18 Procedures in Drainage Surveys

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18.1 Introduction

Previous chapters have covered the various elements of land drainage theory, as well as methods of investigations and surveys. Since these subjects were treated separately and somewhat in isolation, step-by-step instructions on how to proceed when faced with a land-drainage problem will now be given.

True land-drainage projects seldom occur. Land drainage usually forms part of an agricultural development project. The project area may measure from some hundreds of hectares to tens of thousands of hectares.

Planning and implementing an agricultural development project is an interdisciplinary undertaking. The land-drainage engineer is only one of the specialists whose contribution is required. A drainage project may be part of a national, regional, or local development plan. Depending on the activities to be performed during the planned development process, a number of phases can be discerned.

These phases follow a certain sequence, and during the planning process, each phase requires information at an appropriate level of detail. The setting of goals and the formulation of projects is usually based on existing information; little time is spent on fieldwork. On the other hand, drawing up the plan and implementing the project requires a great deal of information, necessitating detailed investigations and surveys. Generally, information at three levels is required: at the reconnaissance, feasibility, and post-authorization level (USBR 1971).

At Reconnaissance Level
When drainage problems have to be tackled, the first step is to conduct a reconnaissance study. Its main objective is to make an inventory of the problems and to formulate possible alternative solutions. The feasibility of the proposed project should be identified on its technical and economic merits.

At Feasibility Level
This phase comprises the additional activities required to select one preliminary plan from among the possible options. The feasibility study should enable financing agencies to appraise the project and to decide whether or not to execute it. Field surveys and investigations are needed to prepare the drainage plan in more detail.

At Post-Authorization Level
The post-authorization phase comprises the final design of the project and the preparation of tender documents.

This chapter will elaborate on the concepts of reconnaissance, feasibility, and

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post-authorization as they are related to land-drainage surveys. It should be borne in mind that the procedures outlined will not be unconditionally applicable under all circumstances. They may have to be modified or adjusted to take local conditions into account, or to comply with the special wishes of a governmental or regional planning commission.

18.2 The Reconnaissance Study

A reconnaissance study comprises the desk and field research needed to obtain a general knowledge of the development potential of the project area. To formulate the project, a broad inventory of the land, water, and human resources has to be made. A great degree of reliance is placed upon existing data or on indirect sources of information. Field work is usually kept to a minimum.

A physical plan has to be prepared so that the technical options can be assessed. Costs and benefits should be estimated to allow an appraisal of the economic feasibility of the project. The study must give a clear picture of possible constraints to development and whether further investigations are justified.

Experience has shown that further investigations will only be justified if the project as a whole is likely to double or triple the gross output. It is stressed that this doubling or tripling of gross output refers to all planned project activities; improved drainage is just one of these.

Frequent consultations are needed between the land-drainage engineer and the other specialists in the team, particularly with the agronomist, the soil scientist, the economist, the irrigation engineer, and the hydrologist. Often the functions of land-drainage engineer and irrigation engineer are combined in the same person, who sometimes has the function of hydrologist as well. In many countries, this multidisciplinary scientist is a civil engineer whose contact with the agronomist and soil scientist is often too superficial. This lack of understanding between them may result in a project with major emphasis on main drainage works, and less on field drainage systems. The ultimate goal, however, is better crop production, and this can basically only be achieved by means of proper field drainage.

Figure 18.1 presents the steps to be followed in a drainage reconnaissance study. These are:
- Collecting and evaluating basic data, such as data on topography, climate, hydrology, physiography, soils, and present land use. The data available may vary in their degree of detail and accuracy. It will therefore usually be necessary to undertake some field trips to get a better appraisal of the nature of the problem (e.g. 'Is there a surface or subsurface excess of water?'), its extent (the size of the problem area), and its magnitude (e.g. a decline in crop yields). Such field trips should preferably be undertaken with the agronomist and the soil scientist;
- Planning the potential land use. This calls for teamwork; the land drainage engineer is only one member of the team. There will usually be several possible alternatives for potential land use. For instance, it may be possible to grow food or cash crops, or to rear cattle, or to irrigate, or to practise rain-fed farming with or without supplemental irrigation, or to grow one or more crops a year. Social constraints

BASE DATA COLLECTION: - topography - climate - hydrology - geology and physiography - soils - present land use
PROJECT FORMULATION: - (preliminary) lay-out main irrigation system - water application - potential land use - flood hazard - defining drainage problem .surface drainage .subsurface drainage .discharge by gravity or pumping
PHYSICAL PLAN: - preliminary lay-out main drainage system - aspects of field drainage system
COSTS AND BENEFITS: - cost estimate land drainage works - estimate benefits land drainage works

Figure 18.1 Steps to follow in a drainage reconnaissance study

or specific soil conditions may prevent some crops from being grown. There may or may not be well-established market outlets or facilities for processing certain crops. Some alternative types of land use, though technically sound at first sight, may have to be dropped for socio-political or agro-economic reasons;

- Defining the land-drainage problems, albeit in general terms, for the various land-use options. The following issues should be addressed:
  - The location and extent of the problem;
  - The origin of the excess water;
  - Inundation and the need for flood control;
  - Salinity and sodicity (alkalinity), acidity, high organic-matter content;
  - Is there a surface and/or a subsurface drainage problem?
  - Can excess water be disposed of by gravity or is pumping required?
  - Can engineering problems be expected?
  - The general layout of the main drainage system;
  - Should drainage works be executed mainly by machinery or can manual labour be employed?
  - The costs and benefits of the land-drainage works;
  - How and by whom are the land-drainage works to be operated and maintained?

The question of operation and maintenance is all too often overlooked. No one will dispute that all constructions, including land-drainage works, require maintenance. The issue is who is responsible for, and who is going to pay for, the operation and maintenance of the drainage systems. In many agricultural development projects, this issue is decided, at least on paper, but, unfortunately, land drainage is usually given the lowest priority. One should remember, however, that it is always the weakest link that determines the success or failure of a project. The land-drainage engineer should be fully aware of this fact. He should therefore conduct opinion polls on the need for land drainage, do extension work on the purpose of land drainage, and work in close cooperation with the users of the land, irrespective of the size of their holdings.

18.2.1 Basic Data Collection

For a proper assessment of the land-drainage problem and the costs of the drainage works, it is essential to have topographic and geological maps, aerial photos, and information about climate, soils, and land use.

Topography

A topographic map on a scale of between 1:50 000 and 1:100 000 showing contour lines of the land surface is an indispensable tool in reconnaissance drainage surveys. The map should show all topographic and physiographic features relevant to drainage: towns, villages, roads, railways, paths and tracks, rivers and streams, natural drainage channels, canals, ditches, cultivated land, waste land, and natural vegetation. If a topographic map of the proper scale does not exist, little else can be done than to have one made, preferably from controlled aerial photo mosaics.

On 1:100 000 maps, contour lines are often presented at 5.0 to 10.0 m intervals. In sloping areas, this may provide sufficient detail, but in flat areas, more precise information is required, say at 1.0 m intervals. The topography of the area governs such matters as the siting of observation points; the alignment and slope of main canals, collector ditches, and field laterals; the maximum length of the field laterals; the installation of weirs; and the selection of the drainage outlet. Spot elevations of the land surface should be shown on the topographic map, enabling the slope of the land to be derived. A simple geodetic field survey will provide this information.

At the proposed drainage outlets, detailed information on the water levels in the river or sea should be available. High river-water elevations and the effect of the tide on drainage-outlet elevations should be established. (Data requirements will be discussed in Chapter 24.) Unfortunately, data on river-water levels during peak discharges are often scanty.

A thorough analysis of topographic data is needed. Such an analysis may, for example, reveal the direction of natural drainage or the concentration point of this flow. Sudden changes in topographic level and specific geomorphic features (e.g. alluvial fans, abandoned and filled stream channels, natural drainage courses, springs, seeps, and abandoned wells) can all have an impact on the drainage problem. Surface drainage difficulties can be expected, for instance, if slopes are less than 0.1%, and especially if they are less than 0.05%.

Climate

Climate has a major impact on the environment and is often responsible for variations in soils, water, and the appearance of plants. It is a decisive factor in determining the type of drainage system to be applied.

In humid climates, drainage is largely required to evacuate excess rainfall, whereas, in arid and semi-arid climates, drainage is needed mainly to remove excess irrigation water.

As the land-drainage measures to be taken are closely related to the crops to be cultivated, an agro-ecological-zone classification of the project area is a useful tool during a reconnaissance study. To determine the project area's agro-ecological zone, the main climatic data needed are the average monthly temperature and the average annual precipitation. In addition, a balance of the water available for the proposed crops should be prepared. This requires data on potential evapotranspiration and monthly rainfall. The agro-ecological-zone classification makes clear whether it is possible to cultivate rain-fed crops or whether there is a need for irrigation.

An assessment of the magnitude of the land-drainage problem also requires information on rainfall intensity. Data on 24-hour rainfall should be examined, and return periods of high-intensity rainfall should be determined. Many countries lack a network of meteorological stations where climatic data have been collected over an extended period of years. Hence, choosing representative climatic data for the project area may not be easy. (For more information on rainfall-data handling, see Chapter 6.)

Hydrology

It is recognized nowadays in hydrology that surface water and groundwater should be considered together. This is especially valid in arid and semi-arid regions, where the hydrology is characterized by a high variability of rainfall, intermittent and sometimes short-lived river flow, high evaporation rates, the importance of the soil moisture in the runoff process, and the sometimes high salinity of surface water, soil moisture, and groundwater.

The hydrological regime of a river depends on the rainfall, the evaporation, and the physiographic characteristics of the river basin (see Chapter 2). In many basins, the rivers have their catchment areas in a region with a climate different from that of their alluvial river plains, so the hydrological regime will then be affected by the hydrometeorological conditions of both regions.

Rivers situated entirely in arid and semi-arid regions have an erratic, flash-type regime, reflecting the variability in rainfall. In contrast, many monsoonal rivers in the humid tropical zone have a long period of sustained high flow during the wet season, followed by a gradual decrease in flow during the dry season. The same holds true for rivers like the Indus, which rise in snow-covered mountains and debouch into arid river plains. Examples of both gentle and erratic river regimes are shown in Figure 18.2.

An understanding of the hydrological regime of the particular river plain in which the project is to be sited gives a good insight into the possibility of natural drainage

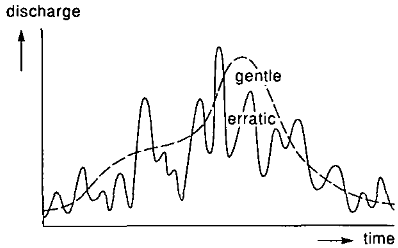

Figure 18.2 Gentle and erratic river regimes

in the upper reaches of the river and into the process of salt-water intrusion in coastal areas.

The natural salinity of the river water also depends greatly on the conditions in the river catchment. Catchments in the arid zone show relatively high salinities. For example, the salinity of the Banas River in India, fed by monsoonal rains and debouching into the Rann of Kutch, varies between 1.0 and 2.0 dS/m salt. In contrast, the water of the Indus River, which is fed by snow-melt water, ranges from 0.3 to 0.5 dS/m salt.

Most alluvial plains contain pervious strata consisting of unconsolidated formations of considerable depth. These pervious strata, which act as aquifers, are interbedded with semi-pervious strata, which act as aquicludes. The groundwater in the aquifers has a salinity that varies with location and depth. The salinity is generally low under the upstream parts of the delta and increases towards the sea. There is also a general increase in salinity with depth.

Nevertheless, there are many departures from this general picture. The distribution of the salinity of the deep groundwater is determined by the geological history of the alluvial plain, with transgressions and regressions that have occurred during the deposition of the subsoil. The actual distribution in a given case cannot be predicted, and extensive geohydrological investigations are required to make an inventory.

Geology and Physiography

During a reconnaissance survey, a certain knowledge of the geology of the project area and its surroundings will be acquired. Since geological conditions can cause drainage problems, a geological map of the region may be most helpful in delineating problem areas.

Geological maps will usually not show detailed information of the geology of alluvial plains. Hence, major and minor landscape features will have to be mapped on the basis of aerial photographs, with a limited amount of field work to confirm their formation.

In a reconnaissance survey, there will usually not be sufficient time or money available for exploratory drillings. Yet, it is of crucial importance that some knowledge be gained of the geological conditions of the project area. The geological map should be supplemented by a number of cross sections showing the lithological sequence, the depth and thickness of water-transmitting layers, and the depth of the impervious layer. For this purpose, a search should be made for the logs of existing wells (both deep wells and village wells). If such logs do not exist, a number of hand auger holes can be made to a depth of 5 m, provided that there are no rocks or encrusted soil layers near the surface. For reasons of efficiency and economy, this work can be coordinated with that of the soil survey.

Soils

A soil map at a scale of between 1:50 000 and 1:100 000, based on a systematic soil survey, will supply plenty of data on the project area's soil resources. The soil map should provide a clear answer to the question of whether the soils are suitable for the proposed crops, or, if not, what other crops could be grown successfully (see Chapter 3). Special attention should therefore be given to the conditions of the upper rootzone (0.0 to 0.3 m): its workability, water-holding capacity, erodibility, and, if irrigation is to be practised, its infiltration rate and whether crusts or impeding layers occur or will form. Factors to be studied in the lower rootzone (0.3 to 1.2 m) are the effective soil depth, subsurface drainage (particularly layers that would limit water percolation), and water-holding capacity.

A classification of the soils according to a standard taxonomy may provide much useful information on the extent of the drainage problem. Systematic field soil surveys will enable the areas with salt-affected soils to be delineated, but the cause of soil salinization still has to be found.

The depth of soil observation in systematic soil surveys is generally limited to 1.2 to 1.5 m. In the case of subsurface drainage problems, some data on soil stratification and the hydraulic conductivity of the shallow substratum (1.5 to 5.0 m) should be acquired.

Land Use

Prior to planning a drainage system, one must know what the land is to be used for. The proposed land use will largely determine the degree of drainage required and the type of drainage system that will be installed. This calls for a proper knowledge of the suitability of the soil for certain crops. The degree and type of drainage depends on whether the land will be used for, say, annual or perennial crops, cotton or rice, wheat or irrigated pasture. The type of crop is an important factor in determining the design of the drainage system and thus the cost of the drainage works.

If rain-fed crops are to be grown, the monthly water balance provides only rough figures on water excesses or deficits. For land drainage, daily rainfall figures are needed.

For irrigation projects, a reliable estimate of the water losses should be made. In existing irrigation projects, data are rarely available on the efficiency of water use or on the water losses, even if the drainage problems are obvious (salinity!). For new projects, irrigation efficiencies are all too often overestimated. Useful data on the various factors that determine the efficiency of water use have been presented by Bos and Nugteren (1990).

Non-agricultural land use, such as pastures, range lands, forests, and nature reserves, should also be considered, particularly when the land is not very suitable, or entirely unsuitable, for cropping, or when heavy investments would be needed to make the land agriculturally productive.

Examples are depressions with a high watertable and high salinity or sodicity, seepage areas along irrigation canals, and areas with very heavy swelling clays that would require costly methods to improve them.

To define alternative land-use systems, it is customary to conduct a land-classification survey. Any land classification involves two steps: a resource inventory, followed by an analysis and categorization. There are a number of land-classification systems that could be adopted. One such system is the U.S. Bureau of Reclamation's Irrigation Suitability Classification, which can be adapted to different environments with potential for irrigation/drainage development.

When a drainage project is being planned, due consideration should be given to any adverse environmental effects that may be created (see Chapter 25).

18.2.2 Defining the Land-Drainage Problem

Soils, climate, topography, and other conditions vary from place to place, and so, too, do the conditions that contribute to a land-drainage problem. Though complex in nature, two types of problems are usually distinguished, though they may occur in combination:

- Surface drainage problems, where there is an excess of water on the land surface. Surface drainage then aims at an orderly removal of excess water from the surface of the land (see Chapter 20);
- Subsurface drainage problems, where there is an excess of water within the soil at close proximity to the land surface. Subsurface drainage then aims at removing the excess water from the soil and maintaining the watertable at an adequate level. In arid and semi-arid areas, a high watertable is invariably accompanied by soil salinization, so accurate watertable management is also required for salinity control (see Chapters 15, 21, and 22).

Surface and subsurface drainage alike require a system to collect all excess water from the problem area and to evacuate this water beyond the project boundary without affecting neighbouring agricultural land.

Surface Drainage Problems

A reconnaissance survey should focus on the following factors:

- Climate (i.e. high-intensity rainfall);
- Topography (i.e. flat land or only slightly sloping land);
- Soil conditions (i.e. soils characterized by a very low infiltration rate or a slowly permeable horizon at shallow depth);
- Hydrology (i.e. flooding resulting from the inflow of water from neighbouring or distant areas).

Areas suffering from flooding must be investigated for the location and extent of the flooding, the frequency, depth, and duration of the flooding, and the time of the year in which flooding may occur. River water levels and discharges should be evaluated and a study made of the rainfall characteristics (depth, duration, and frequency analysis) and of the watershed characteristics (size, shape, relief, vegetation, and soil).

Clear statements must be made on whether flood-protection measures are needed, and whether upstream regulatory works can be implemented to minimize peak river discharges. In large projects, this will usually be the task of a hydrologist, rather than of a land-drainage engineer.

On flat land, the presence of excess water may be due to the inadequate storage capacity of natural water courses, obstructions in such water courses, irregular topography (local depressions), poor topsoil conditions (low infiltration rate), low storage capacity of the subsoil (dense layers close to the soil surface or shallow watertables), or to the absence of an outlet.

Whereas the rainfall characteristics largely determine the amount of excess water to be expected in the project area in a given period, it is the land use and the weather conditions (evapotranspiration) that dictate the time allowed for the removal of the excess water. For example, winter wheat in a subtropical climate can withstand several days of flooding without being damaged if the temperature is relatively low and the sky is cloudy.

The reconnaissance survey should provide clear statements on whether a main drainage system is required, and, if so, whether its task will be to intercept and collect flood water from adjacent sloping land, or to collect and remove excess surface water that occurs locally in the project area, or whether it must perform both tasks. An estimate of the quantities of excess surface water to be removed per unit of time must be made. In regions that are comparatively unexplored, this will require a number of field measurements. (Methods of estimating runoff on flat and sloping lands are presented in Chapters 4 and 20.)

Obviously, to keep the costs of excavation to a minimum, excess surface water from an agricultural area should be removed along the shortest possible routes. The results of a reconnaissance survey will show whether natural drainage ways can be used to remove the water or whether an artificial drainage system will have to be installed. Since the direction and alignment of the main canals depend largely on the topography and the slope of the land, the number of alternative routes for the main canals will be limited, unless ample use is made of weirs, drop structures, pumping stations, etc., which will undoubtedly raise the cost of the venture (see Chapter 19).

Conditions at the outlet merit special attention during a reconnaissance survey. It must be investigated whether the excess surface water can be disposed of by gravity or whether a pumping station will have to be constructed. In addition, the quality of the drainage water should be studied, and whether it is possible to mix it with river water of better quality for conjunctive use. The survey report should be accompanied by a map showing roughly the routes of the main drainage canals and the possible sites for the outlet (with or without a pumping station). If necessary, suggested sites for storage reservoirs, embankments, protection works, culverts, bridges, drop structures, etc., should also be shown on the map, and an estimate of their costs should be included in the report.

Environmental aspects, such as the effect of drainage on health, could have a major impact and should also be reviewed. (This subject will be dealt with in Chapter 25.)

Subsurface Drainage Problems

A reconnaissance survey should focus on the following topics:

- An assessment of the groundwater behaviour (i.e. the depth of the watertable at different times of the year, rapid changes in depth, the general direction of the groundwater flow, the salt content of the groundwater, and the areas of groundwater recharge, transmission, or discharge);
- An assessment of the drainability of the project area (i.e. a study of the possible outlets, of the ability of the subsoil to transmit water, and the depth to a layer of very low hydraulic conductivity).

Maps showing the contour lines of the watertable are not generally available, so its behaviour has to be assessed indirectly from vegetation, land use, or soil salinization. Aerial photo interpretation can be of great help.

When irrigation is introduced, the watertable behaviour usually undergoes a drastic change (see Chapter 2). Data on the geomorphology and the subsoil conditions, as well as estimates of irrigation efficiency, should be evaluated to indicate whether subsurface drainage will be needed in the future (see Chapter 14). As previously mentioned, irrigation efficiencies are often overestimated, and consequently the future need for land drainage is all too often underestimated. The need for drainage thus only becomes apparent after the irrigation project has been implemented and its financial resources have been exhausted.

Soil maps based on systematic soil surveys are often available. Sometimes these maps (or the soil reports) supply some information about the watertable. This information, however, should be handled with great care because it is usually based on a single observation in a soil pit or auger hole. Even so, soil maps can be extremely useful in delineating areas of moist or wet soils.

In the case of subsurface drainage problems, the drainage engineer has to make clear statements on:
- Whether the soil profile is homogeneous or layered;
- The depth to the impervious base, usually a poorly pervious clay bed;
- The presence or absence of a pervious or highly pervious horizon at or below drain depth (between 1.5 and 2.5 m);
- The presence or absence of impeding horizons within the upper 2 m of the soil profile;
- The depth to the watertable and the zone in which it fluctuates during the year (mottling may be an indication);
- The salinity of the groundwater (electrical conductivity and sodium adsorption ratio);
- The type of drainage system (pipe drains or tubewells) to be adopted.

In general, the depth of observation in systematic soil surveys is limited to 1.2–1.5 m. Hence, during a reconnaissance survey, a number of augerings or soil pits should be made to a depth of 2.0 – 2.5 m and a few augerings to a depth of 5.0 m. A rough guide to the number of these deep augerings, which, in alluvial material, can be done by hand auger, is 1 per 200 – 1000 ha. An exact number cannot be given because that will depend on the size of the project area and on the complexity of its geology and physiography. (For more details, see Chapter 2.) Nor can any strict rules be given for the siting of the borings, but the physiography and the direction of sedimentation will serve as guidelines. Borings should be made in each physiographic unit, preferably in a number of cross-sections perpendicular to the natural drainage ways, or in a series of traverses aligned in the direction of sedimentation. For each cross-section, the elevation of the land subsurface, the location of the soil profile, and the depth to the watertable should be drawn. Particular attention should be given to the zone between 1.5 and 2.5 m below the surface, because the hydraulic conductivity of the material below drain depth largely decides the drain spacing. Also, the material at and just below drain depth will indicate whether problems can be expected with drain installation. (Chapter 12 elaborated on this issue.)

To gain some knowledge of the natural drainage out of the project area, or of the inflow of groundwater into it, a number of deep borings should be made along the boundaries of the project area. These borings should penetrate the entire aquifer through which groundwater may be entering or leaving the project area. A few pumping tests should then be performed, which will allow the aquifer's transmissivity to be calculated. This information, together with a watertable contour map, allows the rate of groundwater inflow or outflow to be calculated. In low-lying land partly surrounded by higher-lying land, the inflow of groundwater may considerably exceed the outflow, thus causing waterlogging. This phenomenon should not be underestimated. If deep main canals cut through the top layer, they may intercept unexpectedly large amounts of seepage. (For details, see Chapters 9, 10, and 16.)

In summary, a reconnaissance drainage survey provides information on the need for drainage and on the type of drainage system to be adopted (pipe drains or tubewells), and enables a tentative layout of the main drains and the outlet to be prepared.

At the end of a reconnaissance survey, a statement should be made on whether the drainage works appear to be economically and/or technically feasible. If the answer is positive, the more detailed feasibility study will then have to be done. A brief statement should also be made on the environmental impact of the proposed drainage works.

18.2.3 Examples

Some examples of reconnaissance drainage surveys are presented to indicate how existing data have been used and what additional field data had to be collected. The examples were selected at random; they are not necessarily representative of land-drainage conditions frequently found in nature.

Example 18.1 Peru

Irrigation is important in the agriculture of Peru. About one-third of the agricultural land is irrigated, the greater part of it being located in the river valleys in the arid coastal region. There, the irrigated area covers some 750 000 ha, and yields approximately 50% of the country's agricultural production.

Salinity has long affected crop growth. In the early sixties, it was estimated that 30% of the cultivated area was affected by salinity.

In 1973, a national plan was launched to rehabilitate the coastal agricultural lands. This plan was based largely on the outcome of a reconnaissance survey of the drainage and salinity conditions. The survey covered 757 000 ha in 42 valleys (Alva et al. 1976). About 34% of the area was found to be suffering from salinity and/or drainage problems (see Table 18.1).

Table 18.1 Areas affected by drainage and/or salinity problems in the coastal region of Peru

Problems	Area	
	(ha)	(%)
No problems	501 780	66.5
Slight drainage and salinity problems	102 360	13.5
Moderate to severe salinity problems	19 385	2.5
Moderate to severe drainage and salinity problems	133 485	17.5

A variety of basic data was available:
- Soil maps, scale 1:50 000 to 1:100 000: The maps presented soil-mapping units, suitability for irrigation classes, land use, and sometimes soil salinity. Soil maps were available for 34 of the 42 valleys;
- Aerial photos, scale 1:17 000 or 1:60 000;
- Topographic maps, scale 1:100 000, with contour lines at 10.0 m intervals;
- Discharges of some rivers, although usually no long-term records;
- Geological information, although usually no data on quaternary deposits;
- Watertable observations: A systematic survey of the watertable had been undertaken in only one valley, and few or no data were available for the other valleys.

Photos and maps were studied in the office, and this was followed by a field inspection. The occurrence and the severity of the drainage and salinity problems were to a large extent governed by the geomorphology of the river valleys. In the central and northern part of Peru, where rivers had deposited an alluvial fan, drainage and salinity problems were mainly found in the lower part of the valley, and groundwater salinity was usually high. In the southern part of Peru, the river valleys are narrow and deeply incised because of a geological uplift of the region. There, a braided river system is common, and shallow groundwater, usually of low salinity, is found in many places.

In general, the field inspections were made only in those areas that had been classified as affected on maps and photos. On the average, 3000 ha of land could be inspected daily. Attention was given to the following items:
- Crop growth and signs of salt damage;
- Evaluation of possible sites for the discharge of excess water;
- Inundation by rivers.

In addition, a limited number of augerings were done to a depth of 2.0 to 6.0 m. Occasionally, the hydraulic conductivity was measured. Information was collected from local administrative centres of the Ministry of Agriculture and from the farmers, but usually this information was verbal and was sometimes biased.

This study not only determined the location and the extent of the problem areas, but also indicated the potential for improvement.

Areas suffering only from salinity were considered easily reclaimable, at least in theory. The limited availability of irrigation water, however, and its generally poor quality, has restricted saline soil reclamation to a few hectares.

In areas with only slight problems of drainage and salinity, immediate land-drainage measures were not considered necessary. Of the 133 000 ha of land with moderate to severe drainage and salinity problems, approximately 90 000 ha could be improved. The remaining 43 000 ha are regarded as non-reclaimable for a variety of reasons:
- Availability of irrigation water: Water is not needed solely for leaching, but also for the renewed irrigation of land currently abandoned because of waterlogging and salinity;
- Soil and subsoil conditions: Soils overlying slowly pervious materials at shallow depth require too narrow a spacing between field drains. A spacing of 50 m between field drains was tentatively taken as a minimum;

- Excessive inflow of groundwater, usually limited to small isolated spots. Here also, too narrow a spacing between field drains would be needed to solve the problem;
- Outlet conditions: The discharge of drainage water was considered too difficult if a low topographical location necessitated pumping. Rivers that frequently overflow or erode their banks formed a further constraint.

Example 18.2 Pakistan

The Drainage IV Project area is situated between the Ravi and Chenab Rivers in the Punjab, Pakistan. It has a gross command area of 141 700 ha, of which 118 000 ha is under canal command.

The area is part of the Indus Plain, which consists of a vast stretch of alluvial deposits, mainly of unconsolidated sand and silt, with minor amounts of clay and gravel. The climate is arid and is characterized by large seasonal fluctuations of both temperature and precipitation. Annual precipitation is only about 250 mm, half of which falls in July and August.

The flat topography, with an average gradient of 0.02%, and the absence of a well-defined natural drainage system in the project area have created a severe surface drainage problem. This has been compounded by the construction of roads, railways, and irrigation works that obstruct surface runoff. To alleviate this problem, a system of surface drains was constructed some eighty years ago. This system, however, is inadequate because of poor design and maintenance, as evidenced by clogged channels and insufficient capacities.

Under the Drainage IV Project, it was decided to rehabilitate existing drains, to install new drains, and to construct stream-gauging stations on drains.

The soils are generally medium-textured in the topsoil, and become coarser with depth. Of a total cultivable command area of 188 000 ha, approximately 48 000 ha are broadly regarded as being suitable for subsurface drainage. Of that area, 29 700 ha have been selected for drainage in three units, to be constructed during the currency of the Project.

The area is badly affected by waterlogging and salinity. A survey of the depth of the watertable and the salinity of the soil was made in January-February 1983. The results are presented in Tables 18.2 and 18.3.

A land-use map at a scale of 1:50 000 was prepared in June-July 1983. It distinguished six land-use classes, namely:
- Class I land is good arable land with a watertable deeper than 1.8 m. It covers about 40% of the total area and does not need subsurface drainage;

Table 18.2 Status of waterlogging

Depth of watertable (m below surface)	Percentage of area
< 0.9	54
0.9 - 1.5	31
1.5 - 3.0	12
> 3.0	3

Table 18.3 Status of salinity of the soil (0 – 1.8 m)

Status	Percentage of area
Non-saline - non-sodic	64
Saline	7
Non-saline sodic	6
Saline - sodic	23

- Class II is fairly good arable land that is in need of subsurface drainage;
- Class III is fair arable land in need of subsurface drainage;
- Class IV is fair arable land with higher soil salinity than Class III, and is also in need of subsurface drainage (Classes II, III and IV are lands that are poorly drained with watertables varying from 0.9 m to 1.8 m below the surface);
- Class V is not arable under the existing conditions; it is currently non-productive or has very poor crop productivity due to salinity/sodicity and/or a high watertable (within a depth of 0.9 m): it needs subsurface drainage;
- Class VI is non-arable land that is excluded from development.

On the basis of the land-use map, the depth of the watertable, and the salinity status of the soil, the 29 700 ha selected for subsurface drainage belong to the following classes: Class II, 1300 ha; Class III, 19 200 ha; Class V, 8000 ha; and Class VI, 1200 ha. Figure 18.3 shows the project area and the area ultimately selected for subsurface drainage.

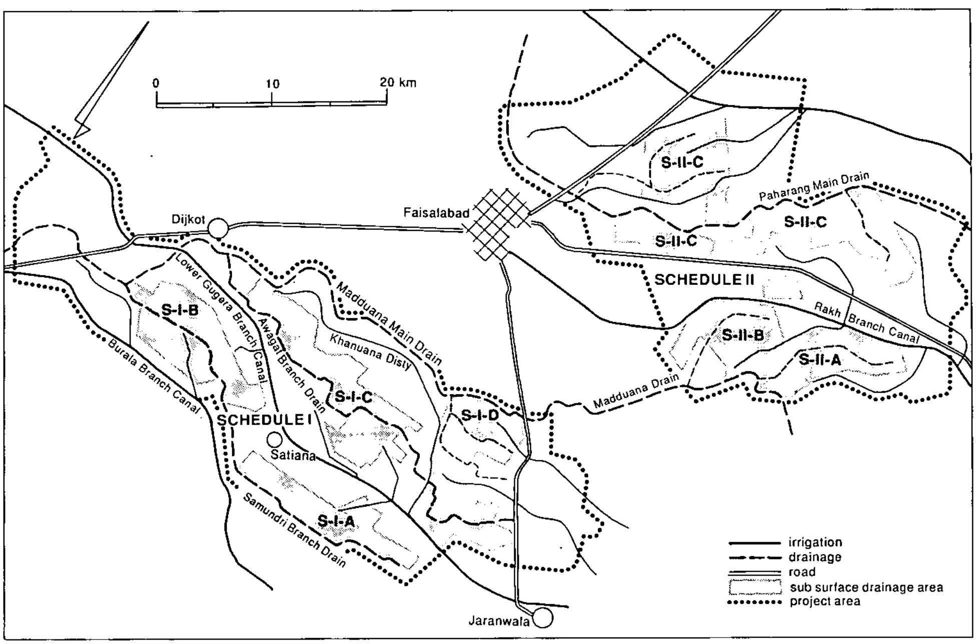

Figure 18.3 Project area and subsurface drainage area of Drainage IV Project