19 Drainage Canals and Related Structures

M.G. Bos[1]

19.1 Introduction

The contents of this chapter follows the design process of a main drainage canal system and the related structures. Section 19.2 discusses the factors that influence the lay-out of the canal system. This discussion is rather general because each situation yields a different lay-out. Section 19.3 gives a review of the most important criteria that determine the shape and the capacity of a drainage canal. Upon availability of a lay-out, the shape and capacity of the canal system, the hydraulic dimensions can be calculated by use of Manning's equation. This is treated in Section 19.4. The next section discusses maximum permissible velocities for earthen canals as a function of soil type, capacity, etc. If the maximum permissible velocity is surpassed, the designer has two basic options: protection against scour by use of a pervious lining of the canal (Section 19.6), or the use of energy dissipators (Section 19.7). The last section deals with culverts and small bridges.

This chapter deals with operation, maintenance and construction factors only as far as they influence the design of the system.

19.2 General Aspects of Lay-Out

Systems of drainage canals and their related structures collect and carry away excess water to prevent damage to crops and to allow farm machinery to work the land. Besides these agricultural functions, a drainage canal system may have to supply water for irrigation in the dry season, act as a means of transport for shipping, etc. In this chapter, we shall concentrate on the agricultural functions of the system.

Broadly speaking, there are two kinds of drainage canal systems:
- A system to intercept, collect, and carry away water from sloping land adjacent to an agricultural area. Most of the water in this system originates from surface runoff. It will be discharged for brief periods only, causing high flow rates and sediment transport;
- A system to collect and carry away water from a relatively flat agricultural area. Here, the main source of water is precipitation on the area or irrigation. Because of surface detention and groundwater storage, water is discharged over a longer period than above. Furthermore, the flat gradient canals have little or no sediment transport capacity.

In designing a drainage canal system for an agricultural area that is partly bounded by sloping lands, the engineer can either design two canal systems, which drain the sloping and agricultural area separately, or he can design a combined system.

[1] International Institute for Land Reclamation and Improvement.

19.2.1 Sloping Lands

If a flat agricultural area is partly surrounded by sloping lands, the surface runoff from these lands should be intercepted and discharged to prevent inundation of the agricultural area. The extent to which drainage problems in the agricultural area are caused by this surface runoff should be determined by making a water balance of the area. Runoff from sloping lands causes two major problems in the downstream areas; (i) rainfall causes high discharges of short duration, (ii) the surface runoff causes erosion, and the related sediment transport down the steep gradient of the channels causes sedimentation in the flatter channel reaches.

Both problems can be eased by a combination of the following techniques:
- Planting trees and encouraging the growth of natural vegetation on steep slopes;
- Contour ploughing and terracing intermediate slopes (up to 10%). Terracing is the levelling of the slopes along the contour lines in combination with the planting of crops;
- Encouraging the growth of crops that give a soil cover during the rainy season;
- Constructing retention reservoirs in the streams to temporarily store peak runoff (see Photo 19.1).

These techniques are a form of erosion control; their application greatly eases the downstream drainage problems.

In sloping areas, the main drainage system usually will be limited to the reconstruction

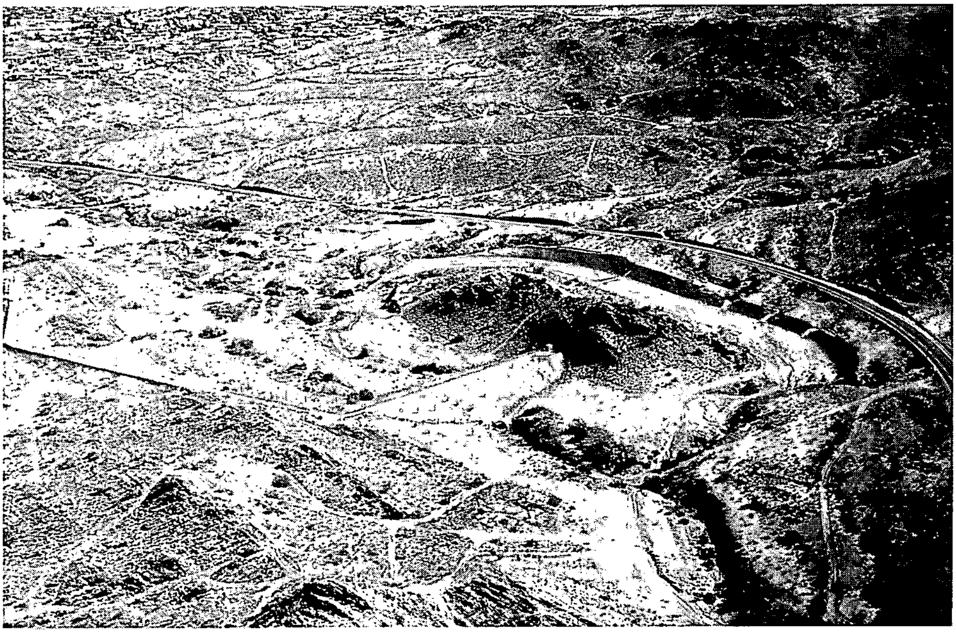

Photo 19.1 A retention reservoir is used to reduce the downstream flow rate

of channel reaches (Section 19.6) and to the construction of energy dissipators (Section 19.7).

Streams originating in sloping areas can be connected to a major river, lake, or sea along two alternative routes; (i) via an interceptor canal, which channels the water around the agricultural area to a suitable outlet, or (ii) via a canalized stream through the agricultural area.
The major advantage of the interceptor canal is that peak discharges and sediments from the sloping lands do not disturb the functioning of the drainage system in the flatter agricultural area.

It is possible to limit the required discharge capacity of a channel that transports water from sloping lands to a suitable outlet if the channel discharges from one of the following two structures:
- A retention reservoir that is filled by the peak stream flow, which is then released through a bottom outlet. As a result, the discharge peak is lower, but of longer duration;
- A regulating structure that consists of a weir of limited discharge capacity in the stream and a side weir immediately upstream of it. If the stream flow exceeds a predetermined rate, it overtops the crest of the side weir. Most of the additional stream flow then discharges over the side weir into an area where inundation or overland flow causes little damage.

  Which of these two lay-outs (or an intermediate lay-out) is the best solution can usually only be decided after a reconnaissance study.

19.2.2 The Agricultural Area

The agricultural areas that require drainage are usually coastal plains, river valleys, or plains where the inefficient use of irrigation water has caused waterlogging. In coastal plains, the drainage problems are exacerbated by some hydrological feature, typical of such plains, being:
- The gentle hydraulic gradient of the rivers in the coastal plain, which leads to low flow velocities and the deposition of sediments;
- The effect of tidal levels on river water levels near the sea and of saline water intrusion;
- The complicated network of river branches and ramifications, which can cause natural drains to disappear in coastal swamps giving the river or stream what is knwon as a 'bad outlet' (Section 19.2.3);
- The rapid changes in channel configuration that can occur after each major flood;
- The low elevation of the coastal plain with respect to the level of rivers and the sea. To prevent the inundation of the coastal plain, dykes along the rivers and the sea shore are essential.

To illustrate alternative lay-outs of the drainage canal system, let us consider an irrigated coastal plain that lies between sloping lands (hills) and the sea. The plain is intersected by parallel rivers and streams and by an irrigation canal system. Depending on factors such as: run-off from the sloping land, construction and maintenance cost of canals, quality of drainage outlets, etc., alternative lay-outs can be considered:

Combined Drainage System

Figure 19.1 shows a drainage canal lay-out that combines the drainage system of the sloping land with that in the plain. All run-off from the sloping land is intercepted and carried away by canalized streams. These streams, and the lateral drains along the river dykes, flow into a main drain that runs parallel to the sea dyke. One drainage sluice with a well-defined, stable (suitable) outlet has been planned on that drain. The other streams are dammed by the sea dyke. Concentrating all the drainage water discharge through one sluice eases sedimentation problems in the outlet channel.

Separate System for Sloping Land

If relatively high discharges come from the sloping lands, or if the plain is wide, intercepting and diverting streams into the nearest river is a sound alternative to the lay-out shown in Figure 19.2. The streams are dammed and the interceptor drains discharge all water from the sloping lands through two sluices into the rivers. As a result, the coastal plain has a separate drainage system that discharges precipitation, unused irrigation water, and groundwater inflow. Drainage has been decentralized into three independent systems: two for the sloping land and one for the coastal agricultural area.

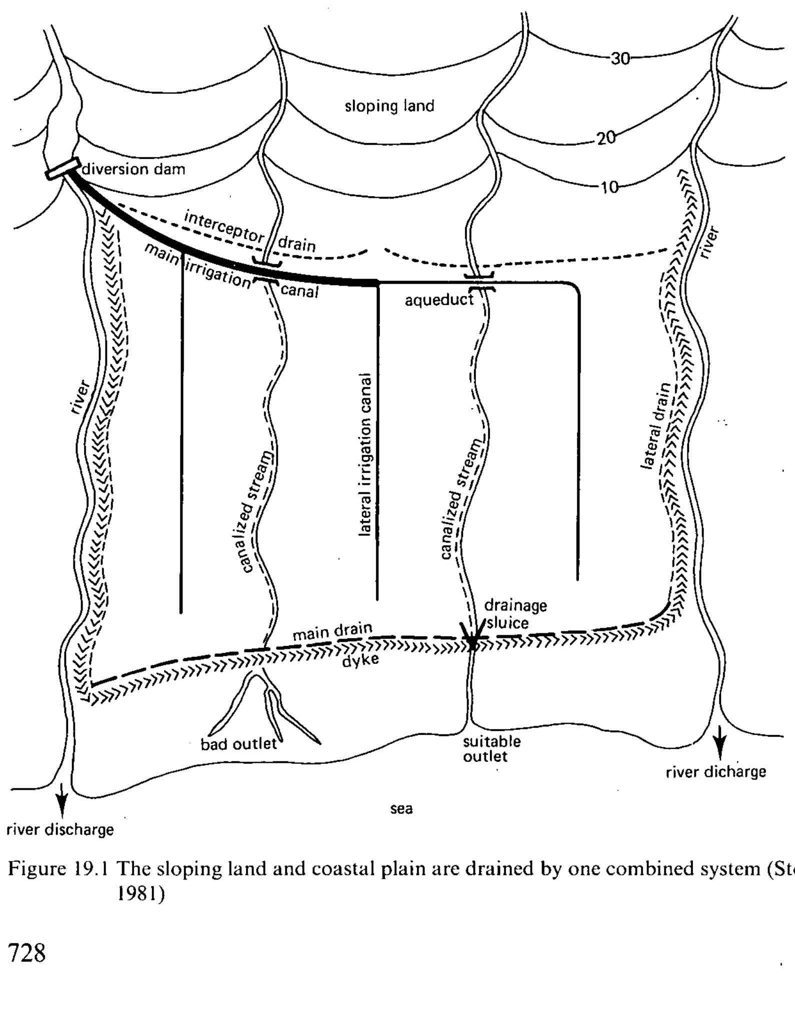

Figure 19.1 The sloping land and coastal plain are drained by one combined system (Storsbergen and Bos 1981)

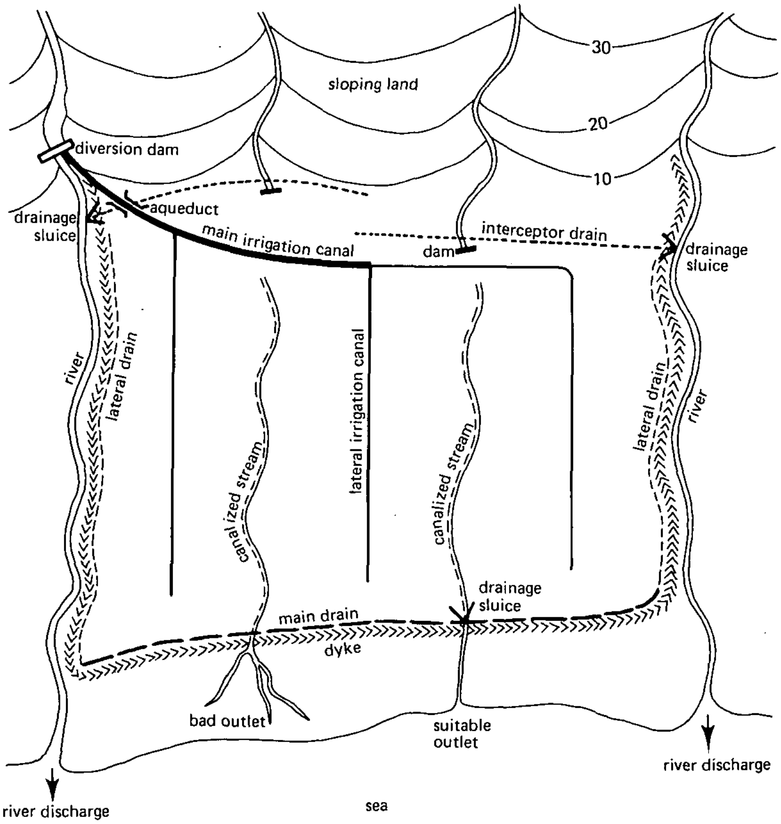

Figure 19.2 The sloping land and coastal plain are drained by three separate drainage systems (Storsbergen and Bos 1981)

Two Drainage Systems in a Coastal Plain

The transport of mud and sand along a coastline often blocks the outlets of all minor streams into the sea, and dredging may be needed to maintain a sufficient depth at the river mouths. Under such circumstances, none of the stream mouths is suitable as a drainage outlet. Water that is collected by the main drain along the coastal dyke is then discharged into the nearest river. Figure 19.3 shows four separate drainage canal sub-systems: two for the sloping lands and two for the coastal plain.

19.2.3 Drainage Outlet

The site where drainage water is to be discharged into a river, lake, or sea influences the lay-out and functioning of the drainage system. To ensure the uninterrupted discharge of water throughout the drainage season, the outlet should not be blocked by a sand bank or vegetated flats, nor should it be at the inner curve of a river, where sedimentation occurs.

At the outlet, the main drainage canal usually cuts through the natural river embankment or the dyke. To prevent flooding of the agricultural area, the outlet is usually fitted with a sluice, which can be closed when the outside water level is high. The sluice should be near the lowest part of the area to be drained. Soil conditions in such a location, however, may cause foundation problems, and the sluice may have to be moved.

To avoid damage if there is a change of the river course or coast line, sluices are built at a certain distance from the river or sea. The entire length of the main canal reach downstream of the sluice must be protected, and some length of river embankment or coast must be protected against erosion.

To operate and maintain the gates properly, it is essential that the sluice be accessible throughout the year. The cost of constructing and maintaining an all-weather access road may influence the choice of a site for the drainage outlet.

If the hydraulic gradient over the outlet sluice is insufficient to discharge all drainage water within a selected period (3 or 5 days), a pumping station may be added to the outlet. In such a case also the cost of power supply to the pumping station influences its location.

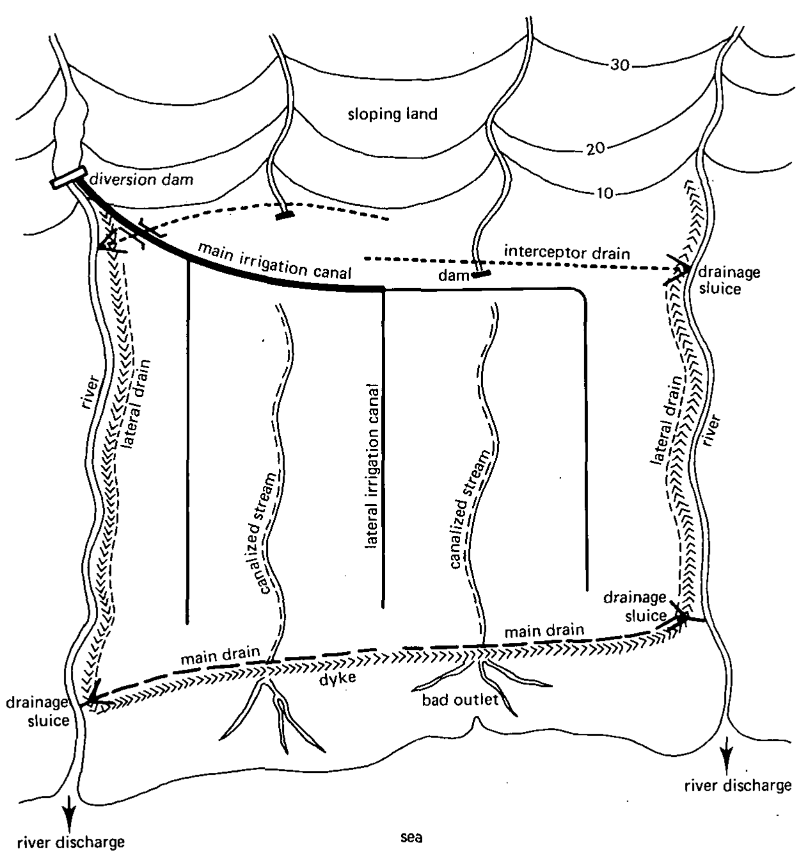

Figure 19.3 The sloping land and the coastal plain are drained by four separate systems (Storsbergen and Bos 1981)

19.2.4 Locating the Canal

To determine the location, hydraulic properties, visual characteristics, and condition of existing channels, planned canals, and related structures, one needs a 1:10 000 scale topographical map with a contour interval of 0.50 m or less, and a 1:10 000 controlled photo mosaic. Maps, especially in flat topography, should be field checked. This step should be done in the earliest planning stage to avoid the need for major revisions later. The following information is needed to plan a canal system (adapted from U.S. Dept. of Agriculture 1977):

1) The drainage area at junctions of existing streams and all flow control points. Drainage areas should also be delineated for the 'land level units' that will be described in Section 19.3;
2) The approximate profiles in existing channels, showing the elevation of the channel bottom, low bank, points of natural low ground away from but subject to drainage into the channel, and elevation and dimensions of all structures in or over the channel. The condition and serviceability of all structures should be recorded. Adequate survey data are needed for all structures to compute the discharge capacity for each;
3) The representative channel and valley cross sections for each hydraulic or economic reach. Additional cross sections should be taken as needed for a reliable estimate of: quantities of excavation and land clearance, damage evaluation in the plain or valley because of high water levels (see Section 19.3.2), and to permit the computation of storage in flood plains, ponds and marshes (see Section 19.3.3);
4) Manning's coefficient 'n' for each existing channel. Even if channel elements are very uniform, the n value should be estimated for each 1-km reach;
5) The location and elevation of all soil investigation sites along the proposed canals. To determine the maximum permissible velocities and bank slopes, soil investigations should extend to a depth of at least 3 m below the anticipated future canal bottom (Figure 19.4). Use the Unified Soil Classification of Section 19.3.4;
6) The landscape character and use patterns along major existing and anticipated drains. Data must include: scenic views, area and density of brush and trees, and isolated but valuable trees;
7) The location and ownership of boundary lines in the vicinity of all probable canals and structures;
8) The other significant features that will be affected such as roads, pipelines, power and telephone lines, buildings, wells, cemeteries, and fences.

Based on the above information, the center line of all the canal system is drawn in pencil on the photo mosaic, showing curves, intersecting angles, and so on. Mark the stationing on these center lines with a short dash at each 100-m point.

After this preliminary design phase at the office, the canal location should be field-checked. For this check, one should walk the full length of the canal's center line, noting the following on the preliminary design drawing:

a) The probable realignment of the center line;
b) The points of significant breaks in the grade;
c) The location of all rock outcrops or critical soil conditions;
d) The approximate locations of points where more cross sections could be obtained;

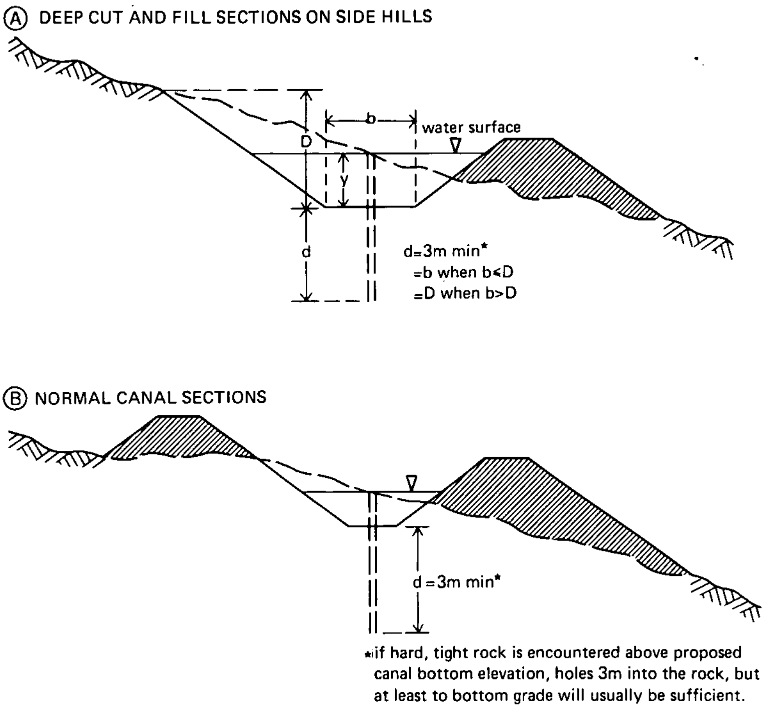

Figure 19.4 Depth of preliminary exploratory holes for canal alignment (after U.S. Bureau of Reclamation 1973)

e) The location of significant canal junctions and places where side inlets may be needed;
f) If not already visible on the aerial photo, note the location of all buildings, utilities and structures that may be affected by the drainage canal works. These include, but are not limited to, facilities that are within 100 m of the alignment and 1 m below the future canal bottom;
g) The location of valuable landscapes and large individual trees adjacent to the alignment.

Following the field check, one should accurately establish the revised center line on the photo mosaic. The final alignment should be based on the previous cross sections, and geological and environmental data. Indicate on the photo mosaic where the cross sections and soil surveys were made.

19.2.5 Schematic Map of Canal Systems

Maps showing the layout of a drainage canal system must give detailed information on the location of canal reaches and related structures. Normally, this information is given on the same map that shows the irrigation canal system, roads, and the boundaries of irrigation units. To keep such maps legible, standard symbols must be used to indicate the center line of the canals and related structures. The schematic map in Figure 19.5 uses these symbols. It shows:

- The location of the center lines of drains and irrigation canals, numbered for each reach;
- The radii of the center lines;
- The reserve boundaries of canals and boundaries of any adjacent obstructions, roads, and land level units. The area of land level units must be shown also;

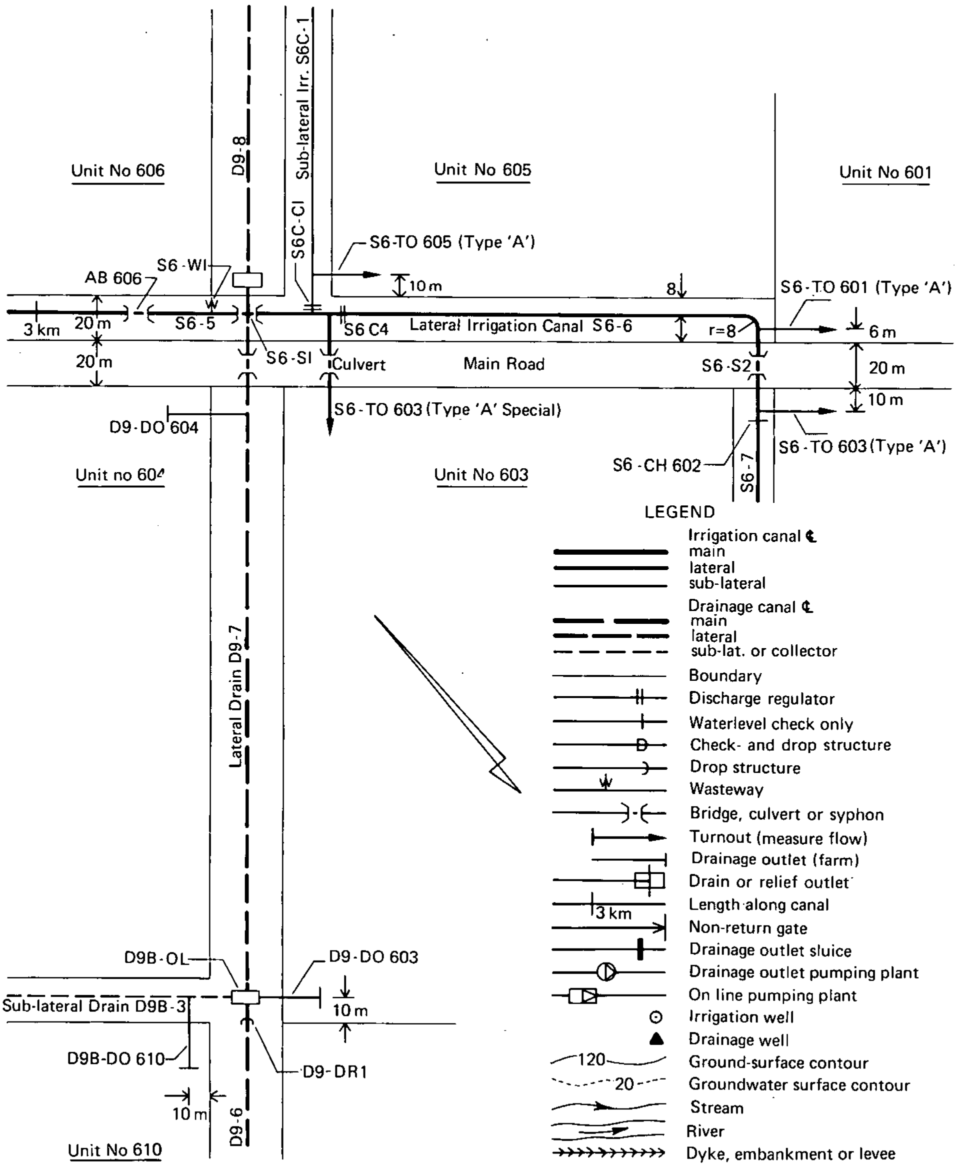

Figure 19.5 Example of a schematic map (after PWD 1967 and own data)

- The boundaries and number of irrigation units (if applicable);
- All structures, numbered and with position dimensioned with respect to center lines or boundaries;
- The north point and scale.

A schematic map must be supplemented by longitudinal profiles of all main and lateral canals. On both the map and longitudinal profile, a certain notation has been used to identify a canal reach and its related structure. After the system has been constructed, this notation must also appear on the structure.

The notation consists of two parts: (i) the number of the canal and (ii) the number of the canal reach or the structure identification number. It is presented below in Table 19.1.

Table 19.1 Notation for canals and related structures

Type of canal or structure	First part of notation (i)	Second part of notation (ii)
Drainage canal:		
main	MD	Number only; assigned consecutively from upstream end of canal or drain
lateral	D9	
sublateral	D9B	
Irrigation canal:		
main	MS	
lateral	S6	
sublateral	S6C	
Discharge regulator		C — Plus number; assigned consecutively from upstream end of canal or drain
Water-level check		CH
Drop structure		DR
Check-and-drop structure		CD
Wasteway		W
Bridge, culvert, or syphon		S
On-line pumping plant		P
Turnout (measures flow)		TO — Number of structure; identical to farm block number or number of irrigation unit served or adjacent
Drainage outlet (farm)		DO
Irrigation well		SW
Drainage well		DW
Farm access bridge		AB
Drain or relief outlet		OL — No number
Non-return gate		NG
Drainage outlet sluice	Proper name only	
Drainage outlet pumping station		
River diversion dam		
Storage dam		