes could be slid onto the bottom of the trench performed this job. The application of the loose envelope material on the pipes had still to be done in another go along the drain line.

The advent of corrugated PE and PVC pipes, which were flexible, light in weight and could be delivered in rolls of long length (50 m. or more) promoted the mechanical installation. The pipes could be pre-wrapped with a synthetic filter. In addition the laser beam controlled installation developed quickly by the end of the 20th century.

Since the research results published by Hooghoudt towards 1940, drain spacing tended to be calculated by a drainage formula in which the hydraulic conductivity was an important factor. From 1960, the measurement of hydraulic conductivity was undertaken at a large scale in new polder projects and in the lands that were to be consolidated with government subsidy putting new infrastructure and joining farm parcels and properties that, through inheritance procedures, got scattered all over the districts. However, in the long run it was found that the natural variability of the conductivity was so great that it became difficult to use in the formulas. Since 1980 the expensive conductivity measurements were abandoned and the drain spacing was fixed according to local experience. The lesson learnt is that subsurface drainage in new areas needs to be developed by experience using a standard set of drain spacing.

Questions box 2

2.1 - Why grew the desire to replaces the ditches for subsurface drainage by pipe drains?
2.2 - What was the reason that eventually pipe-drains also worked in the dense clay soils?
2.3 - Why was pipe drainage in the new polders reclaimed from the sea delayed for some time?
2.4 - What kind of drainage was practised in the new polders before pipes were put in?
2.5 - What was the reason to use reclamation crops before traditional crops could be sown?
2.6 - What can be said about the hydraulic conductivity of the clay soils in the new polders?
2.7 - Why is the design of drainage systems often based on local experience rather than on theoretical drainage formulas?

3. Historic drainage developments in Egypt

(Deltaic region and large river valley, arid zone, irrigated land, clay soils, salinity danger, arable crops, small farmers) using open drains

The rainfall in Egypt is negligible throughout the year. In ancient times all agriculture depended on natural flooding from the Nile River, in the summer period, aided by channels leading the flood water to the more remote parts of the land. Land drainage was not an issue. Crops were merely grown on residual moisture left after the floods withdrew. The floods brought silt particles that fertilised the soil. Later, farmers used lifting devices, especially the animal driven water wheels, to take more water from the flood ways so that agriculture could be intensified. In addition they excavated more flood ways to expand the cultivable land. Many of these still form the basis of the present irrigation system.

To expand the agricultural land even more and to assure the water supply, diversion weirs and dams were constructed in the river. This culminated with the High Dam at Assouan in the South. The civil engineering works made it possible to grow two crops per year: a summer and a winter crop. In summer it even became possible to grow rice. All canals serving directly the agricultural land carried the irrigation water at a level below the soil surface so that lifting devices became more and more important. Since 1980 diesel pumps replaced the animal driven wheels.

The increased and perennial supply of water caused the water table to rise and it introduced more salts to the irrigated land than before, even though the quality of the water is good and its salt content is low. The rise of the water table was aggravated by new irrigation projects in the higher desert lands bordering valley and delta. The shallow water table impeded leaching of salts with an extra dose of irrigation water. Together with the heavy clay nature of the soils, through which the downward percolation of water is limited, some soil salinity problems started to develop and crop yields could be affected. All in all, the field irrigation efficiency attained a high value.

To control the water logging, large open drains were excavated, often in former branches of the river, and pumping stations were erected to discharge the drainage water into the sea. Much of the drainage water was tail water from the irrigation canals. Before the nation introduced large-scale field drainage projects, the farmers combated waterlogging by digging shallow open drains to some 60 cm depth at fairly close spacing. The farmers found the outlet at the open drainage system excavated earlier. The system performed well because it was enough to control the soil salinity and it was not too deep to cause undue deep percolation losses.

The Southern half of the Delta, towards the apex at Cairo, has a small natural drainage to the underground where water percolates down into the large aquifer underlying the clay top, which is several meters thick. The water flows down through the aquifer and it either appears as upward seepage in the northern part of the Delta or, for the major part, it flows out into the sea. This explains why salinity problems in the Southern part are not particularly severe whereas towards the North the incidence of soil salinity increases.

Questions box 3

3.1 - Why was drainage of the Nile Delta originally no issue?
3.2 - Why did the incidence of water logging increase gradually in the course of the time?
3.3 - Why did also the incidence of soil salinity gradually increase.
3.4 - What was the response of farmers to combat the twin problem of water logging and salinity?
3.5 - Why are the problems especially felt in the northern part of the delta and not so much in the south?
3.6 - How could the drainage problems develop along the boundaries of the Nile valley and delta?

4. Later drainage developments in Egypt

4a. Drainage of old lands

Concern of the Egyptian Government about water logging and salinity after the construction of the High Dam at Assoean lead to the initiative to construct massive drainage systems mechanically. Initially clay pipes (tile drains) were used and gravel was applied as an envelope material. Later PVC drains, often without envelope as the deep clay soils, contrary to those in the Netherlands (see 2.) were very stable and entrance of silt and sand was absent. The omission of gravel envelopes considerably reduced the installation costs because the bulky and heavy material gravel had to be mined from far away gravel pits, sieved, transported to the drainage zones and applied to the fairly deep drains (1.3 to 1.5 m depth). In areas with lighter textured soils, e.g. along the borders of the delta, synthetic envelope materials were used.

The drainage systems, in millions of hectares, were composite whereby the smaller lateral drains were connected to larger underground collector pipes. The collectors were put to avoid maintenance problems of open ditches, as there were no farmers' associations to take care of that job. The Government enforced the systems on the farmers who would have to repay part of the installation costs in a 20-year period. Some of the drainage areas were not in need of immediate water table and salinity control, but the systems were laid out in precaution.

The composite systems lead to management problems in areas where during summer both rice and dry foot crops (maize, cotton) were cultivated. The rice farmers blocked the systems to prevent excessive percolation from the submerged rice fields. Research has come forward with the idea to introduce land consolidation programs so that the whole area of influence of one collector (or one sub-collector) would be under one kind of crop only while there would be an annual rotation. The (sub) collectors in the consolidated rice areas would be closed by means of gates placed in the manholes. In practice, this idea has not found much imitation, as it appears to be in conflict with the interests of the many small farmers along the (sub) collectors.

The idea of having controlled drainage systems with gated outlets is not only valid for rice areas because the effect of the systems is that the water losses to the underground are increased compared to the losses occurring in the traditional system and they exceed the requirement for salinity control. The installation of the new drainage systems has lead to an increase of irrigation application per ha. This resulted in extra scarcity of water in downstream areas in a boom of diesel pumps to lift the water due to the increased competition. Also, excessive leaching of the soils would impoverish the soil fertility in the long run, increase the fertilizer demands and deteriorate the quality of the drainage water that is often used for irrigation again in downstream reaches. There are also indications that the depth of the drains could be reduced to about 1 m. This would save on installation costs as the laying costs per m drain length augments proportionally with depth, especially when the drains are laid under the water table.

Questions box 4a

4a.1 - Why did the government pursue the large scale introduction of pipe drainage systems?
4a.2 - Why were the systems composite, i.e. the collectors were also executed as underground pipes?
4a.3 - Why could in many cases the application of envelope materials be omitted?
4a.4 - What is the disadvantage of collector pipe drainage systems in areas where rice and other crops are grown simultaneously?
4a.5 - What is uncontrolled subsurface drainage and what are its disadvantages?
4a.6 – What are the disadvantages of deep subsurface drains?

4b. Drainage of new lands

Along the seashore of the Nile Delta large tracts of land were created by reclamation of marshlands along the large coastal salt lakes. These newly reclaimed lands have immature saline soils with high clay fractions (more than 50%). The immaturity is due to their supersaturated and structure-less condition in the subsoil. The soils have a relatively shallow water table due to there limited elevation with respect to the sea level and the upward seepage of ground water originating from percolation losses in the higher parts of the delta. The soils are difficult to leach. A drainage pilot area with deep subsurface pipe drains at more than 2 m depth did not give the expected success. The drains could not function properly because they were placed in the slowly permeable unripe subsoil. Further it seems that the special agricultural water management requirements could not be met.

The new lands were given out to persons of different social groups. Not all groups managed to bring the soil to good use. The most successful persons were farmers from the old land and some large landholders. They undertake the soil improvement by digging shallow open drains, 0.5 to 0.6 m deep, at short spacing of about 10 m. The reclamation crop is paddy rice and sometimes pasture tolerant to water logging. The permanently submerged land leaches best in the vicinity of the drains. Therefore the layout of the ditches is switched from year to year whereby the existing ditches are filled up with soil and new ditches are excavated in the middle between them. The excavation is done by hand and the shape of the drains is regularly repaired. In this manner it would be possible to obtain excellent yields after 3 years. The virgin clay soils have a high natural fertility. After 3 years it becomes possible to grow other crops than rice with good results owing to the reduced soil salinity and increased hydraulic conductivity of the upper soil layer. The soil is no longer supersaturated, its structure is better developed and the soil is 'ripened').

The soil improvement needs extensive farming experience, much care and close attention, a kind of accuracy that large companies and government organisations can hardly afford. Therefore the soil improvement is not anybody's job, but the successful entrepreneurs are amply rewarded.

It is often argued that the soils need gypsum applications to counteract the sodicity, as the soils were deposited in a marine environment and contain much sodium chloride (practically all saline soils are also sodic). The calcium in the gypsum would be needed to replace the sodium at the adsorption surface of the clay particles. Theoretically enormous quantities of gypsum would be required to effectuate the replacement. On the other hand, the soils are rich in calcium carbonates. These minerals are hardly soluble, but the solubility is increased by the removal of sodium and by the acidity that comes with the roots of the reclamation crops. In practice, relatively small doses of gypsum are applied, perhaps just sufficient to get the first crop started. Thereafter the natural processes must do the job.

Questions box 4b

4b.1 - What are the problems of the heavy clay soils in the northern part of the Nile delta near the coast line?
4b.2 - Which groups of arable land users was the most successful in reclaiming the soils?
4b.3 - How did the successful land users improve the soil?
4b.4 - Which diagnostic factors can be used to judge the soil improvement?
4b.5 - Why may deep subsurface pipe drains sometimes give disappointing results in these soils?
4b.6 - What is the role of gypsum in the process of improving saline soils?

5. Drainage developments in Pakistan

(Semi arid, large river plains, saline soils.)

The Indus basin with its deep and permeable aquifers is semi arid. Rain-fed agriculture in the monsoon season is hardly possible and agriculture depends almost entirely on irrigation. The irrigation water is scarce and it is not possible to irrigate 100% of the land in winter and monsoon seasons. In both periods a considerable area must be left fallow.

Since the introduction of large-scale irrigation projects, water tables have risen and soil salinity problems have developed because the shallow water table and/or the scarcity of irrigation water did not permit a proper leaching of the salts brought in with the irrigation water.

Significant drainage projects were not undertaken before 1960. After 1970 there was a period that deep tube-well drainage schemes were initiated massively. The projects were run by the state and aimed to lower the water table and, in areas with good quality ground water, to use the pumped water for irrigation. The deep tube well schemes were not considered a success. In fresh ground water zones the operation and maintenance of the public wells and pumps faced serious problems and in salty ground water zones the wells were not functional at all. This was because it was not felt attractive to spend funds on pumping salty water that could not be used for irrigation and that had to be dumped in irrigation canals or in the Indus river for want of a proper outlet. This would have badly affected downstream water users.

From 1980 and onwards the development of private shallow tube wells in fresh ground water zones took off rapidly, while the government initiated pipe drainage projects in areas with salty ground water. The projects were composite drainage systems that were put at great depths (from 1.8 to 2.5m). The collectors ended in sumps, from which the water had to be lifted due to absence of a gravity outlet.

The private tube well development in fresh ground water zones aims at recovering the water that was lost by deep percolation to the underground. In this sense, the aquifer can be seen as a storage reservoir. The development faces the problem of competition for and over-extraction of groundwater which causes the water table to descend continuously making it all the time more difficult to extract the water. The process will probably come to equilibrium when a relatively small group of persons remains who can afford to install and operate deeper wells or when the government issues a license system. In the long run another problem will arise: as the water is continuously re-circulated there is no salt export and the salinity of the ground water will gradually increase.

The installation of pipe drainage projects faces the serious problem that it is extremely difficult to install drains at great depth in the saturated and unstable silt soils. Such a job can only be done with powerful drainage machines. Another problem is the blocking of the pipes by silt and sand entering from the soil. Nowadays, the availability of good synthetic pre-wrapped envelope materials relieves this problem, but many projects have opted for the application of gravel envelopes. For this purpose, gravel-sieving plants had to be established, large trucking distance had to be covered, and many auxiliary tractors were needed to feed the drainage machines.

In the southern part of Pakistan, a large project was undertaken to make a disposal drain for poor quality drainage water to reach the sea, so that this water is not any more dumped into the irrigation and river system. In fact the Indus River has become integral part of the irrigation system as almost all of its waters are used for irrigation. Only when peak discharge occur does the river water reach the sea.

Under the Pakistani conditions, drainage projects are not only costly, but they have limited benefit. Due to the scarcity of irrigation water and the existing water rights it is difficult to make extra water available to leach and reclaim the saline lands. It would of course be possible to use monsoon rainwater for this purpose. Unfortunately, in the southern part of the country, where the monsoon rainfall is limited, it is doubtful whether the saline soils can be put to good use. Even if this would happen, the scarcity of the irrigation water permits irrigation only of part of the area. Thus, repayment of the expensive drainage systems is difficult.

For the same reasons given for tube wells, the operation and maintenance of the sump + pump drainage system meets many difficulties.

It is doubtful that land drainage in salinity-ridden lands of Pakistan will ever provide a smooth solution. Eventually one may expect that agriculture will be concentrated on the lands for which enough water is available to maintain a proper salt balance while the saline lands are abandoned. Equilibrium will be reached when the capillary rise and evaporation of the abandoned lands equal the deep percolation of the irrigated part. The percolation water then flows through the aquifer to the abandoned land, which practically serves as a drainage sink. No doubt, that this process will be accompanied by considerably social misery unless the government is able to set up compensation funds for those whose lands were sacrificed to the benefit of the lucky land holders in the safe areas.

Questions box 5

5.1 - Why were the governmental deep tube well projects in areas with fresh ground water not considered successful?
5.2 - What are the advantages and disadvantages of the private shallow tube wells?
5.3 - What was the purpose of the governmental deep tube wells in saline ground water zones and what are the reasons for the lack of success?
5.4 - What were the installation problems of subsurface drains?
5.5 – Assuming a successful installation of subsurface drains, what would still be the problem to obtain a successful land reclamation of saline waterlogged land?

6. Drainage developments in Ganges plain, India

(Semi-arid region in the west, semi-humid to the east, large river plain, irrigation in dry winter season, arable crops and rice)

Drainage in India is not well developed. Main drains have been excavated to some extent but not enough to provide a drainage exit to the farms. Field drainage, with the exception of a few projects supported by external donors, is limited to pilot areas. One such a pilot area is situated in the State of Haryana. Topographically the state is bowl shaped and the pilot area is found in the lower part. This part has waterlogged and saline soils. The water logging is due to the inflow of groundwater through the aquifer that is fed by percolation losses from the irrigated agriculture and the monsoon rainfalls. When high intensity rainfalls occur, farmers pump the excess surface water into the irrigation canals that overtop in the low-lying parts. During the monsoon period the few main drains are unable to discharge the water into the river because the water level in it is too high. In fact these drains need to be pumped, but pumping stations are absent. In the State of Punjab, which is mainly situated in the Indus basin and not in the Gangetic plains similar problems occur.

The selected pilot area was very saline. It was equipped with pipe drains at depths ranging from 1 to 1.5 m. The drains were connected to a piped collector to form a composite drainage system. The collector discharges into a sump from where the water was pumped out. As the soils are light textured several envelope materials were tested to prevent clogging of the pipes. All synthetic materials performed well. The more costly gravel packs showed occasional failures.

The following general conclusions could be drawn:

- the removal of the excess salinity (mainly sodium chlorides) in the soil occurred quickly; although the sodicity of the soil was high no problems occurred because the soils were light textured and the pH values were less than 9
- shallower pipe drains were as effective as the deeper ones
- the most practical drain spacing of 60 m conforming to the standard width of the agricultural parcels was adequate, hence drains could be made along the farm boundaries; a wider spacing would technically be possible, but that would interfere with the parcel boundaries
- pump operation would have to be restricted to the monsoon season so that the leaching of the soils would occur with rain water only
- discharge of saline effluent into the river during monsoon would not constitute a major environmental threat as the river would be swollen in that period and most of its water would reach the sea
- abstaining from pumping during the dry winter season would positively influence the irrigation efficiency and the plants would be able to supplement their evaporation demand from the ground water thus saving on irrigation water; this would give rise to some salinity build up in the root zone but the salinity level is adequately controlled by the drainage during monsoon, even if the monsoon rainfall would be sufficient one out of 5 years only

In the State of Uttar Pradesh and in Northwest India alkaline (non-saline) soils do also occur. The alkalinity results from sodium carbonates which are present in the soil owing to their geologic origin or which are added to the soil when sodium bicarbonate containing ground water is used for irrigation. The mineral causes sodium hydroxide to be formed giving the high alkalinity ($pH > 9.5$). At the same time the adsorption surface of the clay particles will contain a relatively large amount of sodium which leads to swelling of the soil, structure deterioration and impermeability for water. Also the calcium in the soil is immobilized because, due to the high pH, it precipitates as insoluble calcium carbonate. The generally recommended reclamation method of these soils is application of gypsum to provide a source of soluble calcium. In addition reclamation crops (rice, grasses) need to be used in the first years. The calcium will replace the excess sodium at the adsorption surfaces and the reclamation crop helps to lower the pH with organic acids so that the calcium carbonates in the soil can be activated. The excess sodium hydroxide will have to be leached to the underground. When there is insufficient natural drainage to the aquifer, a subsurface drainage system with open ditches or pipe drains needs to be put in place.

In the States of Uttar Pradesh, Bihar, and West Bengal large tracts of land suffer from floodwater brought in by rivers and natural drains, and stagnant pools of rainwater during monsoon. Flood prevention in North India has not been undertaken at a large scale. It is not recommended to install drains in flood prone areas. However, when the surface drainage problem is only due to local high rainfall intensities, and not to flooding from rivers or natural drains, a surface drainage system may need to be installed when the surface water stagnation is so high that it even affects the rice crop.

To avoid confusion of terminology we mention that, in India, main drains are invariably called surface drains. The possibility to use open drains (ditches) for subsurface drainage is not widely recognised. The same holds for the need of surface drainage at field and farm level. There is a general notion that an area prone to flooding and surface water logging can and need be reclaimed by main drains only. Yet the provision of such drains is not ample and the open drainage system is insufficient to provide outlets to all farming communities. In fact, land drainage has never received a high priority in India. Irrigation developments in civil engineering sense, on the other hand, have always received a large portion of the nation's resources.

Questions box 6

6.1 – In the Northwest of India two kinds of soil problems have bee described. Which are these and what are their main characteristics?
6.2 – The subsurface drainage for salinity control in Northwest India needs to make use of the monsoon conditions. Please explain the situation.
6.3 – In the states of Punjab and Haryana farmers have developed their own solution to combat water logging caused by intensive rainfall. Why is their solution harmful to the inhabitants of the downstream areas?
6.4 – What kind of water management problems are found in the States of Uttar Pradesh and Bihar?
6.5 – Why is it not recommended to implement surface drainage systems in areas prone to flooding from rivers and natural drains?

7. Drainage developments in inland valleys, India

(Semi-humid area, valley bottoms, heavy clay soils, soil salinity, rice and arable crops, small farmers, low technology level)

Many small valleys in the central Indian plateau have saline bottomlands. The salinity can be man made due to the introduction of irrigation, or of natural origin. Ground water and surface water flows, apart from entering the natural valley stream, tend to stagnate in the valley bottomlands. Also, during periods of peak runoff, the streams inundate the bottomlands. Here, upon evaporation of the water, the salts remain behind. Often, the natural side drains do not fulfil their original function as they have been filled up and levelled for agricultural use.

In older irrigated areas in undulating topography, where valley bottoms prevail, the normal cropping system consists of cultivating crops in the higher lands that need relatively little irrigation water, the so called light irrigated crops as cotton and chilly. In the middle lands one finds the crops that need more irrigation but that require a fairly deep water table, e.g. sugar cane. The bottomland is most suited for rice.

In some newer irrigated areas almost the entire area is cropped to rice with two cultivations per year. Due to the high irrigation requirement of paddy the tail ends of the irrigation project experience water shortage while, in the upstream ends, the bottomlands become waterlogged.

In several small valleys pilot areas have been established with drainage systems using pipe drains and, occasionally, open drains. The agricultural effects have invariably been successful. Hence, the soils' hydraulic conductivity is usually not a critical factor. Government and university departments laid out the systems. Unfortunately, the costs of the systems were prohibitively high for farmers to imitate the pipe drainage systems.

There have been discussions on whether the drains should be laid out parallel to the valley streams, with a collector to lead the water to the stream itself, or perpendicular to the streams with a direct outlet to them. Contrary to what is often believed, the parallel drains do not function better than the perpendicular ones. The so-called interception effect of ground water by the parallel drains is a fiction that can be countered both theoretically and with the experimental results.

The most natural layout of the drains in small valleys is perpendicular to the valley stream with a direct outlet, just like the natural side streams, which also need to be restored to their original shape. In small farmers' communities, the drains should consist of open ditches of, say, 1 m depth and spaced at 50 to 100 m. The farmers themselves, farmer's communities, or local contractors can construct these more easily. They are quite cheap and do not require a high level of technology. With a paddy crop in the bottom lands, the ditches do not need to control the water table but they only need to discharge enough dissolved salts to reclaim the saline lands. Therefore, the required distance between the drains need not be determined with great precision and the drains can be positioned where they are topographically and socially acceptable. During periods of high rainfall they also help to enhance the surface drainage.

When, after one to three years, the soil salinity has been reduced to a safe level, the open ditches may be equipped with a gate or a mud closure to prevent undue percolation losses from the rice field. Alternatively, the maintenance of the ditches may be postponed for a number of years until the need arises to restore them again. Experiments have shown that the low initial price of the land increases sharply after reclamation with an amount that is a multiple of the installation cost of the drainage system.

Before installing the open ditch drainage system it would be good to verify that the land to be reclaimed is not subject to frequent flooding from the main valley-stream. If so, it is not likely that cropping during the monsoon season is viable, unless flood control measures, such as bund construction, are taken. Nevertheless, the reclaimed land would still provide the possibility to grow post monsoon crops and winter vegetables.

Questions box 7

7.1 - Why would rice be a suitable crop in the Indian valley bottoms?
7.2 - When the valley bottoms are saline, what would be a suitable drainage system for land reclamation?
7.3 - Why would the direction of the open drains preferably be perpendicular to the main drain in the valley bottom?
7.4 - What would be your comment on the design of a drainage system with pipe drains parallel to the main drain connected to collectors leading the drainage water to the main drain?
7.5 – Would it be necessary and feasible to determine precisely the optimum depth and spacing of the drains or could one rather be flexible and locate the drains in practically advantageous locations?
7.6 - Why are the monsoon rains helpful in the reclamation process?
7.7 - Is the presence of a subsurface drainage system in the valley bottoms permanently required and, if not, what could one do with the drains when they are not needed?
7.8 - When the valleys are used by many small farmers, what are the socio-organizational implications when the installation, operation and maintenance of a subsurface drainage system is required?

8. Drainage developments in coastal saline soils in monsoon climates, India

(Rice crop in monsoon season, vegetables in winter, heavy clay soils, small farmers)

Along the Indian coasts there are extensive tracts of land with saline soils due to their formation under marine conditions. The salinity is visible during the dry season when the water table drops to a depth of about 1.5m due to capillary rise and evaporation. The capillary rise brings the salts to the soil surface and post monsoon or winter cropping of vegetables is not successful. In the monsoon period, the water table comes up due to infiltration and percolation of rainwater. Hence the salts are washed down and remain stored at a depth of 0.5 to 1.0 m. Thus, rice cropping during the monsoon season has no salinity hazard. Often, the water table comes quite high above the soil surface and the farming population plants floating rice rather than short straw varieties. The straw of the long rice gives a good material for thatched roofs.

In such regions, the population is often quite experienced in the making of ponds for fish culture, household and drinking water. Also, they dig shallow wells for water provision during the dry season. The local shallow well techniques can advantageously be applied for salinity reclamation as follows.

In the lands suffering from upcoming salinity during the dry season, one may dig temporary shallow open wells some 5 m deep using 5 to 10 of such wells per ha. With a mobile pump, these wells are regularly emptied during the dry season. A temporary shallow open ditch (say 0.2 m deep) must be dug to lead the pumped water to a nearby outfall. Thus the water table will drop to a deeper depth, say 3 m, than the 1.5 m under natural conditions. With the onset of the monsoon, the surface salt will now be washed down to a deeper depth than before, say at 2.0 to 2.5 m where is safely stored and immobilized. During the following dry season, these salts are outside the reach of the capillary action and will no longer hamper the vegetable crops.

Local experimentation is required to determine the most practical depth of the temporary wells and their density in terms of number per ha. Also, it has to be verified whether one year of pumping is sufficient or whether the pumping must be repeated another year. When the salts appear no longer harmful, the temporary wells can be closed or partly used to irrigate the dry season crop.

When much ground water is used for irrigation, it may happen that the salts slowly appear again at the soil surface as they may be re-circulated by the pump action. In that case, the reclamation procedure has to be repeated say once every 10 years. In the long run, the discharge of salty water to the outlet will guarantee that the salinity problem presents itself to a considerably lesser degree and extent.

Questions box 8

8.1 - What is the reason that the coastal saline soils of India, do not permit the cultivation of a second crop after the monsoon season?
8.2 - Why is subsurface drainage by open dug wells applicable to improve coastal saline soils?
8.3 - Are the open dug wells aiming at a permanent form of subsurface drainage or are they only temporarily required?
8.4 - Is the reclamation principle described based on the complete removal of salts or rather on the burial of salts at a deeper, harmless depth?
8.5 - What are the advantages of temporary open dug wells compared to pipe drains or open ditches to reclaim coastal saline soils in India?

9. Water logging in the Rajastan canal project, North West India

(Semi arid zone, light textured soils, undulating topography in wind blown plains)

The Rajastan (Indira Ghandi) canal project is a huge undertaking whereby large areas are brought under irrigation with waters diverted from the Sutlej River, after the Indus water treaty was signed between India and Pakistan. A large part of the newly irrigated areas are under lift irrigation whereby huge pumping stations elevate the water to the higher lying lands.

The project has been able to boost the production of wheat and other trunk crops enormously. However, due to the sandy character of the soils, the deep percolation losses are considerable. These water losses are carried by the aquifers to the depression areas that got waterlogged. Unfortunately, the depression areas were often the areas where people had built their villages because, before the introduction of the irrigation, these were the places with the best water facilities and the most fertile soils. The runoff of the scarce monsoon rainfall would collect in the depressions, carrying with it the finer soil particles. Hence, the depressions have more water supply and better water holding soils.

It is very difficult to drain the depression areas due to the large amounts of water that seep into it. However, the phenomenon of waterlogging could have been predicted fairly easily by skilled geo-hydrologists on the basis of topographic and geological maps. If one would have decided that the depression areas would have to be abandoned and considered as hydrological sink areas, sacrificed to serve the drainage and salinity control of the higher lands, one could have spared project funds to resettle the inhabitants of the depression areas and compensate them justly for the losses suffered. The agricultural benefits of the project in general are so large that a part of the profit could easily have been set aside for that purpose. The waterlogged depressions could then have been reserved as valuable wetlands where aquatic vegetation and fauna could have been protected and the wetlands could even have served recreational purposes.

Questions box 9

9.1 - What was the significance of the depressional areas in the Rajastan canal project before irrigation was introduced?
9.2 - Could the development of water logging problems in the depressions after introducing large scale irrigation have been foreseen and could susceptible areas have been located in advance?
9.3 - Can the waterlogged depressions be easily reclaimed?
9.4 - What socio-economic measures could have been taken to compensate the inhabitants of the depressions for their losses when drainage measures are not feasible?

10. Drainage developments in Peru

(Arid zone, deltaic areas, heavy soils, agricultural enterprises and small farmers)

Some 50 rivers descending from the Andean mountain range traverse the coastal desert of Peru. In the upstream ranges, the river valleys have loamy and sandy soils that are intensively irrigated. The deep percolation losses are carried down slope through large aquifers. Near the coast, the rivers form delta areas with heavy (montmorillonitic) clay soils. Towards the sea, the groundwater flow in the aquifer arises as upward seepage. The seepage water evaporates leaving the dissolved salt behind. The situation is similar to that of the Nile Delta (see 3. and 4.), but the Peruvian deltas are smaller and the availability of irrigation water in terms of quantity per ha per year is much less. Most agrarian undertakings are in the hands of small and medium farmers, but in some valleys very large sugar cane plantations are found that are run by cooperative societies formed after the agrarian revolution out of enormous private estates. Due to the relative scarcity of water, saline lands are not taken into cultivation. Contrary to many saline lands in India (see 6., 7. and 8.), the saline lands in Peru cannot be reclaimed and cultivated using rainfall, as the climate is arid. The climatic situation and availability of irrigation water is somewhat similar as in Pakistan, but the scale of the irrigation projects is much smaller and the summer temperatures are lower.

In an unused salty patch of land in one of the deltas a drainage pilot area was established in the jurisdiction of a small cooperative society for research purposes. The pilot area was operated by a government entity that obtained its irrigation water by government resolution. This meant that the cooperative had less water available for irrigation of their non-saline lands, but in return would receive the reclaimed pilot area with is drainage for free after three years.

The pilot area was equipped with a subsurface drainage system consisting of tile drains (Clay pipes) as local technology on this was available. The drains were placed at 1.2m depth because the soil was less heavy here and it had a better permeability. A subsurface collector drain of clay pipes was installed at 1.5m depth to connect the drain lines to an outlet that consisted of a sump with pump. The drains receive both the irrigation water that percolates down through the soil and the upward seeping ground water. Due to the limited permeability and low leaching efficiency of the heavy clay soil it took three rice crops in three years before the topsoil was sufficiently leached and reclaimed. Thereafter it would be possible to plant other crops like maize. After 3 years, the pilot area gave a very productive soil because its fertility potential was high. However, when the area was returned to the farmers' community it decided not to continue to cultivate the pilot area but it used the irrigation water that came free to irrigate the lands it was previously irrigating. This confirms that reclamation of saline soil in arid zones with scarcity of irrigation water does not seem to be a feasible option.

Scientifically, the pilot area yielded interesting results. It proved that reclamation of very saline heavy montmorrillonitic clay-soils was technically feasible. As with all saline soils, the sodicity was high because the major salt was sodium carbonate. Experiments with gypsum application to prevent structure deterioration of the sodic soil gave the same results as the normal reclamation technique without gypsum. After reclamation, the soil became non saline and non sodic. This is explained by the high mobility of the sodium that leaches out quickly and the availability of calcium-carbonate in the soil so that a source of calcium was available to replace excess sodium at the adsorption surfaces of the clay particles. In montmorrillonitic soils this process needs several years because the adsorption surface per volume unit of soil are very high and the calcium carbonate is only slightly soluble at pH values above 8.

Questions box 10

10.1 – A Peruvian example is given of socio-economic difficulties to reclaim saline land in an arid area with scarcity of irrigation water. Please explain the difficulties and mention a previous case study where a similar problem was met.

10.2 – In a pilot area in Peru it was shown technically possible to desalinise heavy montmorillonitic saline-sodic clay soils in three yaers by subsurface drainage and using ponded rice as a reclamation crop without the use of gypsum. Please explain the technical success and qoute a previous case study with a similar situation.

11. Drainage of an inland alluvial fan, Iran

(Arid zone, alluvial fan, irrigated land, association of small farmers)

The Garmsar alluvial fan has its top at the foot of the Alburz Mountains and wedges out into the Dasht Kavir desert. The agricultural land is irrigated from the Hableh Rud River. The climate is semi arid and the agriculture depends mainly on irrigation from the river. Occasionally flash floods occur. The agricultural calendar has three seasons and the land is used in rotation according to the seasons so that during a particular season only about 30% is cropped.

In the top of the fan, the land has a considerable slope and the soils are deep, sandy and permeable. Here, relatively large amounts of irrigation water are available and a fairly large part of the water applied is lost to the underground at relatively small irrigation efficiency.

The aquifer in the upper part is deep and permeable so that the irrigation losses are transported down slope. In the middle part of the fan, the irrigation is supplemented with water pumped up from the aquifer.

At the foot of the fan, the land slope is reduced, the soils are more silty and clayey, the aquifer is less deep and less permeable, and irrigation water becomes scarce. Hence, the water table becomes shallower and groundwater comes up by capillary action of the soil. The soil salinity becomes high. Licences for pumping of ground water are restricted and the ground water that is not pumped or evaporated flows out into the desert.

A subsurface drainage system in the lower parts of the fan to deepen the water table, prevent capillary rise and salinization to enhance agriculture would only be useful if enough irrigation water is made available to be able to irrigate crops and leach the soil. Given the precarious irrigation situation, it will not be possible to irrigate all the land. Potentially about 50% of the land can be made irrigable and in the irrigable land only 50% or less can be actually irrigated in one year.

To assist the poorer farmers at the down-slope end of the fan, a study is made of the ground water supply to the fringes of the alluvial fan to see if the number of licences for pumping of ground water could be increased here. Further a system of strip cropping is advocated. It consists of strips of land about 100 m wide and 1 km long. The strips are stretching along the slope. Along the strips, corridors are made in which open drains are situated taking care of the flash floods. The corridors have also a width of some 100m and are planted to drought and salt resistant trees. Thus, the water table in the corridors will be relatively deep and they will serve as a drainage sink for the agricultural land. Also, the corridors will beautify the landscape, break winds, harbour flora and fauna and provide fuel wood.

The principle reasons why the strip cropping principle can be used is that the main part of the uncultivated land is government property so that the land consolidation project is not faced with legal problems of private land ownership.

Questions box 11

11.1 – Why are the salinity problems mainly found at the foot of the alluvial fan? 11.2 – Which particular socio-economic conditions make it possible to advocate a strip cropping system? 11.3 – In what respect would the strip cropping system help to check soil salinity and promote bio-diversification? 11.4 - What are the protective functions of the corridors in respect of land and water management?

12. Drainage of acid sulphate soils

(Humid and semi-humid tropics, coastal areas)

Acid sulphate soils occur in coastal marine environments, especially in regions where mangrove vegetations prevail. They are clay soils containing iron sulphides and pyrite. Upon draining the soils they become oxygenised and the iron is converted into insoluble iron (ferri) oxides and iron hydroxides. The sulphides and pyrites are transformed to sulphuric acid. The pH of such soils becomes very low (<4) and unfit for agriculture as well as any other form of life. The soils have a very colourful appearance (grey, yellow, red, and brown) and the water in the area becomes crystal clear, devoid of aquatic life. In the long run, after prolonged drainage, the soluble acids can be removed and the pH attains reasonable values (>5). (It is theoretically possible but practically impossible to reclaim the soils with gypsum, as this would require immense quantities.) Reclaimed acid sulphate soils are very permeable as the remaining iron compounds provide a stable soil skeleton. However, under acid conditions, many nutritive soil minerals are quite soluble and washed out easily. Hence, the soils have a low fertility and need to be fertilised intensively.

More about acid sulphate soils can be found on the FAQ's page of this web site.

The most suitable crop on such lands is rice. In West Africa and India, the soils are cultivated only in the monsoon period when they can be kept submerged under fresh water, restricting the oxygenation and acidification. Dikes and bunds must protect the cultivated lands from the ingress of seawater. Also, the field must be equipped with a surface drainage system so that water can be evacuated during periods of high intensity rainfall. At the dikes, the collector drains must be connected to the seashore and a gate must be placed which can be opened when the inside water level is too high and tide is low. The gate must be closed at high tide, to prevent ingress of salt water, and also when the inside water level is low, to conserve the fresh water. The soils are often allowed to be flooded with seawater during the fallow season. The salty water controls weed growth, prevents oxygen to enter the soil and the magnesium salts of the seawater have a favourable effect on soil fertility. With the onset of the next rainy season, the sodium chlorides that came in with the seawater are rapidly flushed out again.

The reclamation of acid sulphate soils is a long lasting process that must be carefully and patiently accompanied. Small farmers, who bit by bit reclaim small parcels of potentially acid sulphate soils do this to earn an extra income next to the income they get from adjacent non-acid soils. Larger reclamation programs undertaken by governments and large land developers have often failed. It is simply not possible to commercially exploit the soils quickly. Large-scale reclamations in the islands of the estuary of the Orinoco River in Venezuela and in coastal areas have led to disaster. Hereby the original values of the land and the wetland forests, like grazing possibilities of cattle, collection of timber, fish catching, picking of fruits and medicinal products and much more, were lost and replaced by desolate barren land. The original function of the mangroves protecting the shoreline against storm surges from the sea got lost and the sea intrusions became more frequent.

Questions box 12

12.1 - Acid sulphate soils are the opposite of sodic alkali soils. Please explain the differences and clarify which insoluble salts play a role in the processes of acidification and alkalinization respectively? 12.2 - In which environments does one find acid sulphate soils and what causes their appearance? 12.3 - What measures can farmers take to reclaim acid sulphate soils? 12.4 - Please explain why the reclamation of acid sulphate soils is a lengthy process and why large scale commercial development of potential acid sulphate soils seems impossible