GOVERNMENT OF PAKISTAN

SURFACE DRAINAGE MANUAL FOR PAKISTAN

IRRIGATION SYSTEM MANAGEMENT PROJECT - II

USAID Project Number 391-0467

APRIL 1993

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FOREWORD

Surface drainage for agricultural areas is an important part of water management activities in Pakistan. Surface drains are particularly important in irrigated areas to protect crops from damage by flooding, to reduce waterlogging, and occasionally to dispose of excess irrigation flows. Yet, only limited attention has been given to the development of surface drainage systems, and their maintenance tends to be neglected.

Many of the practicing irrigation engineers are not fully familiar with the modern principles of drainage planning, design, construction, and maintenance. Until now, the only official documentation of surface drainage practices in Pakistan was a chapter of the Punjab Manual of Irrigation Practice of 1943. In Pakistan, different agencies are concerned with farm drainage, with design and construction of drainage systems, and with operation and maintenance of the drains. Professionals in one agency are often not familiar with the objectives, methods, and procedures of the other agencies.

The need for an updated and expanded manual of surface drainage was thus recognized in the design of the Irrigation Systems Management Project (ISM-II). This Manual is an output of the Project under the Federal Coordinator in the Office of the Chief Engineering Advisor. The Manual was prepared and published with the financial support of USAID. The principal authors are Richard Wenberg, PE, formerly U.S. Soil Conservation Service National Drainage Engineer, and Zafar Ahmad Khan Burki, formerly Superintending Engineer Drainage, Punjab Irrigation Department, working in a technical assistance team provided by Harza Engineering Company.

The concept of this Manual is to develop and improve upon the drainage practices established in Pakistan, and not to replace them. With the intention of preparing a manual that would be accepted and adopted as an official document, the participation of local authorities was sought. The authors met with drainage practitioners of all of the Provincial Irrigation Departments, and with other agencies concerned with drainage, including WAPDA, the On-Farm Water Management Program, and the Punjab Environmental Protection Agency. After the first draft was completed, it was sent to the Irrigation Departments and other agencies for review. Comments and recommendations were discussed in a two-day workshop held at Bhurban in April 1992 to reach a consensus. After completing the recommended revisions, a second meeting was held in Lahore in September 1992 for final review by representatives of Irrigation Departments.

Although this Manual is intended primarily for use by engineers of the Provincial Irrigation Departments, the scope of the Manual extends beyond their normal responsibilities. It is important for the irrigation engineers to understand the entire spectrum of agricultural drainage so that they can see as to how their role relates to the overall water management objectives and to other agencies. It is expected that the Manual will also be used by On-Farm Water Management personnel of the Agriculture Departments, as well as by WAPDA and other organizations with drainage responsibilities.

The procedures presented in this Manual are intended as guidelines for users who are expected to exercise professional skill and judgement. In many cases, alternative procedures or methods are described so that the user may select what is best for the specific physical and economic circumstances. The Manual includes different procedures used by different Irrigation Departments to meet their specific needs. References are also given for users who may want to go more deeply into certain subjects.

This Manual will be of great help to irrigation engineers and others concerned with surface drainage. I would recommend strongly that the methods and procedures outlined in the Manual be adopted in practice in order to achieve efficient drainage for agricultural areas with consequent benefits.

(ASIF H. KAZI)
Chief Engineering Advisor
Ministry of Water and Power
Government of Pakistan

GLOSSARY

Bank:	Embankment on the side of an irrigation canal or surface drain.
Bed:	Bottom of an irrigation canal or surface drain.
Bed bar:	Grade control structure for canal or drain. Called "***Bed Profile***" in Sindh Province.
Bevelled lip:	Tapered pipe inlet end to improve hydraulic flow.
Bund:	An earthen embankment, often compacted, normally along the side of a river to contain or to divert flood waters. U.S. term is "***levee***". Also, an earthen embankment used to contain water on a field, especially for irrigation.
Chak:	Block of land irrigated from a specific outlet structure.
Chak bandi line:	Line indicating the boundaries of a ***chak***.
Collector:	Buried horizontal drain in a subsurface drainage system which receives water from laterals and conveys it to a submain, main, or an outfall point, i.e., pumping plant or an open drain.
Cross-drainage works:	Structures for carrying drainage water across other civil works, such as roads, railways, canals, and bunds.
Culvert:	Structure to convey water under an embankment or road with a span of eight feet or less. If the span is greater than eight feet, it is considered a bridge.
Cunette:	Small drain constructed in the middle of the bed of a storm cum seepage drain to convey seepage flows.
Cusecs:	Cubic feet per second.
Cut:	Portion of land surface or area from which earth has been removed by excavation; the depth below original ground surface to the excavated surface.
Ditch:	Small drainage channel; often used instead of ***drain***, as in farm ***ditch*** or field ***ditch***.

Drain:

Outfall	Major drain to provide an outlet for a drainage system.
Main	Primary open drain of a Government (Irrigation Department) drainage system providing outfall to branch and tributary drains and draining into a natural stream or river through gravity flow or pumping.
Branch	Secondary level Government (PID) controlled drain providing outfall to tributary drains.
Tributary (Subdrain)	Tertiary level of Government (PID) controlled drain providing outfall to subtributary and farm drains; drains into a branch or main drain. Smallest drain controlled by the Sindh Irrigation Department
Subtributary	Smallest Government (PID) controlled drain in three provinces; provides outfall to farm drains.

(All Government drains above may also provide direct drainage to adjacent lands and receive water from subsurface drainage systems.)

Seepage	Drain collecting seepage flow from adjacent fields by water flowing through the drain bank.
Farm	Small drain/ditch serving one or more farms or holdings, providing outfall to field drains, and draining into a Government (PID) controlled drain.
Field	Smallest drain/ditch serving one or more fields. May serve as much as 10 acres.

Drainage coefficient	Design rate at which water is to be removed from a drainage area, usually expressed in Pakistan in cusecs per square mile.
EC:	Electrical conductivity of soil water extract, measured in decisiemens per meter (dS/m). 1 dS/m = 1 millimho per centimetre (mmho/cm), an earlier term.
EIA:	Environmental Impact Assessment.
EIS:	Environmental Impact Statement.

GLOSSARY (cont't.)

Elevation:	Vertical height above a reference point, often ***mean sea level.***
EPA:	Environmental Protection Agency.
FCL:	Full capacity level (in drains).
Fill:	A built-up piece of land using earth or gravel.
Gatchie:	Earthen lump used in repairing rain-cuts or voids in slope.
Ghat:	Ramp in the side of a canal or drain at a slope less than the adjacent side slope for access by animals.
Hardpan:	Layer of hardened subsoil which often has a high clay content.
HFL:	Highest Flood Level.
Hill torrent:	Channel with high velocity flow usually resulting from intense rain in a hilly catchment.
Hydraulic gradient:	Slope of the free surface of water flowing in an open channel, usually expressed in ***units of feet per foot.***
Irish bridge:	Structure in open drain with brick-lined flattened side slopes and bed for ease in crossing by bullock carts and other vehicles. Also referred to as "***causeway***".
Kallar:	Salts affecting soils.
Karam:	Land measuring unit: 1 karam = 5.5 feet.
Karries:	Wooden purlins or beams, usually four inches square, used for regulating the flow of water through a masonry structure provided with grooves in the sides to hold the ***karries*** in position. U.S. term is "***stoplogs***".
Laterals:	The branch lines in a subsurface drainage system.
Levee:	U.S. term for an earthen embankment, often compacted, normally along the side of a river to contain or to divert flood waters (***bund***).
NGL:	Natural Ground Level. Preferred Sindh term same as NSL.

GLOSSARY (con't.)

NSL:	Natural Surface Level of a field or ground.
Nullah:	A natural stream, smaller than a river, usually with intermittent flow.
Outfall:	Any natural or constructed facility to dispose of drainage water.
Outlet:	In the context of drains, U.S. term for ***outfall***.
Pacca:	Masonry or brick material.
Pancho system:	A system of continuous irrigation of rice fields at one end and draining out at the other end into adjoining down slope fields, and so on, practiced in Sindh. This may be practiced for two or three waterings rather than continuous.
Profile:	A longitudinal (L) section showing dimensions of a canal or drain.
Rain cut:	An eroded channel caused by concentrating water flow. U.S. term is "***rill***".
RD:	Reduced Distance of drain or canal (1000 feet).
Rill:	U.S. term for ***rain cut***.
RL:	Reduced level based on elevation.
Shale:	An easily split rock having laminated layers of fine clay or silt particles.
SSWL:	Subsurface Water Level or Subsoil Water Level.
Spoil:	Any surplus or unused earth from excavation.
Staking and bushing:	Method of rebuilding a bank that has sloughed or eroded eroded by using branches of local plants and wooden stakes.
Stoplog:	U.S. term for ***karrie***
Surface water inlet:	Structure to convey surface water into a drain. Also referred to as ***inlet***.
Swale:	Low or depressed tract of land.

Swamp:	See ***wetland***.
Waterlogged:	Land condition when the water table is within the crop root zone for extended period of time.
Wetland:	Previously called ***swamp***. Land typically with standing water at least part of the year providing habitat for aquatic life.
WSL:	Water Surface Level, often used instead of WSS.
WSS:	Water Surface Slope.

Chapter 1

INTRODUCTION

History and Purpose of Surface Drainage

1.1 Agricultural drainage is the practice of removing excess or unwanted water from agricultural land. Surface drainage facilities not only remove excess precipitation and irrigation water from agricultural fields, but often also serve as conveyance channels for subsurface drainage and for surface runoff from outside agricultural areas.

1.2 At least 2500 years ago, Herodotus wrote about drainage works near the city of Memphis in Egypt. In British India, the need for drainage to reduce waterlogging was noted as early as 1851 in the Western Jamna Canal area (NESPAK et al, 1991). Malaria associated with standing water had become a serious concern. In 1870, waterlogging was reported in the Sirhind Canal area and in 1880 in the Bari Doab Canal area. It became apparent that as irrigation systems developed, problems of waterlogging followed. Ground water monitoring programs were established between 1933 and 1947 to better define potential waterlogging problem areas. As a result of the monitoring, about 2300 miles of surface drains were constructed in British India during this period. Unfortunately, the enthusiasm for constructing open drains was reduced for two primary reasons. One, major maintenance problems, including weed growth in the open drains, developed. Second, many drains were constructed parallel to irrigation canals which did intercept seepage water but did not effectively control waterlogging in the area.

1.3 This manual deals with both natural and artificial drains. Rivers, streams and depressions act as natural drains. Constructed open drains, including main, branch, and field drains, are called artificial drains. Drains are effective if they remove excess accumulation of water within a reasonable time.

1.4 There are both positive and negative effects of surface ponding and saturation of the soil profile. The presence or absence of water either on the surface or in the soil affects the soil's temperature, aeration, and other important characteristics. Wet soil absorbs and tends to retain heat for longer periods than drier soil. Saturated soil has its void space filled with water rather than a mixture of water and air. Many plants, especially cultivated crops, need an aerated root zone to live and to produce food or fibre in a cost effective manner. Drainage reduces the time required for evaporation, plant absorption and deep seepage to remove water from the soil pore spaces. This drainage permits adequate air to enter the soil profile, and provide oxygen to the root zone. However, there are also benefits of ponded and saturated soil conditions. These conditions often provide habitat for waterfowl and fish, as well as rare and endangered flora and fauna. Stagnant, ponded water provides a good environment for bacteria, viruses and other microorganisms creating a public health hazard. Vectors, such as mosquitos that carry and transfer yellow fever and malaria, are also associated with standing water conditions.

1.5 Surface drainage removes ponded water which is the primary objective of field drainage for agriculture. This reduces the time the root zone portion of the soil profile is saturated. Saturated soil, which is generally referred to as waterlogged soil, not only restricts needed aeration of the root zone but may lead to salinisation. Salinisation is the accumulation of salts in the soil profile to the extent it restricts uptake of water from the soil by plant roots. Subsurface drainage removes excess water from the soil profile. Tubewells and horizontal drains (tile or tube drains), are used for subsurface drainage with the objective of removing excess soil water and salts from the root zone.

1.6 Surface drainage for agriculture is very important with or without subsurface drainage but surface drainage alone can not be expected to prevent waterlogging or salinisation in irrigated agriculture. Either natural or man made subsurface drainage is needed to remove excess salts from the root zone. On an average annual basis, a balance of root zone salts must be maintained. This is accomplished by removing as much salt from the root zone as enters with the applied water. Irrigation in Pakistan has been successful for many decades without installed subsurface drainage systems. The needed salinity balance in the root zone was provided by deep percolation of excess irrigation water. This percolation carried the salts out of the root zone down to the water table. These salts were safely away from the crops. Later, the water table rose with dissolved salts to the root zone and to within the capillary range for surface evaporation. The evaporation leaves salts on the soil surface. Surface wetting of the soil followed by surface drainage can dissolve and remove some exposed salts. However, it is a rare and unique situation where subsurface drainage is not needed for reclamation of a salinised area.

1.7 Sources of excess water are direct precipitation, irrigation water and surface runoff from outside the area flowing into or across developed lands. Seepage from canals, irrigated fields and ponds adds to the amount of soil water. The corresponding rise of the water table level has injurious effects as stated above. Extensive areas in each of Pakistan provinces are suffering from this problem. One remedy is to reduce the amount of water entering the soil. Another remedy is to lower the water table by abstraction.

1.8 Reducing the amount of water entering the soil may be accomplished by: (1) lining the canals and watercourses; (2) improving water management; and (3) removing rain and spill waters as quickly as possible with efficient surface drainage systems. Abstraction can be done by: (1) subsurface drainage systems; (2) natural seepage; and (3) evapotranspiration by plants.

Wetlands

1.9 Agricultural drainage has both beneficial and adverse impacts on the environment. Lack of drainage usually results in waterlogging and salinisation, while excessive drainage may dry established wetlands. They are of great ecological value and contribute significantly to environmental stability. However, wetlands sustain a large variety of aquatic life, fauna, and flora. Other important environmental components in a drainage project area are natural scenery, quality of air and water, hydrology of the area, places of historical and archaeological importance, and the overall ecosystem of the surrounding area.

Water Quality

1.10 For agriculture, the primary water quality concern is salt loading or salinity and sodicity levels in the soil water. However, all toxic elements need to be identified and managed correctly. Drainage effluent from agricultural land may contain not only agricultural chemicals and nutrients but frequently industrial and municipal wastes, especially in the vicinity of towns and industrial installations. In cases where a drainage system includes a large city or industrial complex in its catchment area, the municipal waste water and factory effluent often forms the major component of the normal flow. For example, the Paharang Drain carries all the industrial effluent and municipal waste water of Faisalabad city. This is only one of many situations in Pakistan where municipal and industrial waste water is intermingled with agricultural drainage in channels constructed for agricultural use.

1.11 An Environmental Protection Agency of Pakistan (EPA Pak) was created in 1983. The ordinance (Appendix D) provides for an environmental impact assessment (EIA) for projects. Where a project is likely to adversely affect the environment, an environmental impact statement (EIS) must be prepared by the project sponsor and submitted for EPA review.

Maintenance Needs

1.12 Maintenance is emphasized in this Manual because it is vital for sustainable agricultural surface drainage systems. If maintenance is delayed or neglected, the system will cease to perform as intended and the anticipated benefits cannot be realized. Commitment to maintenance must be made and supported during the planning and design phases. For example, drain side slopes designed for stability reduce future maintenance requirements.

Pakistan Drains

1.13 In Pakistan, natural drainage outfalls are not always available. Many outfall channels have been constructed within irrigation projects. The design and installation of large drainage systems with primary and secondary open drains are generally implemented by the Water and Power Development Authority (WAPDA). After construction, the respective provincial irrigation department assumes responsibility for operation and maintenance. Tributary drains are planned and constructed by the provincial irrigation departments.

1.14 The major drains in Pakistan's four provinces are shown in Figures 1.1 to 1.4. General maps of Pakistan's irrigation systems, mean annual rainfall, and soils are presented in Figures 1.5 to 1.7.

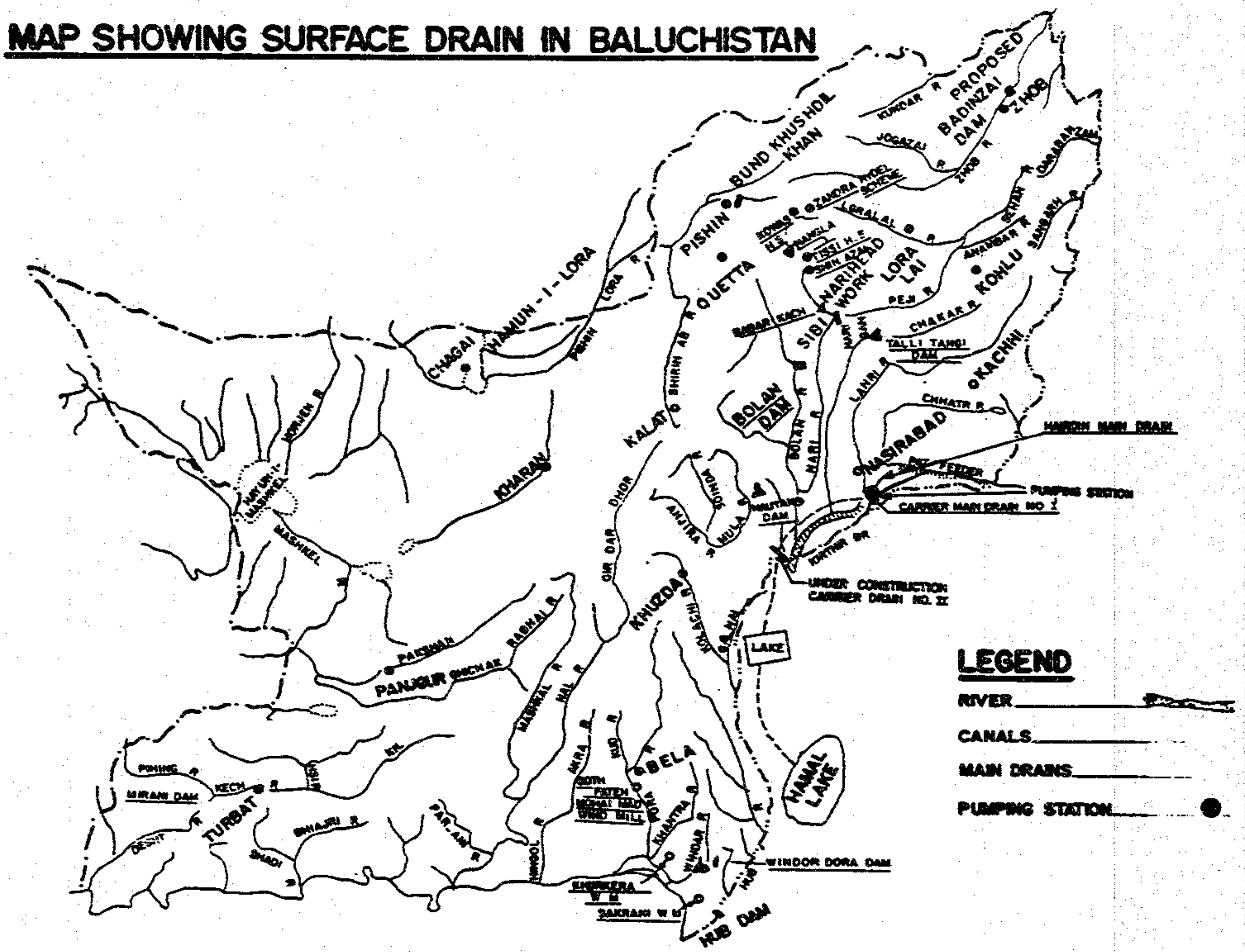


Figure 1.1. Baluchistan surface drains.

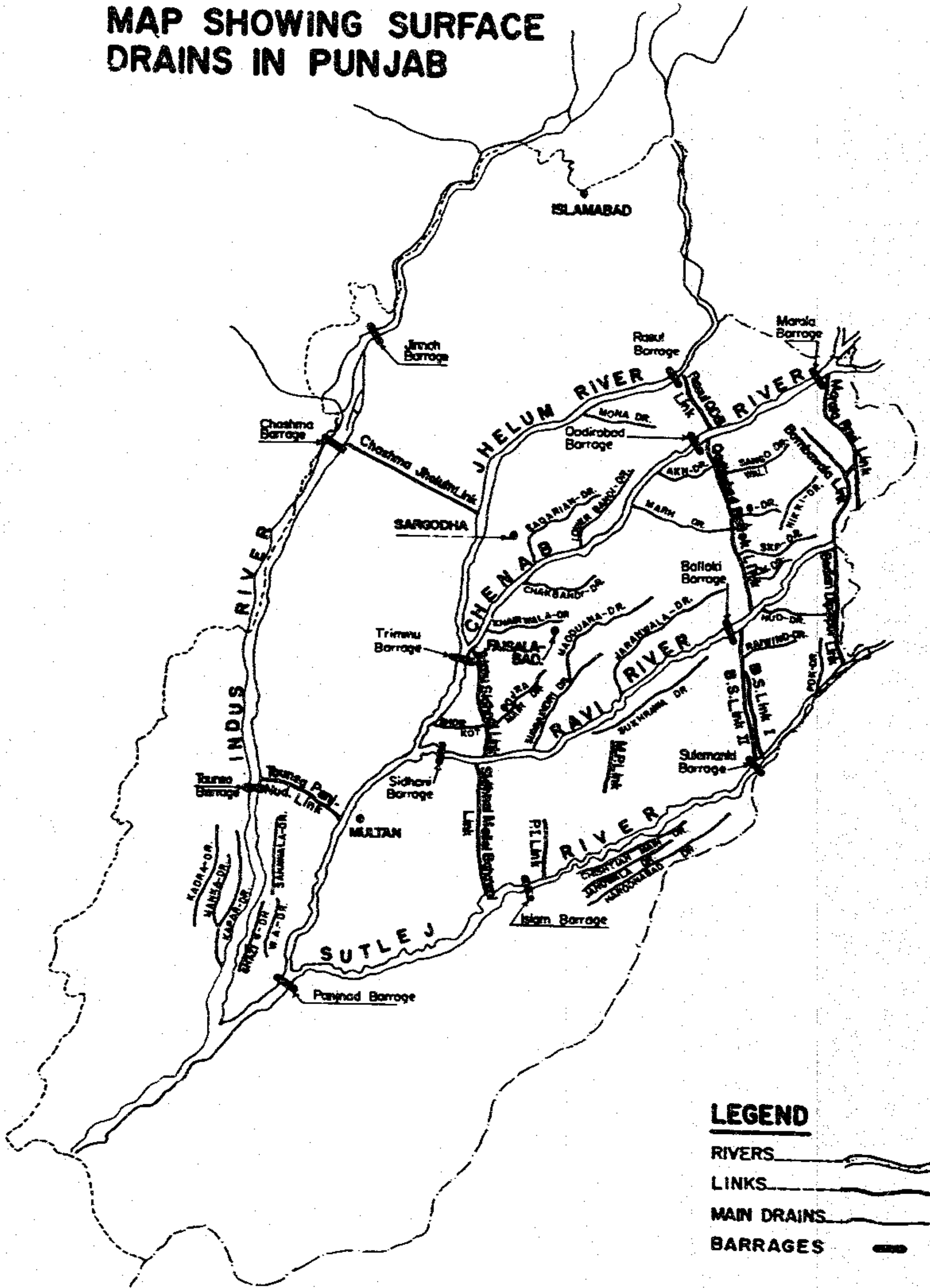


Figure 1.2. Punjab major drains.

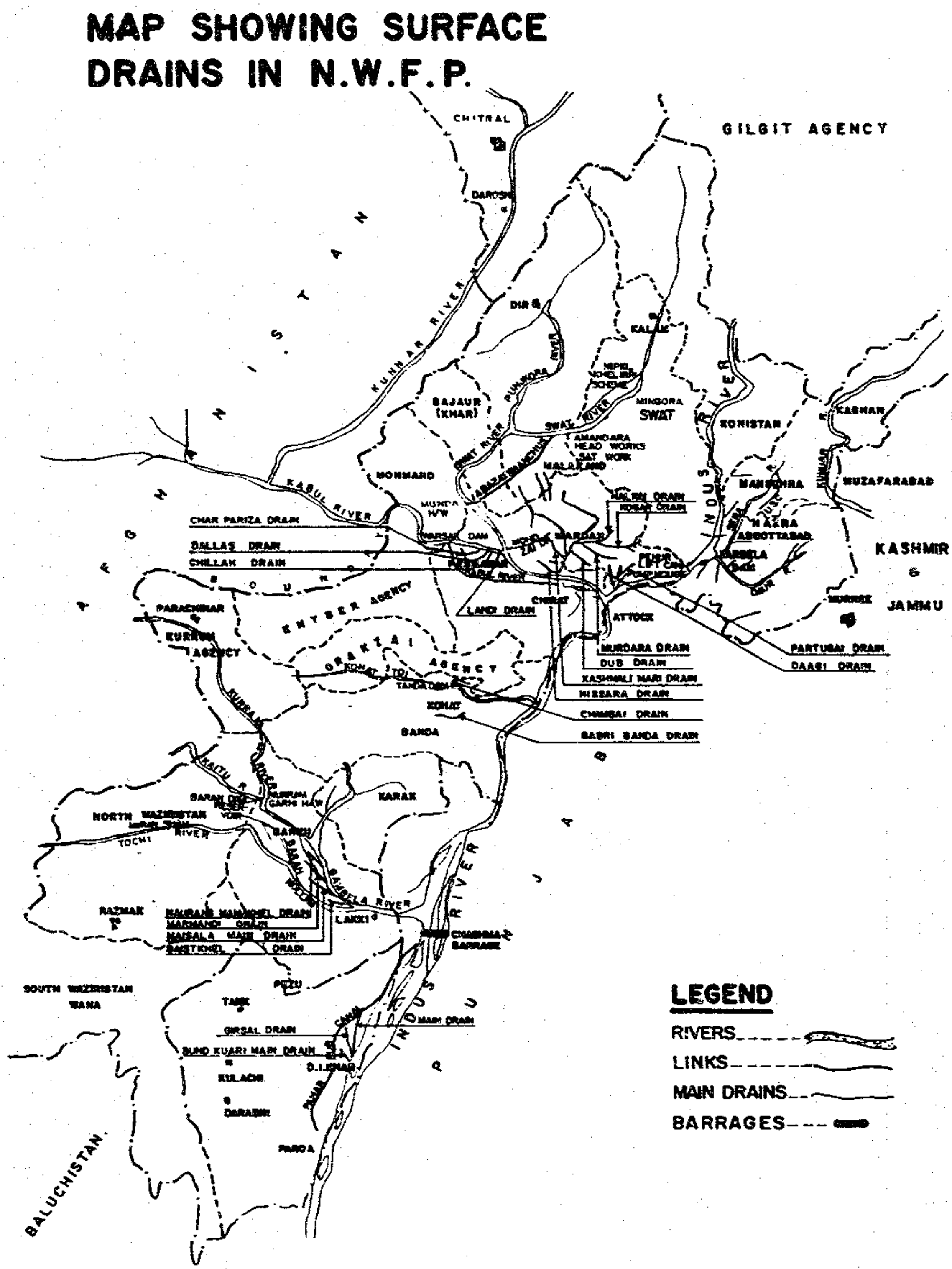
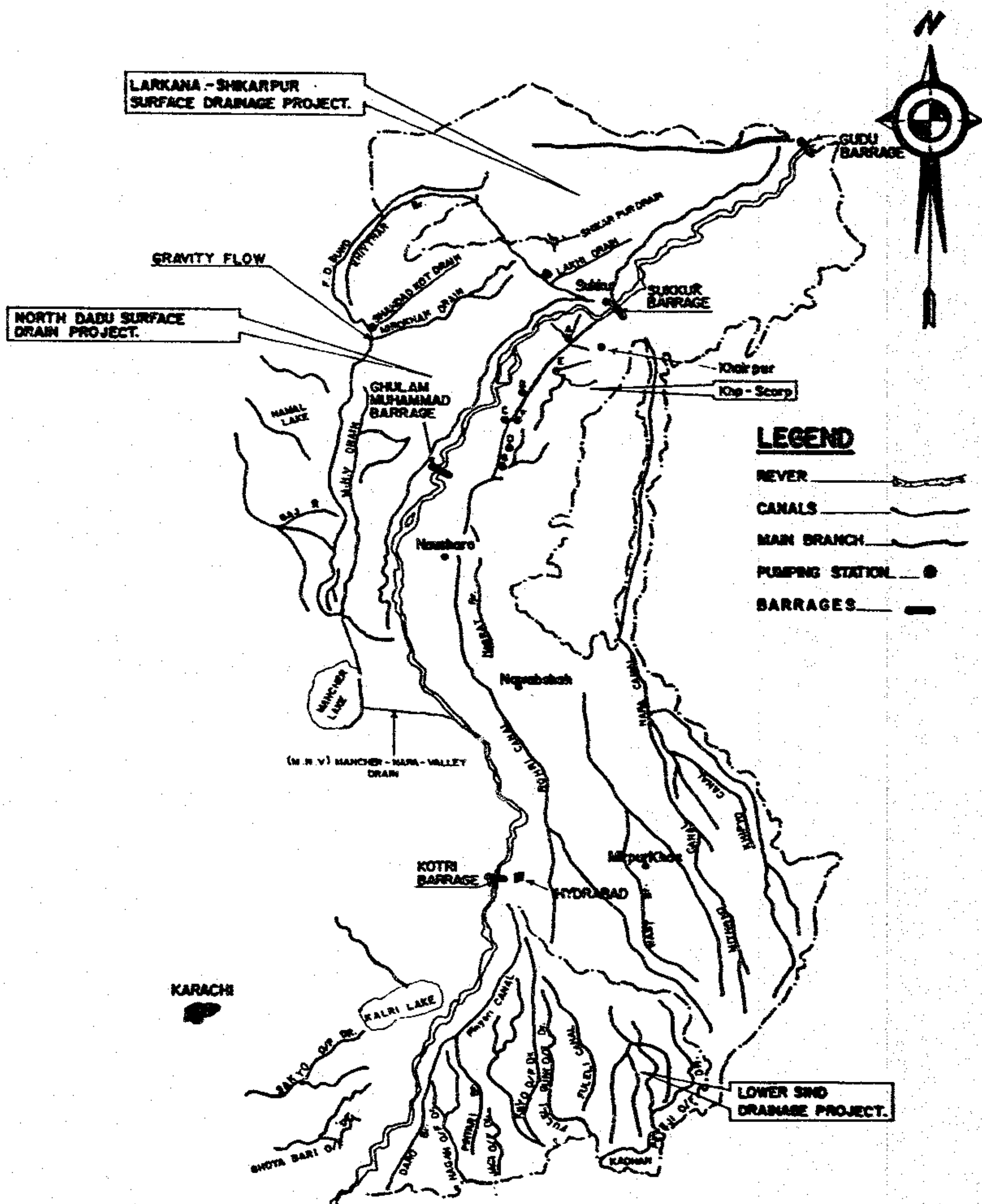


Figure 1.3. North West Frontier Province drains.



MAP SHOWING SURFACE DRAINS IN SIND

Figure 1.4. Sindh major drains.

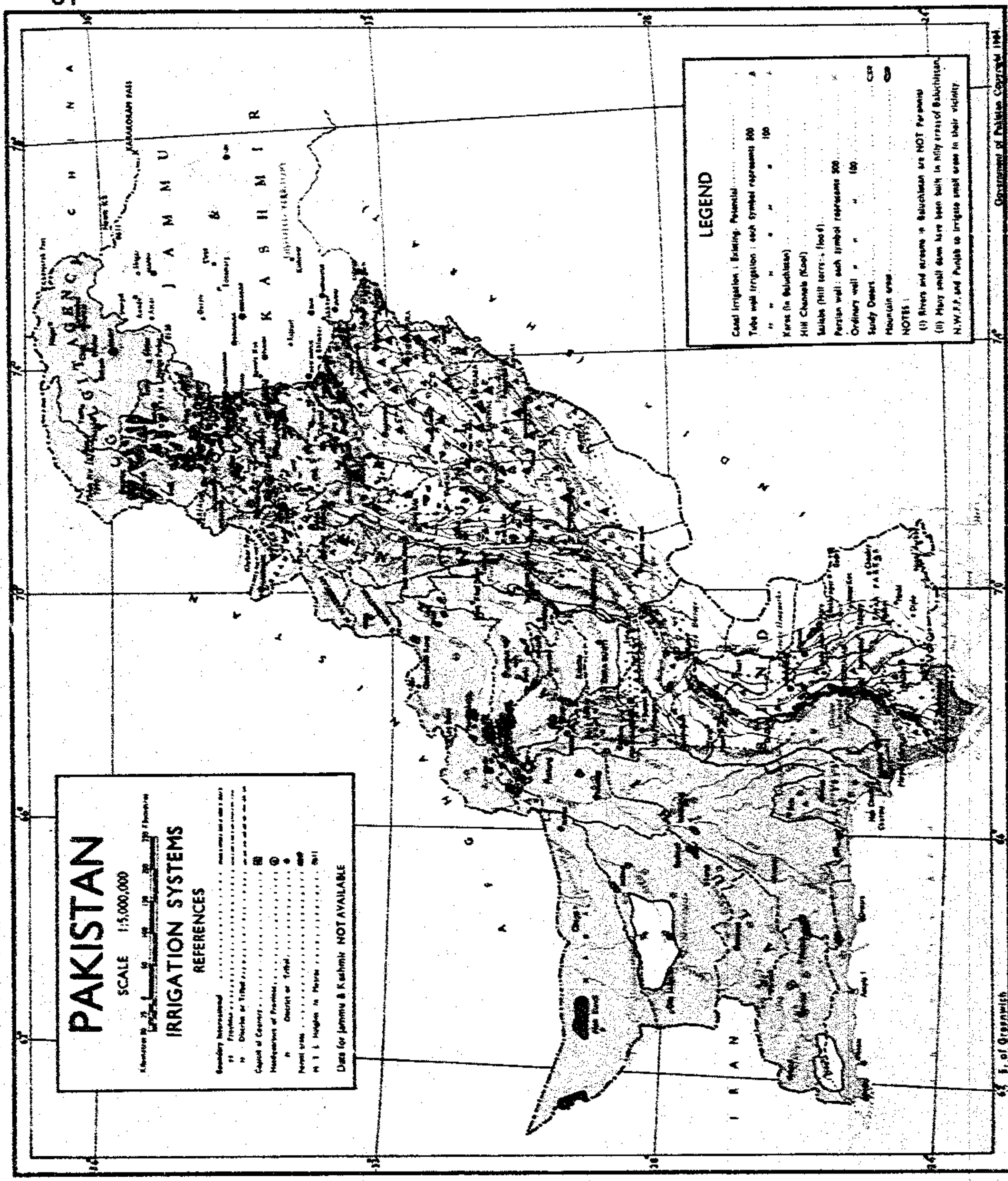


Figure 1.5. Irrigation systems (Source: Atlas by Survey of Pakistan).

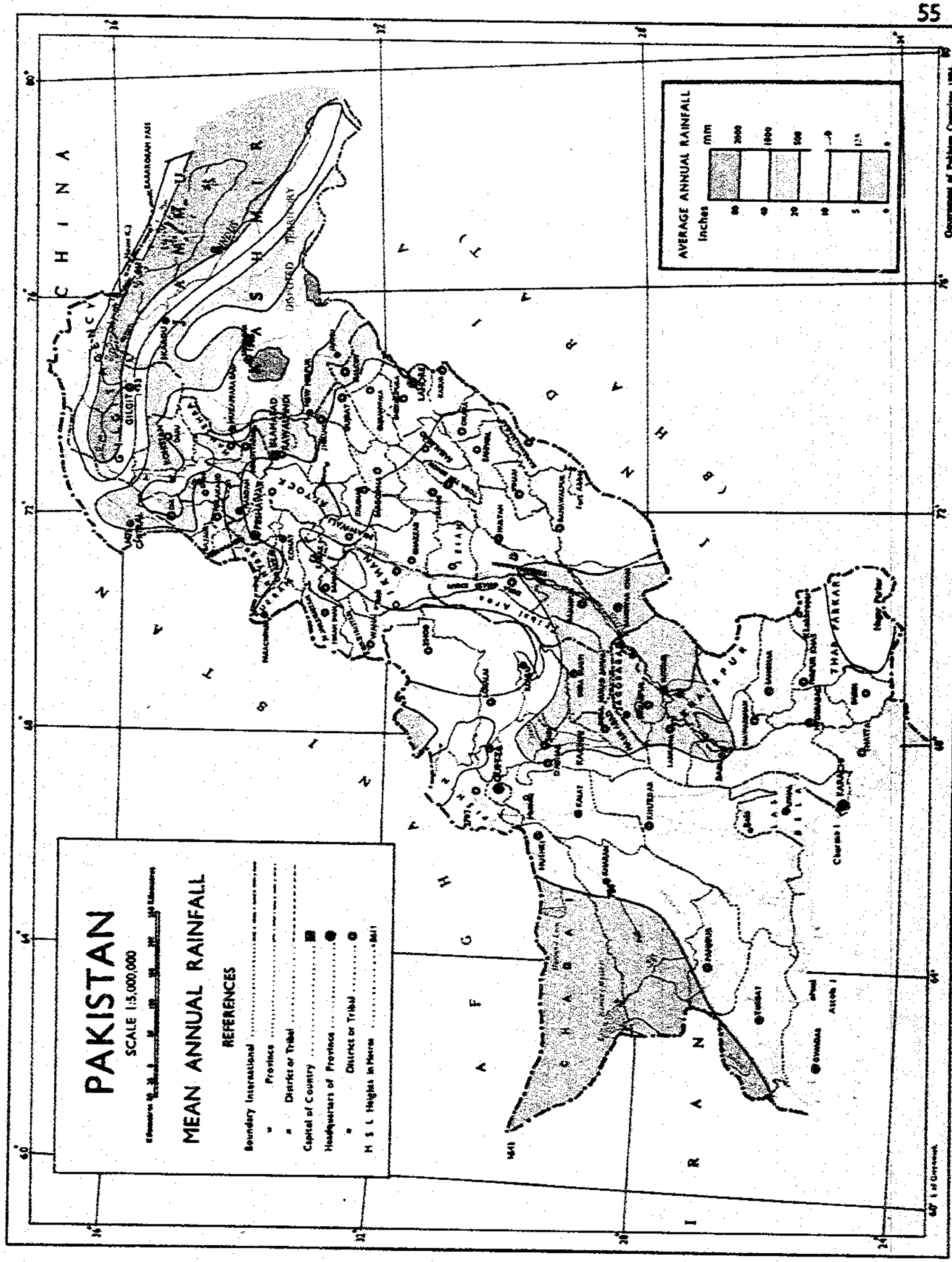


Figure 1.6. Mean annual rainfall (Source: Atlas by Survey of Pakistan).

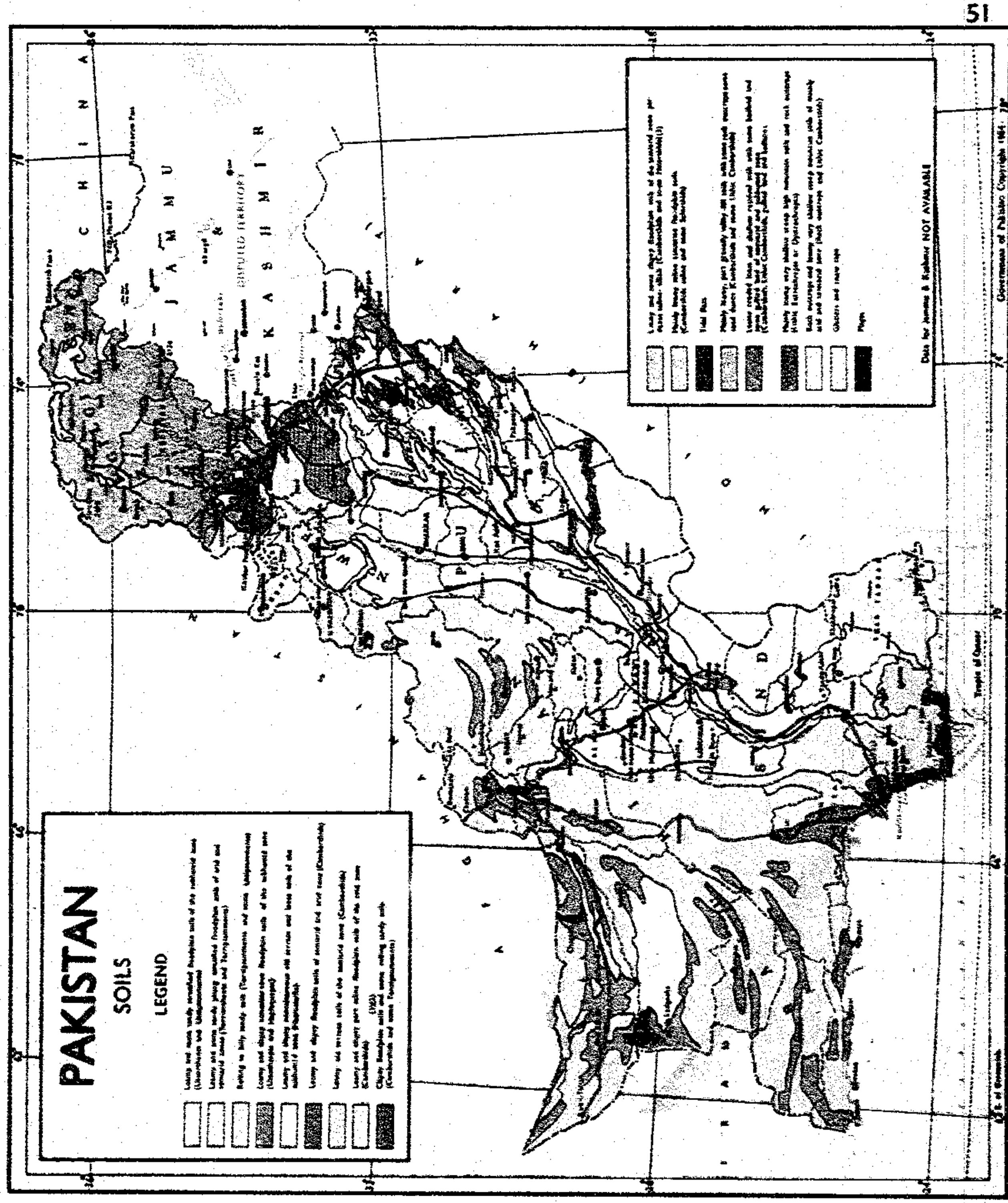


Figure 1.7. Soils (Source: Atlas by Survey of Pakistan).

Chapter 2

PLANNING

General

2.1 Planning of surface drainage systems must be comprehensive. The total land use, including allocated environmental areas, such as wildlife corridors and wetlands, needs to be established in planning the system. The intended maintenance procedures are critical for selecting some of the design parameters and the methods of construction and access. Monitoring of facilities should be part of the written project plan.

2.2 All concerned individuals and groups should be involved as early as possible. Their concerns and alternative approaches need to be considered in the planning phase before starting initial designs. The desires and capabilities of persons with maintenance responsibility, especially, need to be considered and incorporated throughout the planning, design, and construction phases.

Planning Considerations

Water Management

2.3 The primary objectives of water management for drainage of irrigated lands and rainfed agricultural lands are:

- Timely removal of surface water;
- Prevention or correction of waterlogging;
- Provision of outfall facilities; and
- Provision for uniform and timely irrigation application.

2.4 Cropping Patterns. Drainage must be related to the needs of the potential cropping patterns. The drainage system, as well as the irrigation system, should be designed to allow the greatest flexibility to the farmer in selecting crops to be grown in response to market and changing economic conditions. Water management for agriculture in Pakistan is primarily differentiated on the basis of rice production land and nonrice production land. This is true for both irrigation supply and drainage volume and timing. Rice can tolerate and thrive on ponded water conditions for the entire growing period. However, rice will also produce very well in unsaturated soil water conditions but weed control may be a problem. Even where rice is to be consistently grown in an area, drainage to permit timely harvesting and to enhance double cropping should be considered. Unless it is quite certain that rice is the only crop to plan for, the design capacity should be for crops with a shorter allowable ponding time.

2.5 Additional Positive Features. Examples of additional planning considerations are: 1) establishing environmental values; 2) developing and retaining wetlands; 3) maintaining natural waterways; 4) disposing of irrigation spill water; acquiring land for drainage systems; 5) evaluating potential use of industrial and municipal effluent; 6) using spoil containing municipal waste; and 7) reusing drainage water.

2.6 "Dry Drainage" is a water management practice to partially solve waterlogging and salinisation. However, it is not a recommended solution to substitute for a needed drainage outlet. Dry drainage is the practice of irrigating part of an area while leaving the remaining adjacent land fallow. Surface and subsurface waters containing leached salts flow from the irrigated area to the fallow area. The fallow area becomes salinised as the salts are concentrated due to evaporation losses. Thus, there is an import of salt from the irrigated cropped area without an export of salt from the fallow ground.

2.7 Dry drainage has been proposed in lieu of developing an outfall facility or to alleviate salinisation until an outfall is provided. A paper presented at the 5th International Drainage Workshop in Lahore in February 1992, addressed this subject with specific reference and analysis of the Left Bank Outfall Drain (LBOD) area in Sindh (Gowing & Wyseure, 1992). Mott MacDonald proposed dry drainage as an alternative solution only for irrigating rice land areas. The ponded water on the rice would provide a head to develop a downward flux with lateral movement of the ground water toward the fallow area (WAPDA, 1991).

Environmental Values

2.8 Wetlands have numerous environmental values, such as: habitat for fisheries, habitat for wildlife, water storage, flood peak reduction, sediment and contaminant trapping, nutrient retention, food chain support, recreation use, and heritage preservation. These values are described in Chapter 5 of a comprehensive description of farm drainage in the United States (ERS, 1987). Wetlands differ from site to site and only some of these values will be found at a specific location. In addition to the above values, the temporary or permanent storage of salts in wetlands that would have negative effects on the adjacent farm land is a significant economic contribution to the immediate area or region as discussed in the Developing and Retaining Wetlands Section below.

2.9 The Environmental Protection Agency (EPA) of Pakistan has recently been organized. There is also to be an EPA for each province, but only Punjab has been staffed at this time. For project area planning, environmental values need to be assessed and an

Environmental Impact Assessment (EIA) prepared as outlined in the Pakistan Environmental Protection Ordinance (Appendix D). Water quality standards should be coordinated with the intended use of the water or water body. For example, water to be used only for crop irrigation can be of poorer quality than water to be used for human consumption. Table 2.1 is the latest list of effluent standards furnished by the Punjab EPA. The Relaxed Standard values in the table were to be replaced by the Ultimate Standard values in 1990, but the Relaxed values are still in effect. The pertinent provincial EPA should be consulted for the most recent standards in effect in the province.

Developing and Retaining Wetlands

2.10 Natural lower elevation areas may be set aside for collecting drainage water with the intent of developing wetlands. Historically, seepage from canals has created wetlands that serve valuable functions. Retaining these induced wetlands may be beneficial provided they are properly managed. Surface water management is essential to protect public health. Standing water areas provide an environment for vectors, such as mosquitos and snails. These transmit malaria and yellow fever and schistosomiasis, respectively.

2.11 A wetland area needs an outlet for entering flows. Routing of drainage water into a wetland area without providing an outlet can result in toxic concentrations of chemical and basic elements, such as heavy metals. For example, selenium accumulation in Kesterson reservoir, California, USA caused major destruction of wildlife. Such a reservoir and wetlands must be flushed with flood flows or diluted in some manner to reduce contaminants to nontoxic concentrations. Routing flows through a wetland without a bypass drain, however, may cause excessive backwater above the wetland area.

Maintaining Natural Waterways

2.12 Project planning often must include drainage water from catchments outside the irrigation area which originally crossed this land and should continue to do so. Hill torrent floods are routed through a project area when it is not feasible to route the flood flows around the proposed irrigation area. It is typical and reasonable to design for safely passing a 50-year return period flow or greater under a major irrigation canal, such as the Chasma Right Bank Canal, generally through box culverts, to minimize overtopping and serious damage to important structural facilities. Box culverts should preferably be on a level or sloping grade, which are self-cleaning, rather than in the form of an inverted syphon which may become clogged with coarse texture earth or rock. The same flows should be routed through the irrigation project area to a natural drain or river outfall, if feasible. In such situations, provisions for temporary storage of flood waters outside the project area on rangelands may be incorporated to avoid out-of-bank flow within developed irrigation land.

Table 2.1. Environmental Quality Standards for Municipal and Liquid Industrial Effluent (mg/L, unless defined)

No.	Parameter	Relaxed Standard	Ultimate Standard
1.	Temperature	40° C	40° C
2.	pH	5.5 - 9.5	6.0 - 9.0
3.	5-day Biochemical Oxygen Demand[a] (BOD) at 20° C	200	80
4.	Chemical Oxygen Demand[a] (COD)	400	150
5.	Total Suspended Solids	400	200
6.	Total Dissolved Solids	5000	3500
7.	Grease and Oil	20	10
8.	Phenolic Compounds (as Phenol)	1.5	0.3
9.	Chloride (as Cl)	1000	1000
10.	Fluoride (as F)	20	10
11.	Cyanide (as Cn)	2	1
12.	Anionic Detergents[b] (as MBAS)	30	20
13.	Sulphates (SO_4)	1000	1000
14.	Sulphide (S)	2	1
15.	Ammonia	75	40
16.	Pesticides, Herbicides, Fungicides, and Insecticides	0.75	0.15
17.	Cadmium[c]	2	0.1
18.	Chromium[c] (trivalent and hexavelant)	2	1
19.	Copper[c]	4	1
20.	Lead[c]	2	0.5
21.	Mercury[c]	0.1	0.01
22.	Selenium[c]	1	0.5
23.	Nickel[c]	2	1
24.	Silver[c]	2	1
25.	Total toxic metals[c]	10	2
26.	Zinc	10	5
27.	Arsenic	2	1
28.	Barium	4	1.5
29.	Iron	10	2
30	Manganese	10	6
31.	Boron	10	6
32.	Chlorine	1	1

[a] Assumes minimum dilution of 10:1 on discharge, if more stringent local standards are not necessary.

[b] Assumes biodegradable detergents (stringent standards required for nonionic surfactant).

[c] Subject to total toxic metal discharge.

Source: Environmental Protection Agency of Punjab.

2.13 Figure 2.1 is a view of a syphon under the Chasma Right Bank Canal. This is an expensive concrete lined canal that appears to have significant temporary flood storage available on rangelands outside of the project area. Temporary impoundment of flood waters reduces the size of floodway needed to convey those flows safely through the irrigated land to a river. For this situation, the canal embankment should be designed to provide the temporary flood storage. The additional cost for such an embankment must be compared to the potential benefits of protection for facilities and crops.

2.14 Depressional areas within the proposed project area might be suitable for temporary storage of routed flood flows. In this case, it would be appropriate to dedicate this area as a floodway and not develop it for irrigation.

Figure 2.1. Level syphon under main irrigation canal (CRBC) with view outside project area.

Disposing of Irrigation Spill Water

2.15 One of the major concerns with the existing, typically level fields, surrounded by bunds, is the disposal of irrigation canal water: 1) during heavy rainfall periods; and 2) delivered at the end of watercourses when it is not needed. By design, tail escapes have generally not been provided in Pakistan, a water short region. For improved water management, it would be desirable for all canals, as well as watercourses, to have provisions for routing unneeded water back to a canal or to a natural or artificial open drain. Even when irrigation water is directed to an open drain it is not lost. Most of the water will be diverted again and used for irrigation further downstream. A spill gate discharging into an open drain is shown in Figure 2.2. Collector drains and field ditches in a pilot on-farm water management project in the D. G. Khan administrative area provide improved management of excess water.

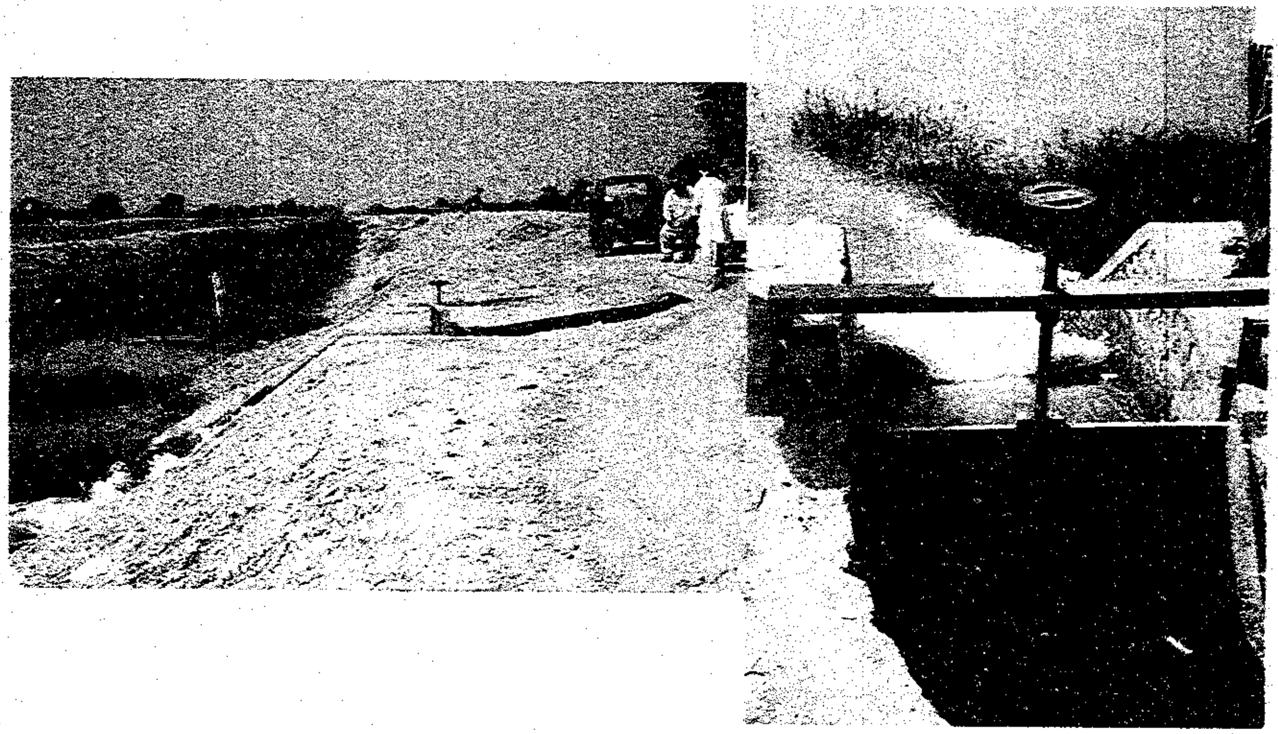


Figure 2.2. Spill gate side view and end view.

Acquisition of Land for Drainage Systems

2.16 The design and installation of a drainage system may be deferred but the land needed for open drains should be reserved or purchased when planning an irrigation project. At this stage, land values of undeveloped areas are low. Furthermore, there is less resistance to sell a strip of land at this time compared to its protection after it is developed and in production.

Industrial and Municipal Effluent in Drains

2.17 Even though industrial and municipal effluent should not be released to a drainage system without the permission of the owner, it is often done. Heavy metals are often present in industrial waste water or sludge. Before approving release of municipal or industrial waste water into an agricultural drainage system, analyze the effluent to determine its suitability for possible uses. Soil has the capacity to assist in biodegrading many chemical compounds, but potential downstream users must know the composition of the effluent. If the quality of the waste water is not acceptable, the water must be treated or an acceptable location must be found to use or dispose of it. For example, municipal waste water containing heavy metals (copper, zinc, iron,, and manganese) from Giza, Egypt, was used successfully on citrus in sandy soils (USCID, 1989). For control of untreated effluent entering drains, refer to Section 70 of the Canal and Drainage Act (Appendix A).

Use of Spoil Containing Industrial Waste

2.18 As stated above, heavy metals are usually a problem in sludge or waste water from industry. When industrial waste water is routed through drains, heavy metals will probably accumulate with the silt in the drain beds. The placing or spreading of spoil from such drains on agricultural land must be carefully managed and monitored. It is possible for plants to accumulate toxic levels of some metals (phytotoxicity) when growing in contaminated soil. General concentrations of trace elements (heavy metals) in soils are listed in Table 2.2 (ASCE, 1990). The Deficiency level indicates yields are restricted due to insufficient amount of the element; Adequacy indicates the normal range for good crop growth; and the Phytotoxcity level indicates yield is restricted due to excessive amount of the element harming the crop. The values in Table 2.2 are only approximate; all crops are not affected uniformly.

Table 2.2. Trace Elements in Soils

	Extractable levels in mg/kg		
Element	Deficiency	Adequacy	Phytotoxicity
Copper	0 - 0.2	0.3 - 0.5	> 0.5
Iron	0 - 3.0	3.1 - 5.0	> 5.0
Manganese	0 - 0.5	0.6 - 1.0	> 1.0
Zinc	0 - 0.2	0.3 - 0.5	> 0.5

Reuse of Drainage Water

2.19 Drain effluent is normally of lower quality than the original irrigation water. Reusing the drain water depends on the intended use and the nature and amount of solids or contaminants in the effluent. Monitoring of the water quality is necessary. Water with only a small quantity of salts is referred to as *sweet water* and can be used to irrigate any crop.

2.20 With proper management it is reasonable and practical to use saline ground water for irrigation of certain crops. Salt tolerance data for a wide range of agricultural plants are presented in Appendix E. The threshold values represent the salinity level just prior to yield reduction. The slope factor represents the percent of yield reduction per unit increase in salinity. The ratings in the last column are general crop sensitivity to salt concentration: Tolerant, T; Moderately Tolerant, MT; Moderately Sensitive, MS; and Sensitive, S.

2.21 Using saline water for irrigation is only recommended where there is both the capability to monitor the salt concentration in the soil water extract and the willingness to actually monitor water quality and adjust crop and irrigation practices as needed.

2.22 If surface drains are unavailable for disposal of saline ground water from drainage tubewells, the water is mixed with the sweet water in irrigation channels and reused. All ground water is saline to some extent, sweet water contains some salts; only distilled water is salt free. Soil water extract is not considered saline, if the electrical conductivity (EC) is less than four decisiemens per meter (dS/m) (ASCE, 1990). Decisiemens per meter is equal to millimhos per centimetre (mmhos/cm).

Economic and Social Concerns

2.23 Project plans normally include economic evaluation. The evaluation may be for portions of the project as separate units or as one all-inclusive evaluation. Social concerns are integrated with monetary costs and benefits to determine acceptability.

2.24 The economic return of incremental levels of protection should be evaluated. Acquisition costs of land for ultimate drainage facilities are to be included, even if drainage is minimal or deferred in the initial installation phase.

2.25 Various design discharges should be evaluated for optimum benefits versus costs. As discussed in Chapter 3, installation costs will increase with larger design discharges, but the structural and crop benefits may increase at a greater rate providing an improved overall benefit/cost ratio.

2.26 Estimates of maintenance costs must be developed at this stage to provide annual cost information for the economic evaluation.

Monitoring

2.27 Monitoring of water quality parameters should be carried out in conjunction with periodic maintenance reviews and coordinated with the EPA and other concerned agencies. Irrigation departments should work with EPA to establish water quality standards and to monitor quality of water bodies, including drains. A system of monitoring of water quality needs to be developed with the cooperation of EPA, PIDs, and other departments, including Agriculture and Wildlife. Monitoring for maintenance needs and operations activities of open drains are presented in Chapter 6, Operation and Maintenance.

Requirements of the Canal and Drainage Acts

2.28 Obstructions in either artificial or natural channels will lower their efficiency. The Canal and Drainage Act of 1873 defines artificial and natural channels as any river, stream, or drainage channel. For removal of obstructions, Sections 55, 56, 61 and 62 of the Canal Act outline the procedure to be followed, including recovery of costs and compensation. These sections of the Canal and Drainage Act are in Appendix A. Also, see Sindh Irrigation Act (Appendix B), Section 12, and Baluchistan Canal and Drainage Ordinance, 1980 (Appendix C), Section 50.

2.29 Public notification for planned work on a natural drain is required in accordance with: Section 55 of the Punjab Canal and Drainage Act, 1873; the NWFP Canal and

Drainage Act, 1948 (same provisions as the Punjab Act); Section 12 of the Sindh Irrigation Act; and Section 50 of the Baluchistan Canal and Drainage Ordinance, 1980. The notification is to be confined, however, to those portions which are actually operative or likely to become operative within a reasonable period. The notification must clearly define the limits within each village.

2.30 In the case of a natural drain or reaches thereof where a well defined bed exists within a village, it will suffice if the limits are defined as within 100 feet of the bed of the channel. In this case, demarcation at the site is unnecessary. Where a well defined bed does not exist, land plans (for the areas to be notified) to the usual scale of 1/2000, as well as the usual index plan, should be prepared. The limits in the notification will then be specified as widths of land required in each village. The limits must be demarcated on the ground by boundary pillars 500 feet apart on the straight and closer on curves, as necessary. It must be realized that notification under Section 55 does not establish any right other than removal of obstructions.

Chapter 3

SURFACE RUNOFF

Introduction

3.1 Surface water runoff from agricultural lands is a major consideration for surface drainage planners. This runoff depends on topography, soils, vegetative cover, land use, and climatic characteristics of the area. It originates from precipitation, as well as from excess irrigation.

3.2 Precipitation records are not included in this Manual since they are usually available for local rain gauge stations. If rainfall data are not readily available, they may be requested from a meteorological office, hydrology unit of the relevant irrigation department, or WAPDA. Long-term rainfall records are available for some railway stations. If precipitation analysis for rainfall depth is needed, the procedure described in the Modified Unit Hydrograph Method below may be used.

Runoff Methods - General

3.3 Both surface and subsurface drainage waters normally flow in the same disposal channel, since water moves toward topographic low points. Channel design must include the total capacity for flow from both sources (see design sections in Chapters 4 and 5). Surface drains should be designed to handle flows from 5- to 15-year storm recurrence interval. Where relatively expensive structures are involved and where damage to the structures may dictate the need for a more conservative design, the 25- or 50-year storm recurrence interval should be used depending on economic evaluation.

3.4 Many formulas and analytical methods are available for estimating storm runoff. The runoff methods discussed in this chapter are presented because they have been in use in Pakistan in varying degrees. The Empirical Equation method is used most often and is applied in all cases as a check, even though other more precise methods are used. This equation is simply the product of the catchment area in square miles times a customary runoff value (drainage coefficient) per square mile in cusecs (cubic feet per second). A method of utilizing more than one drainage coefficient in a catchment area is discussed in the Composite Drainage Coefficients Section. Also included is a procedure for adjusting design discharge downstream from confluences of branches of drains that approach the same size of subcatchment areas, known as the 20-40 Rule. The Runoff Curve Number method is used either alone or in combination with other methods. The Modified Unit Hydrograph method includes the Runoff Curve Number Method and is extensively used. The U.S. Army Corps of Engineers developed the HEC-1 Procedure in IBM personal computer format

(USACE, 1990). This model needs to be calibrated for the characteristics of the catchment area within the constraints of historical measured precipitation and resultant runoff. Other computer runoff models are briefly discussed.

3.5 Irrigated lands in the Indus Plain are generally flat, surface irrigated within bunded boundaries, and divided predominately into one-acre fields. Surface runoff from these bunded fields is about as low as from contour terraced fields. However, it is anticipated there will be more on-farm drainage in the future. Drain capacities will need to be larger to accommodate excess water released from bunded fields.

3.6 The Fourth Drainage Project was evaluated for degrees of drainage versus benefits and crop damages and damages to structural facilities, including roads and bridges (WAPDA, 1988). Four cusecs per square mile and less indicated positive benefit-cost ratios. Benefit-cost ratios were the greatest at 10 to 12 cusecs per square mile.

3.7 Usually, the design discharge for surface drains to safely remove surface runoff has been determined by using drainage coefficients. For example, four cusecs per square mile has normally been the maximum drainage coefficient adopted in the Punjab, with a maximum of two cusecs per square mile in Sindh. Even though these values are lower than normally required for effective drainage, the absence of field drains and staggered flows to an outlet due to temporary storage in bunded fields have contributed to their successful use in the past. However, it was acknowledged in the Manual of Irrigation Practice (PWD, 1961) that higher values are justified.

3.8 Runoff is determined above and below the outfall of contributing drains and streams, at points of change in the channel slope, at culverts and bridges, and at its outfall. These are discussed more completely in Chapter 5, Open Drains. Open drains with seepage flow should be designed essentially as a storm water drain.

Empirical Equation

3.9 The Empirical Equation as generally used in Pakistan is:

$$Q = CM$$

where, Q = design discharge, cusecs
C = drainage coefficient, cusecs per square mile
M = catchment area, square miles.

3.10 The design discharge should be modified as the catchment area increases. Since not all of the catchment contributes runoff uniformly, as the area of the catchment increases the resulting runoff per square mile typically decreases. An adjustment factor commonly used outside of Pakistan and recommended by Tipton and Kalmbach (WAPDA, 1963) is the exponent, 5/6 = 0.833, often rounded to 0.83. An exponent of 0.667 was recommended in the Manual of Irrigation Practice (PWD, 1961). Using the 5/6 adjustment factor, the Empirical Equation becomes

$$Q = CM^{0.83}$$

3.11 Figure 3.1 is a graph for direct solution of "M" in square miles to the 0.833 power to simplify the use of the Empirical Equation. Computing design discharges can be further simplified by using a curve developed for specific "C" values frequently used in the area. A curve of discharge, Q, versus $CM^{0.83}$ is plotted for each "C" value similar to Figure 3.1.

3.12 This Empirical Equation provides an economical and effective design for open drains, if the drainage coefficient (C) is selected properly. A range of drainage coefficients are presented in Table 3.1 as general guidance. There has been considerable experience in applying these coefficients, especially in the lower end of the tabulated ranges resulting in satisfactory performance of the constructed drains. Current runoff data have been from irrigated fields within bunds without farm drainage. For future designs, drainage coefficients should be selected on the basis of existing and potential on-farm drainage facilities. More intensive on-farm drainage systems will dictate the selection of larger "C" values near the upper end of the ranges. The coefficients in Table 3.1 should be limited in use to catchment areas of ten square miles or less. Values in Table 3.1 are also restricted to bunded field conditions in the command areas of the Lower Indus Plain, since only that management factor is given in the table.

Table 3.1. Range of Drainage Coefficients, "C", for Lower Indus Plain

Region	Crop & Mgt. Factor	Range Minimum	Range Maximum
North Punjab	Bunded Rice Fields	4	10
& NWFP	Bunded Veg. & Grain	6	15
South Punjab	Bunded Rice Fields	2	8
& Baluchistan	Bunded Veg. & Grain	3	10
Sindh &	Bunded Rice Fields	2	4
Baluchistan	Bunded Veg. & Fruit	2	6

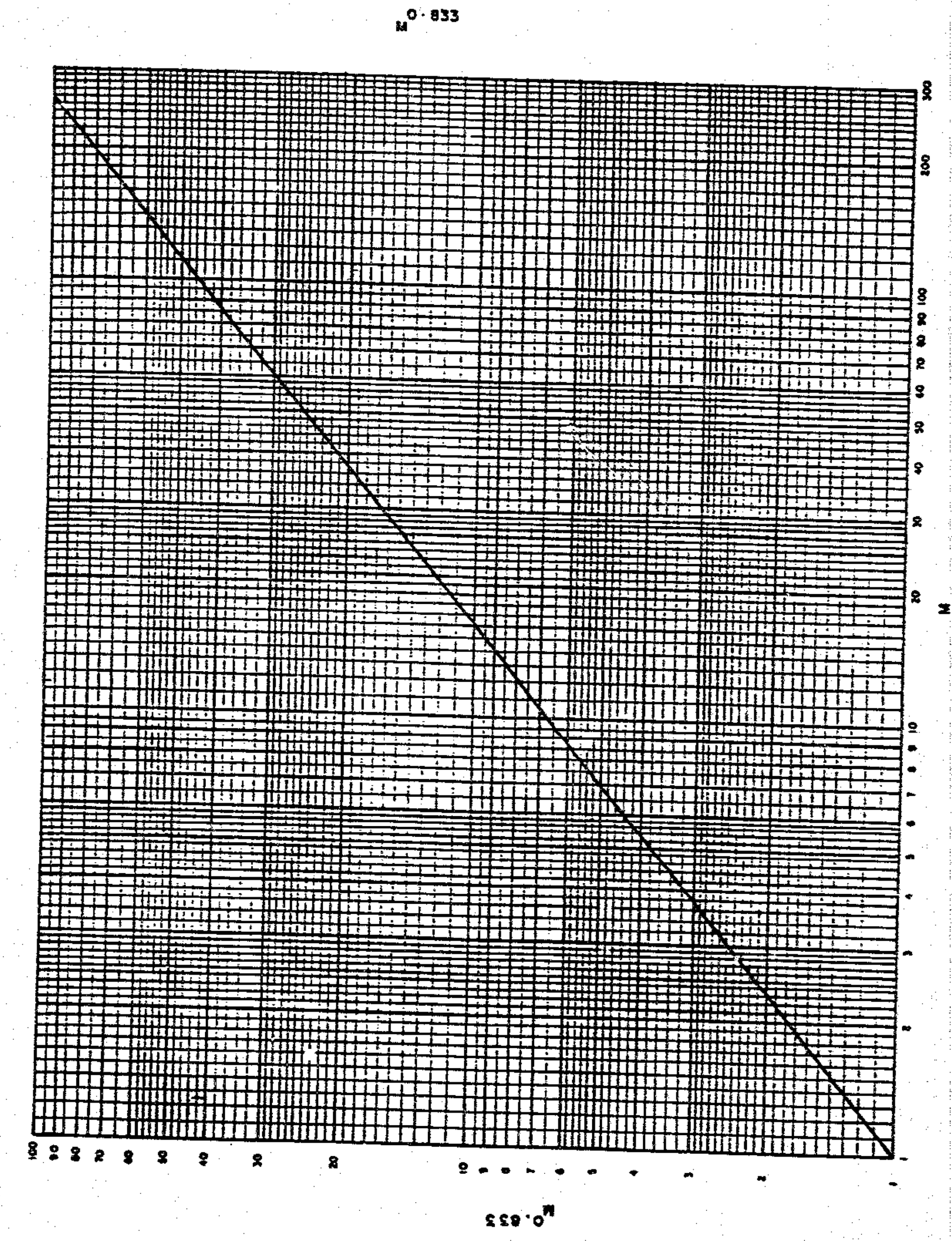


Figure 3.1. Catchment area (M) to 5/6 (0.833) power versus catchment area in square miles.

3.13 The values in Table 3.1 are justified by extensive satisfactory experience in the use of "C" factors, as stated above. For Northern Punjab, Mott MacDonald developed justification for "C" values up to 10 or 12 cusecs per square mile (WAPDA, 1988). Haigh recommended a "C" value of 12 for areas not subject to river floods and 16 if there is river flooding (PWD, 1961). Due to the large variations in rainfall, soils, crops, and topography in Pakistan, drainage design should be based on drainage coefficients selected on the basis of local conditions.

3.14 Even though the Empirical Equation is justified by continued satisfaction with system design and performance resulting from its use, it is an empirical formula. There should be an on-going review to rationally evaluate the effectiveness of drainage coefficients used on actual installed systems over time. In addition, research is recommended to validate or adjust the "C" values by analytical methods using actual rainfall data and gauged runoff information. With additional experience and analytical validation, this method may well be used for larger catchments.

Composite Drainage Coefficient

3.15 A catchment area may contain subareas with distinct drainage coefficients. Computing equivalent catchment areas for these subareas is a method for determining the design discharge of an open drain serving the entire catchment. The method is:

1. Select one of the drainage coefficients, usually for the largest subarea or for the major area below the subject catchment, if the next reach of the drainage system is to be designed.
2. Calculate the runoff from each subarea with an appropriate "C" value.
3. Calculate the equivalent area for each subarea of Step 2.
4. Add the equivalent areas to the subarea with the drainage coefficient selected in Step 1.
5. Calculate the total runoff using the drainage coefficient of Step 1 and the total area from Step 4.

3.16 The detailed procedures of the Composite Drainage Coefficient Method are illustrated in the following example:

> A 6000-acre catchment contains 5000 acres (7.81 square miles) of land with characteristics represented by a "C" value of 10 and 1000 acres (1.56 square miles) of land with characteristics represented by a "C" value of four. It is necessary to convert one of the subareas to an equivalent area with the same "C" as the other subarea. Select 10 as the common "C" value. The discharge from 1.56 square miles with "C" = 4 is 4 x $M^{0.83}$ = 5.8 cusecs. To convert the 1.56 square mile area to an equivalent area with a "C" value of 10, use 5.8 = 10 $M^{0.83}$. Then, $M^{0.83}$ = 0.58 and M = 0.52 square miles. The total equivalent catchment area is 7.81 plus 0.52 square miles equals 8.33 square miles. The total discharge from the 6000-acre catchment with "C" of 10 = 10 x $8.33^{0.83}$ equals 58 cusecs. For drain design below this point in the catchment the 8.33 square miles and the 58 cusecs are used in the computations.

20-40 Rule

3.17 It is general practice to begin runoff calculations at the source or upper end of a drain and proceed downstream. An empirical procedure termed the "20-40" rule may be used in computing required capacities for a drain below a junction with a tributary. It is a simplified form of flood routing used by the Soil Conservation Service in the U.S. (SCS, 1971).

3.18 For larger drainage areas, the application of the procedure may have considerable effect on the drain design. On smaller areas, the change in required drain capacity may be so small that the procedure does not need to be applied. Experience in applying the "20-40" rule will guide the designer in its use.

3.19 The "20-40" procedures for two channels are:

Rule 1. Where the catchment area of one of the drains is from 40 to 50 percent of the total catchment area, the required capacity of the channel below the junction shall be determined by adding the required design capacities of each drain above the junction. This is based upon the assumption that the flows from two watersheds or catchments of about the same size may reach the junction at about the same time. Therefore, the drain capacity below the junction should be the sum of the two flows.

Rule 2. Where the catchment area of a tributary is less than 20 percent of the total watershed area, the design capacity of the drain below the junction is calculated using the design characteristics, e.g. drainage coefficient, for the total watershed area.

Rule 3. Where the catchment area of a tributary is between 20 to 40 percent of the total catchment area, the discharge shall be proportioned between the smaller discharge at 20 percent and the larger discharge at 40 percent. The discharges are computed by both Rules 1 and 2 and the difference between them determined. Then, the design discharge for the channel below the junction is obtained by adding a proportion of the difference to the discharge obtained using Rule 2.

Example:

A tributary drain for a 3.5 square mile catchment area joins a drain for a 6.5 square mile catchment area. Thus, the total catchment area below the junction is 10.0 square miles. The smaller watershed is 35 percent of the total watershed and Rule 3 applies. Assume that the Empirical Equation is to be used with "C" = 10. The results using Rules 1 and 2 are in Table 3.2.

Table 3.2. Example Application of 20-40 Rule

	Watershed Area square miles		Runoff $Q = 10\ M^{0.83}$ cusecs
Rule 1	3.50		28.3
Rule 1	6.50		47.3
Rule 1		Total	75.6
Rule 2	10.00		67.6
		Difference	8.0

The difference between 20 and 35 percent is 15 percent. Thus, 35 percent is 15/20 (0.75) of the difference between 20 and 40 percent. Then, 0.75 times 8.0 cusecs equals 6.0 cusecs. Add 6.0 cusecs to 67.6 cusecs to arrive at 73.6 cusecs for the capacity of the drain below the junction.

Runoff Curve Number Method

3.20 The Runoff Curve Number Method (CN) for estimating runoff developed by the U.S. Soil Conservation Service has been used extensively in Pakistan. It is a method of estimating runoff from precipitation, based on soil and cover conditions of a catchment area. A CN is selected and used with a precipitation amount to determine the depth of runoff.

3.21 The detailed procedures are presented in the SCS National Engineering Handbook, Section 4, Hydrology, published in 1972 and revised in 1985 (SCS, 1985). The procedures are also included in Technical Release 55, "Urban Hydrology for Small Watersheds", (SCS, 1986), and Engineering Field Manual, Chapter 2, "Estimating Runoff and Peak Discharges", (SCS, 1990). The procedures are based on observations of runoff from watersheds up to 2000 acres in size, although they have been used satisfactorily on 50 square mile (32 000 acres) catchments and larger.

3.22 The factors considered in determining the CN are: hydrologic soil group, cover type, treatment, hydrologic condition, and antecedent moisture condition. Curve numbers appropriate for use in Pakistan for the first four factors are presented in Table 3.3. Antecedent moisture condition factor represents the influence of soil moisture on surface runoff prior to the time being considered in selecting a CN. However, there is no research or documented basis for adjusting CN's for antecedent moisture conditions other than II, i.e. I or III, for the arid conditions of Pakistan. Thus, no correction factor is recommended.

3.23 The hydrologic soil groups are primarily dependant on infiltration rates. The subsurface permeability, as well as the intake rate, affects the rate of infiltration. Definitions of hydrologic soil groups A, B, C, or D (SCS, 1985) are:

A. Low runoff potential and high infiltration rates even when thoroughly wetted. Consist chiefly of deep, well to excessively drained sands or gravel with high rate of water transmission (greater than 0.30 in/hr). The sandier parts of the Jhang soil series are in this group (WAPDA, 1963).

B Moderate infiltration rates when thoroughly wetted. Consist chiefly of moderately well to well drained soils. Moderately fine to moderately coarse texture; water transmission rates of 0.15 to 0.30 in/hr. Farida and much of the Jhang soil series are in Group B (WAPDA, 1963).

C. Low infiltration rates when thoroughly wetted. Consist chiefly of soils with a layer that impedes downward water movement. Moderately fine to fine texture with a slow rate of water transmission (0.05-0.15 in/hr). The Buchiana and most of the Chuharkana soil series are in this group (WAPDA, 1963).

Table 3.3. Runoff Curve Numbers (CN)[a]

Cover Description	A	B	C	D
	Soil Group			
Rice, irrigated with bund, & without on-farm drainage system.	55	57	59	60
Rice, irrigated with bund, & with on-farm drainage system.	57	60	63	65
Grain, irrigated with bund, & without on-farm drainage system.	55	62	67	70
Grain, irrigated with bund, & with on-farm drainage system.	60	68	72	75
Row Crop, irrigated with bund, without on-farm drainage system.	63	70	75	78
Row Crop, irrigated with bund, & with on-farm drainage system.	68	75	79	83
Rangeland, semiarid, herbaceous mixture of grass, weeds, low growing shrubs in poor HC[b].	[c]	80	87	93
Fair HC		71	81	89
Good HC		62	74	85
Rangeland, semiarid, desert shrub in				
Poor HC	63	77	85	88
Fair HC	55	72	81	86
Good HC	49	68	79	84
Urban areas				
Commercial and business with 85% impervious area	89	92	94	95
Industrial with 72% impervious area	81	88	91	93
Residential with 65% impervious area	77	85	90	92
38% impervious area	61	75	83	87
30% impervious area	57	72	81	86
25% impervious area	54	70	80	85
20% impervious area	51	68	79	84
12% impervious area	46	65	77	82

[a] - Basic references used are (SCS, 1985) and (SCS, 1986) with all research based on U.S. conditions. Judgmental adaptation was used for local crop and land conditions.

[b] - Hydrologic condition (HC): Poor - less than 30% ground cover; Fair - 30% to 70% ground cover; Good - more than 70% ground cover.

[c] - Curve numbers for Group "A" have not been developed.

D. High potential of runoff with very low infiltration rates when thoroughly wetted. Consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. Low rate of water transmission (0-0.05 in/hr). Some of the Chuharkana and all of the Nokar soil series are in this group (WAPDA, 1963).

3.24 Recommended CNs for irrigated cropland in the Pakistan Indus Plains (WAPDA, 1963) were considered in developing Table 3.3. The recommendations in that report are: good cropping pattern of millet, sugar cane, and maize (A - 51; B - 67; C - 76; D - 80); and poor cropping pattern of cotton and rice predominantly (A - 61; B - 72; C - 79; D - 82). Even though there have been satisfactory results using this method, field scale research is recommended to validate or adjust the CNs presented in Table 3.3.

3.25 If more than one CN is needed based on catchment area characteristics, then a weighted average CN is determined. Multiply each CN by the area of the respective subcatchment and divide the summation of these products by the total catchment area to determine a weighted average CN. After the curve number has been determined, Figure 3.2 can be used to obtain the direct runoff for a given amount of precipitation.

<u>Example</u> Given:

1. Catchment area = 1000 acres.

2. Soil profile has fine texture soil with low infiltration rate and slow rate of water transmission.

3. Crop is irrigated rice primarily.

4. A three-inch rainfall event.

Procedures:

1. First determine which soil group is represented. Based on the definitions of the four hydrologic soil groups (pages 29 & 31), the given soil profile description matches that for hydrologic soil group C.

2. The cropland is irrigated rice. It is not given whether an on-farm drainage system is or will be in place. Assume an on-farm drainage system will be installed. Select CN of 63 from Table 3.3.

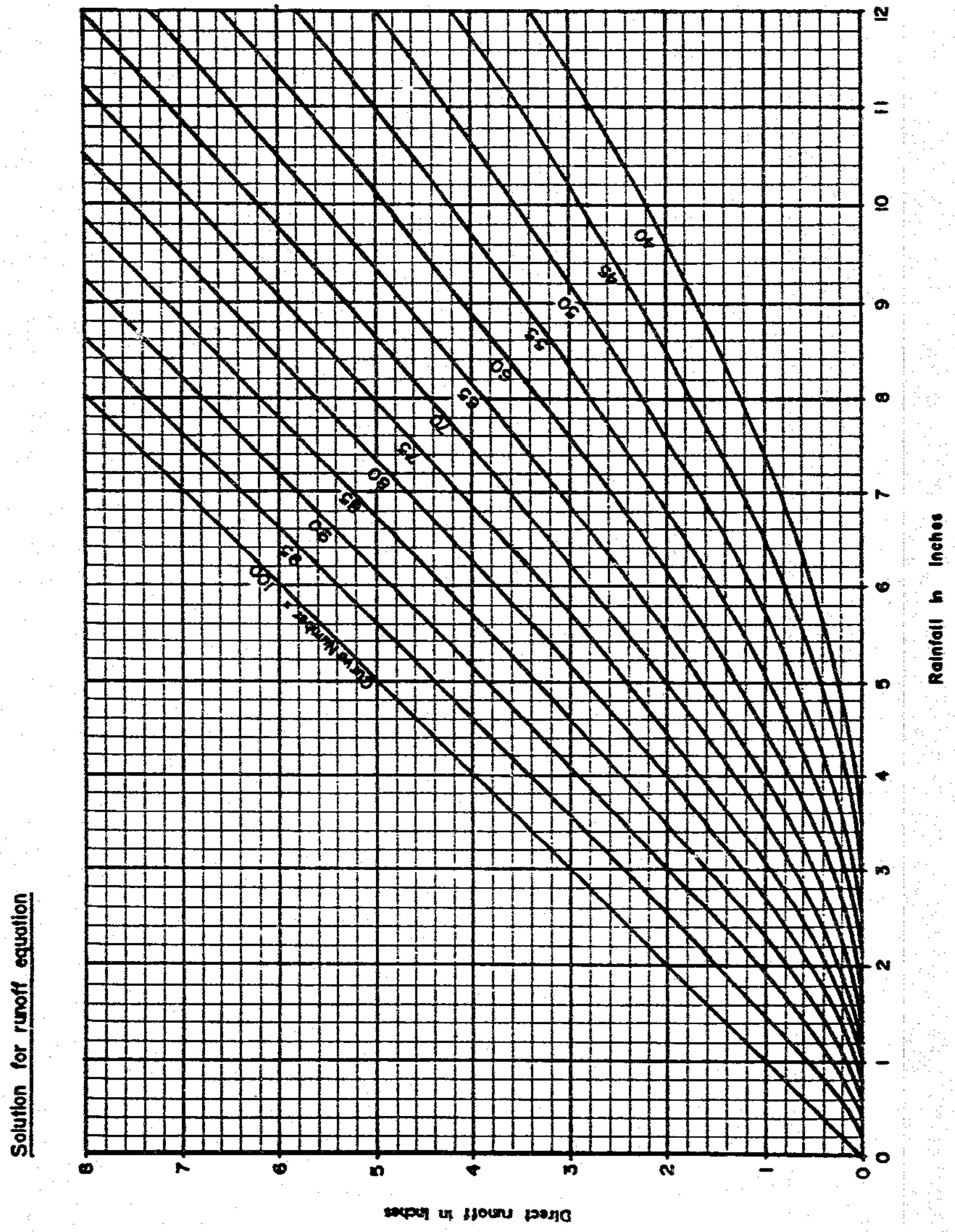


Figure 3.2. Direct runoff versus rainfall with runoff curve number (CN).

3. Using a CN of 63 and precipitation of three inches, the direct runoff of about 0.4 inches from the storm is read from Figure 3.2. For the 1000-acre catchment, total runoff is 0.4 x 1000 = 400 acre-inches. Dividing this amount by 12 inches per foot, the total runoff is 33.3 acre-feet.

3.26 This total runoff is the volume of runoff over the entire catchment. To determine the required design discharge in cusecs, it is necessary to select an acceptable time period for removal, such as 48 hours. Since a flow of one cubic foot per second will remove about two acre-feet in one day[1] or four acre-feet in two days, the 33.3 acre-feet will be removed in about two days with a constant flow rate of 8.3 cusecs.

3.27 For maize with an on-farm drainage system on the same soil, the CN from Table 3.3 is 72. From Figure 3.2 with rainfall of 3.0 inches and CN of 72, the direct runoff is 0.8 inches.

3.28 This method can be applied to large basins with various soils and crops. However, the distribution of the conditions must be known to estimate the weighted average curve number and total runoff from the basin.

Modified Unit Hydrograph Method

3.29 The Modified Unit Hydrograph Method is used extensively for runoff evaluation in Pakistan. Tipton and Kalmbach Inc. (WAPDA, 1963) introduced the method presented here for use when rainfall intensity and recurrence interval data are not available.

3.30 The procedures for the method include the calculation of runoff based on a rainfall storm that is continuous over a period of sufficient duration to develop runoff from the entire area. The 24-hour interval is usually used because daily records are most numerous. In some cases, the peak runoff will be developed by a short intense storm rather than a storm of longer duration. Both cases should be investigated when required. Separate analyses of 24-, 48-, and 72-hour rainfall storms may be made from the records of stations in the area of interest to determine the magnitude of storms that occur for various recurrence intervals. The recurrence interval of various rainfall intensities shall be developed by the "station-year" method (Wisler & Brater, 1959) on a maximum annual rainfall storm basis (Linsley et al, 1958).

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1 $$\frac{\frac{1\ ft^3}{s} \times \frac{60\ s}{min} \times \frac{60\ min}{hr} \times \frac{24\ hr}{day}}{\frac{43\,560\ ft^2}{acre}} = \frac{2\ acre\text{-}feet}{day}$$

Rainfall Frequency Analysis

3.31 The station-year method is based on the assumption that all locations are in a meteorologically homogeneous area and will experience similar rainfall frequencies. The primary factors affecting the meteorological homogeneity of an area are:

- Distance from the ocean
- Direction of prevailing winds
- Mean annual temperature
- Altitude

3.32 As reported by Tipton and Kalmbach (WAPDA, 1963), these factors are similar throughout the Upper Indus Basin plains below the Himalayan "piedmont plain" and between the Sutlej and Jhelum Rivers. There is a gradual decrease in total precipitation from the northeastern boundary of the plain toward the Arabian Sea. The major storms do not follow any particular pattern over the area. High-intensity rains occur throughout the general Indus Basin but with greater frequency in the northern zone. It was concluded that zones having similar monsoon rainfall depth (within reasonable limits) would be considered meteorologically homogeneous.

3.33 Rain gauge stations selected for analysis by the station-year method should be completely independent with respect to the effect of major storms. That is, no two stations should record a yearly maximum rainfall from the same major storm.

3.34 Design storm duration and recurrence interval shall be selected based on the area and the type of project under consideration. Generally, the analyses of storms of various durations are required as there is no direct way of determining the critical storm duration without the following considerations:

- mean intensity
- time pattern of rainfall
- condition of catchment area
- storage-discharge relationship

3.35 Point rainfall is defined as the recorded rainfall over an area of ten square miles or less. Recorded rainfall representing areas greater than ten square miles shall be reduced in accordance with an areal distribution curve specifically prepared for the area.

3.36 The areal distribution curve shall be prepared by plotting the area-depth relationship for several major storms. The areal distribution curve for each storm shall be derived by the isohyetal method (Linsley et al, 1958). An isohyetal map should be drawn for each selected storm from which the average rainfall depth and area shall be determined for each isohyet. Then the ratio of each average rainfall depth to the maximum point rainfall of the same storm shall be determined and plotted versus the area. When all storms are thus plotted, an average curve may be determined for use in the design process. This average distribution curve shall be used for each 24-hour period of a multiday storm.

3.37 Modified Unit Hydrograph Method Example (furnished by Project Planning Directorate, WAPDA):

The catchment is the Upper Rechna Remaining (SCARP-IV) between Lahore and Gujaranwala. The precipitation data from 13 rain gauges were analyzed for point rainfall of 24- and 48-hour durations with recurrence intervals of 5, 10 and 40 years (Table 3.4).

Table 3.4. Rainfall Recurrence Interval for Upper Rechna Remaining

Recurrence	Point rainfall, inches	
interval, years	24 hours	48 hours
5	4.7	6.0
10	6.0	7.75
40	8.2	12.50

The maximum annual rainfall for any duration shall be analyzed as follows:

Step 1. Select the necessary records for the analysis. The longest available records, not necessarily continuous, should be used. Ten years of independent record is considered as a minimum and the stations selected must be in an area that is meteorologically homogeneous.

Step 2. Tabulate the maximum annual 24-hour and 48-hour rainfall for each station for the period of record (Table 3.5 {24 hours} and Table 3.6 {48 hours}).

Step 3. Retabulate the rainfall amounts in decreasing order of magnitude[1] and compute the recurrence interval for each rainfall storm using the following equation (see Tables 3.7 and 3.8):

$$R_i = \frac{n + 1}{m}$$

[1] Rainfall amounts less than two inches were not used in the analysis.

Table 3.5. Maximum Annual 24-hour Rainfall

Year	Ram-nagar	Hafiz-abad	Wazir-abad	Daska	Har-poke	Sial-Kot	Shah-Jamal
1955						2.20	4.20
1956						2.30	2.49
1957						4.00	2.62
1958						4.40	3.87
1959						3.95	5.47
1960						1.90	4.47
1961						4.50	10.12
1962						4.50	4.94
1963	2.15	1.90	2.30	2.12	4.20	1.41	2.75
1964	3.10	4.40	7.64	2.90	3.50	7.62	3.96
1965	2.53	1.65	1.38	1.55	3.15	1.10	1.56
1966	3.50	5.08	5.49	8.00	4.00	2.79	7.50
1967	2.75	3.08	3.30	2.55	3.15	2.41	1.50
1968	1.20	1.15	3.10	3.25	3.40	4.40	1.40
1969	3.50	5.90	6.32	2.80	1.30	7.00	2.86
1970	2.35	2.65	4.90	2.30	2.70	5.19	1.25
1971	2.94	7.70	3.90	3.16	3.50	4.58	3.10
1972	2.00	1.57	1.90	1.90	2.30	2.51	2.10
1973	4.65	4.50	4.90	4.20	3.25	3.10	2.50
1974	1.60	1.60	1.15	2.50	2.30	7.19	2.60

Table 3.5. Maximum Annual 24-hour Rainfall (cont.)

Year	Bado-ratta	Sheikh-upura	Sango-wali	Warpal	Metha-suja	Gujran-wala
1955	2.20	3.50	3.30	3.90	5.00	3.20
1956	5.30	3.50	4.40	3.35	3.50	3.70
1957	5.60	8.70	7.10	7.10	4.70	10.25
1958	4.50	5.42	2.85	3.50	6.50	2.50
1959	8.60	9.60	5.70	5.10	6.50	7.40
1960	2.70	1.20	2.30	2.30	2.25	2.70
1961	3.20	2.00	4.90	2.50	3.80	2.50
1962	3.75	3.73	3.05	2.00	6.35	3.12
1963	3.95	3.00	1.50	1.80	1.60	3.64
1964	3.83	4.50	3.00	3.00	3.60	2.95
1965	3.50	3.00	1.50	3.40	1.50	2.15
1966	2.35	6.90	4.50	6.00	2.75	2.72
1967	Missing	2.50	6.00	2.25	2.50	9.15
1968	1.75	2.60	6.10	3.50	3.40	2.20
1969	1.50	3.94	3.17	3.25	2.45	3.07
1970	2.60	4.10	3.10	3.10	3.50	3.04
1971	3.50	5.80	3.25	3.00	3.50	3.05
1972	2.25	2.12	1.80	1.75	2.00	2.10
1973	5.12	4.00	5.00	3.50	5.25	4.95
1974	2.50	2.80	2.75	2.85	6.25	0.91

Table 3.6. Maximum Annual 48-hour Rainfall

Year	Ram-nagar	Hafiz-abad	Wazir-abad	Daska	Har-poke	Sial-kot	Shah-jamal
1955						2.70	6.26
1956						2.45	3.37
1957						7.50	4.25
1958						5.50	4.99
1959						6.02	6.99
1960						3.65	6.37
1961						4.50	19.60
1962						7.00	5.45
1963	2.15	3.45	3.69	2.22	4.20	2.13	2.75
1964	3.10	5.12	9.45	3.89	5.50	11.47	5.88
1965	2.53	2.14	1.68	2.25	3.85	2.04	1.56
1966	4.50	5.08	5.88	8.90	4.40	3.34	8.85
1967	3.00	3.08	3.95	2.55	3.65	3.32	1.65
1968	1.30	1.64	3.75	4.00	4.40	5.52	2.07
1969	3.50	6.45	6.32	3.80	1.70	7.00	3.40
1970	3.35	2.65	5.06	4.25	3.00	5.60	1.75
1971	3.90	7.70	3.90	5.32	3.50	5.11	3.10
1972	2.75	2.57	2.56	1.90	2.30	3.12	2.46
1973	7.05	6.78	5.86	5.10	5.50	3.81	4.20
1974	1.90	1.60	1.21	4.45	5.30	9.12	3.10

Table 3.6. Maximum Annual 48-hour Rainfall (cont.)

Year	Bado-ratta	Sheikh-upura	Sango-wali	Warpal	Metha-suja	Gujran-wala
1955	3.30	3.50	3.67	3.90	5.70	3.20
1956	5.30	4.00	6.65	4.85	3.50	3.70
1957	8.95	13.00	11.30	9.10	4.70	15.00
1958	5.60	8.47	4.05	4.15	8.20	3.92
1959	16.40	15.75	7.75	6.80	7.70	13.39
1960	3.17	1.95	2.70	3.75	2.95	4.05
1961	4.75	2.90	5.60	3.15	6.30	3.60
1962	4.85	7.33	3.15	3.95	6.50	3.12
1963	5.15	4.00	2.40	2.50	2.15	4.04
1964	5.98	8.00	4.60	4.60	4.35	4.84
1965	3.85	3.40	2.70	3.70	2.25	3.27
1966	3.65	8.12	5.20	7.00	5.15	8.54
1967	Missing	3.00	7.70	2.50	3.75	9.15
1968	3.00	4.20	6.10	3.50	3.65	2.58
1969	2.00	4.06	3.36	5.00	3.65	5.57
1970	2.89	7.05	3.20	3.20	3.50	3.52
1971	4.10	6.40	5.75	3.75	5.80	4.30
1972	2.70	3.95	2.70	3.25	2.00	3.10
1973	6.80	4.00	6.35	5.50	6.45	4.95
1974	3.50	3.63	2.75	4.10	6.25	1.74

Table 3.7. Frequency Analysis of 24-hour Rainfall

Order[a] m	Rainfall (inches)	R_i (years)	Order m	Rainfall (inches)	R_i (years)	Order m	Rainfall (inches)	R_i (years)
1	10.25	221	57	4.40	3.87	151	2.53	1.46
2	10.12	110.5	61	4.20	3.62	152	2.51	1.45
3	9.60	73.6	64	4.10	3.45	153	2.50	1.44
4	9.15	55.6	65	4.00	3.40	161	2.49	1.37
5	8.70	44.4	68	3.96	3.25	162	2.45	1.36
6	8.60	36.8	69	3.95	3.20	163	2.41	1.35
7	8.00	31.57	71	3.94	3.11	164	2.35	1.34
8	7.72	27.62	72	3.90	3.07	166	2.30	1.33
9	7.70	24.55	74	3.87	2.98	173	2.25	1.27
10	7.64	22.1	75	3.83	2.94	176	2.20	1.25
11	7.62	20.1	76	3.80	2.91	179	2.15	1.23
12	7.50	18.4	77	3.75	2.87	181	2.12	1.22
13	7.40	17.0	78	3.73	2.83	183	2.10	1.20
14	7.19	15.78	79	3.70	2.79	185	2.00	1.19
15	7.10	14.73	80	3.64	2.76			
17	7.00	13.00	81	3.60	2.72			
18	6.90	12.27	82	3.50	2.69			
19	6.50	11.63	96	3.40	2.30			
21	6.35	10.52	99	3.35	2.23			
22	6.32	10.04	100	3.30	2.21			
23	6.25	9.60	102	3.25	2.16			
24	6.10	9.20	106	3.20	2.08			
25	6.00	8.84	108	3.17	2.04			
27	5.90	8.18	109	3.16	2.03			
28	5.80	7.89	110	3.15	2.01			
29	5.70	7.62	112	3.12	1.97			
30	5.60	7.36	113	3.10	1.95			
31	5.49	7.12	119	3.08	1.85			
32	5.47	6.90	120	3.07	1.84			
33	5.42	6.69	121	3.05	1.82			
34	5.30	6.50	123	3.04	1.79			
35	5.25	6.31	124	3.00	1.78			
36	5.19	6.13	129	2.95	1.71			
37	5.12	5.97	130	2.94	1.70			
38	5.10	5.81	131	2.90	1.68			
39	5.08	5.66	132	2.86	1.67			
40	5.00	5.52	133	2.85	1.66			
42	4.95	5.26	135	2.80	1.63			
43	4.94	5.13	137	2.79	1.61			
44	4.90	5.02	138	2.75	1.60			
47	4.70	4.70	142	2.70	1.55			
48	4.65	4.60	145	2.65	1.52			
49	4.58	4.51	146	2.62	1.51			
50	4.50	4.42	147	2.60	1.50			

[a] - Gaps in the order indicate equal rainfall amounts occurred more than once.

Table 3.8. Frequency Analysis of 48-hour Rainfall

Order[a] m	Rainfall (inches)	R_i (years)	Order m	Rainfall (inches)	R_i (years)	Order m	Rainfall (inches)	R_i (years)
1	19.60	221	55	5.70	3.87	130	3.65	1.70
2	16.40	110.5	56	5.60	3.62	135	3.63	1.63
3	15.75	73.6	59	5.57	3.74	136	3.60	1.62
4	15.00	55.6	60	5.52	3.68	137	3.52	1.61
5	13.39	44.4	61	5.50	3.62	138	3.50	1.60
6	13.00	36.8	65	5.45	3.40	145	3.45	1.52
7	11.47	31.5	66	5.32	3.34	146	3.40	1.51
8	11.30	27.62	67	5.30	3.29	148	3.37	1.49
9	9.45	24.55	69	5.20	3.20	149	3.36	1.48
10	9.15	22.1	70	5.15	3.15	150	3.35	1.47
11	9.12	20.1	72	5.12	3.07	151	3.34	1.46
12	9.10	18.4	74	5.11	3.02	152	3.32	1.45
13	8.95	17.0	74	5.10	2.98	153	3.30	1.44
14	8.90	15.78	75	5.08	2.94	154	3.27	1.43
15	8.85	14.78	76	5.06	2.91	155	3.25	1.42
16	8.54	13.00	77	5.00	2.87	156	3.20	1.41
17	8.47	12.27	78	4.99	2.83	159	3.17	1.39
18	8.20	11.63	79	4.95	2.79	160	3.15	1.38
19	8.12	11.05	80	4.85	2.76	162	3.12	1.36
20	8.00	10.52	82	4.84	2.69	164	3.10	1.34
21	7.75	10.04	83	4.76	2.66	168	3.08	1.31
22	7.50	9.60	84	4.75	2.63	169	3.00	1.30
25	7.33	9.20	85	4.60	2.60	173	2.95	1.27
26	7.05	8.84	87	4.50	2.54	174	2.90	1.27
27	7.00	8.18	89	4.45	2.48	175	2.89	1.26
29	6.99	7.89	90	4.40	2.45	176	2.75	1.25
32	6.80	7.62	92	4.35	2.40	179	2.70	1.23
33	6.78	7.36	93	4.30	2.37	184	2.65	1.20
35	6.65	7.12	94	4.25	2.35	185	2.58	1.19
36	6.50	6.90	96	4.20	2.30	187	2.57	1.18
37	6.45	6.69	99	4.15	2.23	188	2.56	1.18
38	6.40	6.50	100	4.10	2.21	189	2.55	1.17
40	6.37	6.31	102	4.06	2.16	190	2.53	1.16
41	6.37	6.13	103	4.05	2.14	191	2.50	1.15
42	6.35	5.97	105	4.04	2.10	192	2.45	1.15
43	6.32	5.81	106	4.00	2.08	193	2.40	1.14
44	6.30	5.66	110	3.95	2.01	195	2.30	1.13
45	6.26	5.52	113	3.92	1.95	196	2.25	1.12
46	6.25	5.26	114	3.90	1.93	198	2.22	1.11
47	6.10	5.13	117	3.89	1.88	199	2.15	1.11
48	6.02	5.02	118	3.85	1.87	201	2.14	1.09
49	5.98	4.70	120	3.81	1.84	202	2.13	1.09
50	5.88	4.60	121	3.80	1.82	203	2.07	1.08
52	5.86	4.51	122	3.75	1.81	204	2.04	1.08
53	5.80	4.42	128	3.69	1.72	205	2.00	1.07
54	5.75	3.94	129	3.67	1.71			

[a] - Gaps in the order indicate equal rainfall amounts occurred more than once.

Where: R_t = Recurrence interval in years,

n = Number of years of record[1]

m = Order of magnitude of the rainfall event.

Step 4. Plot the rainfall in inches versus the recurrence interval in years and draw a smooth curve through the points (Figure 3.3). When drawing a smooth curve, some plotted points may be off of the curve. Values in Table 3.4 are basically consistent with curves in Figure 3.3.

Estimation of Runoff

3.38 The symbols and procedures used in developing a synthetic unit hydrograph to estimate runoff flow in the Modified Unit Hydrograph method (WAPDA, 1963) are (refer to Figure 3.4):

A = Catchment area in square miles above a point of interest.

L = Length of the basin in miles measured along the major channel from the point of interest to the upper catchment area divide.

L_{ca} = Length of the channel in miles measured along the major channel from the point of interest to the point on the channel closest to the centroid of the catchment area.

S_{st} = Mean slope of the channel. Where more than one slope is known, the mean slope can be computed by the equation:

$$S_{st} = [N / (\text{Summation } (1/S_i^{0.5}))]^2$$

N = Number of channel reaches of equal length.

S_i = Slope of the individual channel reaches in feet per foot.

t_r = Unit storm duration in hours.

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[1] In this example, n = 220 which is based on eight stations with 20 years of record each (8 x 20 = 160) and five stations with 12 years of record each (5 x 12 = 60).

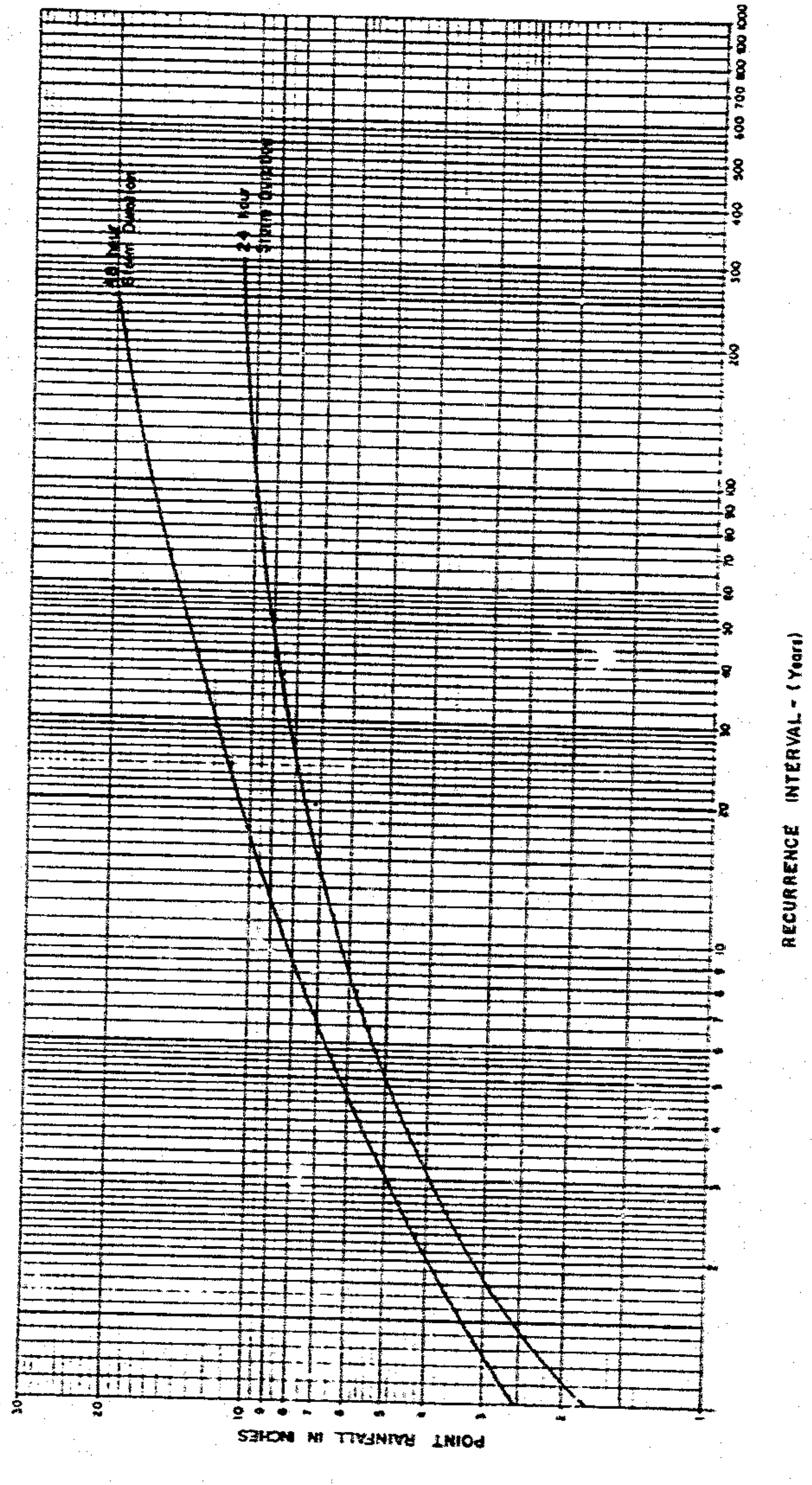

Figure 3.3. Example point rainfall/recurrence interval curves.

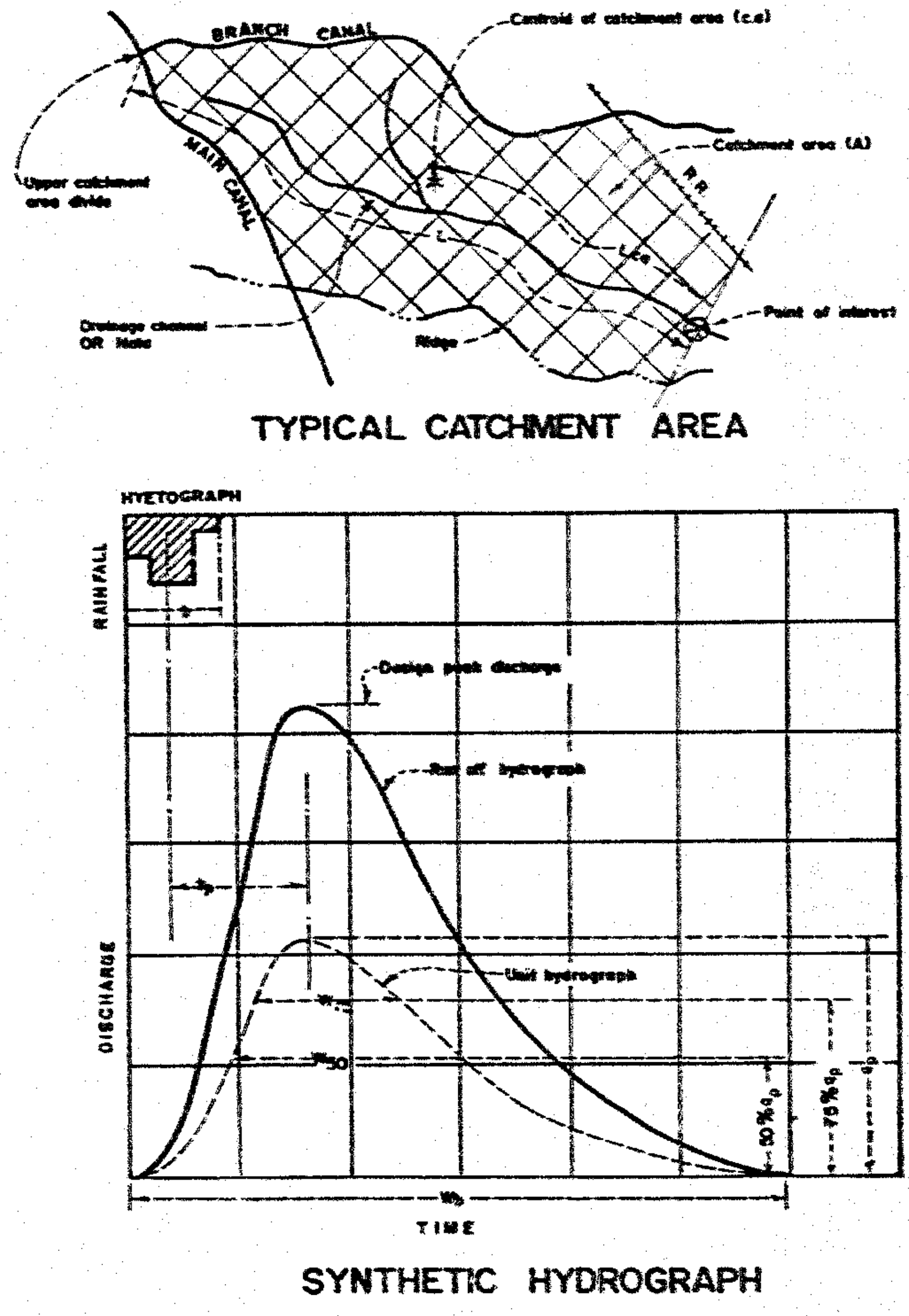

Figure 3.4. Synthetic hydrograph parameters (WAPDA, 1963).

t_p = Lag time in hours from the centroid of the unit rainfall excess to the time when the unit hydrograph peak discharge occurs.

q_p = Unit hydrograph peak discharge in cusecs per square mile from one inch of direct runoff.

Q_p = Catchment area peak discharge in cusecs from one inch of direct runoff.

Q = Catchment area peak discharge in cusecs.

3.39 The basic relationships for computing the lag time and unit hydrograph peak discharge from drainage basin data are:

$$t_p = C_t\,[(L^*L_{ca})/(S_{st})^{0.5}]^n$$

where C_t and n are constants

$$q_p = \frac{640\ C_p}{t_p}$$

C_p = coefficient derived from a similar catchment but with useable flow records.

3.40 Since the similar catchment area characteristics approach is still being used by the Planning Directorate, WAPDA, the Unit Hydrograph Relationships are included in Figure 3.5. Using the Lag Relation Curve after the factor $LL_{ca}/(S_{st})^{0.5}$ is computed (refer to Table 3.9), the t_p value is read directly. Then, using the t_p value in the Lag viz Peak Discharge curve the q_p is read directly. These curves were used in the Upper Rechna Remaining example.

3.41 After determining the unit hydrograph peak discharge (q_p), the catchment area peak discharges (Q_p and Q), as defined above, are calculated from the equations:

$Q_p = A\ q_p$ and $Q = Q_p\ (R.O.)$ where R.O. = runoff

3.42 The Unit Hydrograph produces the peak discharge per unit of runoff, which is an inch. The next step is to determine the runoff amount which is customarily done using the Curve Number Method. For this example, a Runoff Curve Number (CN) of 80 was used (Fig. 3.2). Table 3.9 shows the results for runoff and design discharge values. A more thorough discussion of unit hydrographs may be found in most of the Engineering Hydrology texts, such as Linsley et al, 1958 or 1988, listed in the References.

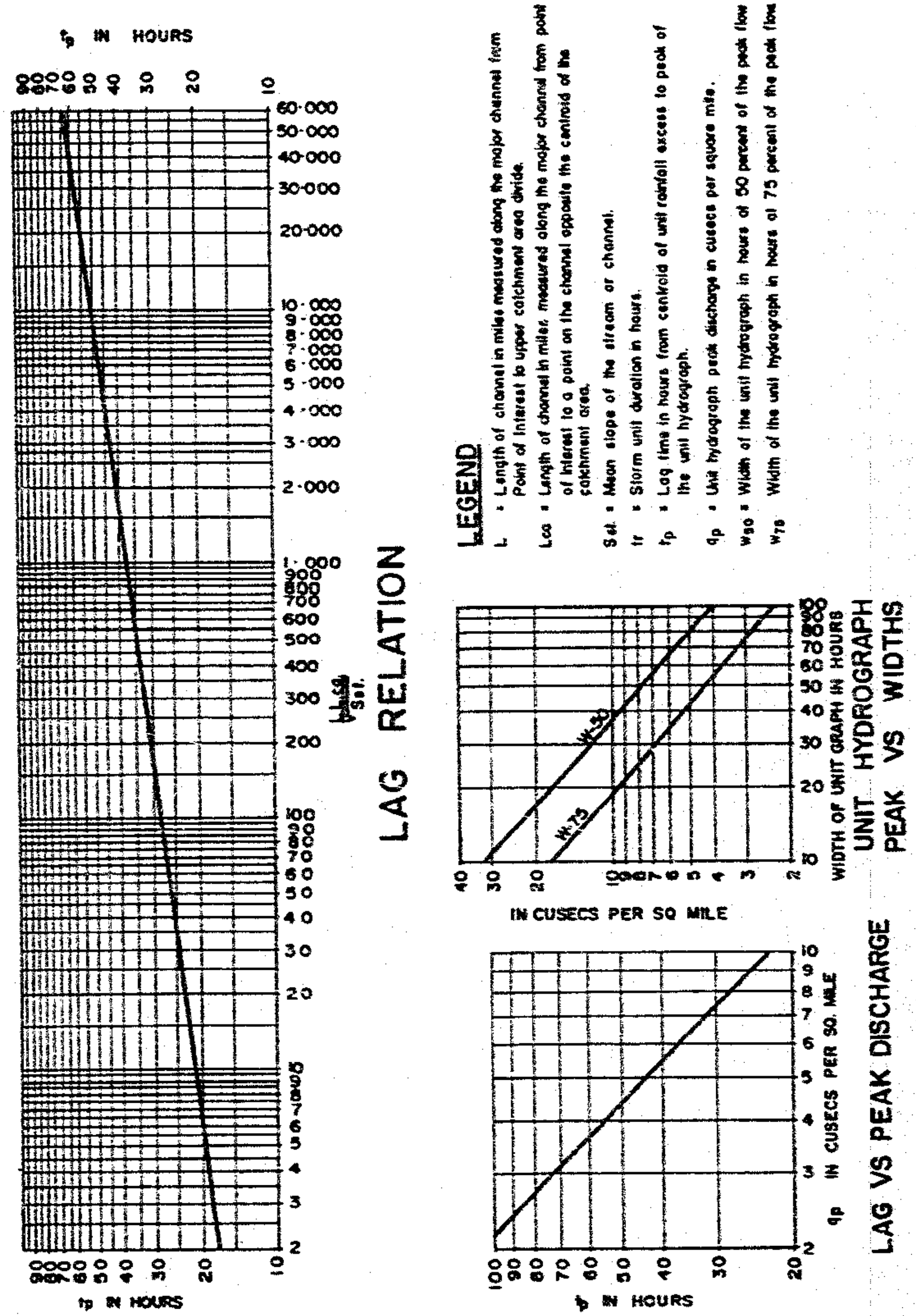

Figure 3.5. Unit hydrograph relationships (WAPDA, 1963).

Table 3.9. Runoff Results for Modified Unit Hydrograph

Example. Upper Rechna Remaining (SCARP IV), Ahmadpur Vaugh Basin

Area No.	L mi.	L_{ca} mi.	S_{st} ft./ft.	Area sq.mi.	$\frac{LL_{ca}}{S^{0.5}}$	t_p hrs.	q_p cusecs/sq.mi.	Q_p cusecs
1	5.0	1.8	.0004	6.0	450	34.5	6.9	41.1
2	9.0	4.5	.0004	20.0	2020	41.5	6.3	106.6
3	14.0	5.0	.0004	43.4	3500	43.2	5.0	214.8
4	3.0	1.5	.0003	3.2	346	33.0	7.0	22.4
4a	1.5	1.0	.0003	2.0	87	28.0	7.8	15.6
5	6.8	3.4	.0003	9.2	1330	38.5	5.9	54.3

(A) Storm Duration of 24 hours.

	5-yr. storm			10-yr. storm		
Area No.	Rain in.	R.O. in.	Q cusec	Rain in.	R.O. in.	Q cusec
1	4.70	2.7	109	6.00	3.8	156
2	4.62	2.6	273	5.89	3.7	393
3	4.52	2.5	531	5.77	3.6	782
4	4.70	2.7	59	6.00	3.8	85
4a	4.70	2.7	41	6.00	3.8	59
5	4.70	2.7	144	6.00	3.8	206

(B) Storm Duration of 48 hours.

	5-yr. storm			10-yr. storm		
Area No.	Rain in.	R.O. in.	Q cusec	Rain in.	R.O. in.	Q cusec
1	6.00	3.8	155	7.75	5.4	220
2	5.90	3.7	397	7.63	5.2	558
3	5.77	3.6	782	7.45	5.1	1100
4	6.00	3.8	85	7.75	5.4	120
4a	6.00	3.8	59	7.75	5.4	84
5	6.00	3.8	205	7.75	5.4	290

Computer Models

3.43 Some of the computer models used for storm runoff evaluations are briefly discussed in this section. User manuals are needed with the programs to fully understand the input and output factors. Caution should be exercised in using computer models as this is a rapidly developing technology and the models are not easy to use correctly. The programs and associated published material for the computer models discussed in this section can be obtained from Water Resources Publications (WRP), P.O. Box 2841, Littleton, Colorado, USA 80161-2841; telephone: 303-7901836; telefax: 303-7909509.[1]

HEC-1 Model

3.44 HEC-1 is a computer model for rainfall-runoff event simulation. The model was developed by the U. S. Army Corps of Engineers for flood studies. It has been tested and successfully used for many years in the United States, and more recently tested in Pakistan. This runoff evaluation program must be calibrated for use on the catchment area. In addition to data for a recorded rainfall event or events, the catchment area soil and land treatment characteristics and gauged runoff are needed for calibration. The program software is available in IBM PC compatible format from Haestad Methods, Inc., Waterbury, CT 06708; telephone: 203-7551666; telefax: 203-5971488 (USACE, 1990).

3.45 Awagat Branch Drain Catchment, which is part of the Fourth Drainage Project, Faisalabad, was evaluated by use of this program. The study on Awagat Drain, which has a total catchment of 83 square miles, was reported to have reasonable results considering limited calibration data (IWASRI/NRAP, 1990).

TR 55 Model

3.46 The Urban Hydrology for Small Watershed's graphical method for determining peak discharge was developed by the SCS (SCS, 1986) based on procedures in the National Engineering Handbook, Section 4, Hydrology (SCS, 1985). It includes a graph for 24-hour duration storms with a time of concentration (T_c) less than 10 hours. Information on land use, soils, and rainfall is required. A computer program of the procedures for IBM compatible computers with MS-DOS 2.1 or later and at least 256 K storage has been written. The program and manual are available from:

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[1] The use of supplier names in this Manual does not constitute endorsement of the products nor are they the only sources for a particular item. The intent is to indicate the types of materials available and identify sample sources.

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161 Telephone: 703-4874650

EFM 2 Model

3.47 The procedures for determining peak discharge from watersheds of 2000 acres or less using the EFM 2 model are presented in Chapter 2, "Estimating Runoff and Peak Discharges" in the *SCS Engineering Field Manual* (SCS, 1990). The procedures are adapted for use in the United States, Puerto Rico, and the Virgin Islands. Data for the peak discharge exhibits were computed using procedures of the SCS National Engineering Handbook (NEH-4), Section 4. NEH-4 or TR-55 should be used to estimate peak discharges beyond the limits of the EFM 2 model. An MS-DOS microcomputer program of the EFM 2 procedures in the *SCS Engineering Field Manual* is available from NTIS.

HEC-2 Model

3.48 The HEC-2 model is a water surface profile computer program. Water surface profiles are developed for steady, gradually varied flow in natural and man-made channels. It handles subcritical and supercritical flows, as well as bridges or other obstructions. This program is also IBM compatible and requires only 390K RAM. Computer software and publication are available from WRP and Haestad.

TR-20 and WSP-2 Models

3.49 TR-20 is a procedure for project formulation hydrology. The program provides hydrologic analysis of catchment areas with present conditions and various combinations of land cover, use and structural or channel modifications using single event storm rainfall data.

3.50 WSP-2 computes water surface profiles in open channels for evaluating flood routing. WSP-2 uses the standard step method to determine flow characteristics and water surface profiles for open channels, including flood plains. It includes the effects of bridges, culverts, and other restrictions.

3.51 TR-20 and WSP-2 procedures were developed by the SCS. There is an SCS microcomputer version of TR-20. The manual and software are available from NTIS. The WSP-2 program is not available on diskette at this time from NTIS, but is available in written form only. Both of these programs are also available from Haestad Methods, Inc.

Chapter 4

FARM DRAINAGE

Introduction

4.1 This chapter is intended to orient provincial irrigation engineers to farm drainage, even though farm drainage is not one of their normal responsibilities. It is not intended to be an on-farm drainage manual.

General

4.2 Farm drainage generally has not been provided for irrigated lands in Pakistan. However, surface drainage of farms is important for reduction of damages due to standing water, prolonged saturation of the root zone (waterlogging), and excessive percolation of poor quality water to ground water.

4.3 The primary problem of inadequate drainage is waterlogging of the soil. Plant roots need oxygen in addition to an adequate supply of water and nutrients. Waterlogging prevents plant roots from receiving oxygen, because the water displaces air/oxygen from the pore space in the soil. A soil profile that is saturated with water becomes anaerobic, which means without air because the soil water restricts the normal exchange of air between the soil and the atmosphere. Also, compounds may be formed in anaerobic conditions that are injurious to plant roots. Plants vary considerably in their ability to tolerate anaerobic conditions or toxic substances in the root zone. Even though there may be no apparent damage to a crop, restricted availability of nutrients reduces potential yield.

4.4 All plants need water for basic development and crop production. However, the availability of water to the plant roots may actually be restricted in a waterlogged soil, if the salinity level of the soil water increases to the point that the osmotic process in the plant roots is limited. The osmotic process involves movement of water through a membrane from a low saline level to a greater salinity level. Therefore, if the salinity level of the soil water approaches the normal salinity level of the plant root cells, water absorption is restricted.

4.5 There must be an acceptable salinity balance in the root zone. Salts are present in the soil crust and in the subsurface water. They are delivered to the soil with the irrigation water, as well as occurring naturally. As the water is removed by evapotranspiration (ET), the salt is left behind. The excess salt must leach below the root zone and be removed by natural or artificial drainage. Surface drainage is important but its limits need to be recognized as it will not directly remove saline water from the root zone. Salts on the soil surface can be dissolved and flushed from the surface but surface drainage by itself will not solve a waterlogged and salinised field condition.

4.6 Where subsurface water is saline, which is a common condition in most areas of Pakistan, the emergence of waterlogged conditions will cause salinised conditions of the land.

4.7 Agricultural land in Pakistan's irrigation projects is normally laid out in 25 acre squares. Each square is five units wide and five units long. A unit is one acre. The one-acre fields are usually surrounded by a bund and are border irrigated as one field. However, it is not uncommon to have a one-acre field divided into 1/2- or 1/4-acre fields, each surrounded by bunds. Individual farmers have their own arrangement for irrigating each segment. This division into small parcels makes it difficult to collect and convey excess surface water to a farm drain.

4.8 When there is excess precipitation, or irrigation spill water is ponded on the field for more than a day or so, the farmer is inclined to breach all bunds necessary to allow the surface water to move toward an outfall. Some irrigation channels, as in the command of the old Paharpur canal in NWFP, have the tail reaches connected to the nearest drains through link channels which carry excess water from the irrigation channels directly to the drains. Elsewhere in NWFP and, generally, in the Punjab and Sindh irrigation systems, the excess irrigation water has no direct outlet to drains. The excess water collects on the farmland causing crop damage and contributing to waterlogging. The introduction of field and farm drains will help alleviate this problem.

4.9 The purposes of field and farm drains must be fully understood and accepted by the concerned farmers for their mutual benefit. The farmers should cooperate in laying out a workable system of farm drains under the guidance and technical assistance of the provincial irrigation departments and the On-Farm Water Management Wing of the agriculture departments.

4.10 While planning new irrigation projects, the provincial irrigation departments and WAPDA should insure that the water distribution system is designed to not have any surplus water at the tail end of irrigation watercourses or have field drains and link channels available to carry such surplus to the next irrigation channel or drain.

4.11 Most field drainage ditches are shallow and intended to collect and remove surplus surface water only. However, shallow ground water may also be intercepted by open surface drainage ditches. In addition, subsurface drainage may have to outfall into surface drains either by means of gravity or pumped flow.

4.12 In Sindh, it is a common practice to have two or more flow-through applications of irrigation water during a rice growing season. Locally, this practice is called the *pancho system*. The purpose of adding fresh irrigation water, while discharging previously applied irrigation water, is to dilute the salinity level in that specific field. However, as the water flows through succeeding fields, it becomes more and more saline. Thus, the down-slope fields receive less and less benefit from the flow-through irrigation water.

4.13 A practical solution to meet the need for intensive farm drainage is to follow the policies adopted for construction and maintenance of irrigation water courses. For irrigation, the Government or project agencies design and construct watercourses. Subsequent operation, maintenance and reconstruction are entrusted to the concerned beneficiary farmers and the Water Users Associations (WUA). Government or project agencies should only become involved in cases of neglect of maintenance and for questions pertaining to operation of the system.

Water Users Associations

4.14 Effective involvement and participation of the beneficiaries is essential for successful implementation of any community development project. Farmers must participate in the planning and construction of field drains. Under the On-Farm Water Management Program, Water Users Associations have been organised at the watercourse command area level. These Water Users Associations could assume the responsibilities of demarcation, construction and maintenance of field ditches and farm drains. Even though farm drains commonly serve two or more farms, the location of a non-PID drain, i.e. *farm drain*, may result in it serving two or more watercourses. Since there probably will be different Water Users Associations for each watercourse command area, the cooperation of all concerned WUAs is needed. The farmers' participation through the association should also result in reducing user dissatisfaction and administrative problems for the on-farm water management agency and in promoting local leadership for making day-to-day decisions on establishing and operating the drains.

4.15 A Water Users Associations Ordinance was promulgated in 1981, for effective implementation of operation and maintenance of On-Farm Water Management Projects. Formal Water Users Associations with certain legal powers have now been organized and registered under all the On-Farm Water Management Projects (OFWM, 1991). The Associations are assigned responsibilities prior to improvement of the watercourses, during improvement, and in the postimprovement periods. The involvement of the Water Users Associations in properly maintaining the improved watercourses is emphasized. These newly organized farmers' institutions have played a vital role in recovering the local share of the improvement costs.

4.16 The following activities of the Water Users Association, through their Executive Committees, are effective in planning, constructing, operating and maintaining on-farm watercourses. They should also be applied to planning, installing, operating and maintaining farm and field drains.

1. To arrange and provide labour and to distribute the physical and financial involvement proportionately.
2. To settle all matters of disputes between various water users regarding alignment of the watercourse, fixation of nakkas, distribution of work, etc.
3. To make alternate arrangements for irrigation flows during periods when the watercourse is being reconstructed/improved.
4. Carry out works according to standards and specifications under the technical supervision of water management field staff.
5. To safeguard the watercourse construction and operation materials supplied to them, and to keep and maintain proper record of materials received and utilized on the watercourse construction in proper register.
6. To look after and to arrange for periodic cleaning, maintenance and repair of the watercourse after its construction.

Design

Drainage System Layout

4.17 The overall layout of irrigation channels and surface drains for an area of several thousand acres is shown in Figure 4.1. The irrigation system has a main canal with branches and distributaries. Individual irrigation outlets are not shown. A total of eight squares (25 acres each) served by watercourses are shown on Figure 4.2. A branch watercourse serving one-acre fields is shown on Figure 4.3. The end of the branch watercourse is shown in the upper corners of fields 1 and 2. A field drain connected to the branch watercourse to convey spill water to the farm drain is shown at the bottom of the figure.

4.18 The individual fields need to be shaped and managed so that when drainage of the individual field is needed the bund will be breached and the drainage water will flow across the adjacent field toward a farm drain. There may be as many as three or four fields to cross if there is one farm drain provided for each square (25 acres).

Land Forming

4.19 Land forming refers to changing the land surface to provide for the orderly movement of surface water. Land smoothing and precision land grading are methods which

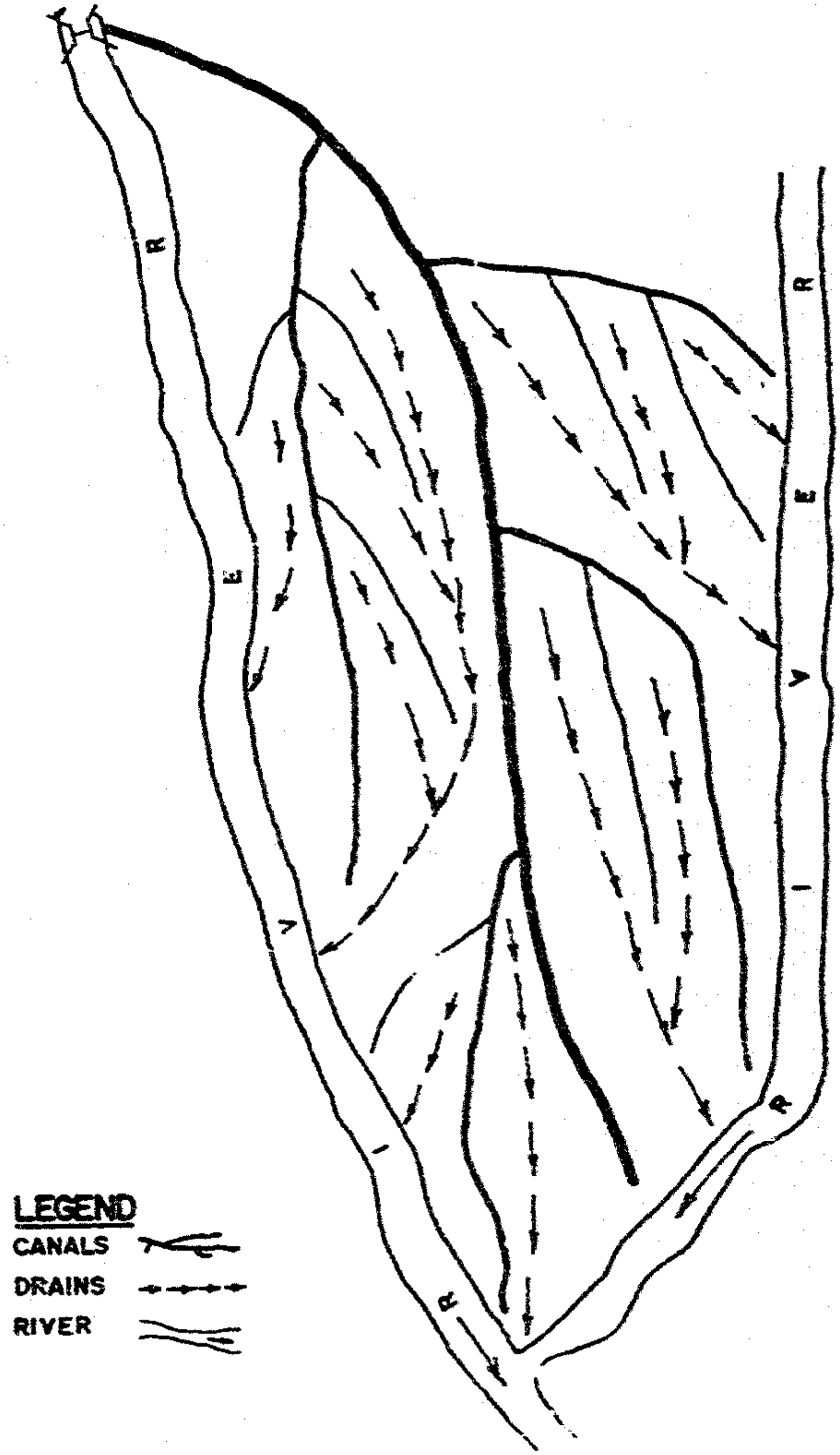

Figure 4.1. Overall layout of irrigation and drainage systems.

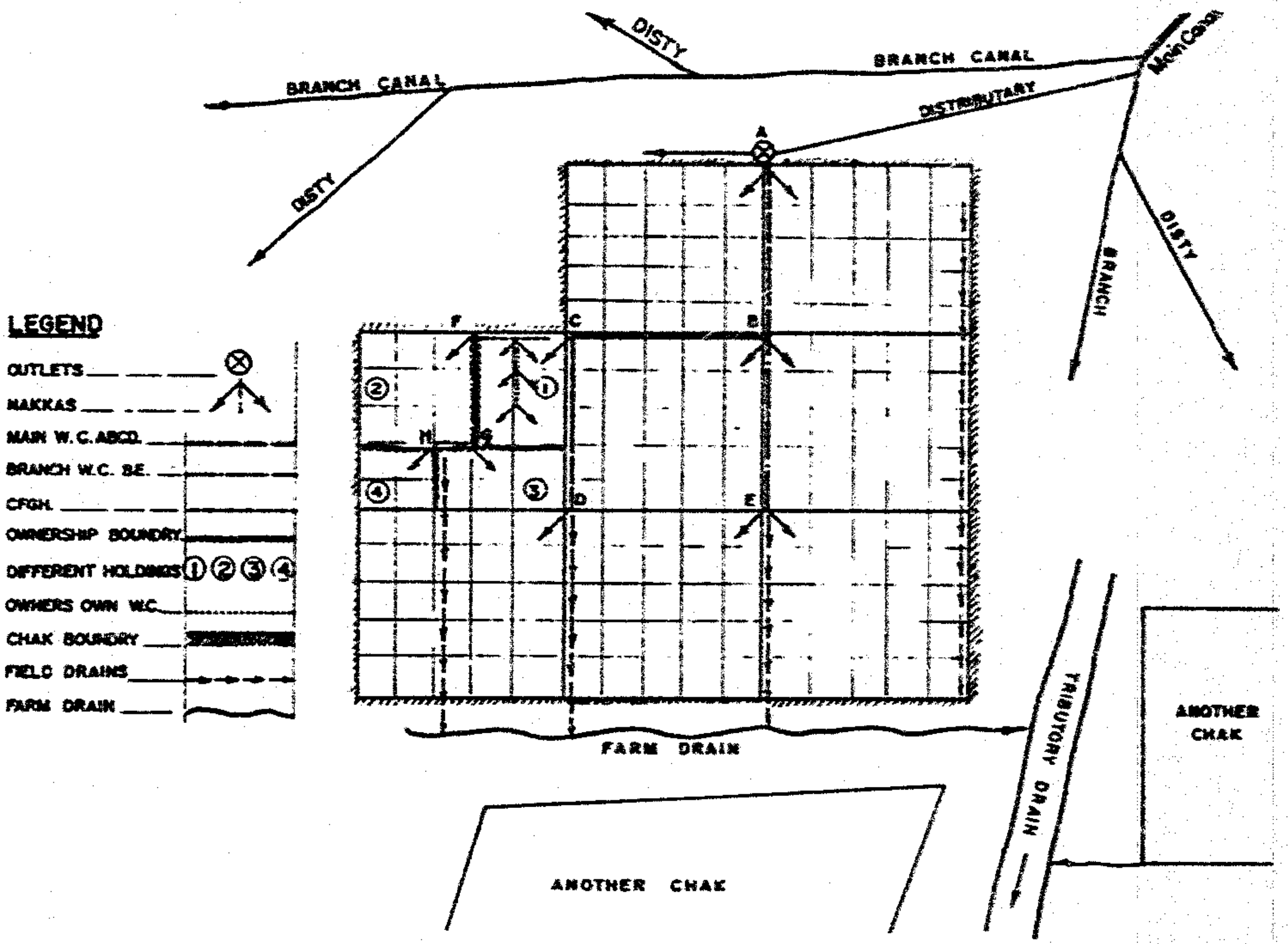

Figure 4.2. Watercourse and field ditch for squares.

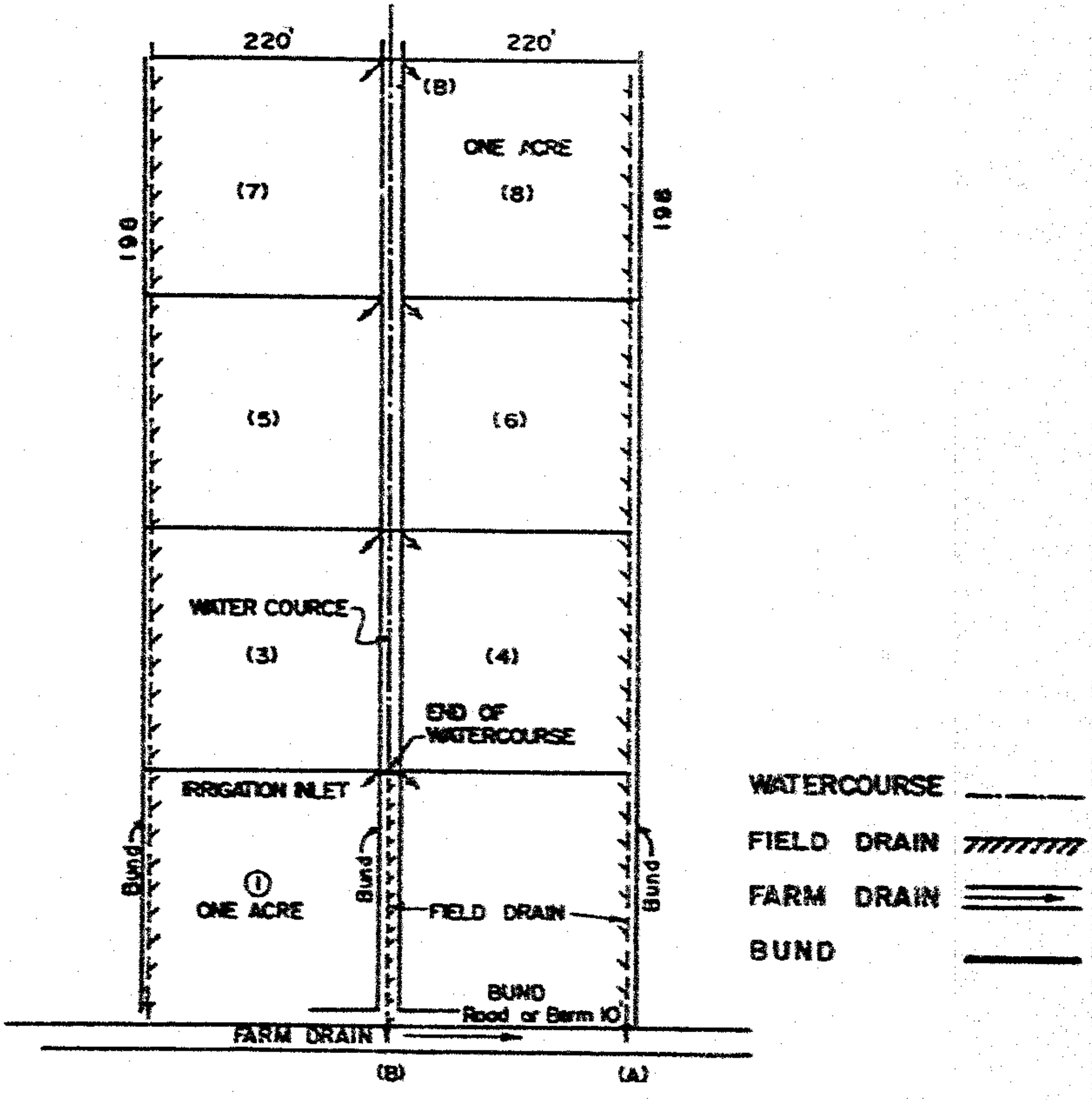

Figure 4.3. Watercourse and drainage ditch for one-acre fields.

may be necessary for surface drainage to improve the effectiveness of the drainage system, as well as improving distribution and uniformity of infiltration of irrigation water. The benefits of improved crop production by smoothing or grading the land prior to irrigation are not to be overlooked, but there are also crop production benefits related to improved drainage conditions. Figure 4.4 shows a field that needs land forming.

4.20 Land smoothing consists of removing small irregularities on the land surface by use of special equipment. Land smoothing is an important practice for good surface drainage. It eliminates minor differences in field elevations and shallow depressions, without changing the general contour of the ground surface. However, it results in better drainage, usually with fewer surface ditches, and enables farm equipment to be operated more efficiently. Land to be smoothed must have a soil profile which will allow small cuts. Except for isolated spots handled by prior rough grading, land smoothing operations seldom involve cuts and fills exceeding six inches.

4.21 Land smoothing is accomplished best by special equipment, such as the landplane or leveller, which can work efficiently to tolerances of 0.1 foot or less. This degree of accuracy is necessary to remove irregularities from very flat land. Rough grading can be done with farm tractors and scrapers or a landplane. In making cuts, avoid removing all topsoil from an area. It would be better to take thin layers from a larger area. Where fills from rough grading exceed six inches, make an allowance for fill shrinkage. Shrinkage of soil is expressed as cut/fill ratio. The allowance is related to the types of soil and soil conditions. Final smoothing operations may be deferred until compaction or natural settlement of such areas has taken place.

4.22 Precision land grading for irrigation is reshaping the surface of the land to planned grades throughout its length to field ditches or other suitable outlet. Typically, however, precision-graded fields in Pakistan have zero grade. The field to be graded must be surveyed with sufficient spot elevations to determine its topography. A grid system with 60-foot (20-meter) intervals is suitable for most jobs. After determining the average elevation of the field, the necessary allowance for shrinkage (cut/fill) should be given. A map showing cut and fill values at the grid points should be made for guidance of the equipment operator. The skill of the operator is very important in the cost of grading. Precision land grading on fairly large tracts is accomplished by earth moving scrapers, land levellers, and landplanes (Fig. 4.5). For fields of an acre or less, the grading and smoothing is usually done with a heavy timber pulled by oxen (Fig. 4.6).

4.23 The On-Farm Water Management Field Manual, Volume II (OFWM, 1986), describes how to survey, design, and stake for precision land grading.

4.24 To facilitate levelling operations, the ground surface should be chiselled or disced prior to levelling operations and should be free of bulky vegetation and trash. Loosening

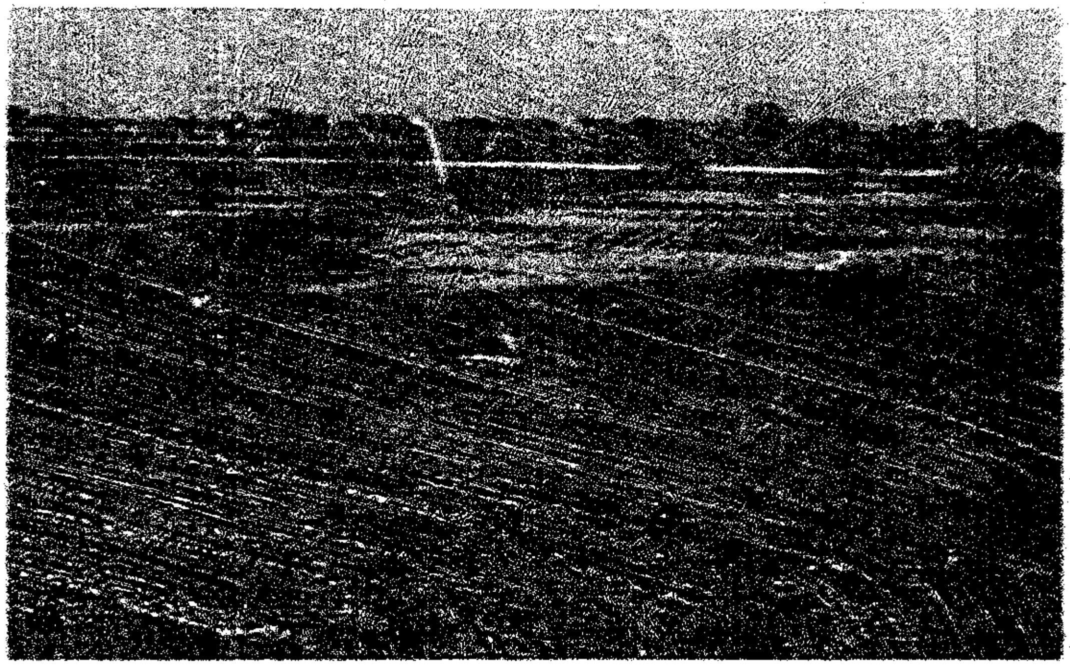

Figure 4.4. Field showing need for land forming.

Figure 4.5. Land levelling with trailing scraper.

Figure 4.6. Land smoothing with oxen.

the soil facilitates moving it by the leveller, as well as mixing crop residues into the soil, thus preventing vegetation from collecting on the leveller blade.

4.25 Land smoothing requires annual maintenance to retain effective water management. After the field has been properly graded to achieve good surface drainage, ordinary farming practices involving tillage, planting, cultivating, and harvesting, as well as wind and water action, will disturb the surface enough to impound water unevenly and cause crop damage. The irregularities from farming practices, such as implement scars, need to be erased before the seed bed is prepared for the next crop. Therefore, each year a leveller or plane should be operated over the area to provide a base for a good seed bed. This operation also will take care of settlement in fill areas.

4.26 A diagonal method of operating a plane to maintain a smooth field is shown in Figure 4.7. With this method, it is possible to resmooth most of a field with a plane in minimum time.

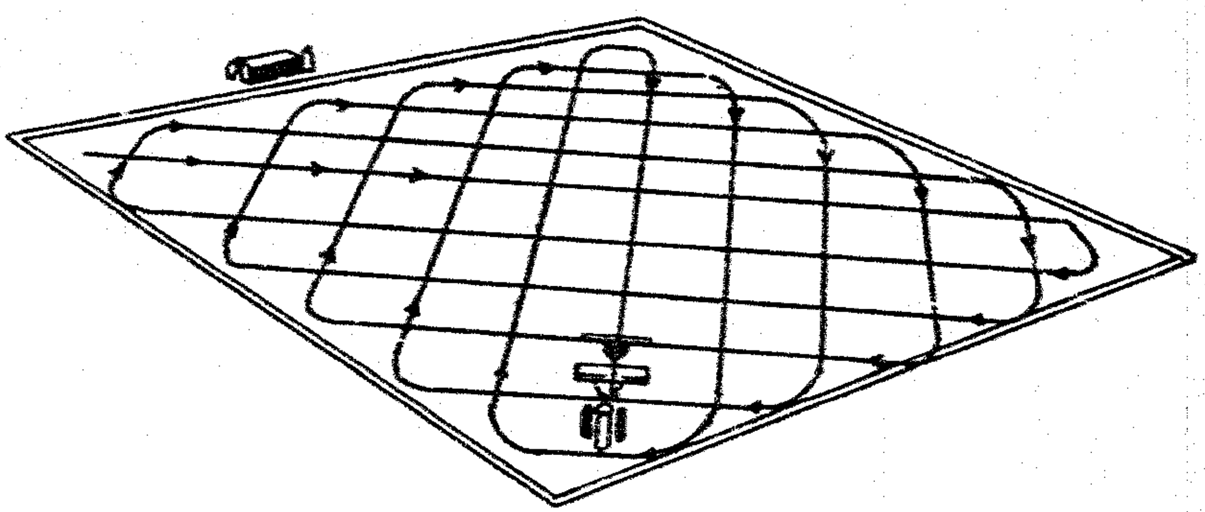

Figure 4.7. Land smoothing procedure.

Bedding

4.27 Another form of drainage within a field is bedding. Bedding resembles a system of parallel field ditches with the intervening land shaped to a raised rounded surface. This system of drainage is generally used on lands with flat slopes and slowly permeable soils.

Bedding systems usually involve small land areas and ordinarily are installed with hand tools or farm equipment. Beds are established to run with an existing land slope or in the direction of the most desirable outlet.

4.28 For many crops, a raised bed to keep the plants above free water and improve soil aeration for a shallow root zone is beneficial. The raised bed may be for a single row but is often for two or, sometimes three, rows. Cotton is often planted on a two row bed. The bedded crop in Figure 4.8 is a single row planting in a precision levelled field that demonstrates uniform distribution of irrigation water. The furrows facilitate water removal, as needed.

Ditches

4.29 Farm and field drains for areas with common field crops usually are designed to remove surface water from the drainage area within a 24-hour period following a rain event.

Figure 4.8. Single-row bedded crop in precision levelled field in Punjab.

Some surface flooding of the land during this period is permissible. Some high-value and specialty crops, especially vegetables, may require a more rapid rate of removal of runoff water to prevent damage. It has been customary to use 1, 2, or 4 cusecs per square mile as a drainage coefficient, assuming among other things that field and farm drains serving a square or less didn't exist.

4.30 A hand dug ditch with dimensions in Figure 4.9 (a) to serve a one acre or less field will also satisfy typical removal rate requirements, if an outfall system is available and the bunds are opened to allow the system to operate.

4.31 If the minimum size of farm ditch constructed with a tractor mounted ditcher is 2.5 feet deep with a 0.5 foot bed width and a top width of 2.5 feet (Fig. 4.9 (b)), the excavated area is 3.75 square feet. This drain size is adequate as an outfall for 60 acres or more assuming a drainage coefficient of 10 cusecs per square mile and a velocity of 0.25 feet per second. This drainage coefficient is near the upper end of the values in Table 3.1. The velocity results from a water surface slope of 0.0001 and Manning's "n" of 0.45 used in Manning's equation.

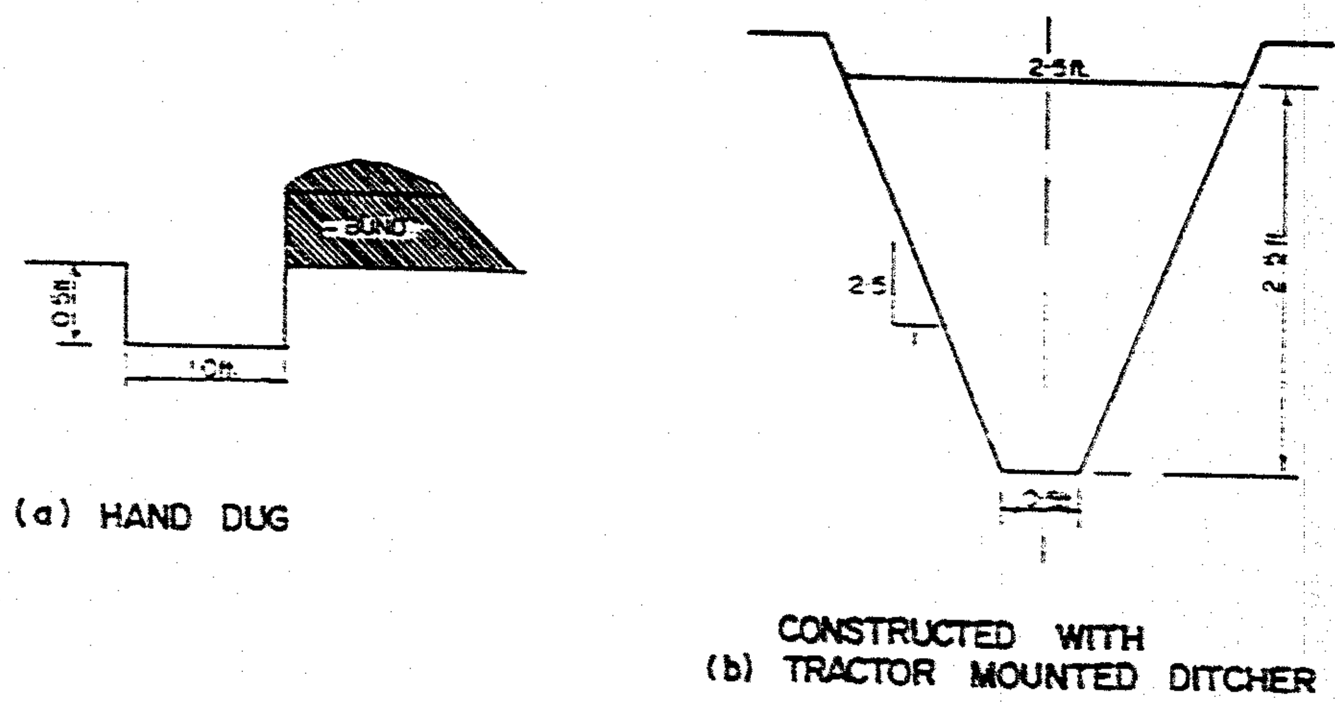

Figure 4.9. Field ditch cross sections.

Construction

4.32. Construction practices are shown in Figures 4.10 to 4.13.

Figure 4.10. Constructing field ditch by hand.

Figure 4.11. Field ditch construction by tractor mounted ditcher.

Figure 4.12. Levelling construction with trailing scraper.

Figure 4.13. Levelling construction using laser plane.

Maintenance

4.33 Field and farm drains should be kept open. If a farm ditch has lost a third of the constructed depth, i.e. six inches of silt in a 18-inch deep drain, then it should be rehabilitated. Nevertheless rehabilitation by mechanically reconstructing the drains by either hand shovel or tractor mounted ditcher is inexpensive and should be done at least annually. The necessity, as well as the opportunity, to keep the weeds mowed or removed is more evident to the farmers since they visit the fields frequently and have a personal interest in keeping the field ditches and farm drains functioning properly.

Chapter 5

DESIGN and CONSTRUCTION of OPEN DRAINS

Introduction

5.1 Outfall, main, branch, tributary, and subtributary drains are open drains constructed for receiving and transporting surface and subsurface drainage water to a safe outfall. Surface and subsurface drainage water may be from rain water, as well as from irrigation sources. The drains may be used to intercept ground water, control ground water levels, or provide an outlet for leaching saline or sodic soils.

5.2 Open drains may be natural nullahs or man-made. Man-made drains are referred to as artificial drains. General categories of artificial drains are:

1. Storm water drain intended for speedy disposal of rain water;
2. Seepage drain with its bed below subsoil water level to intercept and take away seepage.
3. Seepage cum storm water drain which is a combination of both.

5.3 Whether the drains are designed and constructed by provincial irrigation departments or by WAPDA, the maintenance responsibility is with the respective provincial irrigation department.

5.4 Factors affecting the size and shape of drains are drainage runoff, water surface slope, depth, bed width, side slopes, roughness of the bed and banks, and limiting velocities. Local design and performance experience have been incorporated in this chapter.

Investigations

Topographic Surveys

5.5 Topographic surveys are made in preparation for designing open drains. In some cases, accurate surveys may have been prepared previously for planning or other preliminary studies. These prior surveys should be thoroughly reviewed in the field to verify the original work and, if needed, to collect supplemental data. The scale to plot topographic surveys should not be based on rigid requirements. Local site conditions and amount of detail needed for design and construction are the primary considerations in selecting the scale. However, a common scale is one inch to a canal mile (5000 ft.).

Soils

5.6 Soils along the alignment of a proposed drain must be evaluated for slope stability and for bearing strength for structures. Where the bed of a drain will be excavated below the water table level and at other locations where the soil may be unstable, the drain design must be based on analysis of soil samples from bore holes or pits. Soil samples for analysis should be obtained at no more than half mile intervals. The depth of soil log and collection of soil samples are based on site conditions, anticipated design depth of drain and structures, and potential maintenance problems.

5.7 When soil samples on a drain alignment are to be taken, the Engineer should have the services of a Research Assistant. The Executive Engineer should provide the services of an Sub-Engineer to indicate the alignment of the drain and to assist the Research Assistant in taking samples.

5.8 To relate soil particle size percentages to textural classification use Figure 5.1.

Design

Open Channel Flow

5.9 The area, A, of a drain section for any flow, Q, is determined from the equation $A = Q/V$. The velocity, V, is computed using Manning's equation:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Where:

- V = velocity in feet per second
- n = roughness coefficient of channel
- R = hydraulic radius, which is the area divided by the wetted perimeter.
- S = slope of hydraulic gradient, usually longitudinal slope of channel bed/water surface (WSS) in open channel flow

5.10 Velocities from Manning's equation can also be obtained from published hydraulic tables and a nomograph (Fig. 5.2). Graphical presentations of geometric and hydraulic elements of trapezoidal channels with side slopes of 1:1 to 4:1 are in Figures 5.3. Manning's equation is used to determine velocities for surface drainage channels. Lacey and Kennedy equations are appropriate for canal design with silt laden flow conditions but not for drains. Agricultural drain waters are not anticipated to have significant amounts of silt.

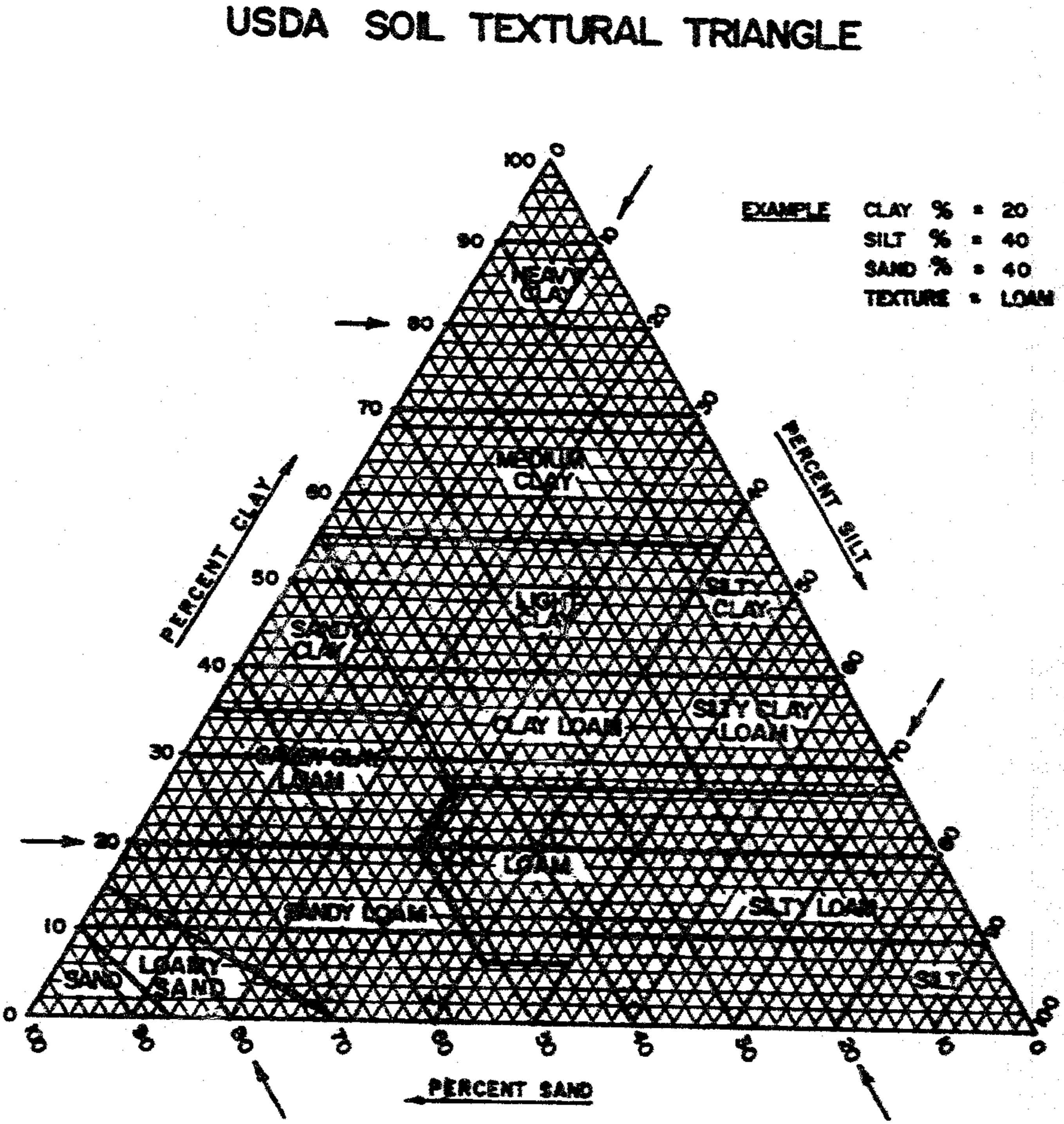

Figure 5.1. Soil textural triangle.

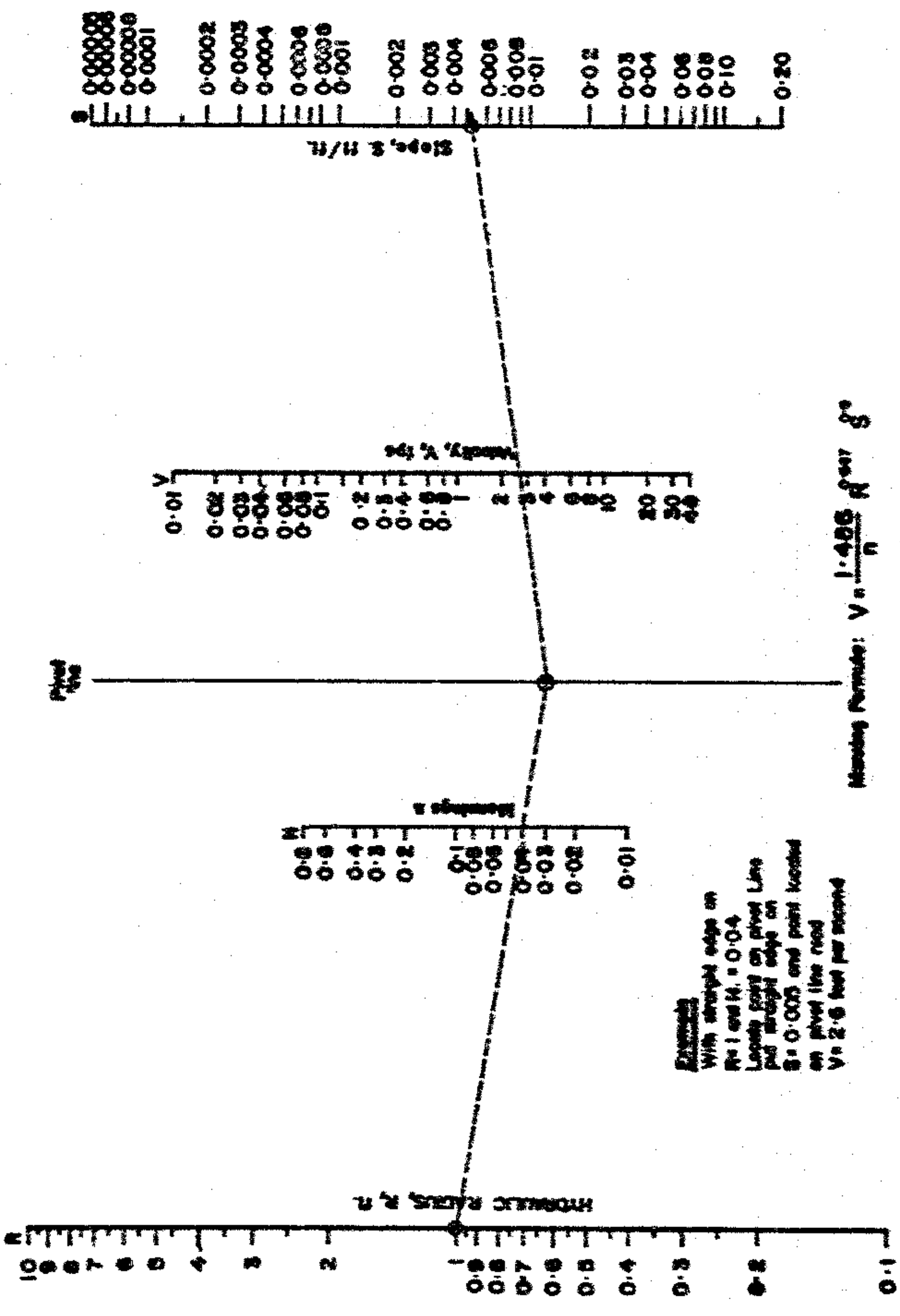

Figure 5.2. Nomograph solution of Manning's equation.

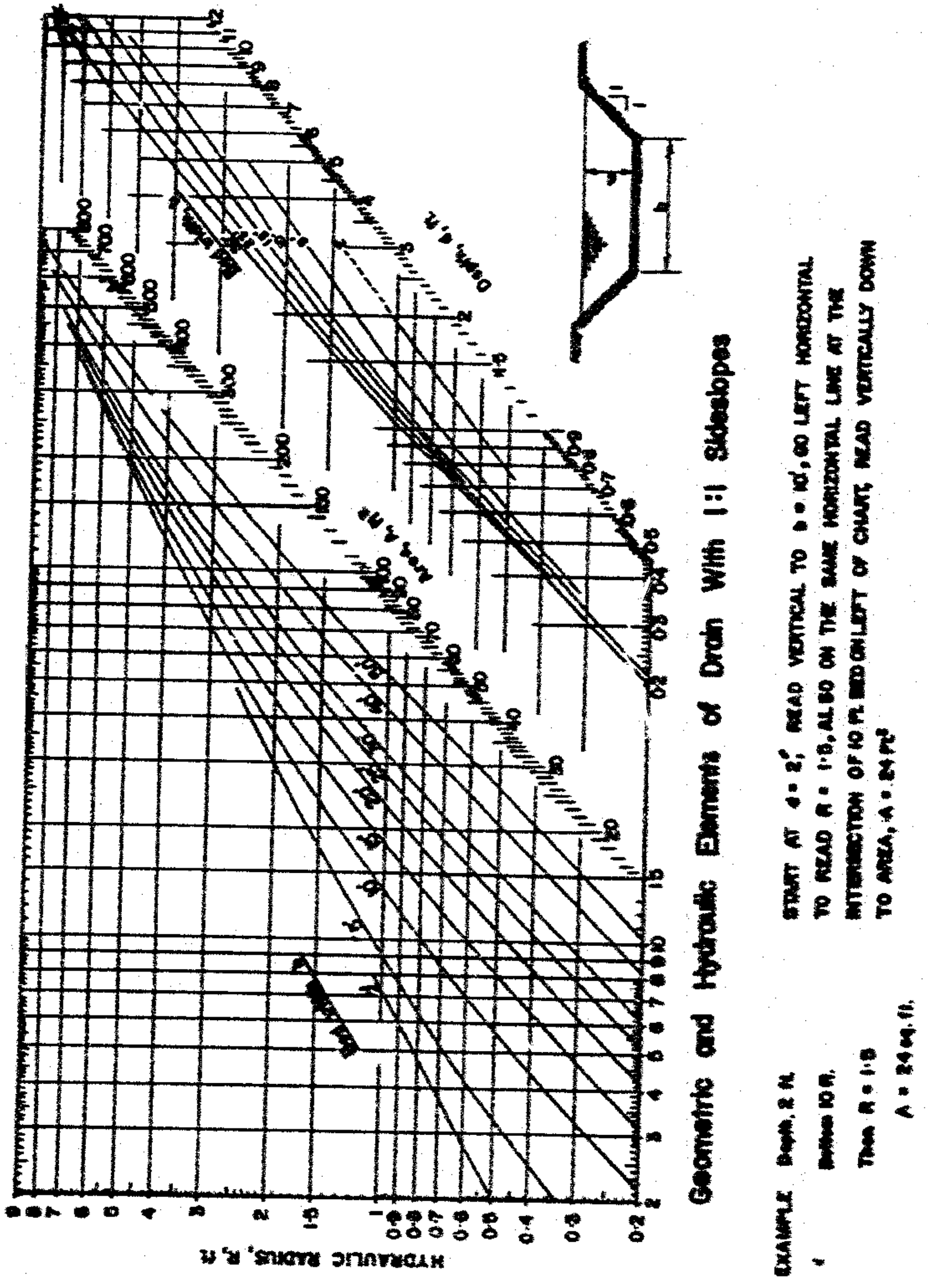

Figure 5.3. Geometric and hydraulic elements of drain with 1:1 side slopes. (Sheet 1 of 6)

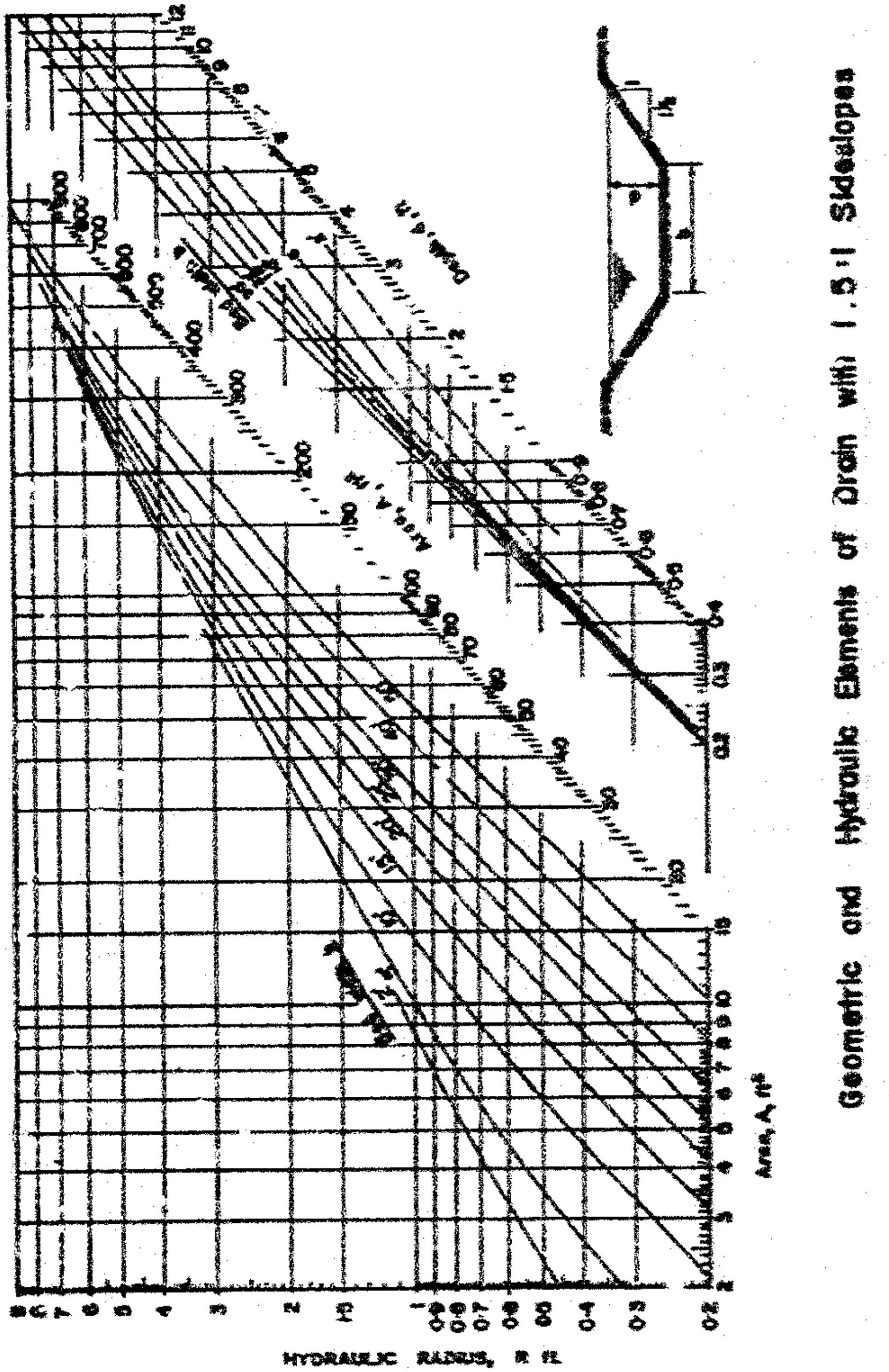

Figure 5.3. Geometric and hydraulic elements of drain with 1.5:1 side slopes. (Sheet 2 of 6)

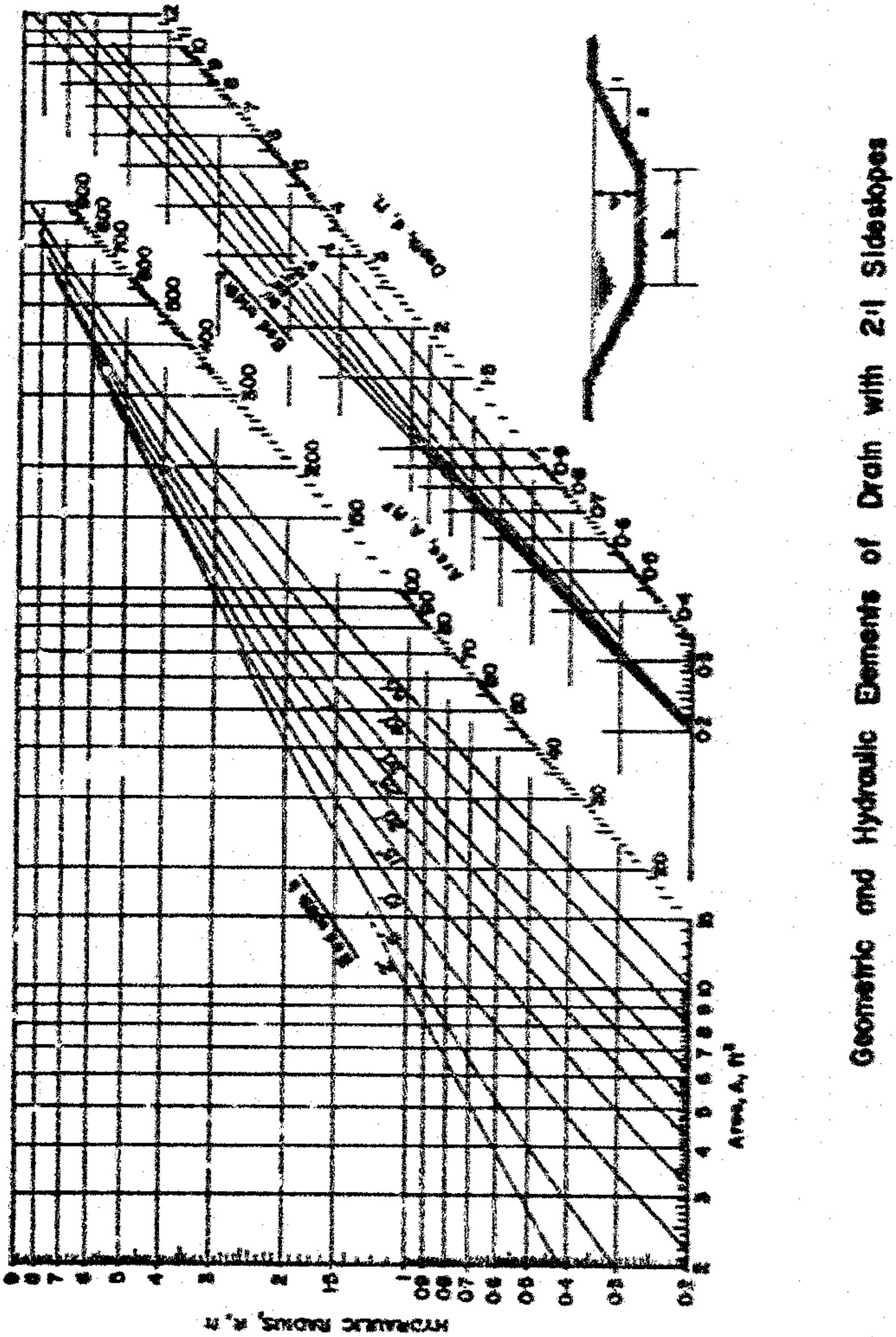

Figure 5.3. Geometric and hydraulic elements of drain with 2:1 side slopes. (Sheet 3 of 6)

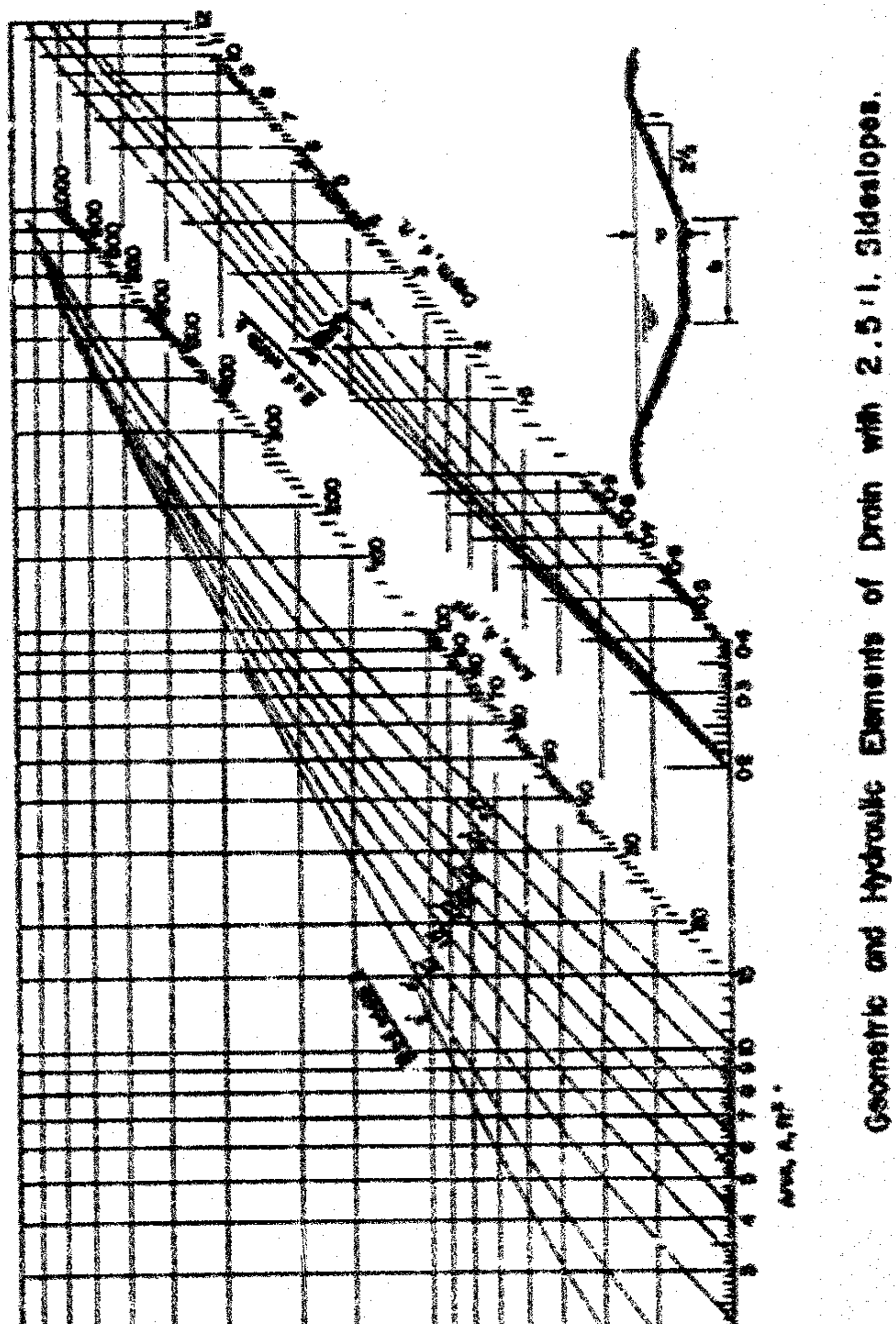

Figure 5.3. Geometric and hydraulic elements of drain with 2.5:1 side slopes. (Sheet 4 of 6)

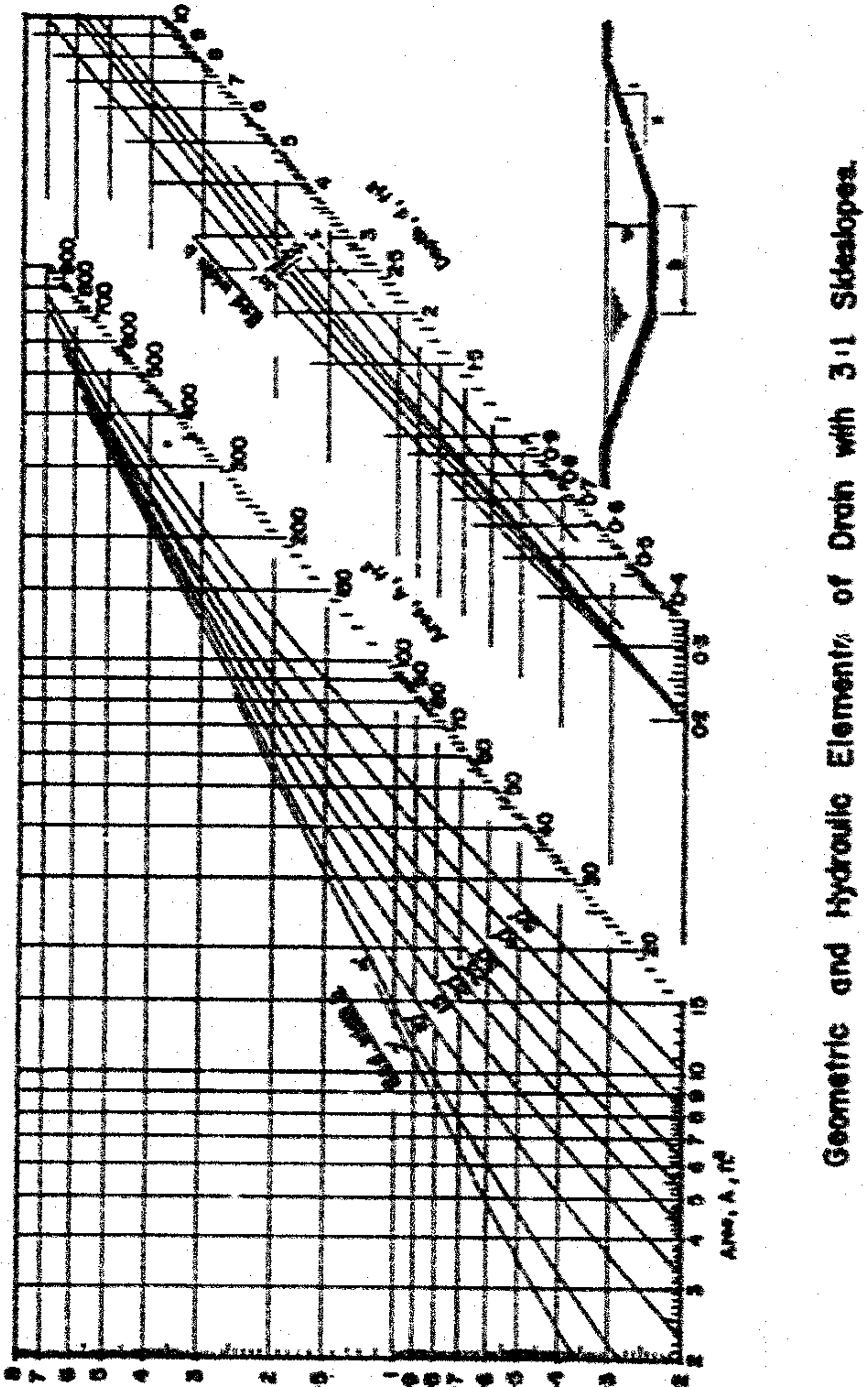

Figure 5.3. Geometric and hydraulic elements of drain with 3:1 side slopes. (Sheet 5 of 6)

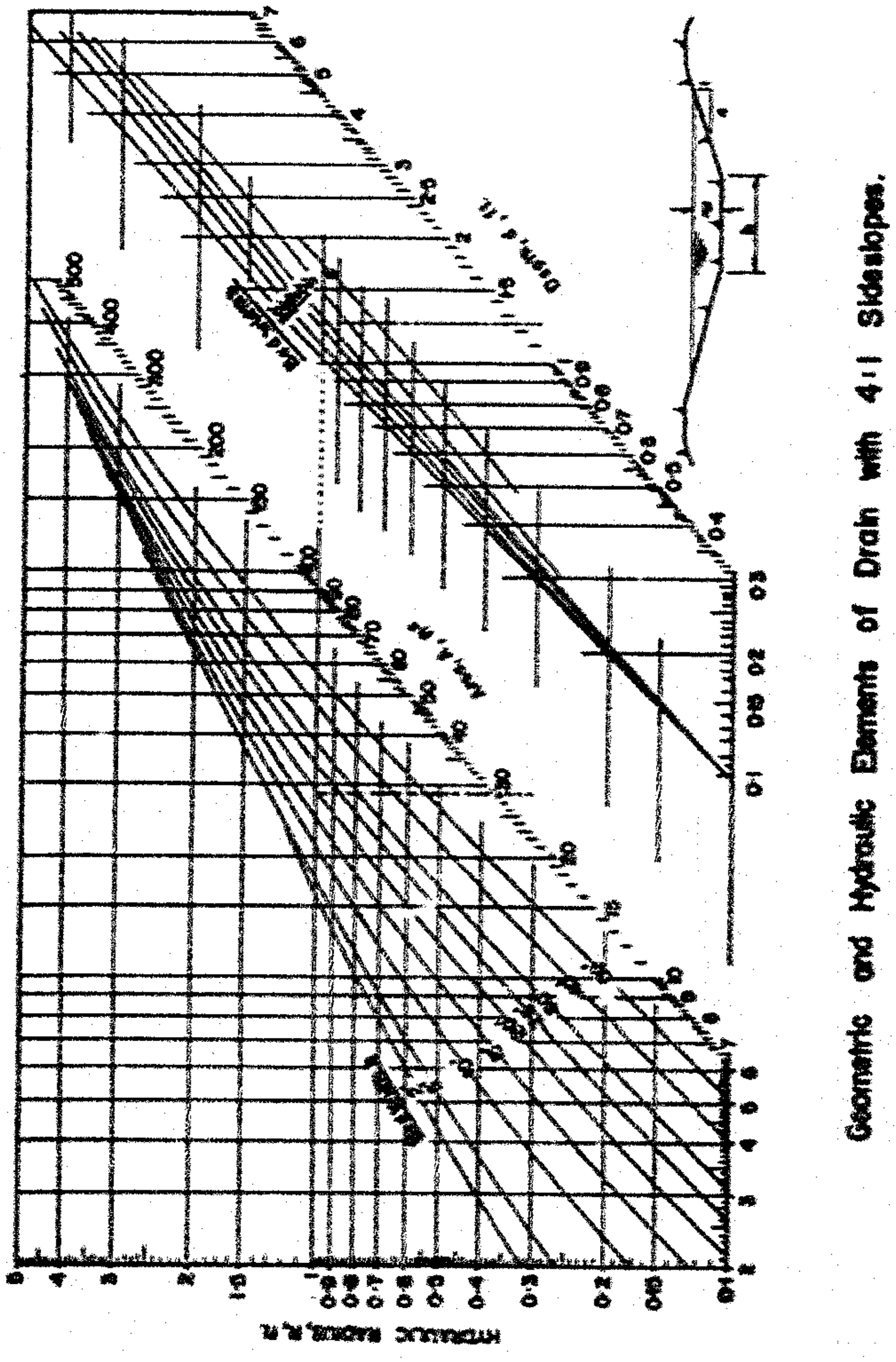

Figure 5.3. Geometric and hydraulic elements of drain with 4:1 side slopes. (Sheet 6 of 6)

Design capacities

5.11 The required design capacity of an open drain depends on rainfall and other characteristics, as well as the type, slope, area and surface characteristics of the catchment.

5.12 Recommendations and procedures for determining design capacities of open drains are provided in Chapter 3, Surface Runoff. In general, design capacities for open drains serving irrigated cropland should handle flows from at least five year recurrence interval storms. Temporary ponding of storm flows in the field has been considered in surface drain capacity estimates. Ponding on arable land should not normally be permitted for periods exceeding 24 hours. In the past, ponding of three to seven days on cropland was allowed in planing to make the drainage system more economical, but if ponding exceeds 48 hours, most crops suffer reduced production and many are destroyed.

5.13 Capacities for open drains should be sufficient to carry normal flow of ground water accretions, irrigation surface waste or surplus, estimated storm flow, municipal and industrial drainage, and the quantities delivered by subsurface drains. Open drains with seepage flows should be designed essentially as storm water drains. Refer to Chapter 3, Surface Runoff, for specific procedures best suited to the site conditions and objectives.

5.14 For many drains in arid irrigated areas the necessary depth, rather than the capacity, will govern the required size of the drain. Adequate depth may be needed to provide proper outfall conditions for seepage flow, subsurface horizontal drainage, or field ditches in the surrounding agricultural areas. The capacity of the open drain must be adequate to contain the expected escape discharge from canals. The outfall should be enlarged as necessary or the escape discharge should not exceed the drain capacity. It may be feasible to restrict the escape discharge by redirecting some of the flow to other locations.

5.15 In many instances, a natural channel is planned as an open drain for conveyance of excess irrigation and storm waters. The addition of runoff water and, in some cases, subsurface drainage flow may change a normally dry stream to one with continuous flow, at least during the irrigation season. The continuous wetting of the natural channel banks may result in an unstable condition when a flood flow occurs or in excessive weed growth that hampers flood capacity.

5.16 Tractive force analysis based on particle size or plasticity indices of soil textures may be used to check scour stability of natural channels used as open drains. Stability should be determined for 5-year recurrence interval flood flow, plus irrigation waste flow. The tractive forces used to check stability are affected by the wetted banks and the type of sediment transported by the channel. If instability is indicated, control structures will be required. The tractive force method is in several texts and in the SCS technical release for design of open channels (SCS, 1977). However, the velocity limitations and other criteria discussed below are more commonly used for drainage channel design.

Velocities

5.17 Flow velocity in drains ideally should be low enough to avoid scouring and high enough to minimize sedimentation. Since flows in most drains are intermittent, the velocity will fluctuate. Drains are usually designed using a selected maximum allowable velocity. Table 5.1 contains recommended maximum velocities at design flow depth for various soils and materials above which scour and erosion may take place (SCS, 1969). Raw, newly constructed drains may have lower surface roughness than older drains. Therefore, velocities higher than design velocities may be experienced temporarily in new drains. When vegetation on the channel side slopes is slow in developing, the limiting velocities may need to be reduced to reduce erosion. Desirable minimum design velocities should be at least 1.0 foot per second to minimize sedimentation.

Table 5.1. Maximum Recommended Velocities for Earthen Channels

Soil texture	ft/s
Fine sand	1.5
Sand and sandy loam (noncolloidal)	2.5
Silt loam (also high lime clay)	3.0
Sandy clay loam	3.5
Clay loam	4.0
Stiff clay, fine gravel, graded loam to gravel	5.0
Graded silt to cobbles (colloidal)	5.5
Shale, hardpan, and coarse gravel	6.0

5.18 The value of "n" indicates not only the roughness of the sides and bed of the channel but also other types of irregularities of the channel, such as alignment and vegetation. The value of "n" is used to indicate the net effect of all factors causing retardation of flow. Situation analysis should be used in evaluating the material in which the channel is constructed, irregularity of surfaces of the drain sides and bed, variations in the shape and size of cross sections, obstructions, vegetation, and meandering of the drain.

5.19 For man-made channels that are trapezoidal in shape and reasonably well maintained, "n" values are related to the hydraulic radius and the "n" values decrease as the hydraulic radius increases. Table 5.2 gives the values of "n" recommended for design of earthen channels under different conditions (SCS, 1969). These are the values which may be expected after aging with a minimum of vegetation. The "n" value actually occurring immediately after construction will be lower than the values given in the table. An "n" value of 0.03 is recommended by the Bureau of Reclamation for design of open drains (USBR, 1984), which is consistent with the values in Table 5.2 for a hydraulic radius of 5.0 which may be quite representative of major outfall drains.

Table 5.2. Value of Manning's "n" for Earthen Channels

Hydraulic Radius (ft.)	"n"
Less than 2.5	0.040 - 0.045
2.5 to 4.0	0.035 - 0.040
4.0 to 5.0	0.030 - 0.035
More than 5.0	0.025 - 0.030

Alignment of Drain

5.20 Alignment of a storm water drain or storm cum seepage drain ordinarily should follow the natural depression. However, may be desirable to short circuit loops or to improve flow conditions by increasing the slope of the hydraulic gradient. In short circuiting large loops, part of the severed loop may serve as a branch drain.

5.21 In general, an open drain should be straight. To change direction, a simple curve should be used. Curves with a radius of not less than 600 feet are desirable, but sharper curves may be used if needed to follow old drains or swales. decrease the waste area caused by the use of long radii curves, or to conform to ownership boundaries. When a curve radius must be smaller than recommended and the average velocity is greater than two feet per second, it is common practice to protect the outer slope from erosion with stone pitching placed over stone spall. When the drain discharges are small (less than 20 or 30 cusecs) and the velocities low (less than 2 ft/s), gentle curvature is not as important.

5.22 To minimize the number of water course crossings, the drain should follow a chak bandi line or the boundary of a square. If the proposed alignment severs an area from the existing irrigation source, alternative arrangements for the source of irrigation water must be made. In cases where zamindars refuse to accept the new arrangements, a notice as per the Canal and Drainage Act should be issued.

5.23 For ecological reasons, drain alignment should not go too near wetlands and ponds. If an objective is to save the wetland, then the relationship of the hydraulic conductivity of the soil between the wetland and the drain and the drain depth should be analyzed to determine a safe distance. Also, excavation through marshy land is extremely difficult and expensive, if timbering of excavator tracks is needed. Similarly, the maintenance of such reaches is very difficult. Wetlands and ponds should normally be protected, but may be connected by branch drains to the main drain, depending on planned objectives.

5.24 Drain length is normally stationed with reduced distances (RD) beginning at the outfall. References to left or right bank are looking in the downstream direction.

Drain Side Slopes

5.25 Drain side slopes are determined primarily by the stability of the soils through which the drain is constructed and by the maintenance methods to be used. The steepest side slopes (horizontal:vertical) recommended for four soil types are in Table 5.3. Flatter side slopes may be desirable for more satisfactory and economical maintenance.

Table 5.3. Recommended Side Slopes Based on Soils

Soil	Side Slopes
Sand	3:1
Loam	2:1
Clay	1.5:1
Peat, and muck	1:1

5.26 Drain side slopes which may be used with various maintenance methods are given in Table 5.4 (SCS, 1969). Side slopes should be as flat as feasible, considering the width of right-of-way required and the ease of maintenance and access. In most areas of Pakistan, drains are not fenced and are commonly subject to foot and animal traffic which causes maintenance problems. These problems may be reduced by using flatter side slopes, e.g. three horizontal to one vertical, and by providing proper access points.

Drain Depth

5.27 Factors considered in establishing the depth of a drain are: sufficient capacity below the design hydraulic gradient (WSS) to remove the design surface runoff; provision of outfall for subsurface drainage; and sufficient waterway clearance for existing bridges, if feasible. If there is not adequate depth through an existing culvert bridge, the culvert bridge floor may need to be depressed.

Table 5.4. Recommended Side Slopes Based on Planned Maintenance

Type of maintenance	Steepest Side Slopes	Remarks
Mowing & grazing	3:1[a]	Flatter slopes desirable
Dragline or Excavator	1:1	Usually used on steep side slopes, for drains over four feet deep.
Blade equipment	3:1	Flatter slopes desirable.
Chemicals	Any	Use caution near crops and open water[b]

[a] - Hydraulically operated booms with 10'-14' reach may be used to mow side slopes as steep as 1:1.

[b] - Follow manufacturer's recommendations.

5.28 Sufficient depth must be provided below the design hydraulic gradeline (WSS) to allow surface runoff to flow freely into the drain under design conditions. When the hydraulic gradient line has been established, as in Figure 5.4, the depth of the bed is measured down from the hydraulic gradient. When the bed slope is established first, the depth is measured upward to locate the water surface. Using this last method, the water surface elevation obtained must be checked in relation to control points. The depth of each reach should be determined to meet the discharge needs of the specific area involved.

5.29 Subsurface discharge needs to be considered. Subsurface drainage is primarily by tubewells which discharges into open drains or irrigation canals. There is an increase in the amount of horizontal subsurface drainage being installed for water logging and salinity management. A majority of the horizontal drains have pumped outlets, but some use gravity flow into an open drain. Open drains required to serve as a gravity outfall for subsurface drains should have at least one foot of drop to the normal low water in the open drain. This required depth of the open drain may sometimes result in the drain capacity exceeding the design requirements for surface runoff and the actual elevation of the hydraulic gradeline may be substantially lower than required. This often occurs at the upper ends of small drainage systems.

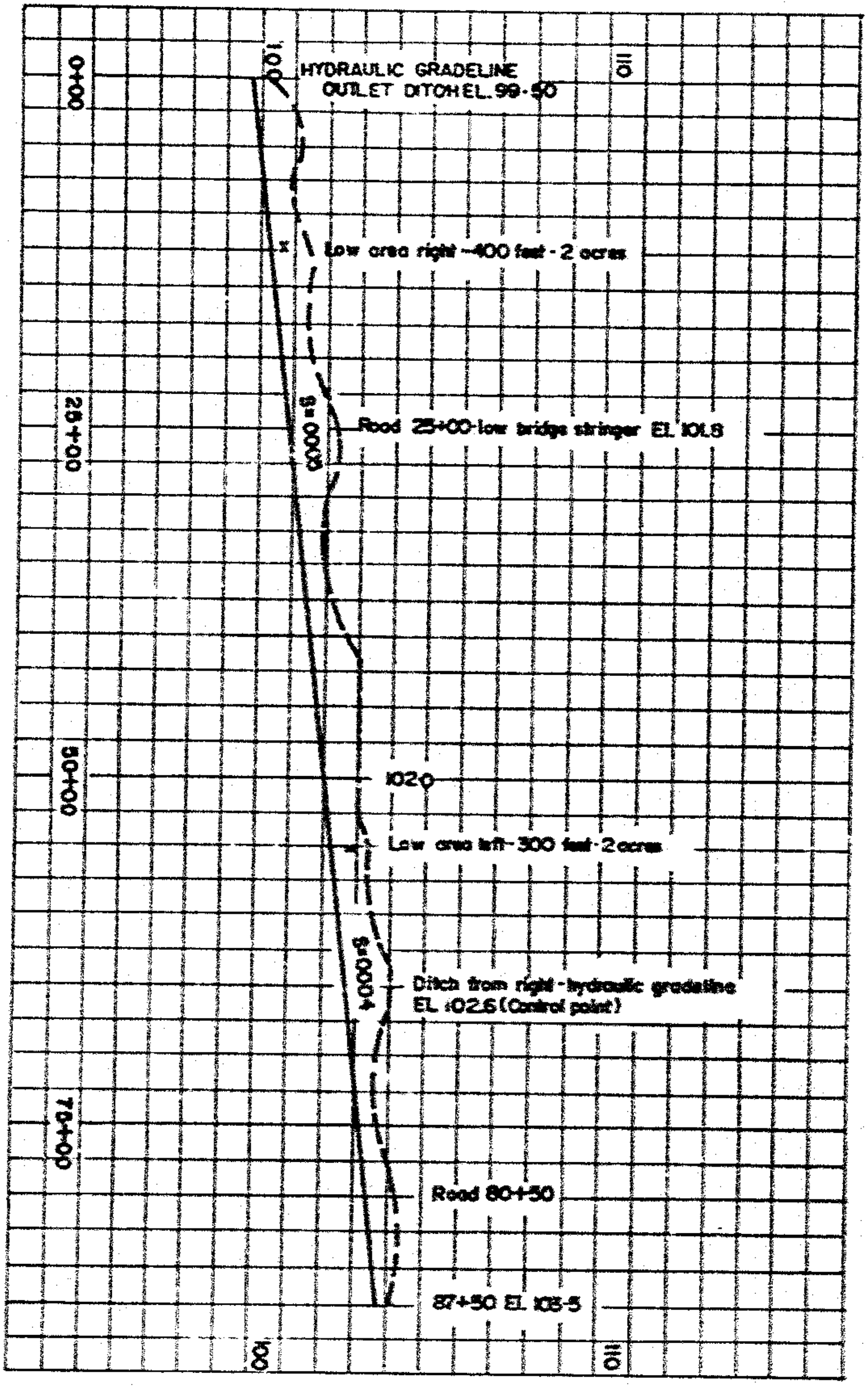

Figure 5.4. Establishing hydraulic g.adeline.

Width of Bed

5.30 The type of machinery to be used for construction should be considered in the selection of drain bed width. "V" type drains without a bed may be built with bulldozers or blade equipment. Flat bed drains are normally designed for construction by scrapers, hydraulic excavators, or draglines. Depth of drain and soil conditions affect the type of equipment used. Specified minimum bed widths are often based on the types of equipment available.

5.31 The relationship between drain depth and bed width may determine the most economical cross section, which approaches that of a semicircle. As a general rule, a deep, narrow drain will carry more water than a wide, shallow drain of the same cross-sectional area. An excessively wide, shallow drain tends to develop sand or silt bars which cause meandering and bank cutting. A deep, narrow drain tends to increase velocities and to reduce siltation and meandering. In some situations, it may be necessary to sacrifice economy and hydraulic efficiency in the interest of channel stability and ease of maintenance. Judgement of all factors is required to select the design section.

Hydraulic Gradient

5.32 The hydraulic gradient is the slope of the hydraulic gradeline (same as water surface in a open channel with uniform flow). It is important in determining flow velocity. The importance of proper location of the gradeline increases as drain discharges become greater. The drain profile (L-section) should be plotted and the location and elevation of control points shown. Control points are used to help select the elevation of the desired hydraulic gradeline. The control points may include, but are not limited to, the following:

1. Natural ground elevations along the route of the proposed drain.

2. Elevation of critical low areas to be drained. Note size and location. These are obtained from the topographic surveys or from maps.

3. Elevation of hydraulic gradeline for side drains or tributaries serving the critical areas. Plot the elevation where the side drain hydraulic gradeline meets the main drain.

4. Elevation of known or desired hydraulic gradient of tributary drains or natural nullahs at entrance location.

5. Elevation of bridge deck and lower side of stringers. It has been customary for the provincial irrigat... departments and WAPDA to use a design discharge

equal to twice the design capacity of the earthen section of the open drain for bridges and other significant structures. The hydraulic gradeline should be placed at least one foot below the stringers or lowest part of the bridge.

6. Allowable head loss on culverts should be kept as low as possible. In agricultural drainage, the allowable head loss should not exceed 0.5 foot.

7. Elevation needed to protect buildings or other property within the area from overflow.

8. Elevation of hydraulic gradient of outfall. If the drain being designed is to outfall into an existing drain or natural stream or nullah, the elevation of the water in the outfall drain or stream should be used as the controlling elevation or level. The water surface level in the outfall drain or stream may be determined from recorded data, from local people, or from high water marks. Another method of obtaining this elevation or level is to determine the depth of flow in the receiving drain by applying the same flow design basis as used for the proposed drain. For small receiving channels in rather flat topography, the water elevation may be estimated at the bank full (full capacity) stage.

5.33 The control point elevations should be plotted and connected. This drawn line gives the upper limit of the hydraulic gradient which is often the hydraulic gradient used for design. The resulting reaches should be as long as possible, broken only where necessary to stay close to or below the control points, as shown on Figure 5.4.

5.34 If the hydraulic gradeline has been well established, it will be altered only at structures with head losses. At these points, the head loss will be shown upstream from the structure as a backwater curve which will change the hydraulic gradient, usually only for a short distance.

Slope of Bed

5.35 To determine the bed slope, the required drain depth is determined and measured down from the hydraulic gradeline. The resulting points are connected to show the bed slope of the drain. This method of locating the drain bed is generally satisfactory in designing the bed slope of a new drain. The example (Fig. 4.4) illustrates the use of surface control points to establish the hydraulic gradelines.

5.36 In the case of reconstructing or remodelling existing drains, the elevations of the existing drain bed, bridge floors, and soil strata must be considered as control points in establishing the bed levels of the remodelled drain. At times, it may be more convenient to locate the bed line of the drain from these control points and add the design depths to locate the design hydraulic grade line (water surface). Care should be taken to avoid bed slopes that will tend to be erosive during low flows when the bed slope is steeper than the design hydraulic gradient.

Drain Section Design Procedure

5.37 Procedures for designing slopes and sections are:

1. Select elevation of outfall water surface (W.S.) for purposes of the drain design. The elevation may be controlled by expected high water levels in the receiving channel backing up in the drain. The natural ground surface (N.S.) level of the drain alignment may also be a control.

2. Set the water surface slope (WSS) with reference to the average N.S. of the alignment, the control points, and the minimum slope considered suitable for the drain.

3. Draw the hydraulic gradient line of drain, i.e. a line from or above the outfall W.S. level parallel to the water surface slope set in (2) above. Refer to tributary intersection discussion below for guidance on joining hydraulic gradelines.

4. Determine the design discharge of drain by procedures in Chapter 3.

5. Select the drain section to carry the discharge, i.e. section having acceptable depth of flow, desired velocity, etc.

6. Plot the resulting bed line as determined in (5).

7. Compare this bed line with the subsoil water level line and decide whether excavation is practical.

8. If not practical, raise the bed line obtained in (6) to the necessary extent and revise the width of bed.

5.38 The discharge for seepage drains is dependent on the head provided by the water table elevation, the source of water, and the hydraulic properties of the soil. The major concern in practice is the construction and maintenance difficulties. The seepage discharge should enter the drain between the drain bed and the low flow water level in the drain.

5.39 If perennial seepage flow is expected, a cunette should be dug in the bed of the drain to carry the perennial flow in a compact and hydraulically effective channel instead of spreading over the entire width of the drain bed. This type of drain is called a storm cum seepage drain.

5.40 Drain design may be done by reaches between two adjacent control points. One method is to design the drain for the required capacity at the lower end of the reach and use that section throughout the reach. If this method is used, the upper end of the reach will be over designed. Reaches should be selected to keep over designing within reasonable limits. To reflect the flow conditions as accurately as possible, the selection of the length of reach is important. The beginnings and the ends of reaches usually are determined by the following:

1. Tributary junctions where drain capacity changes.

2. A change in the water surface slope.

3. An increase in the area drained to a long reach may be divided into two or more shorter reaches. A knowledge of where and how much additional water enters the drain will determine how the reach should be divided to minimize the over designing of the drain.

4. Bridges, culverts, or other permanent structures may be used to begin or end a reach.

5.41 After establishing the hydraulic gradeline, determine the drainage area and the required drain capacity at the upstream and downstream end of each reach.

5.42 Drain design may be done by the point method. In this method, the required drain depth is determined at the control points for the discharges at those points. This assumes that the runoff throughout the reach is uniform. In reality, the depth at the beginning and end of a reach will differ. The depths are established below the hydraulic gradeline and the line of the drain bed is drawn between the points. The slope of the drain bed normally will not be parallel to the hydraulic gradeline. At points where concentrated flows enter, a change in either depth or width, or both, may be required.

5.43 A flow chart of design procedures for open drains is shown on Figure 5.5.

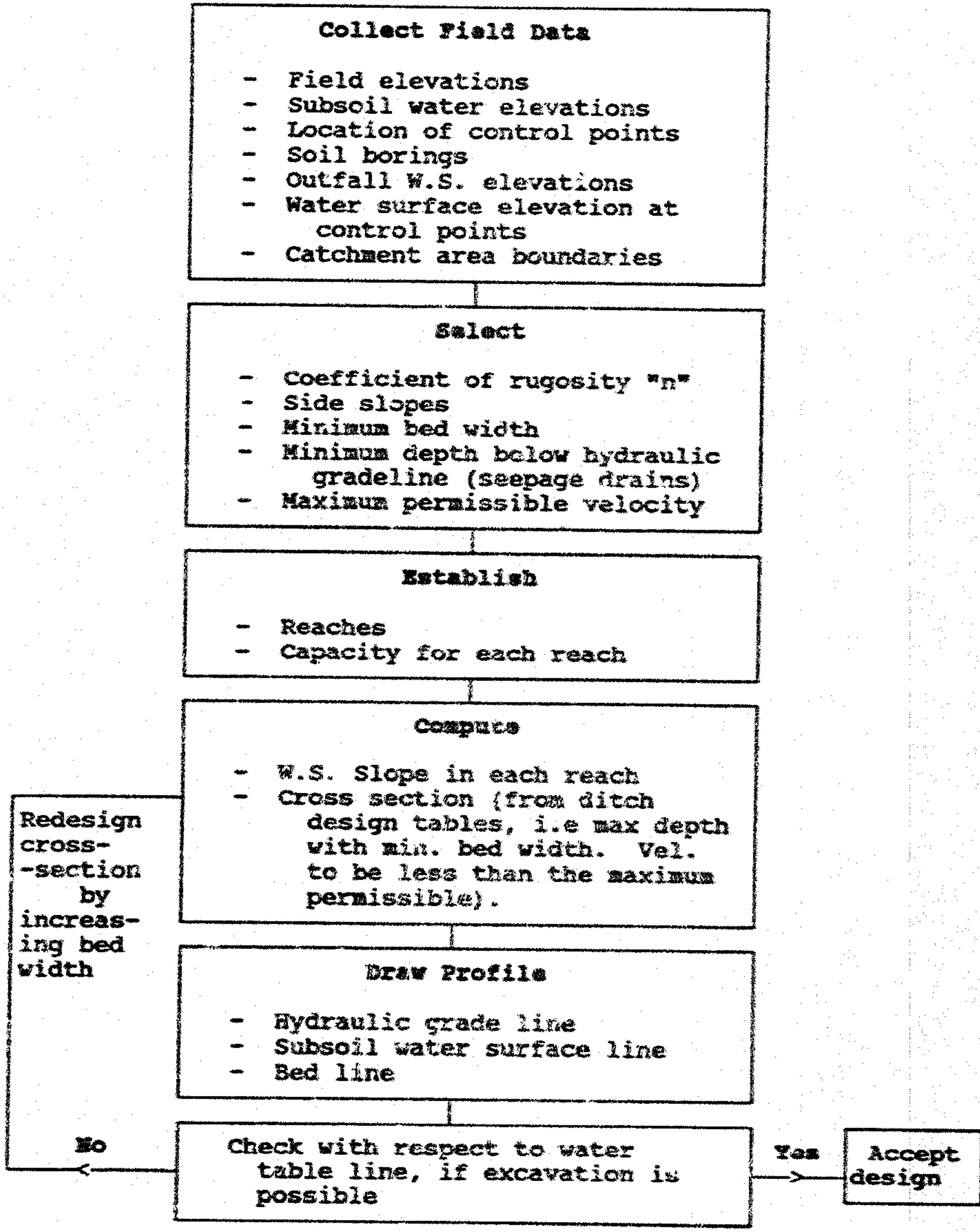

Figure 5.5. Design flow chart.

Tributary drain intersections

5.44 Open tributary drains should enter a main or branch drain with the hydraulic gradients either at the same elevation or allow for a fall in head of 0.25 to 0.5 feet. The WAPDA Design Directorate uses 0.5 feet.

Transition Sections

5.45 When changes are to be made in the drain depth or bed width, the changes should not be made abruptly. It is better to form a transition section where the section is gradually widened or deepened as needed. The length of transition section needs to be only long enough to avoid having an erosive bank obstruction. Where there is an increase in depth of drain going downstream, the transition should be gentle enough to avoid scouring at low flows when the bed slope exceeds the slope of the design hydraulic gradient.

5.46 Where a shallow drain enters a much deeper drain, a 10 to 100 feet transition upstream in the shallow drain is designed on a zero grade at the elevation of the deeper drain before beginning the transition. The transition should be on a non-erosive grade not to exceed one percent.

5.47 Where the difference in the bed levels of two drains is considerable and transition grades seem impractical, a structure should be used to control the drop from the shallow drain to the deeper drain.

Berms

5.48 Berms should be designed to: (1) provide room for movement of the maintenance equipment; (2) provide for work areas and to facilitate spoil spreading; (3) prevent excavated material from washing back into drains; and (4) prevent sloughing of banks caused by placing heavy loads too near the edge of the drain.

Banks

5.49 Banks are designed and constructed along open drains to control water flows within or outside of the designated land width. They are commonly used in the Sindh Province to either retain the drain water within the land width in conjunction with pumping plants or to control sea water from entering the drain upstream of two-way structures and encroaching on farmland. Banks may also aid in controlling surface water inlet locations or to protect low lying areas from flooding. Bunds, however, are generally designed and installed for flood protection purposes.

5.50 The design height of banks to protect pumping systems should be set at the highest elevation expected for backwater or high water level associated with at least a 50-year recurrence interval storm. Potential backwater stage upstream of pumped outfall systems, caused by pumping system shutdown, should be considered in setting elevations of other structures such as bridges.

5.51 The height of banks for outfall drains to the sea must be high enough to contain the backwater effect of long duration gate closure during high tide periods. Structures upstream, such as bridges, must be set at an elevation high enough to protect against the associated backwater.

5.52 Banks should have the minimum top width and freeboard given in Table 5.5 depending on type of drain and whether the bank top is to be used as an inspection road or not. The freeboard is specified above the design water surface slope (WSS) or above the NGL, whichever is higher. In addition, the minimum additional construction height to allow for settlement is one inch per foot of height.

5.53 Drain banks should be designed as either an extension of the excavated side slope of the drain or set back a specified distance by use of a berm. Depending on allowable earth loading, a berm may be necessary at a specified maximum fill height.

Table 5.5. Minimum Top Width and Freeboard for Banks, ft.

	Top Width		
	Used as Inspection Road	Not used as Inspection Road	Freeboard Height
Main Drain	20	15	3
Branch Drain	15	12	3
Subdrain	12	5	2

Inspection Roads and Spoil Banks

5.54 Spoil levelling or shaping is a common and desirable practice. The degree of levelling, the placing of spoil, and other practices related to the spoil are usually determined locally and are dependant primarily on operation and maintenance needs and expectations.

5.55 Excavated earth from the drain should be disposed on the sides of the drain as shown on typical sections (Fig. 5.6). Two situations are:

1. When water surface is below the natural ground surface (N.S.) refer to Figure 5.6, Section A.

   a. Form a road 15 feet wide and not more than two feet high above natural surface as an inspection road.

   b. On the opposite side of the drain from the inspection road there should be an obstruction to free flow into the drain in the form of a stout dowel with a 5-foot top width and minimum 2-foot height[1]. While this is essential where the drain traverses cultivated land, it is also recommended in other areas to prevent erosion of the side slopes. Such dowels should be set back far enough from the drain edge to enable the bed width to be subsequently increased by 50 percent and still leave room for a mechanical excavator to work. This is particularly important if the drain has a seepage flow of more than two feet deep.

   c. Form a spoil bank outside the road leaving space for a drain with a two-foot bed at a level one foot below the top of the road.

   d. If additional earth is available, it can be placed in a road bank not higher than two feet above N.S. and not wider than 20 feet. This may be done provided a saving in land results. If the available earth is in excess of this quantity, the road should then be formed three feet high above N.S. and the surplus should be disposed of as spoil as shown in Section A, of Figure 5.6.

2. When water surface is above the natural surface refer to Figure 5.6, Section B, C, or D as indicated.

   a. If adequate spoil is available, a road 15 feet wide should be formed two feet above "Water Surface", as shown in Section B. A stout dowel on the opposite side is needed as mentioned above.

   b. If spoil is inadequate, Section C or D may be adopted. Section C is suitable where flooding outside of the drain is considered unimportant.

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[1] The standard practice of the WAPDA Design Directorate is to specify a minimum 3-foot height.

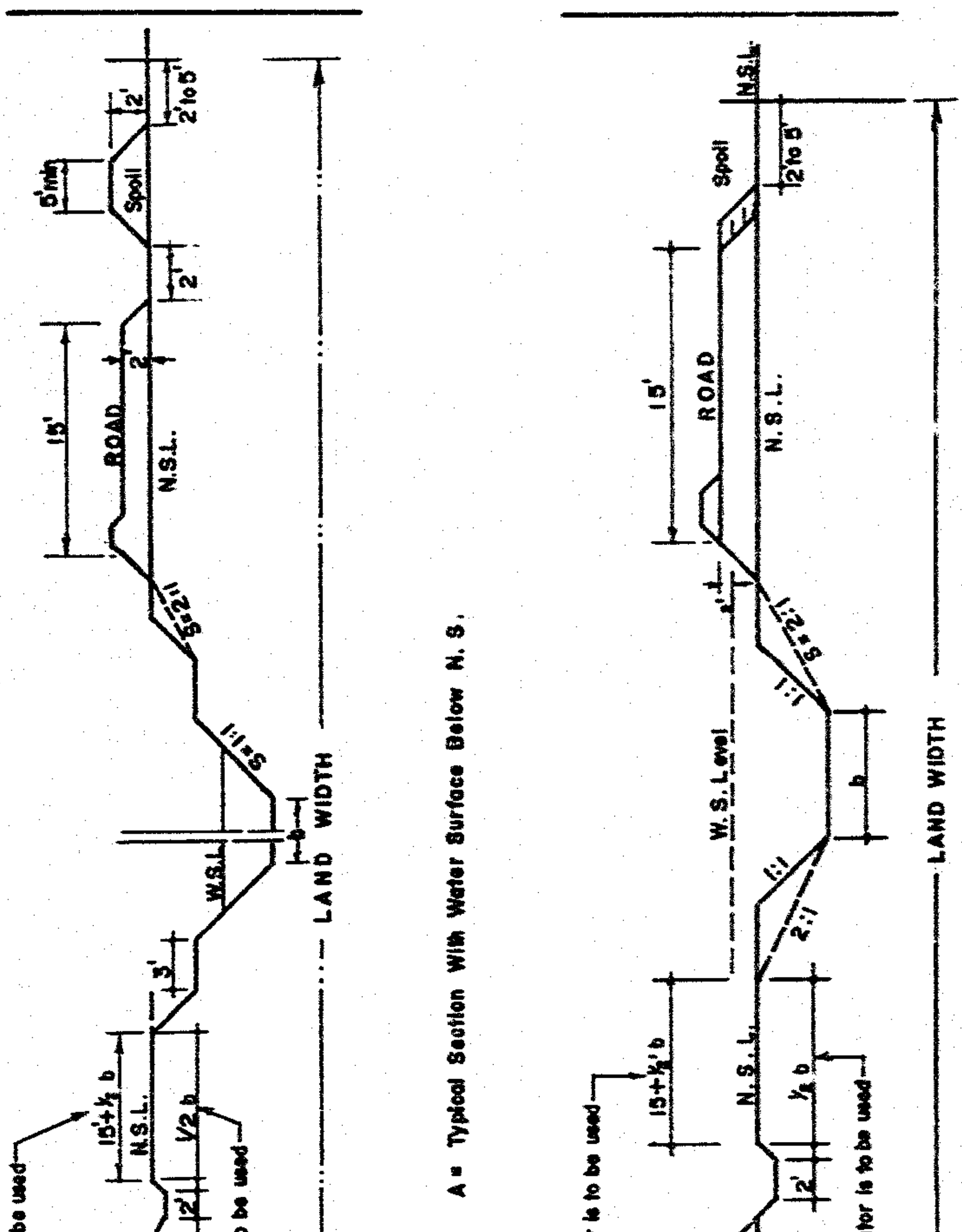

Figure 5.6. Typical sections of open drains (Sheet 1 of 2).

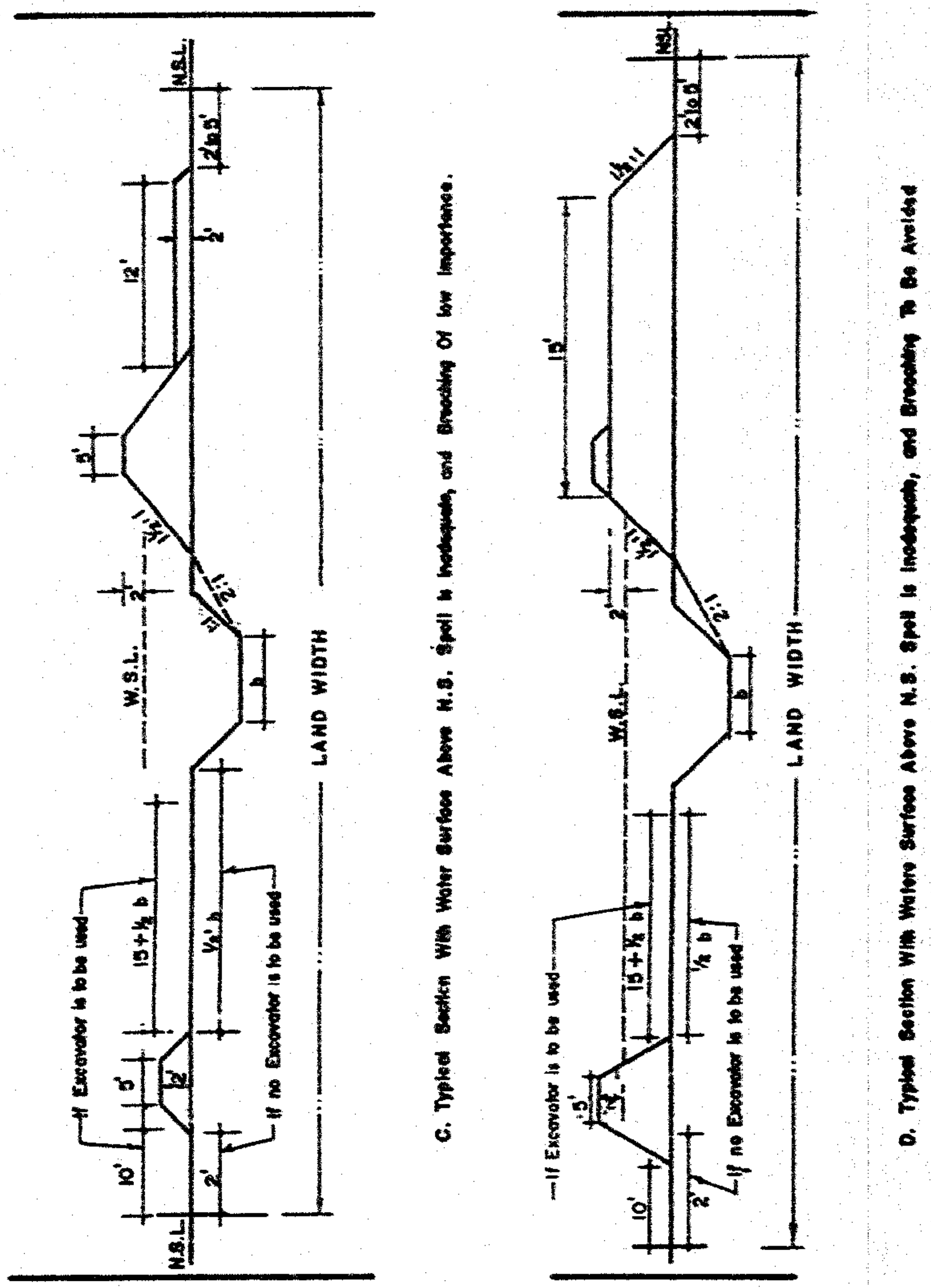

Figure 5.6. Typical sections of open drains (Sheet 2 of 2).

Section D should be adopted where it is desired to avoid flooding of depressions and where a road is considered essential. The necessary spoil in both cases must be obtained from borrow pits in the bed or from judicious widening of the drain.

Land Widths

5.56 The land width needed on the inspection bank side should be as shown in Sections A through D. No increase in width for subsequent spoil will be needed on this side, since the spoil will only be obtained from manual labour in the bed. All subsequent spoil from mechanical excavation will be placed on the opposite side of the drain.

5.57 For the land width on the opposite side, the five-foot wide, two-foot high dowel should be set back a sufficient distance to allow a dragline or excavator to work on N.S. A strip of land 10 feet wide from the outer toe of the dowel should be acquired for the spoil bank. Where the drain flow is entirely storm water and silt clearance by mechanical excavator will not be required, the land widths may be as below:

1. Where land is cultivated, allow two feet from the outside toe of the dowel.

2. Where land is not cultivated or soil is "kallar" (salt affected), allow for 1:6 angle of repose plus 10 feet beyond the outer toe of the dowel.

5.58 Land widths should be in multiples of "Karam" or any other smallest unit of land measurement in use locally for ease in land acquisition proceedings.

Surface Water Inlets

5.59 Surface water inlets need to be properly sited to manage the surface water flows into the drain. Surface runoff should not be allowed to flow into the drain except at planned locations through inlcts, which may be either pipes or masonry structures. Surface water inlets should normally be located in depressions. Spoil banks and collector ditches should be constructed to manage the flow and direct surface runoff to these inlets. Other types of inlets are chutes, drop spillways, box inlets, and culverts. See Figure 5.7 for an example drawing of a surface water inlet.

5.60 Since inlets reduce erosion of side slopes and silt collection in the drain, the value of inlets can not be over emphasized. Liberal use of surface water inlets is recommended.

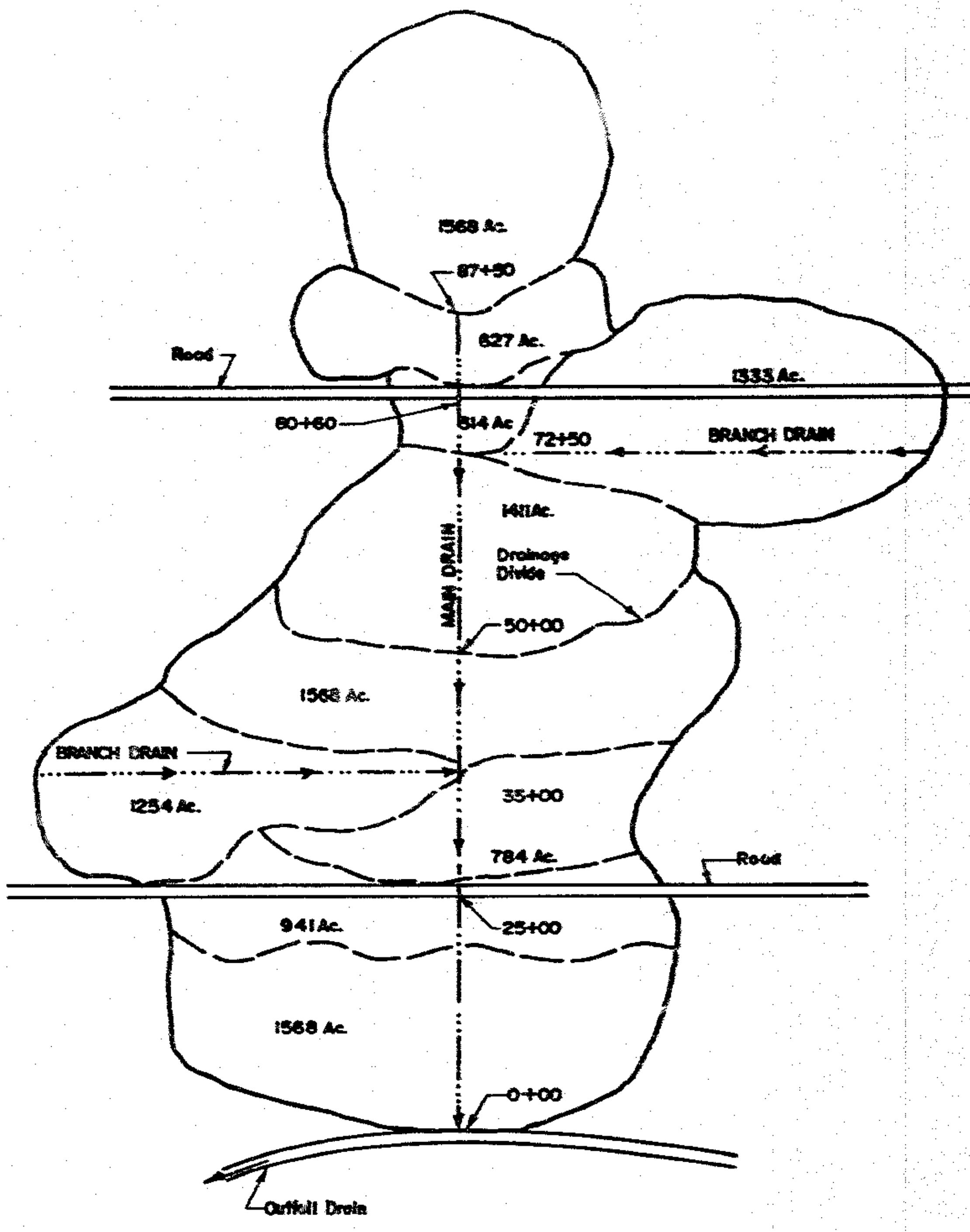

Figure 5.7. Design example #1 catchment area.

5.61 The sill level of inlets should be placed at or a little below the N. S. level. In reaches where normal high flood level in the drain is higher than the adjoining areas and where flooding is undesirable, a simple inlet design may be a pacca regulator with earth fill between two sets of karries. After the flood in the drain passes, karries and earth can be removed to drain the low adjoining area. However, the karries and earth need to be replaced prior to the next flood event. Automatic or hand operated winched gates can also be used for this purpose.

5.62 The number of inlets depends on the catchment area, its slope towards the drain, soil characteristics, and whether the drain passes through cultivated or uncultivated areas. In irrigated areas, the last consideration is generally the most important. For example, a minimum of two inlets per mile on each side of the drain is recommended initially in irrigated areas. For uncultivated areas, one inlet per mile is recommended.

5.63 Careful on-site observations by the Sub-Divisional Officer during surface runoff periods will help determine where additional inlets are needed.

5.64 Drainage inlets should be designed for higher runoff capacity than the associated outfall.

Design Examples

Example No. 1.

Given: Drainage area = 11 368 acres (Fig. 5.8)
Use the Empirical Equation with C = 4 on upstream catchment of 1568 acres.
Use C = 10 on remaining 9800 acres.
Profile of drain (Fig. 5.9)
Side slopes = 2:1
Value of "n" = .045
Minimum bottom width = 4.0 feet

Required: Design of drain for surface water removal.

Solution:

1. Locate control points and hydraulic gradeline as shown in Figure 5.4.

2. Draw subdivides for reaches and other design points as shown Figure 5.8 and determine their drainage areas.

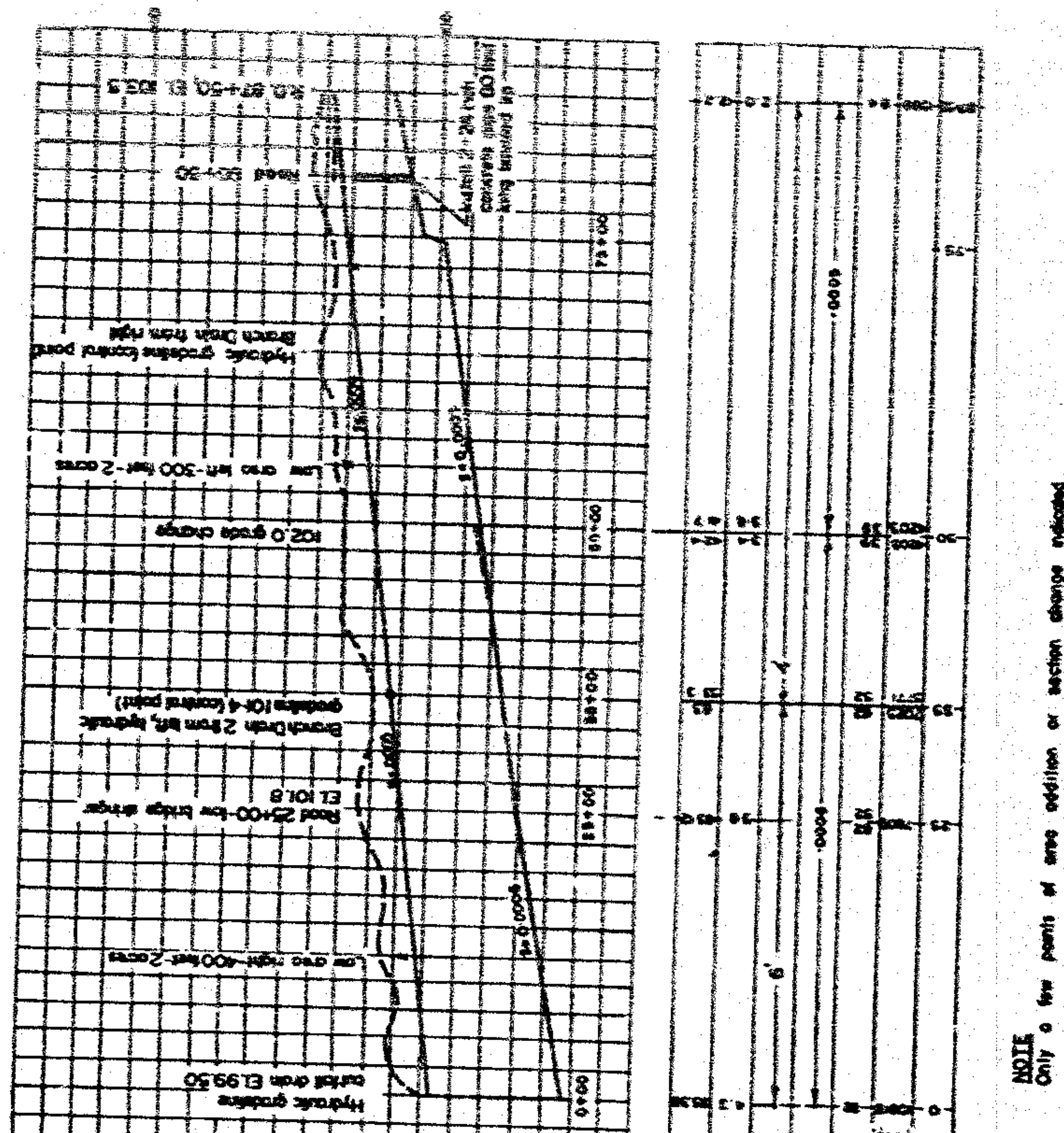

Figure 5.8. Design example #1 catchment area.

3. Begin preparing the hydraulic design. Determine the discharge for design points using applicable drainage formulas. The area above station 87+50 (1568 acres) applicable to the C of four is adjusted to an equivalent area of 518 acres for C equal to 10. This is necessary to be able to add the upper area to the areas below this point. The "20-40" Rules 1 and 2 were applied as necessary.

4. Prepare hydraulic computations for Figure 5.8. Show the RD's, catchment areas, design discharge in cusecs, slope of bed, bed width, depth, and capacity in cusecs. The control elevations are shown on the plotted L- section.

5. Begin with a trapezoidal cross-section, using a bed width of four feet, determine the depth and velocity for each design point. This may be done by using computer programs, appropriate hydraulic tables, or use curves as included in Figure 5.3. For this problem use Figure 5.3, Sheet 3 of 6. The bed width, depth, and velocity should conform with the previously specified requirements for drain design. If they do not conform, assume a different bed width and/or channel cross-section shape and recalculate.

6. Measure the calculated depths downward from the hydraulic gradeline to establish the bed of the drain. Figure 5.8 shows there are drops at stations 25+00 and 75+50 and a rise at station 50+00. This rise is eliminated by continuing the upstream bed slope until it blends with the downstream bed slope. The bed is satisfactory for design regardless of the drops; however, the drops should be eliminated, if feasible. Most machine work is not done so precisely that small drops will be noticeable or detrimental to the drain. For larger drops, the design should be changed or a transition section, drop structure, or chute designed to control erosion at the drops.

7. Bridge at station 25+00. Field information on this existing bridge indicates that the flow area at the bridge is not less than the required flow area of the new drain and there will be no head loss at the bridge. Therefore, the hydraulic gradient will not be changed at that point.

8. A new crossing is to be established at station 80+60 where Q = 18 cusecs. Assume that two 24-inch concrete pipes, 60 feet long with bevelled lip (i.e. smooth end) will be installed. Determine the head loss.

Example No. 2

This example design is a typical drain being designed by the WAPDA Design Directorate. Terkhanwala Drain is southwest of Sargodha and outfalls into the Jhelum River. The drainage area is approximately 25 square miles. The drain is designed with about six cusecs per square mile capacity. The runoff analysis was done by use of the Modified Unit Hydrograph Method with the Runoff Curve Method used for the volume of runoff. The culvert and bridge structures were designed for twice the drain capacity as is the customary practice.

The plan and profile sheets, which include the hydraulic data, are included as Figure 5.9.

Example No. 3

This example is an L-section (Fig. 5.10) of Nasrana Branch Drain located in the Faisalabad Drainage Circle. The side inlet structure in Figure 5.11 is also part of this drainage system.

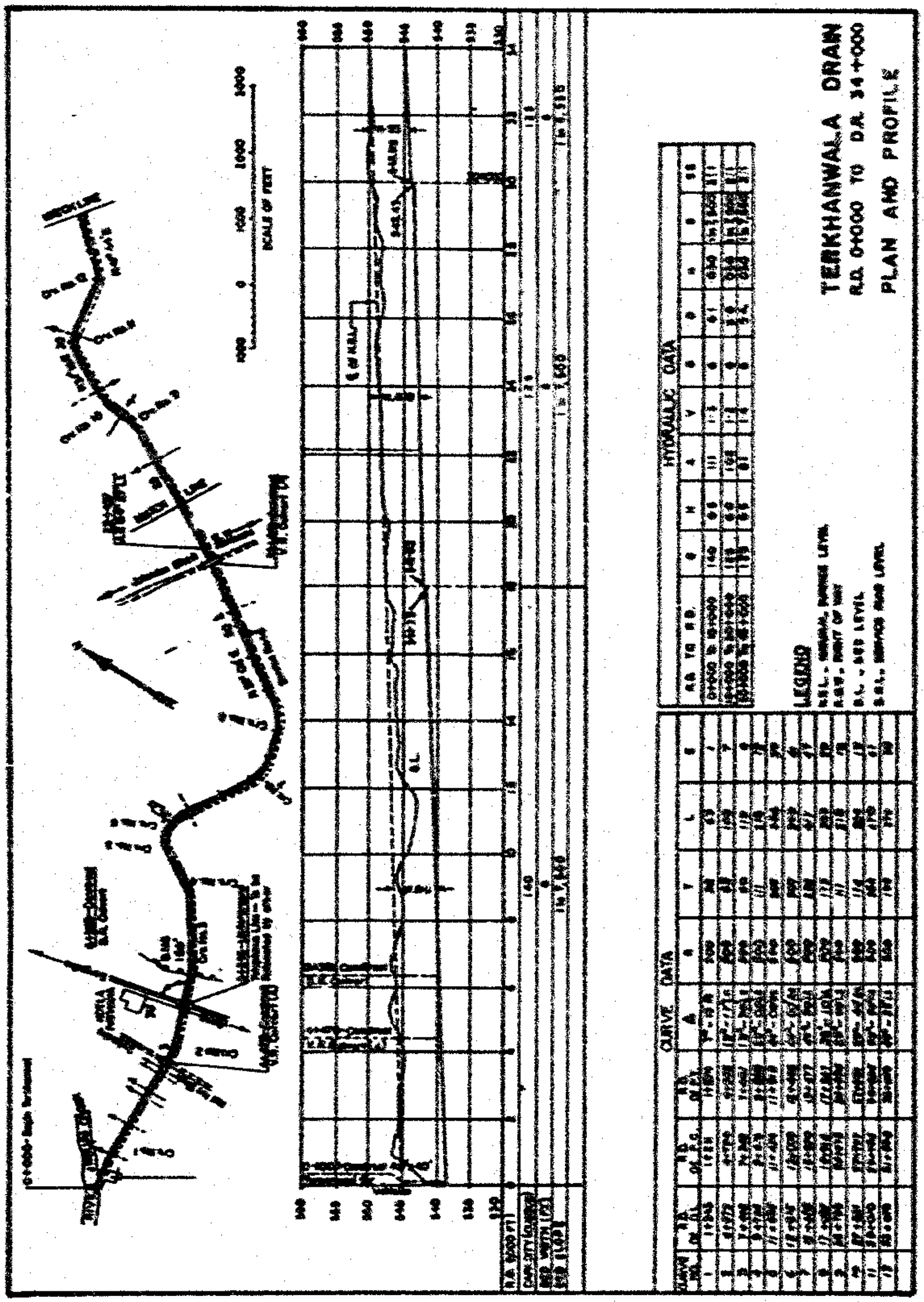

Figure 5.9. Design example #2 plan and L-section (Sheet 1 of 2).

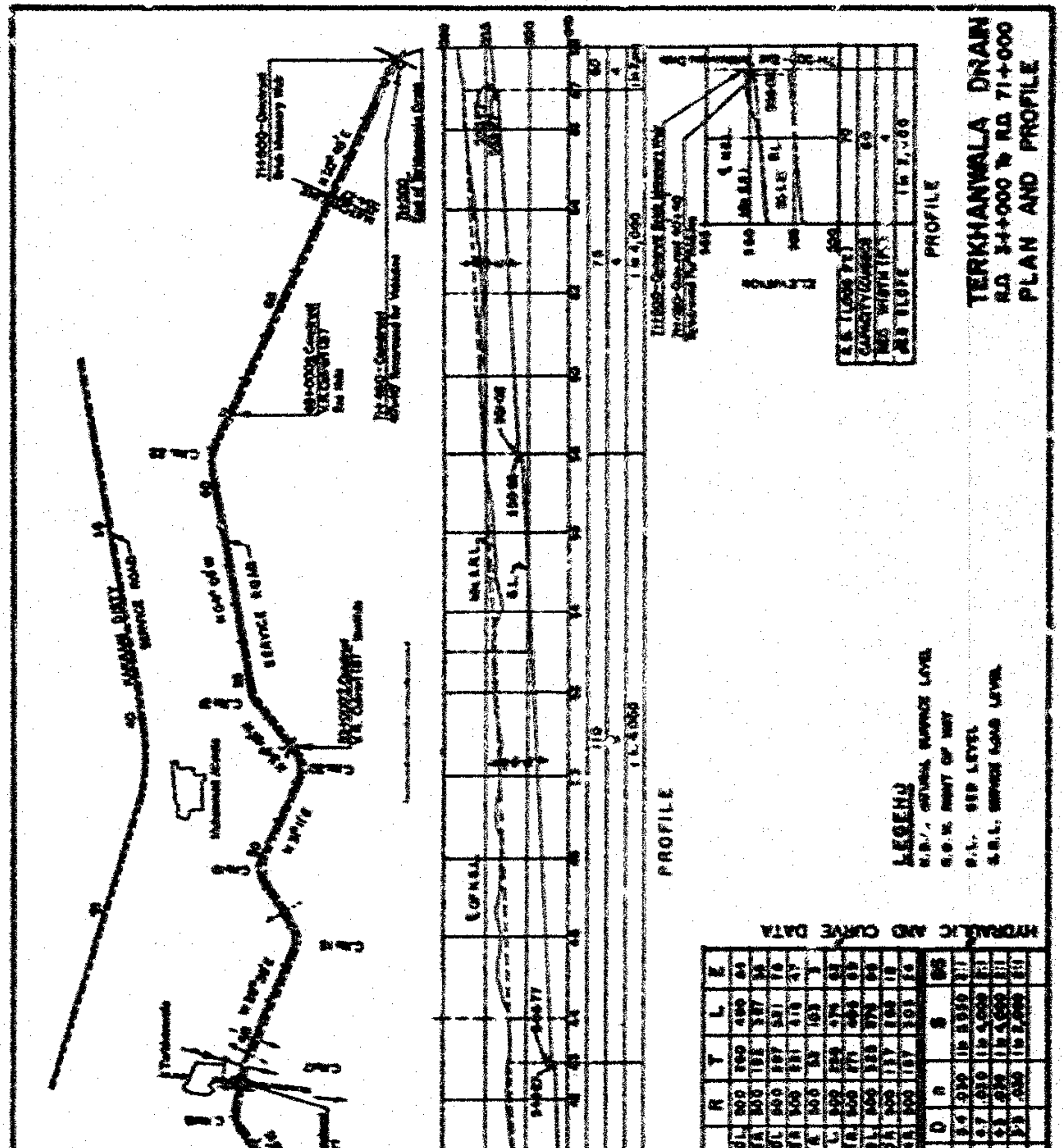

Figure 5.9. Design example #2 plan and L-section (Sheet 2 of 2).

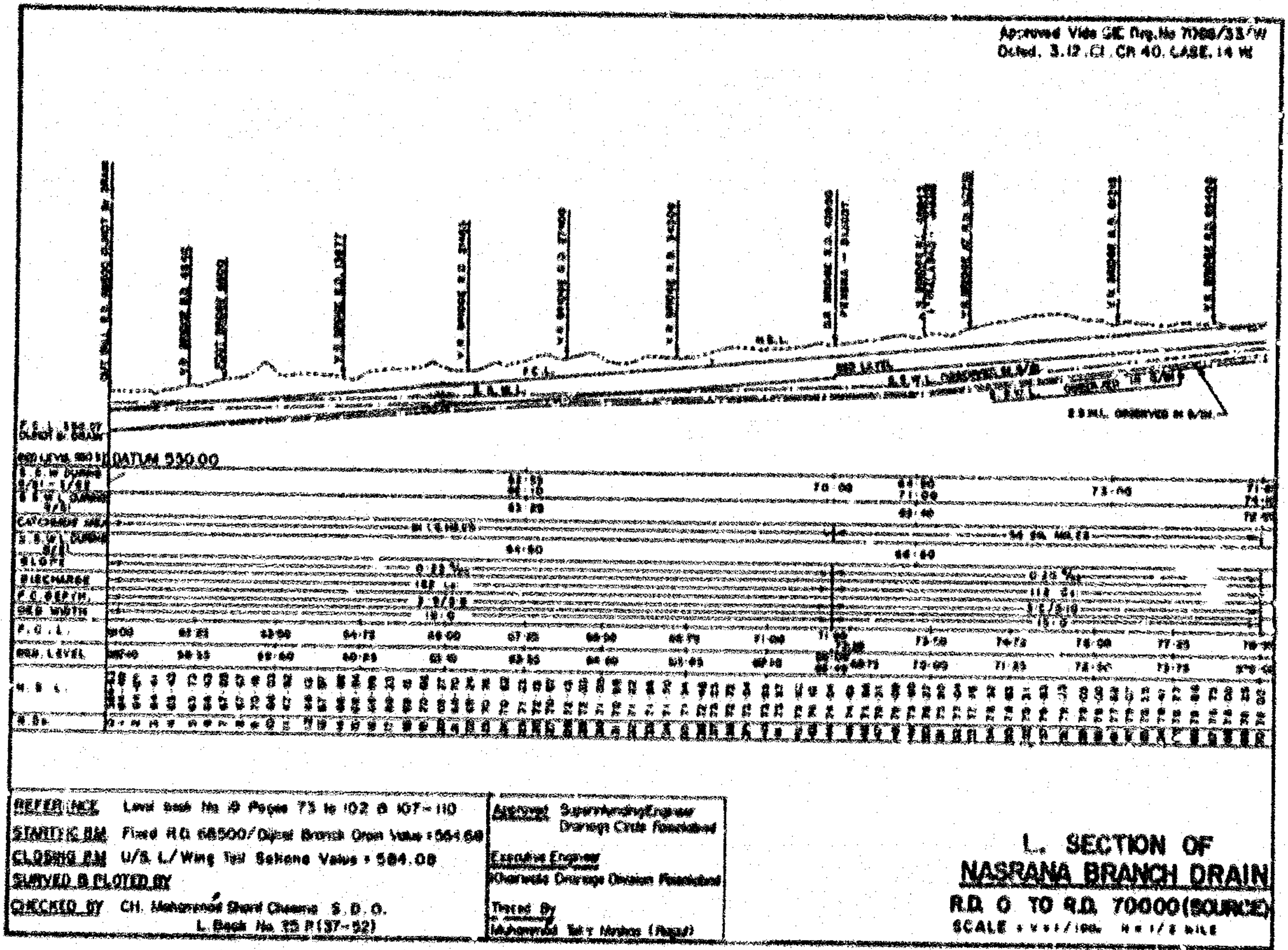

Figure 5.10 Design example #3 L-section

Structures

Inlet Structures

5.65 Surface water inlets are generally pipes or box culverts with masonry facewalls (Fig. 5.11).

Drops and Chutes

5.66 There are several situations where drop structures or chutes are needed as described in Surface Water Inlets and Transition Sections above (examples shown in Figures 5.12 and 5.13).

Bridges

5.67 The design of bridges and other masonry works are usually sized for two times the capacity of the earthen drain. This capacity is normally achieved by increasing the velocity through the bridge with an associated head loss upstream that does not overtop the bridge. Design details of bridges depend on the requirements of the site. New bridges should be designed to span the drain with the bottom of the stringers, or lowest part of the bridge, at least one foot above the HFL. In the case of smaller drains of 10- to 12-foot bed width, there should be no piers located in the centre portion of the drain.

5.68 A large selection of designs are available for bridges over drains in the Design Directorate. "Irish bridges", or grade crossings, are unpopular with the cultivator but are only suitable near the head of a drain.

5.69 The waterway area of bridges should be kept equal to the area of the drain. The top of open foundations should be at least two feet below the designed bed level. This second criterion permits the waterway area of the bridge to be increased, if the capacity of the drain is increased at a later date.

5.70 ***Fluming*** is having the entrance area of a bridge or other structure less than the area of the drain upstream of the structure. In general, fluming should not be used. However, if fluming is economically necessary for existing structures, the WAPDA Design Directorate uses a maximum reduction in cross section area of 25 percent. The bridge opening below the F.S. level will then be at least 75 percent of the designed earthen section.

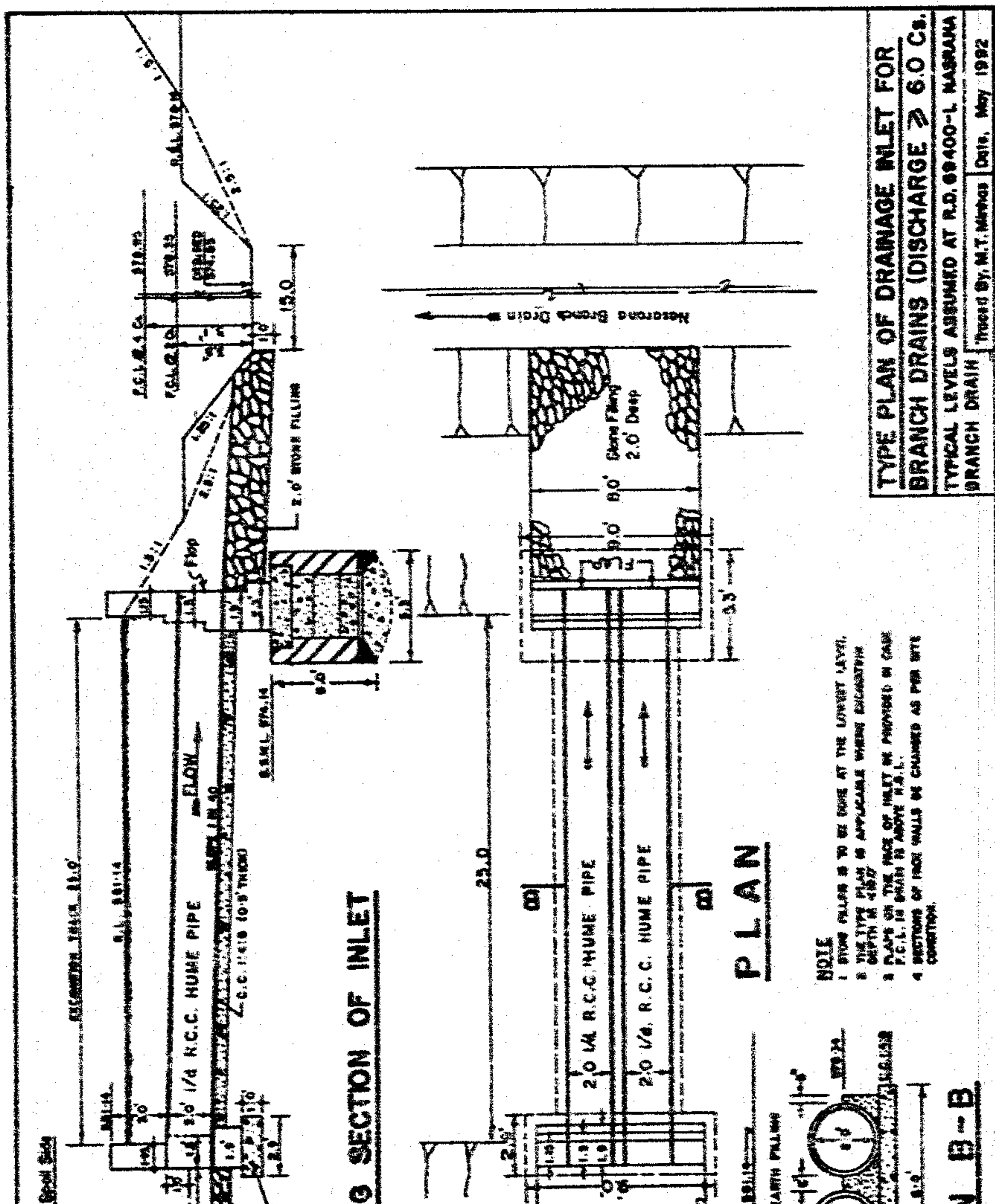

Figure 5.11. Surface water inlet.

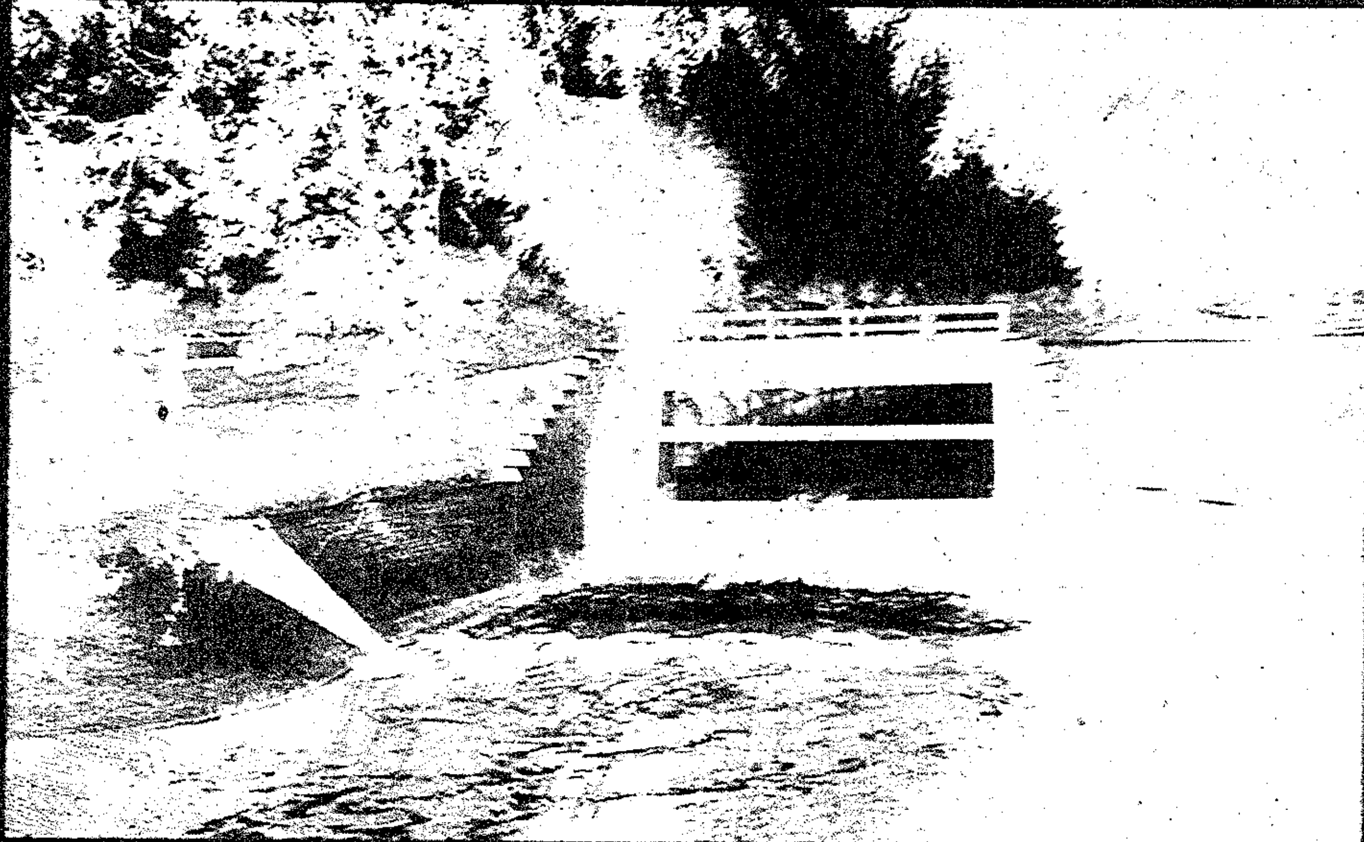

Figure 5.12. Example brick masonry drop structure looking upstream.

5.71 The possible future need to deepen or widen a drain should be considered when preparing the design. Many bridge designs in the past, by general practice, provided for deepening of the bed at a later date. This was done by placing the pier foundations suitably deep. For possible later widening, protected end piers were used rather than permanent abutments on one side of the drain to enable additions of catchment areas with new branch drains.

Drainage Crossings

5.72 Crossings should be provided in accordance with Section 17 of the Canal and Drainage Act. When projects for new railways or roads are referred to the Irrigation Department, it is the responsibility of the Superintending Engineer to assure that the design drainage capacity is sufficient for present and anticipated future drainage needs. Such provision is essential and must include having the floors of the crossings at a reasonable level.

5.73 There should be full cooperation between Railway Officers and Irrigation Department Officers concerning information on drains. For example, the Railway

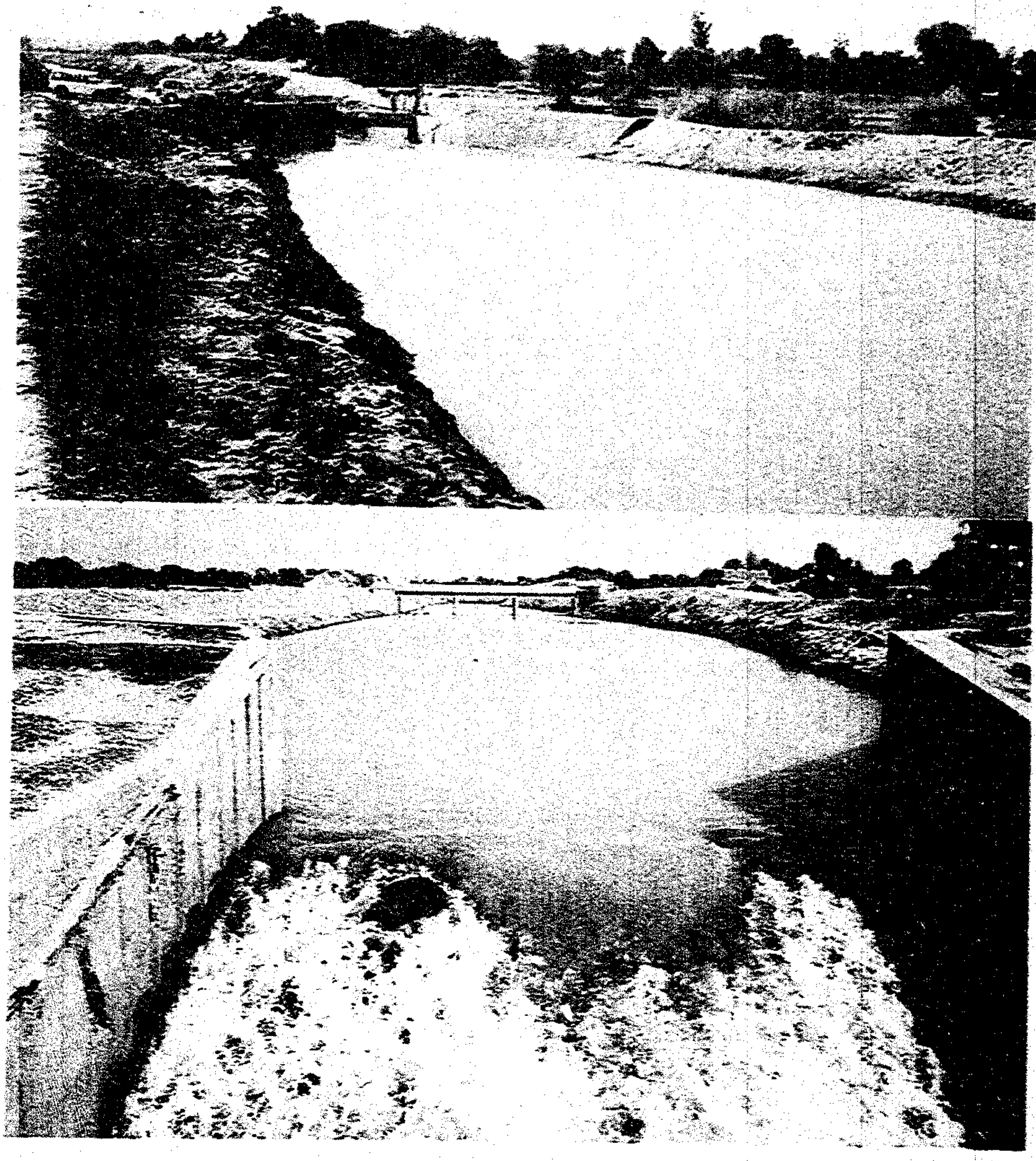

Figure 5.13. Example concrete chute grade control structure looking downstream (top) and upstream (bottom).

Department should have the responsibility for determining the discharge of catchments above railroad bridges in regard to the safety of the railway line. Also, the Railway Department is often a good source of topographic maps, and discharge records.

5.74 Design criteria for bridges or other cross drainage structures over drains, i.e. canals, watercourses, roads, rail roads and other facilities that cross the drain, are specified by the authority responsible for the construction and maintenance of the structure. In the case of railways in Pakistan, the structure is designed and constructed by the Railway Department at the expense of the owner of the drain.

5.75 Watercourse crossings are structures often required in conjunction with drainage systems. Usually the watercourse is an open channel above NGL. Generally watercourse crossings are provided over the drain by a RC aqueduct. Less often a syphon structure may be used for canal flow. The drainage flow should not be placed in a syphon because the low velocity may cause serious maintenance problems.

5.76 The capacity requirement for some structures may be for flood flows which are much greater than the drainage requirement. This extra capacity also allows an extension of the drainage system without necessitating a remodelling of existing structures. Existing structures should be measured to determine their capacity, if the construction drawings or designs are not available. An existing structure may be considered adequate, if it will pass the design drainage flow with a head which will cause no overflow on the side banks upstream of the structure.

5.77 Structures used on some private and field roads may only need to be designed to carry drainage flow. These structures need to meet two requirements:

1. The structure must be of sufficient size and located to pass the design flow within the allowable head loss.

2. The structure must have adequate strength, size, and durability to meet the requirements of traffic or other intended usage. For pipe crossing structures, the minimum length of pipe should provide for side slopes of the road fill unless masonry headwalls are as high as the roadway.

5.78 Head loss through pipe culverts should ordinarily not exceed 0.5 foot. The head loss may be reduced by increasing the size of the structure. New pipe culverts for storm drains usually are designed for 25 percent more capacity than the drain design as a factor of safety.

5.79 There are several types of flow through pipe culverts. Under some situations, detailed knowledge of hydraulics is necessary for the design. Refer to hydrauiic texts for determining pipe capacity considering site conditions. Three common flow conditions are:

1. Culverts flowing full with both ends submerged.
2. Culverts flowing full with non-submerged or free discharge.
3. Culvert flow limited by entrance conditions (submerged entrance).

Outfall Structures

5.80 In Sindh there is a special concern with outfall structures because some of the irrigated land is close to sea level elevation. It is necessary to use two-way gates in the outfall drains for these low lying lands. Full-time Irrigation Department staff operate the gates. They are open when the tide is out to allow outflow of the drainage water and closed before the sea water can flow into the outfall drain. It is necessary to use banks in conjunction with these outfall structures to prevent unwanted water flow around the structures. Refer to Figures 5.14 and 5.15 for layouts of example outfall structures in Sindh.

5.81 In Baluchistan Province a major surface drainage system, the Hairdin Carrier Drain, was constructed with a pumped outlet (Fig. 5.16). In Sindh the Larkana-Shikapur Drainage system has eight pumping stations to lift drain water from open drains to irrigation canals. Khairpur SCARP is a tubewell drainage project, pumping saline ground water to open drains which in turn is lifted by pumping systems to irrigation canals. Drain water is mixed with sweet water to reach a desired salinity level of 400 parts per million. The Left Bank Outfall Drain is under construction. It will provide more alternatives in managing drain waters. The Kotri Barrage system has both a right bank and left bank outfall drain outfalling to the Arabian sea via numerous creeks.

5.82 Outfall structures or systems described above are normally designed by WAPDA or by consulting firms. Typically, written instructions for operation and maintenance are provided with the design and construction plans.

5.83 In conjunction with structures in the drains, it is appropriate to incorporate gauges or hydraulic measuring devices as shown in Figure 5.17.

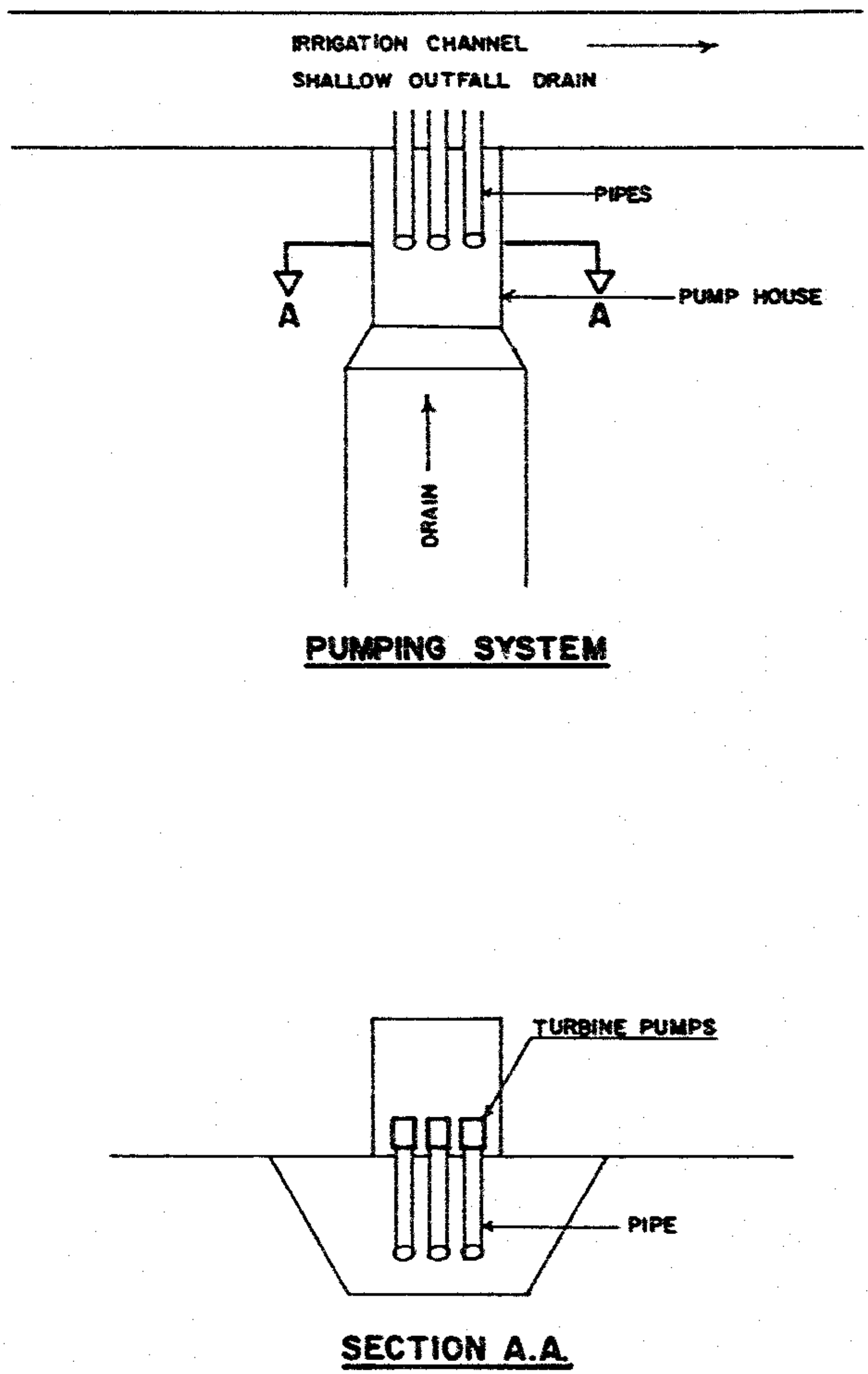

Figure 5.14. Typical pump lift station in Sindh to either an irrigation canal or shallow outfall drain. Similar outfall structure in Fig. 5.16.

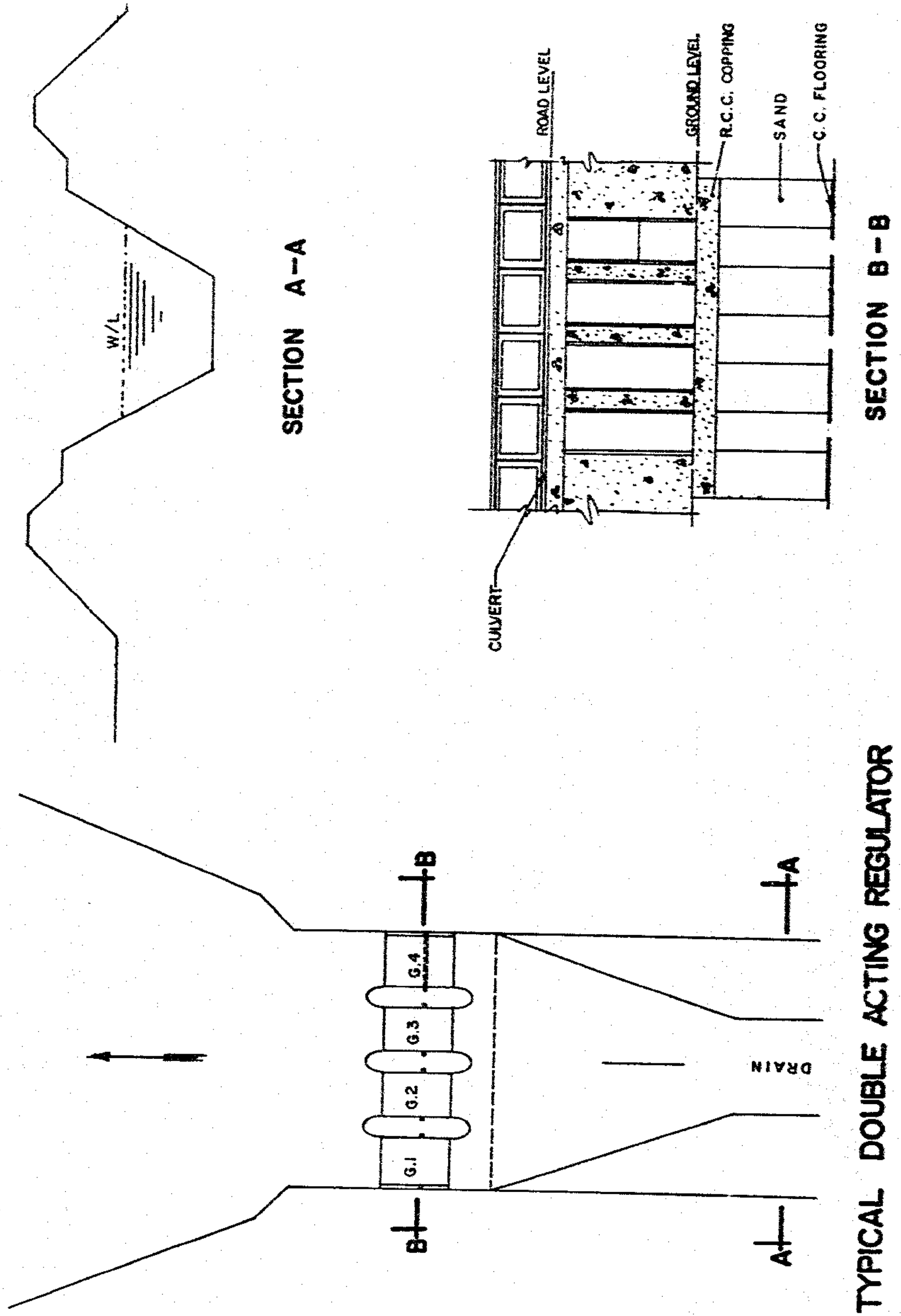

Figure 5.15. Typical tide gate structure in Sindh having four gates that are manually controlled.

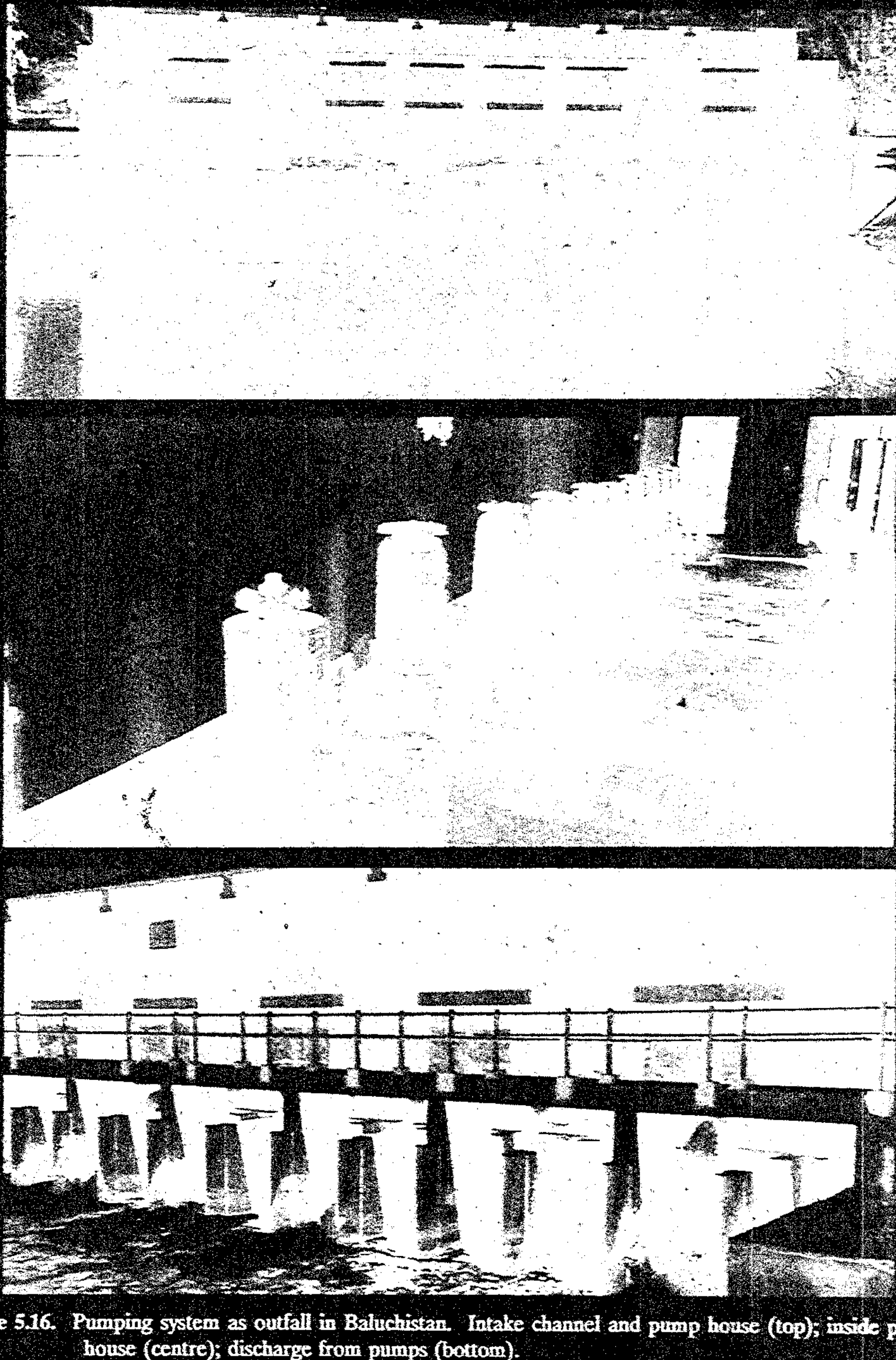

Figure 5.16. Pumping system as outfall in Baluchistan. Intake channel and pump house (top); inside pump house (centre); discharge from pumps (bottom).

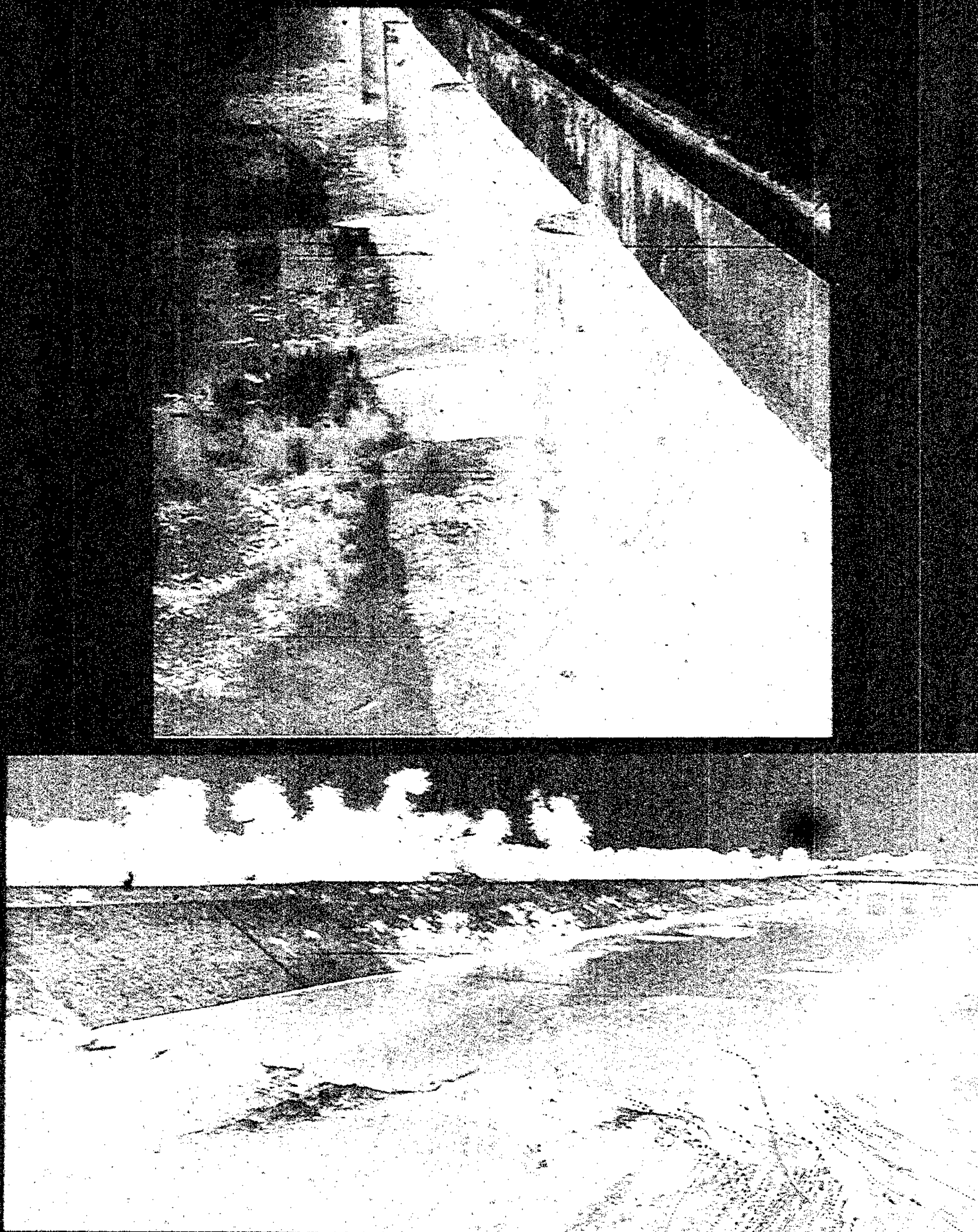

Figure 5.17. Example drain structure with gauge. Staff gauge on bridge (top); staff gage on masonry side slope (bottom).

Construction of Open Drains

Drain Layout

5.84 The number of stakes required tor making the drain layout on the ground depends on topography, size of drain, the type of equipment to be used, and the experience of the contractor or installer. A centre line stake, slope stakes, and offset reference stakes may be set at every station. Sometimes the centre line cut or fill is marked on the centre line stake. In many cases, staking is not required at every station but a sufficient number of stakes should be set to obtain the intended result.

5.85 *Distance Marks* provide permanent reference of the reduced distance (R.D.) along the length of drains and canals. Stone is the most suitable material for distance marks on drains. The portion of marks appearing above the ground should be suitably finished with the R.D. number cut into the sloping faces of the stones, as shown in Figure 5.18.

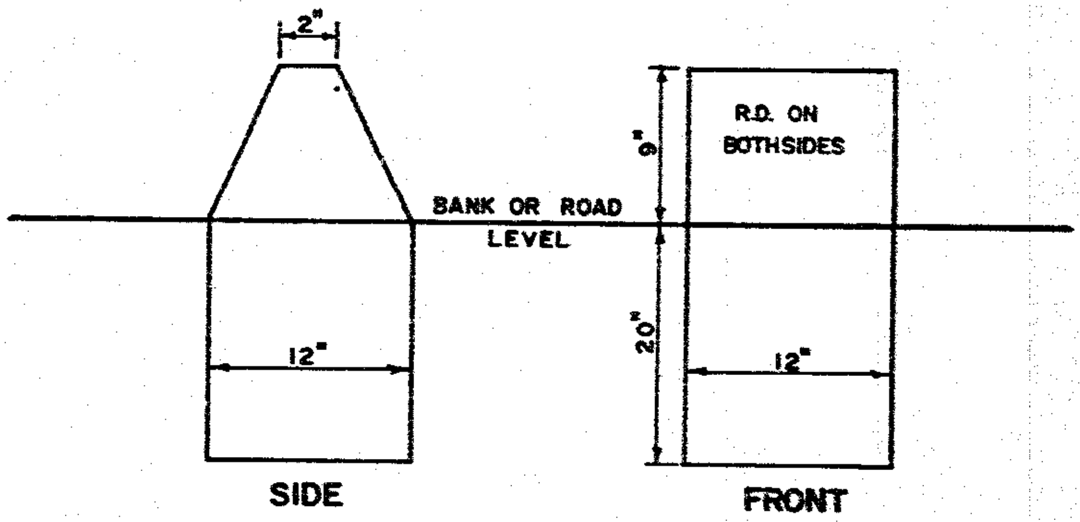

Figure 5.18. Distance mark detail.

Excavation

5.86 The excavation should be to the line and grade as specified in the plans and staked in the field. It is generally advisable to limit lowering of the water table to two or three feet at one time. If the water table must be lowered more that this amount to attain the design depth, the excavation should be done in stages. Staged construction should be considered for dewatering the high water table areas with sufficient time between stages to permit the water table to recede to each succeeding depth level.

Slope Protection

5.87 The placement of stone or masonry for slope protection should be in accord with the design drawings and as staked in the field. If the natural bank soil material will not readily drain, permeable material, such as sand and gravel, should be placed on the slope before placing the stone or masonry surface.

Bridges

5.88 Bridges should be constructed or remodelled prior to the excavation of the earthen section in the immediate vicinity. Depending on site condition, it is often necessary to provide a bypass for the channel along with temporary traffic arrangements. Dewatering during construction is a frequent requirement that often varies with the season of construction.

Culverts

5.89 All culverts should be installed or remodelled prior to the site excavation. Where multiple pipe culverts are used, the space between the barrels or pipes should be at least one half the diameter of the pipe. All backfill should be carefully and firmly compacted.

Surface Water Inlets

5.90 Pipe overfall structures should be installed to discharge into areas recessed in the banks of the drain, especially if the drain is a flowing stream. The flowing water and debris in the drain will normally not damage a pipe structure in such a location. Also, the structure will not impede flow in the drain.

5.91 The installation of inlet structures, especially in fills, should be very carefully done. The pipe should be well bedded by shaping the base area to conform to the shape of the pipe. This fine grading should extend up the sides of the pipe to a point where the backfill can be easily reached with a hand or mechanical tamper. All joints should be as watertight as feasible.

5.92 The installation should be completed by tamping the soil around the pipe. Moisture control of the backfill soil will facilitate placement and uniform compaction. The fill over the pipe should be high enough to force any overflow water to the sides of the structure to prevent a failure by washout at the inlet structure.

Berms, Spoil Banks, and Roadway

5.93 Typical sections of drains including dimensions of berms, roadway and spoil disposal areas are shown in Figure 5.6. Specific design dimensions may be specified by PID Circular. The design drawings provide more specific information applicable to the site. These types of information are used by the construction engineer and construction contractor.

5.94 The practice of leaving berms on drains, the levelling of spoil, and the seeding of drain slopes, berms, and levelled areas vary with the locality. The spoil should be shaped to facilitate maintenance. When no berm is left and spoil is shaped into a road, the height of the road should be designed to minimize sloughing of the drain banks.

5.95 In all cases, the spoil should be shaped in such a way that the minimum amount of water will flow directly back into the drain. Directing surface runoff water to designated surface water inlet locations must be finally determined in the field during construction. Surface water inlets may need to be located at stations other than shown on the plans to enable directing of surface runoff with a minimum of spoil and roadway shaping. The number of surface water inlets may also need to be changed. Consideration should be given to controlling erosion of the spoil, as well as the other parts of the cross section and construction site.

Seeding

5.96 Frequently, disturbed areas are not seeded. However, seeding and fertilizing drain banks, berms, and spoil disposal areas for erosion protection and ease of maintenance are recommended. The seeding should be done as construction progresses rather than after construction is completed.

Chapter 6

OPERATION & MAINTENANCE

General

6.1 Operation and maintenance activities of open drain systems are inseparable and are discussed together for that reason. Monitoring and inspection are important functions of drain system operations. Much of the following discussion relates to maintenance as though it stands alone, but it is the emphasis on maintenance that is being stressed. A definite maintenance programme should be developed when the drainage system is being planned, since maintenance can materially affect design, installation, and operation. The maintenance programme should include monitoring, periodic review, estimated funding needs, and how the funding will be obligated. Maintenance may be preventive, normal, or urgent in nature.

6.2 The agency responsible for operation and maintenance may be different than the design or construction organization. It must be involved in decision making at the earliest possible stage, however, if the project is to be successful.

Importance of Maintenance

6.3 Proper maintenance of drainage systems is a fundamental necessity, if irrigation is to be carried out indefinitely. The following appropriate statement is from the paper "Maintenance of Drainage Systems", presented at a Pakistan Engineering Congress (Zaidi et al, 1990); "Timely performance of preventive and regular maintenance of drainage systems is absolutely necessary if the systems are to perform the functions for which they are designed and built. Unfortunately, the importance of timely maintenance is often overlooked, resulting in the requirement of additional expenditure for repair of the damages caused by deferred maintenance."

6.4 Unless the major problems with open drains, growth of vegetation and silting, are controlled by regular maintenance, they may quickly decrease the effectiveness of the drain. The capacity of an open drain may be reduced significantly in one year by sediment or a heavy growth of weeds or brush.

Maintenance Objectives

6.5 The maintenance objectives of drainage systems are:

1. Keep the system in proper operating condition;
2. Obtain the longest life and greatest use of the system; and
3. Achieve the above objectives at the lowest feasible cost.

6.6 As stated in the Operation and Maintenance of Irrigation and Drainage Systems Manual (ASCE, 1980), "The history of irrigation and drainage is replete with examples of the folly of neglecting maintenance. The best constructed system will eventually fail if maintenance is neglected.".

Maintenance Problems

6.7 In reviewing the performance and condition of open drains in Pakistan with provincial irrigation department personnel, consensus was that the two major maintenance problems are: (1) controlling weed growth, which includes algae and floating vegetation that restricts flow; and (2) satisfactorily repairing bank sloughing caused by high ground water seepage into the drains during certain periods of the year. Other problems that were identified include: silt accumulation, water quality deterioration by industrial waste, inadequate budgets, priority or allocation decisions relative to available budgets, operating condition of structures, lack of access and maintenance roadways, and availability and condition of outfall systems.

6.8 Standing water, even in small areas for any length of time, is indicative of poor maintenance of open drains. In addition to maintaining the system, more surface water inlets may be needed to drain such areas.

Vegetation

6.9 In seepage drains with clear water flowing during the entire year, one of the most important maintenance concerns is to keep the bed free of weed growth. In reaches where subsoil water is appreciably above the bed, heavy weed growth is generally prevalent, making it difficult to keep the drain clear. It is essential to clear the drains at least twice a year, such as in June and December. Figure 6.1 shows an open drain with a heavy growth of Gul Bakouli or Water Hyacinth (*Eichhornia crassipes*), and Gul Abbasi (*Pontederia cordata*).

Figure 6.1. Typical vegetation problems in open drains. Above: extensive weed growth; Lower left: *Gul Abbasi*; Lower right: *Gul Bakouli*.

6.10 In tidal areas, the high level of salinity restricts vegetative growth in the drains, but when tide gates are installed and the salt water inflow is restricted, weed growth becomes a problem.

Silt Accumulation and Obstructions

6.11 It has been observed that at ghat sites and at other crossings, the bed generally tends to become higher due to siltation. Therefore, it is recommended that at these locations the bed should be maintained one foot lower than the designed level. Siltation very often restricts the outfall capacity of a drain, especially when the open drain is a seepage drain or serves as a gravity outlet for horizontal subsurface drains.

Sloughing of Banks

6.12 Sloughing of banks in reaches where subsoil water level is appreciably above the bed is a common problem. Repairing these side slopes has been difficult. It is generally not practical to anticipate all locations where this will happen while the drain is being planned or designed even with soil investigations. Bank sloughing typically occurs when the adjacent water table is quite high and the flow level in the drain is low, so that the hydraulic head is more than two or three feet. Thus, the drain bank in that zone is saturated with the water moving into the drain. Slope stability is adversely affected by the saturated condition which reduces soil strength causing classic soil slides or mud flow conditions on a bank that otherwise had been stable.

Banks, Service Road and Spoil Areas

6.13 Drain systems may become useless, if they are not properly maintained. For efficient monitoring and maintenance, a well maintained service road providing access to the entire drainage system is essential. Banks or service roads may be breached by storm flows, which may seriously affect operation of the system. If spoil deposits are intended to restrict surface water flows, they need to be monitored. Also, the associated surface drains intended to direct surface water to surface inlets must be monitored and maintained to keep the drainage system operating as intended.

Damaged or Worn Structures

6.14 Structures that may be damaged or worn include side inlet pipes or culverts, gauges, bridges, pumping plants, and two way gates. Significant structures, especially pumping plants and tide gates, require specific operation and maintenance plans.

Solutions for Maintenance Problems

6.15 To accomplish needed maintenance, the responsible organization must be properly organized and staffed. Urgent repair conditions need to be recognized and addressed early to allow time needed for technical consultation and shifts in budget allocations.

Control of Vegetation

6.16 Weeds may be removed by hand as shown in Figures 6.2 and 6.3. A weed rake mounted on an excavator or tractor, can also be very effective in controlling vegetation within the open drain (Fig. 6.4). Mowing to control vegetation on spoil banks, berms, and within the drains is both economical and effective, if the side slopes are not too steep. For safety, side slopes on which farm tractors are to be operated should be made 3:1 or flatter; 4:1 slopes are preferred. Side slopes as steep as 1:1, as well as channel beds, may be mowed using mowers mounted on hydraulically operated booms (Figs. 6.5 to 6.7). All models shown in Figures 6.5 to 6.7 are available from Herder[1] (see References) The weed rake shown in Figure 6.4 and mowers of all types are available from Engineering & Hire, Ltd (see References).

6.17 Removal of grass and other vegetation from inside slopes is required. The vegetation should be cut off rather than uprooted The mowing or cutting is just above the surface of the side slope, and the roots are left intact to protect the slopes and help prevent formation of rain cuts. Vegetation clearance of this nature should be done in June before the rains begin.

6.18 There are also amphibious or boat mounted mowers (Fig. 6.8). The models shown are made by Aquarius Systems (top picture), Botman (centre), and Herder (bottom picture) as examples of available mechanized equipment. Addresses for these firms are in References.

6.19 Sometimes burning can be a good method of controlling undesirable vegetation in open drains. However, burning dry vegetation may be hard to manage without creating a hazard for adjacent crops or property. Care must be taken not to destroy bridges, plastic pipe outlets, or other property. Any burning activity should be in compliance with local laws and ordinances. Burning generally has a negative impact on air quality and also destroys

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[1] The use of manufacturer and supplier names in this Manual does not constitute endorsement of the products nor are they the only sources for a particular item. The intent is to indicate the types of equipment that are available and sample sources.

Figure 6.2. Weed removal by hand.

Figure 6.3. Removing weeds by use of long handled rake.

potential animal fodder. An advantage is that minimum equipment is needed. However, adequate fire fighting equipment with properly trained personnel may be required.

6.20 Chemicals to control undesirable vegetative growth have produced some excellent results. Caution should be used in application to prevent crop damage or water pollution from the drifting chemicals. Broad leaf crops and most vegetable and fruit crops are particularly susceptible to damage. Information on appropriate chemicals usually may be obtained from local dealers or current publications. Major chemical companies have prepared considerable information relative to usage of specific products.

6.21 For guidance in the use of chemicals on common weeds on drain banks, refer to manufacturer's recommendations or local technical material. The most current information available, including data on new herbicides, should be followed. Laws or regulations governing use of herbicides shall be followed. All chemicals should be used according to label on the chemical container. The EPA discourages the use of chemicals in perennial drains or nullahs, as the water is frequently used for human and animal consumption.

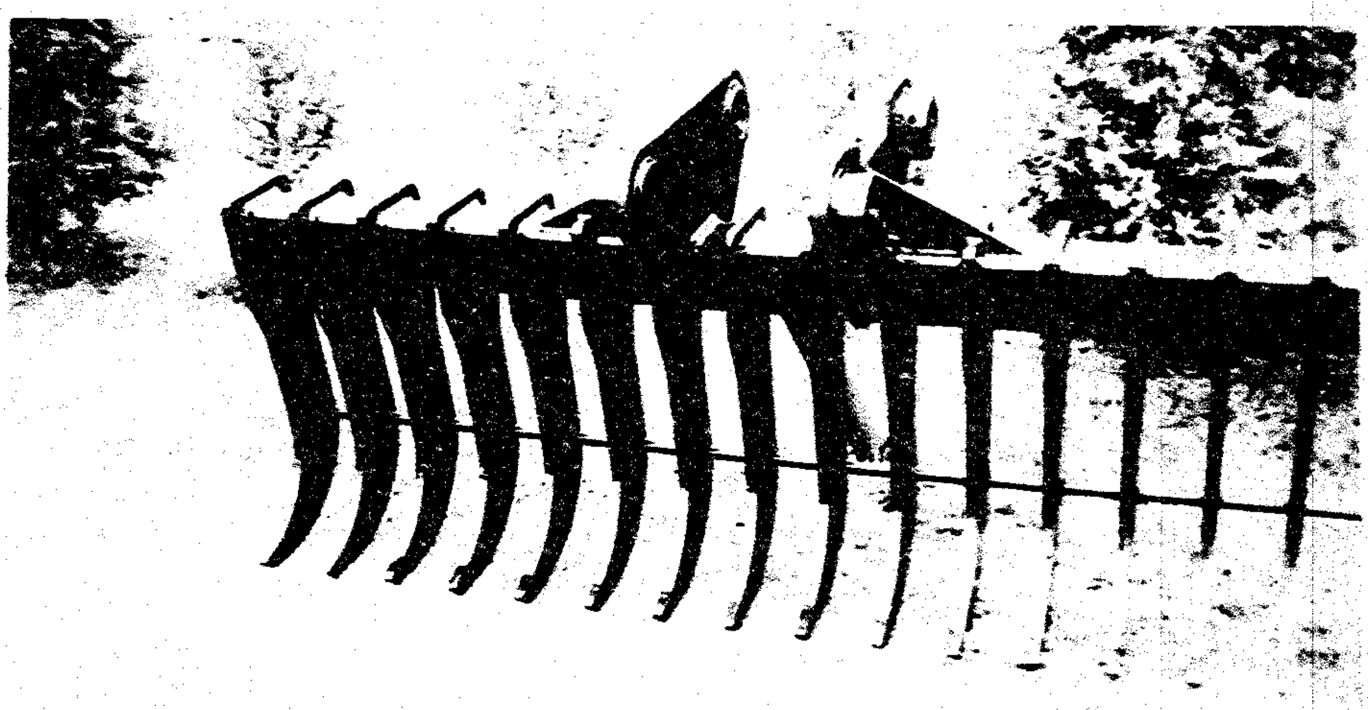

Figure 6.4. Weed rake for use with excavator.

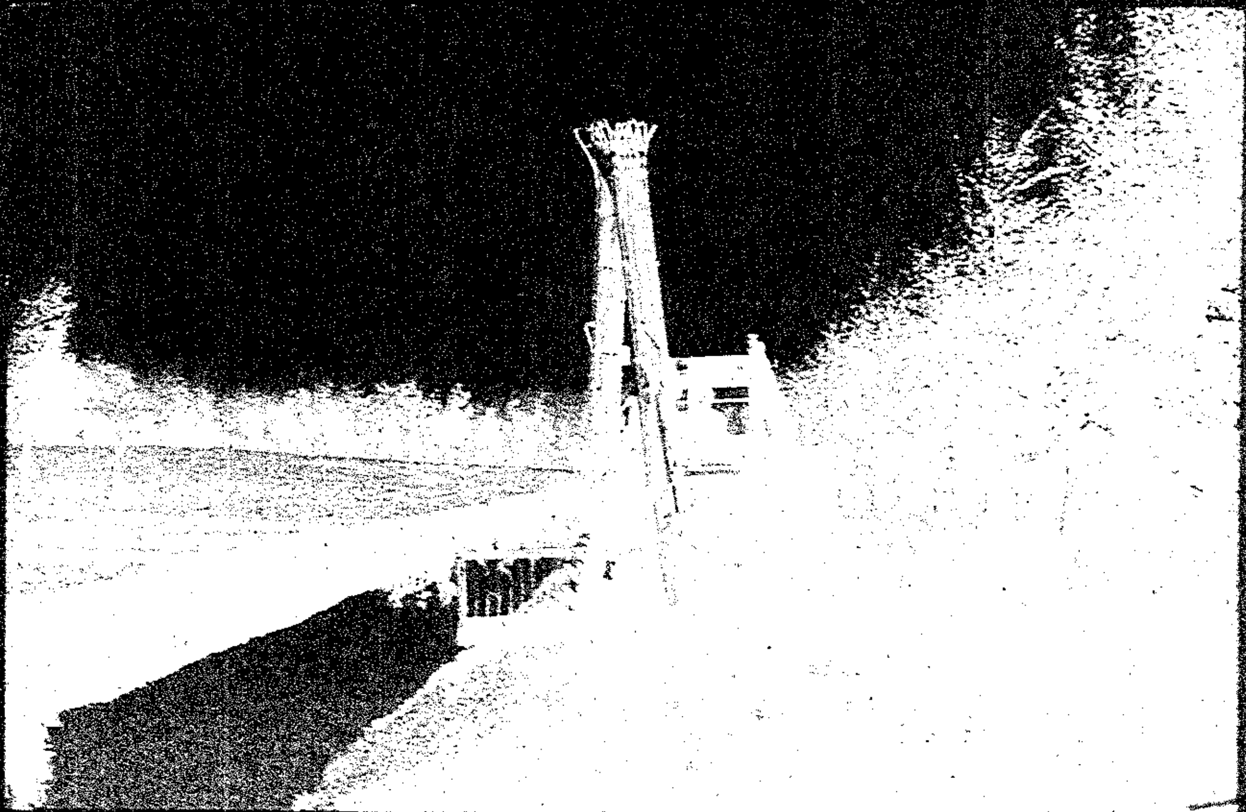

Figure 6.5. Tractor mounted mower and rake. The reciprocating mower on front edge of rake is shown in top photograph.

Figure 6.6. Maintenance by mowing.

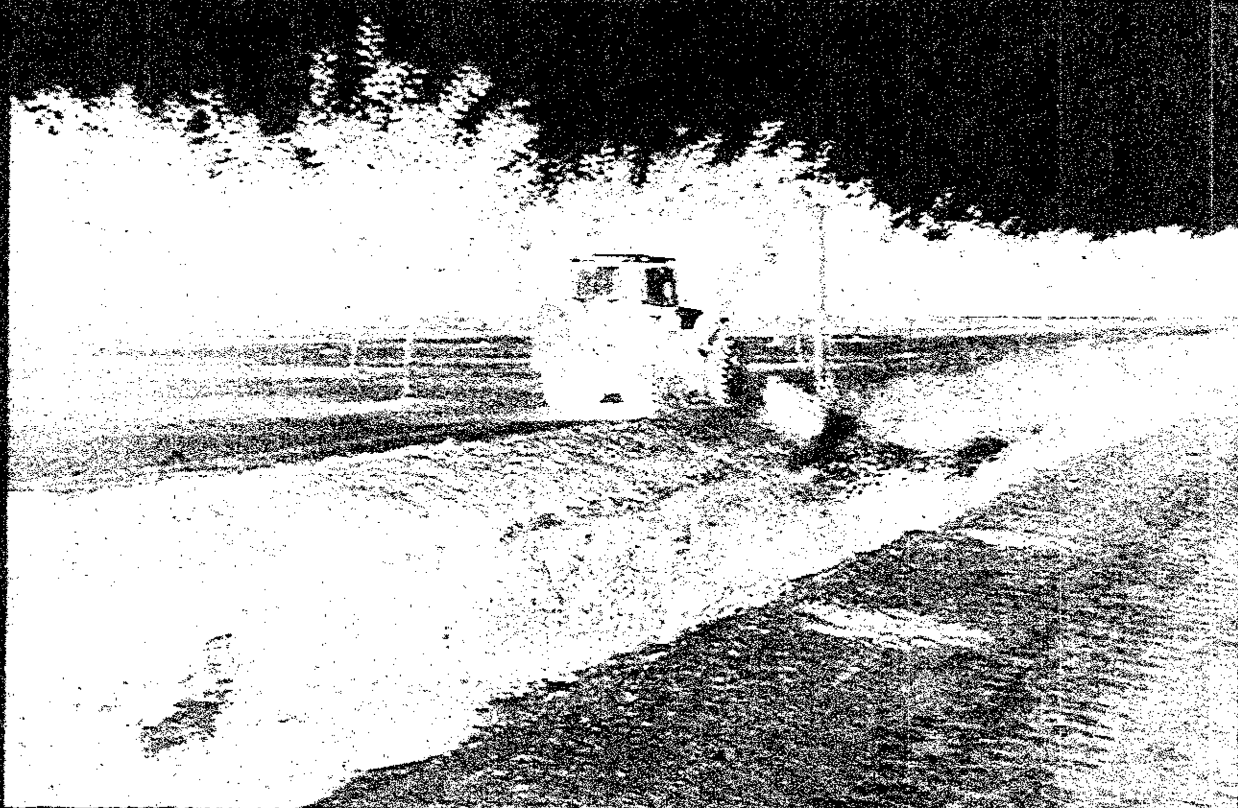

Figure 6.7. Open drain well maintained by mowing.

Figure 6.8. Boat mounted mower and weed collector. Upper picture includes an unloading conveyor by Aquarius; Centre: Botman B.V; Bottom: Herder B.V.

Chemical control is very controversial. The primary consideration is that the water is used over and over by animals and by people for personal use without treatment. Also, herbicides may enter the drain water which is often used for irrigation again and may harm the irrigated crops.

6.22 Biological control of vegetation needs research and evaluation. Under some conditions fish may be effective for the control of algae or submersed species (ASCE, 1980). The Grass or Amur Carp (*Ctenopharyngodon idella*) and Israel Carp (*Cyprinus carpio*) are two species being used and studied. During preparation of this Drainage Manual, introducing fish that live on vegetation was discussed with staff of the irrigation departments and others. The general conclusion was that this would not be feasible. A common concern with Grass Carp is that, as a non-native species, they have no natural predators and may have uncontrolled population growth crowding out native species. Another opinion expressed was that the local people would probably catch and eat the fish faster than they could be stocked. Technically, fish are feasible under controlled conditions in selected locations.

6.23 Removal by hand or mechanical management of weed growth is probably the most reasonable and feasible.

Silt Removal

6.24 Debris and soil from adjoining lands are carried into open drains by surface runoff. Silt, as defined for irrigation channels, is not found in a drain. However, a drain with debris and earth from the adjoining lands is often referred to as being aggraded or silted. The silt deposits on the bed have to be cleaned out for the efficient operation of the drain. The frequency of silt clearance depends upon the class of the drain and the design objective. Storm water drains may be allowed to silt up to a considerable extent. It may only be necessary to remove silt when the drain is no longer capable of conveying the discharge it was designed to carry. In Figure 6.9 the drain appears to have ample hydraulic capacity, but silt has accumulated to the extent that the present bed is nearly level with the surrounding land. This condition may result in waterlogging the adjoining land.

6.25 For seepage drains, every inch of silt accumulated on the bed reduces efficiency. When the depth of accumulated silt is 12 to 18 inches, the silt should be removed.

6.26 Most seepage drains have a cunette section. The cunette width established for each drain is based on the anticipated seepage water discharge. The depth, as well as the width, should be maintained.

6.27 If the seepage water runs more than two feet deep, then efficient silt clearance cannot be done by manual labour and a mechanical excavator is needed. On the other hand, the machine may not be efficient nor economical for depths less than 18 inches of silt clearance. The relative advantages of manual labour and mechanical excavation must be considered. Silt removal by hand is shown in Figure 6.10 and a drain being cleaned by excavator along with a drain cleaned with dragline is shown in Figure 6.11. A schedule for mechanical excavation of silt from drains should be programmed for at least two and preferably three years and updated annually. The revised schedule should be submitted to the Superintending Engineer in April to arrange for work to commence in October.

Sloughing Drain Banks

6.28 A method to repair sloughed drain banks is to flatten the side slopes to one (vertical) in four (horizontal) or one in five. This can only be done where sufficient land width is available. Redesign of section may allow narrowing the bed and flattening the slopes within the existing right-of-way.

6.29 Staking and bushing is both expensive and of limited application. Figure 6.12 shows the placement of stakes and bushes to collect silt or fill a section of damaged drain bank. With a lot of hand labour available, the staking and bushing approach will solve the problem for the short term. But if the drain is cleared of silt by a mechanical excavator, the staking and bushing will probably be disturbed or destroyed by the machine. In practice, some of the voided area may be filled with earth as shown in Figure 6.12.

6.30 Another method of bank repair is to fill the voided area with earth sections, referred to as, "Gatchie pitching". Pitching the side slopes with large divots of berm earth from nearby irrigation channels is easier requiring less time and effort than staking and bushing but has obvious limitations.

6.31 Bank sloughing can be remedied by intercepting the water a few feet away from the top of slope (5 or 10 feet) by installing a horizontal subsurface pipe drain parallel to the open drain at an elevation approximately 1.0 to 1.5 feet above the low flow level in the open drain. The horizontal drain will intercept the soil water moving toward the open drain as shown in Figure 6.13. The water that is collected by the horizontal drain should be directed to the open drain using a gravity outlet at approximate intervals of one half mile to one mile. Depending on soils and local experience, the horizontal drain may need to be placed in a sand-gravel envelope. It is recognized that this alternative may be relatively expensive.

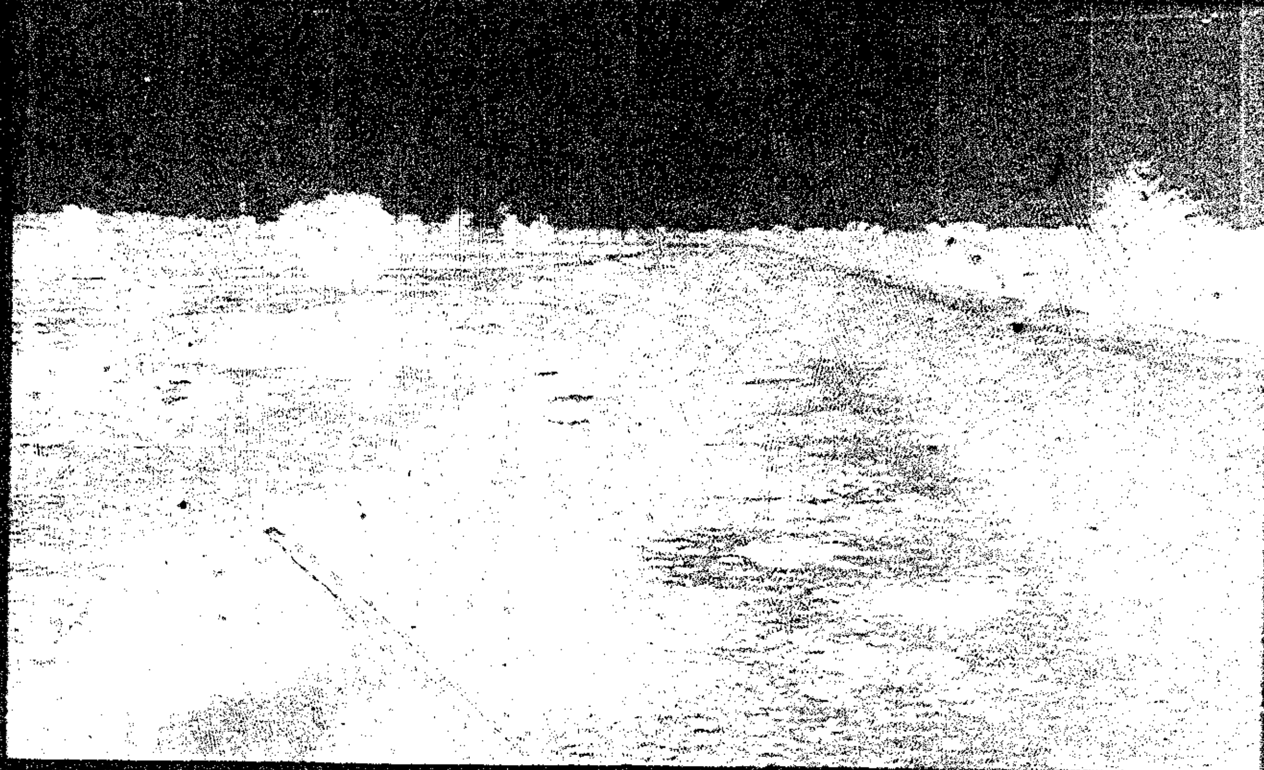

Figure 6.9. Open drain with silt accumulation.

Figure 6.10. Silt removal by hand.

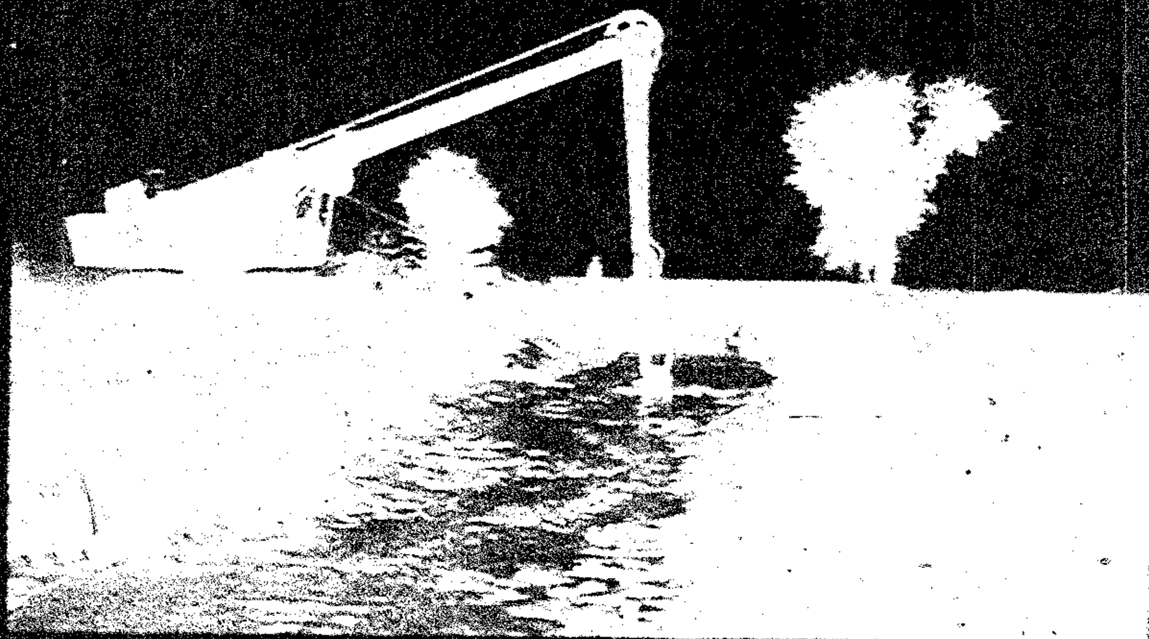

Figure 6.11. Drain maintenance - by excavator (above), by dragline (below).

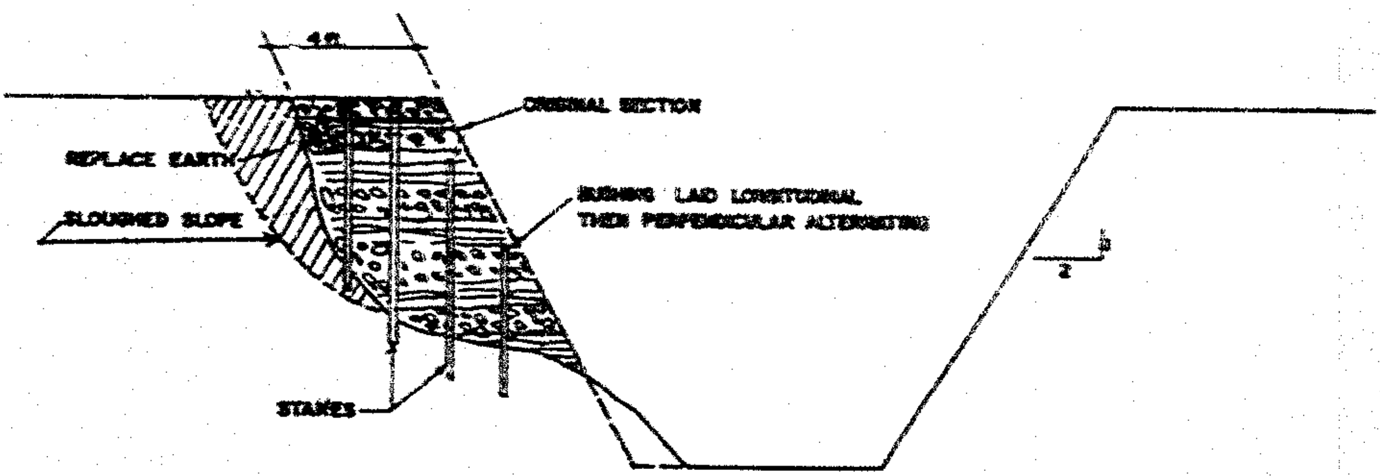

Figure 6.12. Repair of bank sloughing by staking and bushing.

Rain Cuts

6.32 Filling rain cuts by placing and compacting earth is important to maintain the cross section. The cause of the damage should also be considered and corrected. This may mean providing additional surface water inlets or routing surface water to the inlets in place.

Maintaining Banks, Service Roads, and Spoil Areas

6.33 Special attention should be given to [illegible]ng reaches of banks, roadway and spoil deposits, as needed, to maintain the design objectives. A common objective is managing out-of-bank flood flows, as well as controlling the direction of surface water runoff. It is important to insure that normal floods will not breach the bund or spoil and that the surface water inlets are working properly. Filling, compacting, and smoothing the soil should be done in a manner that meets the original design requirements.

6.34 Maintaining service roads is very important. The roadway needs to be inspected frequently and kept in condition for use, as needed. This may require filling depressions and rain cuts occasionally, with more frequent smoothing.

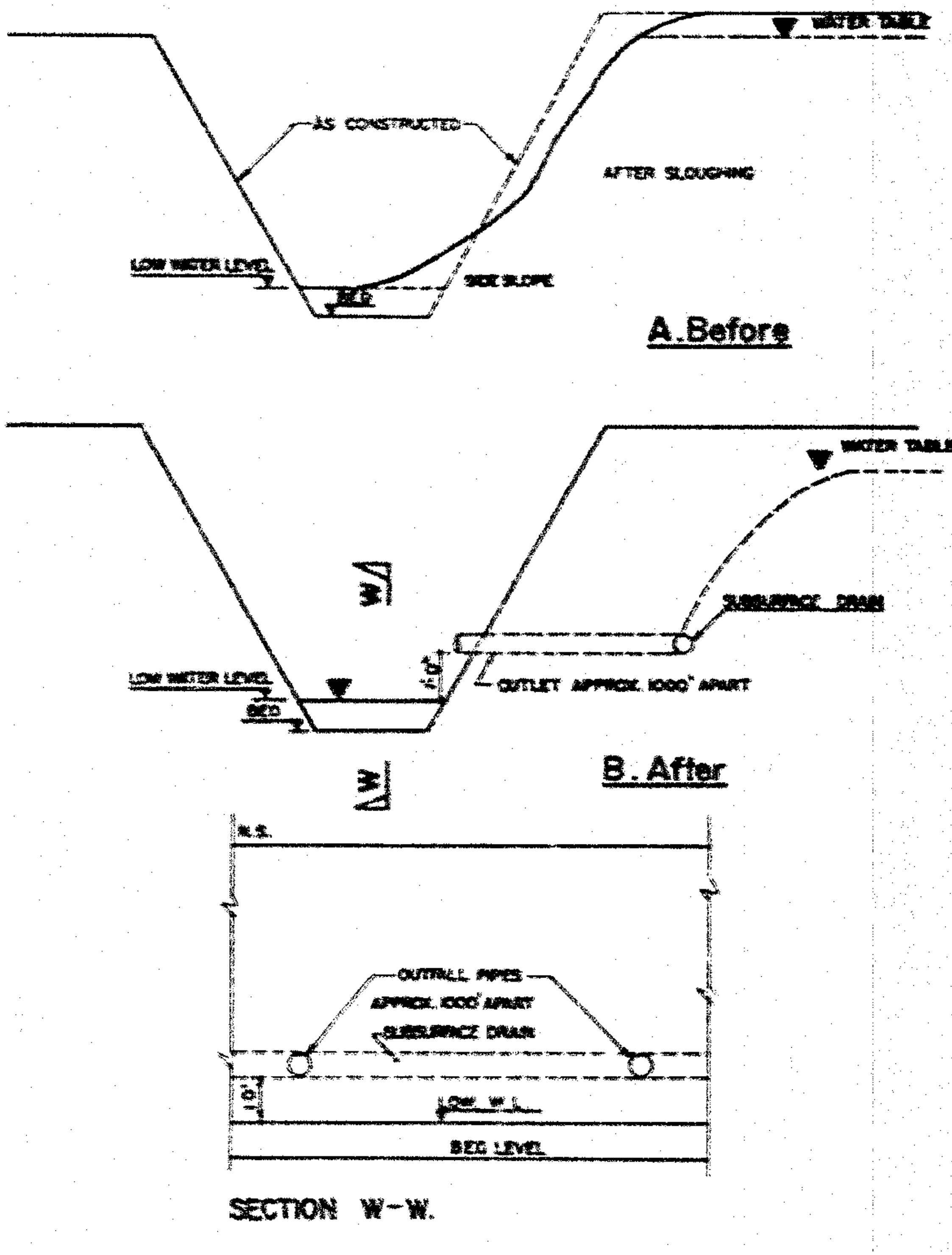

Figure 6.13. Repair of bank sloughing with horizontal drain.

Structures

6.35 It is very important to give specific attention to examining the condition of bridges and other structures during routine inspections to determine if repair is needed and to what extent.

6.36 Distance markers are rarely damaged but repainting them is frequently needed.

6.37 Surface water inlet structures often need masonry repair and filling of eroded banks around them.

6.38 Water crossing structures should be examined for damages to masonry components, including supports. If supports are in jeopardy because of bed degradation, then grade stabilization structures, such as a bed bar (Fig. 6.14), should be used. A bed bar is composed of rock or rock and masonry to control channel degradation. The depth of footer c.: distance between bed bars is dependent on local site conditions. Repairs should be provided quickly to prevent future deterioration. Pipe or flume sections may need replacement.

6.39 Pumping plants are important components of some drainage systems. As mentioned under planning and design, an operation and maintenance plan should be developed for major structures to provide guidance for operating and maintaining them. Each plan needs to be very specific for the particular types of structures and systems. Note under "History" the items that should be included in frequent monitoring reports.

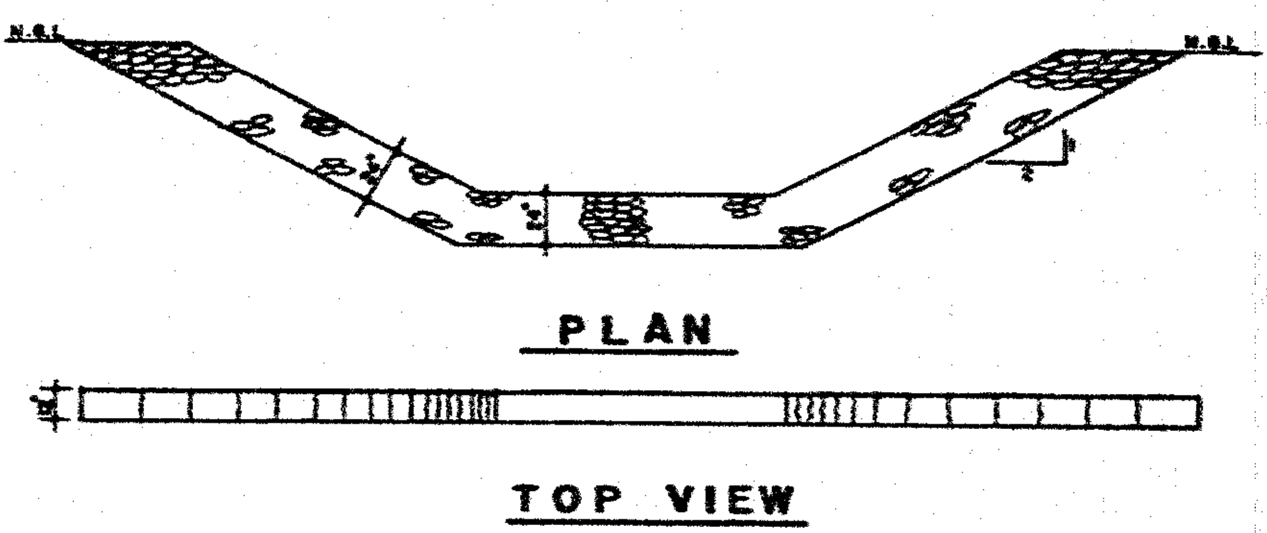

Figure 6.14. Bed bar.

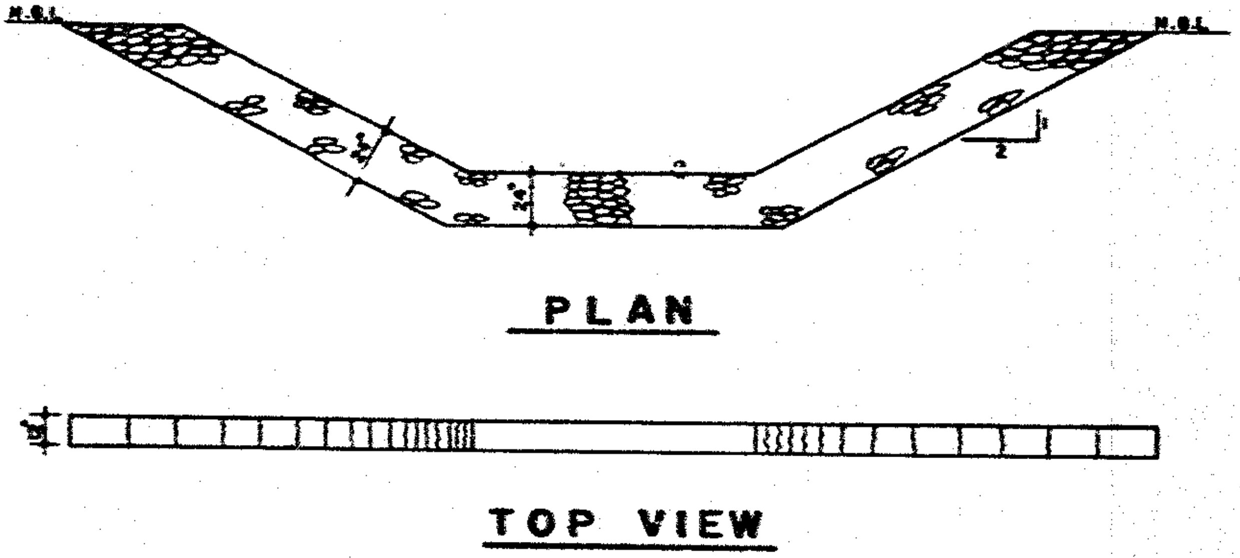

Figure 6.14. Bed bar.

Instructions and Criteria

6.40 Detailed operation and maintenance plans are needed for major structures, including pumping plants, two way gates, and other facilities that are not self- operating. The plans should be developed during the planning stage and modified, if needed, during the design and construction stages. All open drains need to be maintained in accordance with the general guidance in this manual.

Monitoring and Evaluation

6.41 There should be up-to-date detailed records of each drain commencing from its conception. A major responsibility of the owner is to monitor the drainage system to anticipate needed maintenance and repairs.

6.42 The original detailed record (history) and subsequent additions should be prepared and submitted to the Chief Engineer for approval before distributing the report. Each copy of the history should be in a laced file. The copy supplied for record in the Secretariat should have the plans on tracing cloth, while prints will suffice for the other copies. Copies should be supplied to the Superintending Engineer of the Drainage Circle and to each Division and Subdivision with responsibility for the drain. Where a drainage circle does not exist, then copies should go to the concerned Superintending Engineer.

Periodic Review

6.43 Review the entire drain system after each significant flow and on an annual basis. The report of periodic reviews will become part of the history of the system. A short note for each subsequent year should be written giving capital expenditure and general remarks regarding functioning of the drain and any other pertinent information. Remarks, such as the necessity for repairs and construction of additional inlets, should be recorded. These annual additions should be issued by the Superintending Engineer to all officers possessing a copy of the original history.

6.44 During periodic reviews, the evidence of untreated industrial or urban waste water should be noted. Other agencies, including EPA, are to be informed and appropriate follow up action taken to correct the problem. In Figure 6.15 note the colour of the waste water entering the drain.

History

6.45 A procedure for documenting the original and continuing history of a drainage system is:

A. Narrative description of the drainage areas prior to construction of the drainage system. This should contain a brief description of the conditions prevailing at the time of planning and inspection of the drain. Reference should be made to prevalence of salinity and waterlogging, also the depth of subsoil water table, normal flooding from rain and any other factors indicating the need of the drainage system.

The planned objectives for the drain should be stated.

Indicate the planned and the constructed conditions for lowering the water table, altering wetlands, reclaiming salinised land, or public health improvements with reference to the particular villages involved.

B. Technical discussion containing brief notes on:

1. Alignment of the drain as finally accepted, with reference to previous proposals and reasons for the selected alignment over other alternatives considered.

2. Capacity of drain and reasons therefor.

Figure 6.15. Waste water entering drain.

3. Notes on long section, e.g. identifying low points or control elevations for the bed.

4. Type of cross section adopted and reasons for selecting side slopes.

5. Any special features in design of structures.

6. Notes on peculiar difficulties experienced during construction and how they were overcome.

7. A complete and accurate record of pumping plant features, such as: name of pumping station, type of pump, type of motor, make of motor and pump, total suction head, number and capacity of pumps, number of stages, power size of motor, R.P.M., transformer with load.

C. Plans to accompany the History

1. Index plan (tracing), usually at a scale of one inch equals one mile, showing:

a. Contours
b. Drain alignment with R.D's.
c. Important alternative alignments that were considered and rejected.
d. Village and district boundaries
e. Position of important structures
f. Irrigation channels
g. Important roads
h. Railways
i. Boundaries of catchment area
j. Rain gauge stations

2. As-built long-sections (tracing) to the vertical scale 1/100 for deep drains and 1/50 for shallow drain showing:

a. R.D's
b. N.S. levels
c. Bed levels
d. Maximum designed W.S. level
e. Designed discharge
f. Catchment area
g. Bed width

h. Gradient of the channel
i. Subsoil water level with date
j. Position and sketches of masonry works
k. Datum and reference bench marks

3. For old drains only, which have been remodelled after construction, a tracing of the long section on which the original and subsequent designs of the drain are shown in distinctive colours.

4. One tracing sheet showing representative cross sections of the drain as constructed.

D. During monitoring of drain after construction, the following items should be recorded annually:

1. Cost and description of maintenance needed and performed.

2. Statement of flooded areas.

3. Statements of benefits to the land derived from the drain. The collective records of the villages should be used first.

E. For monitoring pumping plant system, the following information should be reported monthly:

1. Name of system
2. Number of pumps
3. Type and capacity of pumps
4. Working hour of each pump
5. Pumped volume (ac. ft.)

Gauging of Drains

6.46 All official discharge sites should be pitched or made as part of structures for crossings or grade control. A typical gage site is shown in Figure 6.16. Consideration should be given to the following:

1. The side slope should be laid at the existing side slope of the drain.

2. There should be a pacca drop wall or cutoff one foot deep both upstream and downstream of the discharge station structure.

3. A pacca rib 0.65 feet thick is required at each end of the side slope pitching.

4. The overall length of the discharge structure should be 20 to 40 feet.

5. R.L. of the bed of the discharge structure or bed bar should be at the same elevation as the designed bed.

Figure 6.16. Typical gauge site.

6.47 Where discharge observations will be required in a reach of drain with widely varying cross sections, the side slope pitching should conform to the particular section of the drain at the selected discharge site. This will help establish steady uniform flow conditions.

6.48 Proper location of a gauge is very important. A gauge should be far enough back from an outfall to minimize the effect of either backwater, or low water level in the outfall.

6.49 Discharge measuring sites with flow above the natural surface level should be avoided where possible. If such a site is selected, then a combination of the observation methods discussed in the next section should be adopted for the site.

6.50 Automatic recording gauges are recommended, but the location and number of gauges need serious consideration as their installation and replacement costs may be quite expensive. Also, these gauges require a high level of service and maintenance and considerable effort is required to analyze the data recorded.

6.51 A practical gauge previously used in Pakistan to record the maximum flood water level attained may still be used. This gauge consists of a wooden rod placed between a steel plate and an enamel iron gauge. The wooden rod has a square cut every 0.2 foot in which a ball made of a mixture of clay and sand is placed. The balls disintegrate when submerged as the flood water rises. The last ball dissolved indicates the height of maximum flood. The enamel iron gauge can be read directly, but the reader must be present at the time of flood flow. With this gauge, care must be taken that the gauge reader replaces all dissolved balls.

Discharge Observations of Drains

6.52 The objective of observing discharge of drains is to acquire data regarding the runoff from various types of catchment areas in various parts of the country. Detailed annual data exists for many drainage projects. Such runoff data are beneficial in evaluating and refining surface runoff procedures in Chapter 3, especially if data are consistently acquired and recorded each year. For additional information on this subject refer to the Hydraulic and Sediment Monitoring Manual for Provincial Irrigation Departments (USAID, 1992).

6.53 Systematic methods of observing discharges should be adopted. Pygmy current meters, if available, should be used where the velocity is less than 0.75 feet per second. Pygmy current meters are especially useful for shallow flow depths. If a pygmy meter is not available, velocity rods or floats may be used as follows:

1. Velocity rod discharge meters should be used, if the velocity is less than 0.75 feet per second and the depth is one foot or more.

2. Float discharge method should be used with a coefficient of 0.7, where the velocity is less than 0.75 feet per second and the depth is less than one foot.

6.54 Standard current meter should be used where the velocity is 0.75 feet per second or more. For standardization of discharge data, it is important that the appropriate method be adopted. For additional information refer to the Hydraulic and Sediment Monitoring Manual (USAID, 1992).

6.55 Flow measuring gauges on drains should be observed daily from June to September and other times of the year when flows are noted. If it is anticipated that flows may cause bed scour or other damage, it is very important to have gage readings. This record, together with observed discharges, should be dispatched every ten days by the Subengineer to the office of the Executive Engineer with a copy to the Subdivisional Officer.

6.56 When abnormally high floods occur, arrangements should be made to estimate peak discharge data. When drain banks may probably be breached in many places, it is advisable to carry out a hydraulic survey as soon as possible, showing the extent of the flooding and the levels it attained at various points from which the hydraulic slope can be determined and an estimate of the discharge determined. Care should be taken to correct the levels at sites where the water has been artificially headed up.

6.57 When abnormally high floods occur, water may spill over the ridge of a catchment area into another catchment that was blocked. The quantity of water collected in the overflow catchment area should be estimated as soon as possible after the flooding. Also, the duration of the ponding should be recorded in the annual drainage report. These data are to be included in the computations of the runoff from the original catchment area.

Institutional Constraints and Opportunities

6.58 The Irrigation Departments have had more experience and better success in managing the delivery of water than installing and maintaining satisfactory drainage systems. The drainage needs and maintenance of drainage systems have not had high priority status.

6.59 Operation and maintenance of drainage systems in Pakistan by the Provincial Irrigation Departments using annual budget allotments should be very effective, but in reality it has not been. Instead of adequate annual maintenance, it is often necessary to defer maintenance and perform rehabilitation later which may be much more expensive.

6.60 Annual maintenance grants quite often are much less than the maintenance needs. The drains deteriorate, becoming choked with weed growth and silt, necessitating a special repair/rehabilitation programme every five or six years at great cost. If part of the rehabilitation cost were used towards yearly maintenance, it would be more usefully spent and help keep the drains in proper operating condition throughout the operational period.

6.61 Many of the drainage systems have been planned, designed and installed by the PIDs. Some of the drainage systems may be designed by one agency, such as WAPDA, and turned over to the PIDs for maintenance. The cost of operation and maintenance should be considered along with original design and installation costs. It is especially important for coordination between WAPDA and the responsible PID on all planning and design decisions that may affect maintenance activities or needs. As discussed in Chapter 2 on planning, it is important for all directly concerned individuals, groups, or agencies, as well as some groups or individuals that are only remotely impacted by the project, to have an input into these overall decisions.

Budgets

6.62 During project planning, it is important to estimate the average, or at least minimum, annual maintenance costs and make arrangements for adequate funds to be available. It is generally much less expensive to perform minor maintenance activities annually or as soon as the need is noted. The benefits of the project drainage system can not be realized, if the drainage system is not kept in good operating condition. Decreased crop yields due to prolonged ponding and other related results from the impaired operation of the drainage system should be considered during the planning phase right through the design, installation, and operation phases.

6.63 If maintenance is not performed on a regular basis, then the total system may have to be replanned and rehabilitated. The cost of performing the rehabilitation is often more than the maintenance costs would have been, if performed in time. This cost difference may be discounted by the owner of the system as there has been rehabilitation work performed as a capital outlay rather than as a maintenance expenditure which comes under the nondevelopment budget. In reality, it takes a few years to obtain approval for capital outlays for rehabilitation of a system, during which time there will probably be additional crop and property damages incurred by the owners or farmer tenants. In summary, it should be viewed as less expensive and economically advantageous for the maintenance funds to be raised in a timely manner and the maintenance work performed as soon as the need is apparent.

6.64 For each open drain system, the yardstick for maintenance costs needs to be developed. This should be part of the planning and design process so that funding arrangement can be established for maintenance before the system is installed. Yardsticks for structures need to be developed separately. The development and annual revision of yardsticks for drainage systems have been done similarly in each PID, but individual preferences in frequency of weed or sediment removal and the unit costs are different. Since this is more of a local preference item, each PID or Drainage circle should do as they have done in the past.

REFERENCES

Aquarius Systems, P.O.Box 215, 220 N. Harrison, North Prairie, WI 53153, USA. Phone (414) 392-2162. Fax (414) 392-2984.

ASCE. 1980. Operation and Maintenance of Irrigation and Drainage Systems. ASCE Manuals and Reports on Engineering Practice # 57. American Society of Civil Engineers, 345 East 47th. St., New York, NY 10017. 265 pp.

ASCE. 1990. Agricultural Salinity Assessment and Management. Edited by Keneth K. Tanji. ASCE Manuals and Reports on Engineering Practice # 71. American Society of Civil Engineers, 345 East 47th. St., New York, NY 10017. 619 pp.

Botman B.V. Oosterwijzend 1, 1616 LE Hoogkarspel Nederland. Phone 02286-4353. Fax 02286-4393.

Engineering & Hire Ltd. Marsh Lane, Laughterton, Lincoln, England, LN1 2JX. Telephone (0427) 71561/718019. Fax (0427) 718016.

ERS. 1987. Farm Drainage in the United States: History, Status and Prospects. Edited by George A. Pavelis. Misc. Publ. No. 1455, USDA, Economic Research Service, Washington, DC. 170 pp.

Gowing, John W., and Guido C. L. Wyseure. 1992. Dry Drainage: A Sustainable and Cost-Effective Solution to Waterlogging and Salinisation. Proceedings of 5th International Drainage Workshop. Lahore Pakistan, Feb. 8-15, 1992. Edited by W. F. Vlotman, Program Chairman was F. A. Zuberi, Director General, International Waterlogging & Salinity Research Institute. Published by WAPDA and ICID/CIID, Vol. III pp. 6-26 to 6-34.

Herder B.V., Postbus 8010, Herculesweg 6. 4330 EA Middelburg, The Netherlands. Phone 01180-29356. Fax 01180-38730.

IWASRI/NRAP. 1990. HEC-1 Model Oriented Rainfall-Runoff Relationship for Awagat Branch Drain. Muhammad Naveed Khaliq, and Willem F. Vlotman. January 1992. NRAP REPORT No. 31. International Waterlogging and Salinity Research Institute, WAPDA, Lahore, Pakistan. 66. pp.

Linsley, R.K.Jr., M.A. Kohler, and J.L.H. Paulhus. 1958. Hydrology for Engineers. McGraw Hill. (SI Metric Edition. 1988)

NESPAK, Mott MacDonald. 1991. Pakistan Sectorial Environmental Assessment (National Drainage Program). Working Paper No. 1, History of Land Drainage in Pakistan, 1851/1991. 60 pp.

OFWM. 1991. On Farm Water Management Programme Punjab. Review of Progress 1990 - 1991. Directorate General On Farm Water Management Punjab, 21 Sir Agha Khan Soyyam Road, Lahore. 55 pp.

OFWM. 1986. On Farm Water Management Field Manual, Volume II, Precision Land Levelling. Director General, Water Management Wing, Ministry of Food, Agriculture & Cooperative, Government of Pakistan, 14 N. Riaz Plaza, F 8 Markaz, Islamabad. 40 pp.

PWD PAKISTAN. 1961. A Manual of Irrigation Practice, Chapter 12 -Drains, 2nd Edition, 1961. Public Works Department, Irrigation Branch, Government of West Pakistan

SCS. 1969. Engineering Field Manual, Chapter 14, "Drainage", USDA Soil Conservation Service, P.O.Box 2890, Washington, DC 20013. 111 pp.

SCS. 1971. Drainage of Agricultural Land. National Engineering Handbook, Section 16. USDA, Soil Conservation Service, P.O.Box 2890, Washington, D.C. 20013. 410 pp.

SCS. 1977. Design of Open Channels. Technical Release # 25 (TR-25). USDA, Soil Conservation Service, P.O.Box 2890, Washington, D.C. 20013. 258 pp.

SCS. 1985. Hydrology. National Engineering Handbook, Section 4. USDA Soil Conservation Service, P.O.Box 2890, Washington, DC 20013. 400 pp.

SCS. 1986. Urban Hydrology for Small Watersheds. TR-55, USDA Soil Conservation Service, P.O.Box 2890, Washington, DC 20013. 141 pp.

SCS. 1990. Engineering Field Manual, Chapter 2, Estimating Runoff and Peak Discharges. USDA Soil Conservation Service, P.O.Box 2890, Washington, DC 20013. 91 pp.

USAID. 1992. Hydraulic and Sediment Monitoring Manual for Provincial Irrigation Departments. July 1992. ISM II Project. Harza Engineering, Development Alternatives Inc., Associated Consulting Engineers. Published by United States Agency for International Development (USAID), Washington DC. 124 pp.

USACE. 1990. HEC-1 Flood Hydrograph Package: User's Manual. Haestad Methods Civil Engineering Software, Waterbury, CT 06708, USA. pp. 283.

USBR. 1984. DRAINAGE MANUAL. U.S. Dept. of Interior, Bureau of Reclamation, Engineering and Research Center, P.O.Box 25007, Denver, CO 80225-0007. 286 pp.

USCID. 1989. Toxic Substances in Agricultural Water Supply and Drainage. Proceedings of the Second Pan-American Regional Conference on Irrigation and Drainage. Ottawa, Canada, June 8-9, 1989. Published by the U.S. Committee on Irrigation and Drainage, P.O. Box 15326, Denver, CO 80215, USA. 424 pp.

WAPDA. 1963. Indus Basin Project Link Canals, Design Methods and Data, Chapter 12. Surface Drainage. Prepared by Tipton and Kalmbach, Engineers, Inc. August 29, 1963. West Pakistan Water and Power Development Authority, Lahore, Pakistan. 63 pp.

WAPDA. 1988. Fourth Drainage Project, Faisalabad. Prepared by Sir M. MacDonald & Partners Ltd., Demeter House, Cambridge CB1 2RS, United Kingdom. 51 pp.

WAPDA. 1991. Lower Indus Region Study for Right Bank Master Plan., Supplement S6.3, Dry Drainage. Mott MacDonald International Limited, and Hunting Technical Services Limited. Hemel Hemstead, UK. May 1991. 33 pp.

Wisler, C.O., and E.F. Brater. 1959. Hydrology, 2nd Edition' John Wiley & Sons, Inc. pp 86-91.

Zaidi, Monsoob A., Haroon Shami, and M. Mehdi Zaidi. 1990. Maintenance of Drainage Systems. Published in the Proceedings of the Pakistan Engineering Congress, Paper 180, Volume 22, 1990. pp 149-164.

APPENDIX A

THE CANAL AND DRAINAGE ACT 1873
THE CANAL & DRAINAGE ACT (VIII OF 1873)

An Act to regulate Irrigation, Navigation and Drainage.

Preamble: WHEREAS throughout the territories to which this Act extends, the (Provincial Government) is entitled to use and control for public purposes the water of all rivers and streams flowing in natural channels, and of all lakes, (subsoil water) and other natural collection of still water; and whereas it is expedient to amend the law relating to irrigation, navigation and drainage in the said territories; it is hereby enacted as follows:

PART I

PRELIMINARY

1. Short title: (1) This Act may be called the Canal and Drainage Act, 1873.

(2) Local extent: It extends to the Punjab and applies to all lands whether permanently settled, temporarily settled, or free from revenue.

Extended to the Divisions of Quetta & Kalat except Tribal Areas & III Lora Canal of Bannu District & area irrigated by Rohri Canal.

(3) Commencement: It shall come into force at once.

3. Interpretation clause: In this Act, unless there be something repugnant in the subject or context:-

(1) "Canal" includes, -

(a) All canals, channels, (tube-wells) and reservoirs constructed, maintained, or controlled by the Provincial Government for the supply or storage of water.

(b) All works, embankments, structures, supply and channel or reservoirs;

(c) All water-courses as defined in the second clause of this section;

(d) All parts of a river, stream, lake or natural collections of water or natural drainage channel, to which the Provincial Government has applied the provisions of Part II of this Act, (but does not include a Kareze not constructed at the cost of the Provincial Government or the contribution of the Provincial Government in the construction where of does not exceed rupees ten thousand; and not maintained or controlled by the Provincial Government).

(3)"Drainage work" includes escape-channels from canal, dams, weirs, embankments, sluices, drains and other works for the protection of lands from flood or from erosion, formed or maintained by the Provincial Government under the provisions of Part VII of this Act, but does not include works for the removal of sewerage from town;

17. Provincial Government to provide means of crossing canals: There shall be provided, at the cost of the Provincial Government, suitable means of crossing canals constructed or maintained at the cost of the Provincial Government, at such places as the Provincial Governments thinks necessary for the reasonable convenience of the inhabitants of the adjacent lands.

On receiving a statement in writing, signed by not less than five of the owners of such lands, to the effect that suitable crossings have not been provided on any canal, the Collector shall cause enquiry to be made into the circumstances of the case, and if he thinks that the statement is established, he shall report his opinion thereon for the consideration of the Provincial Government, and the Provincial Government shall cause such measure in reference thereto be taken as it thinks proper.

55. Power to prohibit obstruction or order their removal: Whenever it appears to the Provincial Government that injury to any land or the public health or public convenience has arisen or may arise from the obstruction of any river, stream or drainage-channel, such Provincial Government, may by notification published in the Official Gazette, prohibit, within limits to be defined in such notification, the formation of any obstruction, or may, within such limits, order the removal or other modification of such obstruction.

Thereupon so much of the said river, stream or drainage channel as is comprised within such limits shall be held to be a drainage-work as defined in Section 3.

56. Power to remove obstruction after prohibition: The Divisional Canal Officer, or other person authorised by the Provincial Government in that behalf, may, after such publication issue an order to the person causing or having control over any such obstruction to remove or modify the same within a time to be fixed in the order.

If, within the time so fixed, such person does not comply with the order, the said Canal Officer may himself remove or modify the obstruction and if the person to where the order was issued does not, when called upon, pay the expenses involved in such removal or modification, such expenses shall be recoverable by the Collector from him or his representative-in-interest as an arrear of land-revenue.

57. Preparation of schemes for works of Improvement: Whenever it appears to the Provincial Government that any drainage works are necessary for the improvement of any lands, or for the proper cultivation or irrigation thereof;

Or that protection from floods or other accumulation of water, or from erosion by a river, is required for any lands;

The Provincial Government may cause a scheme for such drainage works to be drawn up and published together with an estimate of its cost and a statement of proportion of such cost which the Provincial Government proposes to defray and a schedule of the land which it is proposed to make chargeable in respect of the scheme.

59. *(Rate on Land benefitted by works: An annual rate, in respect of such schemes, maybe charged according to rules to be made by the Provincial Government, on the owners of all lands which shall, in the manner prescribed by such rules, be determined to be as chargeable:

Provided that in the case of agricultural land, no such rate shall be charged for the first two harvests immediately following the completion of scheme).

Legislative Amendment:

*Substituted by Canal & Drainage (West Pakistan Second Amendment) Act IV of 1970.

61. Disposal of claims to compensation: Whenever, in pursuance of a notification made under Sec. 55, any obstruction is removed or modified;

Or whenever any drainage work is carried out under Sec. 57;

All claims for compensation on account of any loss consequent on the removal or modification of the said obstruction or the construction of such work may be made before the Collector, and he shall deal with the same in the manner provided in Sec. 10.

62. Limitation of such claims: No such claim shall be entertained after the expiration of one year from the occurrence of the loss complained of, unless the Collector is satisfied that the claimant had sufficient cause for not making the claim within such period.

70. Offences under the Act: Whoever, without proper authority does any of the following acts, that is to say:-

(1) cuts through, pierces, damages, alters, enlarges or obstructs any canal or canal outlet or drainage work;

(2) interferes with, increases or diminishes the supply of water in, or the flow of water from, through, over or under any canal or drainage work, or by any means raises or lowers the level of the water in any canals;

(3) interferes with or alters the flow of water in any river or stream, so as the endanger, damage or render less useful any canal or drainage work;

(4) makes any dam or obstruction for the purpose of diverting or opposing the current of a river on the bank whereof there is a flood embankment or refuses or neglects to remove any such dam or obstruction when lawfully required so to do;

(5) prevents or interferes with the lawful use of a water-course by any person authorised to use the same;

(6) being responsible for the maintenance of a water-course, or using a water-course, neglects to take proper precautions for the prevention of waste of the water thereof, or interferes with the authorised distribution of water therefrom, or uses such water in an unauthorised manner;

(7) dismantles water-course, or internal khal thereby interrupting or obstructing the irrigation of the land of another person;

(8) corrupts or fouls the water of any canal so as to render it less fit for the purpose for which it is ordinarily used;

(9) causes any vessel to enter or navigate any canal contrary to the rules for the time being prescribed by Government for entering or navigating such canal;

(10) while navigating on any canal, neglects to take proper precautions for the safety of the canal and of vessels thereon;

(11) neglects, without reasonable cause, to assist or to continue to assist in supplying the labourers required of him or being a labourer to supply his labour for the execution of any work, when lawfully so bound to do under part VII of this Act;

(12) destroys, defaces or moves any land or level mark rain-gauges or water-gauge fixed by a public servant;

(13) destroys, tampers whit or removes any apparatus, or part of any apparatus for hydrological observations or for controlling, regulating or measuring the flow of water in any canal, river or stream;

(14) passes or causes animals or vehicles to pass on or across any of the works, banks or channels of a canal or drainage work contrary to rules made under this Act;

(15) causes or knowingly and wilfully permits cattle to graze upon any canal or drainage work or tethers or knowingly and willingly permits cattle to be tethered upon any such canal or drainage work, or uproots grass or other vegetation growing on any such canal or removes, cuts or in any way injures or causes to be removed cuts or otherwise injures any tree, bush, grass or hedge intended for the protection of such canal or drainage work;

(16) makes or in any manner voluntarily abets the making of an encroachment of any kind within the limits of a canal or drainage work, or refuses or neglects to remove any such encroachment when so required to do by Canal Officer, or

(17) violates any rules made under this Act, for breach whereof a penalty may be incurred;

shall be liable, on conviction before a Magistrate of such class as the Provincial Government directs in this behalf, to a fine not exceeding two hundred rupees or to imprisonment not exceeding three months or both.

(2) Whenever any person is convicted under this section the convicting Magistrate may order that the cost as certified by the Sub-Divisional Canal Officer for removal of the obstruction or repairing the damage in respect of which the conviction is held, shall be payable by him; an if such person neglects or refuse to obey such order within the period to be fixed, the cost of such removal or repair shall be recoverable from such person by the collector as arrears of land revenue.

APPENDIX B

THE SINDH IRRIGATION ACT 1879

(SINDH ACT NO.VII OF 1879)

An Act to provide for Irrigation in the (Province of Sindh).

WHEREAS it is necessary to make provision for the construction, maintenance and regulation of canals for the supply of water there from made for the levy of rates for water so supplied, in the (Province of Sindh); It is enacted as follows:-

PART I

1. This Act may be called the (SINDH) Irrigation Act, 1879.

It extends to the whole of the (Province of Sindh).

3(1) "canal" includes -

(a) all canals, channels, tubewells, pipes and reservoirs constructed, maintained or controlled by (any Government) for the supply or storage of water;

(b) All works, embankments, structures and supply and escape-channels connected with such canals, channels, pipes or reservoirs, and all roads constructed for the purpose of facilitating the construction or maintenance of such canals, channels, pipes or reservoirs;

(c) all water-courses, drainage-works and flood embankments as hereinafter respectively defined;

(d) any part of a river, stream, lake, sub-soil water, natural collection of water or natural drainage-channel, to which the (Provincial Government) may apply the provisions of section 5, or which the water has been applied or used before the passing of this Act for the purpose of any existing canal;

(e) all land belonging to (the Crown) which is situated on a bank of any canal as hereinbefore defined, and which has been appropriated under the orders of (any Government) for the purposes of such canal;

3(3) "drainage-work" means any work in connection with a system of irrigation or reclamation made or improved by (any Government) for the purpose of the drainage of the country, whether under the provisions of section 15 or otherwise, and includes escape-channels from a canal, dams, weirs, embankments, sluices, groins and other works connected therewith, but does not include works for the removal of sewage from towns;

7. Whenever it shall be necessary to make, any inquiry or examination in connection with a projected canal, or with the maintenance, of an existing canal, any Canal-Officer duly empowered in this behalf, and any person acting under the general or special order of any such Canal-Officer, may:-

(a) enter upon such land as he may think necessary for the purpose, and

(b) exercise all powers and do all things in respect of such land as he might exercise and do if (the Provincial Government) had issued a notification under the provisions of section 4 of the Land Acquisition Act, 1870, to the effect that land in that locality is likely to be needed for a public purpose, and

(c) set up and maintain water-gauges and do all other things necessary for the prosecution of such inquiry and examination.

8. Any Canal-Officer duly empowered in this behalf, and any person acting under the general or special order of any such Canal-officers, may enter upon any land, building or water-course, on account of which any water rate is chargeable, for the purpose of inspecting or regulating the use of the water supplied or of measuring the land irrigated thereby or chargeable with a water-rate, and of doing all things necessary for the proper regulation and management of the canal from which such water is supplied.

9. In case of any accident being apprehended or happening to a canal, any Canal-officer duly empowered in this behalf, and any person acting under the general or special order of any such Canal-officer, may enter upon any land adjacent to such canal, and may take trees and other materials, and execute all works which maybe necessary for the purpose of preventing such accident or repairing any damage done.

10. When a Canal-officer or other person proposes, under the provisions of any of the three last preceding sections, to enter into any building or enclosed court or garden attached to a dwelling house, not supplied with water from a canal, and not adjacent to a flood-embankment, he shall previously give to the occupier of such building, court or garden such reasonable notice as the urgency of the case may allow.

Canal Crossings

11. Suitable means of crossing canals shall be provided at such place as the (Provincial Government) (or (any Commissioner if empowered by (the Provincial Government) in this behalf) thinks necessary for the reasonable convenience of the inhabitants of the adjacent

land; and suitable bridges, culverts or other works shall be constructed to prevent the drainage of the adjacent land being obstructed by any canal.

Removal of Obstructions to Drainage

12. Whenever it appears to the (Provincial Government) that injury to the public health, or public convenience,or to any canal or to any land for which irrigation from a canal is available has arisen or may arise from the obstruction of any river, stream or natural drainage course, the (Provincial Government) may, by notification published in the (Official Gazette), prohibit, within limits to be defined in such notification, the formation of any such obstruction or may, within such limits, order the removal or other modification of such obstruction.

Thereupon so much of the said river, stream or natural drainage channel, as is comprised within such limits, shall be held to be a drainage work as defined in section 3.

Construction of Drainage works

15. Whenever, it appears to the (Provincial Government) that any drainage work is necessary for the public health or for the improvement of the proper cultivation or irrigation of any land, or that protection from floods or other accumulations of water, or from erosion by a river, is required for any land, the (Provincial Government) may cause a scheme for such work to be drawn up and carried into execution, and the person authorized by the (Provincial Government) to draw up and execute such scheme may exercise in connection therewith the powers conferred on Canal Officers by sections 7, 8 and 9, and shall be liable to the obligations imposed upon Canal officers by sections 10 and 34.

Summary Decisions

34. In every case of entry upon any land or building under section 6, section 7, section 8 or section 9, the Canal-officer or person making the entry shall ascertain and record the extent of the damage, if any, caused by the entry, or in the execution of any work, to any crop, tree, building or other property,
and within one month from the date of such entry compensation shall be tendered by a Canal-officer duly empowered in this behalf to the landholder or owner of the property damaged.

If such tender is not accepted the Canal-officer shall forthwith refer the matter to the Collector for the purpose of making inquiry as to the amount of compensation and deciding the same.

APPENDIX C

THE BALUCHISTAN CANAL AND DRAINAGE ORDINANCE, 1980

THE BALUCHISTAN GAZETTE
PUBLISHED BY AUTHORITY

NO. 241 QUETTA WEDNESDAY DECEMBER 10, 1980

GOVERNMENT OF BALUCHISTAN
LAW DEPARTMENT

NOTIFICATION
Dated Quetta, the 10th December, 1980.

No. Legis, 1-54/Law/80. The following ordinance made by the Governor of Baluchistan on 3rd December, 1980, is hereby published for general information:-

BALUCHISTAN ORDINANCE No. XX OF 1980.

THE BALUCHISTAN CANAL AND DRAINAGE ORDINANCE, 1980.
AN
ORDINANCE

to regulate Irrigation, Navigation and Drainage.

PART-I
PRELIMINARY

1. (1) This Ordinance may be called the Baluchistan Canal and Drainage Ordinance, 1980.

(2) It extends to the whole of the Province of Baluchistan, except the tribal areas.

(3) It shall come in force at once.

2. In this Ordinance, unless there be something repugnant in the subject or context:-

(1) "Canals" includes:-

(a) all canals, channels, tube-wells and reservoirs constructed, maintained, or controlled by the Provincial Government for the supply or storage of water;

(b) all works, embankments, structures, supply and escape channels or reservoirs;

(c) all water-courses as defined in the sub-section(2) of this section;

(d) all parts of a river, stream, lake or natural collection of water or natural drainage, channel, to which the Provincial Government has applied the provisions of Part II of this Ordinance, but does not include a Kareze not constructed at the cost of the Provincial Government and not maintained or controlled by the Provincial Government or in the construction of which the contribution of the Provincial Government does not exceed rupees ten thousand;

(2) "Water-course" means any channel which is supplied with water from a canal, but which is not maintained at the cost of the Provincial Government and subsidiary works belonging to any such channel;

(3) "Drainage-work" includes , escape-channels from a canal dams, weirs, embankments, sluices, grains and other works for the protection of lands from flood or from erosion, formed or maintained by the Provincial Government under the provisions of Part VII of this Ordinance, but does not include works for the removal of sewerage from towns;

PART-VII
OF DRAINAGE

50. Whenever it appears to the Government that injury to any land or the public health or public convenience has arisen or may arise from the obstruction of any river, stream or drainage-channel, such Government, may by notification publish in the Official Gazette, prohibit, within limits to be defined in such notification, the formation of any obstruction, or may, within such limits, order the removal or other modification of the such obstruction.

Thereupon so much of the said river, stream or drainage channels as is comprised within such limits shall be held to be drainage work as defined in section 2.

51. The Divisional Canal Officer or other person authorized by the Government in that behalf, may after such publication issue an order to the person causing or having control over any such obstruction to remove or modify the same within a time to be fixed in the order.

If, within the time so fixed, such person does not comply with the order, the said Canal Officer may get the obstruction removed or modified; and if the person to whom the order was issued does not, when called upon, pay the expenses involved in such removal or modification, such expenses shall be recoverable by the Collector from him or his representative in interest as an arrear of land-revenue.

Appendix C

52. Whenever it appears to the Government that any drainage works are necessary for the improvement of any lands, or for the proper cultivation or irrigation thereof, or that protection form floods or other accumulation of water, or from erosion by a river, is required for any lands;

The Government may cause a scheme for such drainage works to be drawn up and published together with an estimate of its cost which the Government proposes to defray and a schedule of the lands which it is proposed to make chargeable in respect of the scheme.

53. The person authorized by the Government to draw up such scheme may exercise all or any of the powers conferred on the Canal Officer by section 10;

54. An annual rate, in respect of such schemes may be charged, according to rules to be made by the Government, on the owners of all lands which shall, in the manner prescribed by such rules, be determined to be so chargeable,

Provided that in the case of agricultural land no such rate shall be charged for the first two harvests immediately following the completion of the scheme.

55. Any such drainage rate may be collected and recovered in the manner provided by section 40, 41 and 42 for the collection and recovery of water-rates.

56. Whenever, in pursuance of a notification made under section 50 any obstruction is removed or modified;

or whenever any drainage-work is carried out under section 52;

all claims for compensation on account of any loss consequent on the removal or modification of the said obstruction or the construction of such work may be made before the collector, and he shall deal with the same in the manner provided in section 12.

57. No such claim shall be entertained after the expiration of one year from the occurrence of the loss complained of, unless the Collector is satisfied that the claimant had sufficient cause for not making the claim within such period.

APPENDIX D

ORDINANCE ESTABLISHING ENVIRONMENTAL PROTECTION AGENCY

THE GAZETTE OF PAKISTAN
EXTRAORDINARY
PUBLISHED BY AUTHORITY
ISLAMABAD, SATURDAY, DECEMBER 31, 1983

PART 1
Acts, Ordinances, President's Orders and Regulations Including Martial Law Orders and Regulations.

MINISTRY OF LAW AND PARLIAMENTARY AFFAIRS
(Law Division)
Islamabad, the 31st December 1983

No. F.17 (1)/83-Pub.- The following Ordinance made by the President is hereby published for general information:

ORDINANCE NO.XXXVII of 1983

AN
ORDINANCE

to provide for the control of pollution and preservation of living environment.

WHEREAS it is expedient to provide for the control of pollution and preservation of living environment and for matters connected therewith or ancillary thereto:

And WHEREAS the President is satisfied that circumstances exist which render it necessary to take immediate action:

Now, THEREFORE, in pursuance of the Proclamation of the fifth day of July 1977, and in exercise of all powers enabling him in that behalf, the President is pleased to make and promulgate the following Ordinance:

1. Short title, extent and commencement.-(1) This Ordinance may be called the Pakistan Environmental Protection Ordinance 1983.

(2) It extends to the whole of Pakistan and its territorial waters, Exclusive Economic Zone and historic waters.

(3) It shall come into force on such day as the Federal Government may by notification in the official Gazette specify in this behalf.

2. Definitions- In this Ordinance, unless there is anything repugnant in the subject or context. -

(a) "Agency" means the Pakistan Environmental Protection Agency (PEPA) established under section 5;

(b) "Air pollutant" means any substance that causes pollution of chemical, physical biological or radiological integrity of air and includes soot, smoke particulates, combustion exhaust, exhaust gases, obnoxious gases and radioactive substances;

(c) "Council" means the Pakistan Environmental Protection Council established under section 3;

(d) "discharge" means spilling, leaking, pumping, pouring, emitting, emptying or dumping;

(e) "effluent" includes any material in solid, slurry, suspension, liquid vapour, fumes or gaseous form coming out as of from any industrial activity or any other sources.

(f) "effluent standards" means the permissible limits prescribed by the Agency regarding the quality and quantity of effluent and wastes.

(g) "emission standards" means the permissible standards for emission of air pollutants prescribed by the Agency;

(h) "Exclusive Economic Zone" shall have the same meaning as in the Territorial Waters and Maritime Zones Act, 1976 (LXXXII of 1976).

(i) "Government agency" includes a division, department, bureau, section, commission, board, office or unit of the Federal Government or a Provincial Government;

(j) "historic waters" means such limits of the waters adjacent to the land territory of Pakistan as are of the time being specified by notification under section 7 of the Territorial Waters and Maritime Zones Act, 1976 (LXXXII of 1976).

(k) "industrial activity" means any process for manufacturing, making, alerting, repairing, ornamenting, finishing, packing or otherwise treating any article or substance with a view to its use, sale, transport, delivery or disposal or for pumping oil, water or sewage or for generating, transforming or transmitting power.

(l) "industrial waste" means waste resulting from an industrial activity.

(m) "local authority" includes any agency set up or designated by the Federal Government or a Provincial Government to be a local authority for the purposes of this Ordinance.

(n) "local council" means a local council constituted or established under a law relating to local government;

(o) "municipal waste" includes sewage, refuse sludge and human excreta and the like;

(p) "pollution" means any matter which, on being discharged into the air, soil or public waters, alters unfavourably the chemical, physical biological or radiological integrity of the air, soil or public waters unclean, noxious or impure or injurious or disagreeable or detrimental to the health, safety, welfare or property of persons or harmful to aquatic life, animals, birds, fish, plants or other forms of life;

(q) "prescribed" means prescribed by rules or regulations;

(r) "public waters" means water areas in public use and includes streams, nullahs, canals, seepage drains, natural or artificial water courses, rivers, wells, ponds, ditches, lakes reservoirs, underground or artesian water, territorial waters, the Exclusive Economic Zone and historic waters;

(s) "regulation" means regulations made under this Ordinance;

(t) "rules" means rules made under this Ordinance;

(u) "sewage" means liquid wastes from sanitary conveniences, kitchens, laundries, washing and the like;

(v) "standards" means effluent standards and emission standards;

(w) "territorial waters" shall have the same meaning as in the Territorial Waters and Maritime Zones Act, 1976 (LXXXI) of 1976).

(x) "treatment works" means the various processes and devices used in the treatment of wasters; and

(y) "wastes" includes liquid wastes, suspended wastes, industrial wastes, municipal wastes, wastes from mining processes and wastes from farm and agricultural activities, such as poultry, cattle, animal husbandry, abattoirs and the use of fertilizers and pesticides.

3. Establishment of the Council. (1) The Federal Government shall, by notification in the official Gazette, establish a Council to be known as the Pakistan Environmental Protection Council and consisting of:

(i) the President of Pakistan	..	Chairman
(ii) the Minister in charge of the subject of Environment	..	Vice Chairman
(iii) Ministers in charge of the subject of Environment in the Provinces	..	Members
(iv) such other persons as the Federal Government may appoint	..	Members
(v) the Secretary to the Government of Pakistan dealing with the subject	..	Secretary

(2) The members of the Council, other than ex-officio members, shall hold office for a term of three years.

(3) The Council shall frame its own rules of procedures.

(4) The council shall hold meetings as and when necessary:
Provided that not less than two meetings shall be held in a year.

(5) The council may, by general or special order and subject in such conditions as it may consider fit, delegate any of its functions under this Ordinance

4. Functions of the Council. (1) The functions of the Council shall be to -

(a) ensure enforcement of this Ordinance;

(b) establish comprehensive national environmental policy;

(c) give appropriate direction to conserve the renewable and expendable resources;

(d) ensure that environmental considerations are interweaved into National Development Plans and Policies;

(e) ensure enforcement of the National Environment Quality Standards; and

(f) give directions to any Government agency, a body or a person requiring it or him to take measures to control pollution being caused by such agency, body or to refrain from carrying out any particular activity prejudicial to public interest or the purposes of the Ordinance.

(2) The Council may, or if so required by the Government or any Government agency shall, direct the Agency to prepare, submit and promote projects for the prevention of environmental pollution or to undertake research in any specified aspect of environment.

<u>5.</u> <u>Establishment of the Agency.</u> (1) The Federal Government shall, by notification in the official Gazette, establish an Agency to be called the Pakistan Environmental Protection Agency to exercise the powers and perform the functions assigned to it under the provisions of this Ordinance or the rules and regulations.

(2) The Agency shall be headed by a Director General who shall be appointed by the Federal Government on such terms and conditions as it may determine;

(3) The powers and functions of the Agency shall be exercised and performed by the Director General.

(4) The Agency shall have such administrative, technical and legal staff as the Federal Government may appoint.

(5) To assist him in the discharge of his functions, the Director General may establish such Advisory Committees as he may deem fit and appoint as members, thereof eminent representatives of universities, research institutes, the business community and other professions and fields of knowledge.

<u>6.</u> <u>Functions of the Agency</u>- (1) The Agency shall -

(a) administer this Ordinance and the rules and regulations;

(b) prepare national environmental policy for approval of the Council;

(c) publish an annual report on the state of environment;

(d) establish National Environmental Quality Standards with the approval of the Council;

(e) revise the National Environmental Quality Standards as and when deemed necessary;

(f) coordinate environmental policies and programmes nationally and internationally;

(g) establish systems for surveys, surveillance, monitoring, measurement, examination and inspection to combat environmental pollution;

(h) take measures to promote the development of science and technology which will contribute to the prevention of environmental pollution, such as the consolidation of survey and research system, the promotion of research and development, the dissemination of the results of such research work and development work, and the education and training of research experts and other governmental functionaries;

(i) provide information and education to the public on environmental matters and to recommend to the Council the introduction of environmental information in the syllabi of educational institutions; and

(j) coordinate and consolidate implementation of measures to control pollution with Provincial Governments agencies.

(2) The Agency may-

   (a) request any Government agency to furnish any information or data relevant to the functions of the Agency;

   (b) with the approval of the Federal Government, initiate requests for foreign assistance in support of the objectives of the Ordinance and enter into arrangements with foreign agencies or organizations for the exchange of material or information and participate in international seminars or meetings;

(c) establish and maintain laboratories to conduct research in various aspects of environment and provide grants to institutions for specific projects;

(d) delegate any of its powers under this Ordinance and the regulations to any Government agency;

(e) identify the needs for legislation in the environmental field;

(f) at the request of the Federal Government or a Provincial Government or any Government agency, provide advice and assistance in environmental matters; and

(g) perform any other function which the Council may assign to it.

7. Powers of the Agency- Subject to the provision of this Ordinance, the Agency may -

(a) lease, purchase, acquire, own, hold, improve, use or otherwise deal in and with any property, both movable and immovable;

(b) sell, convey, mortgage, pledge, exchange or otherwise dispose of its property and assets;

(c) execute instruments, incur liabilities and do all acts or things necessary for proper management and conduct of its business; and

(d) appoint such advisers and consultants as it considers necessary for efficient performance of its functions on such terms and conditions as may be prescribed by regulations.

8. Environmental Impact Statement, etc. to be submitted to the Agency-

(1) The provisions of this section shall apply to such -

(a) persons or class of persons, or

(b) industrial activity or class of industrial activity, or

(c) category, type or volume of discharges of air pollution or wastes, or

(d) area or class of ares, or

(e) classes of public waters

as may be prescribed by regulations.

(2) Every proponent of a project the construction or completion of which is likely to adversely affect the environment shall file with the Agency, at the time of planning the project, a detailed environmental impact statement including information on:

(a) the impact on the environment of the proposed industrial activity;

(b) the treatment works of the proposed project;

(c) the unavoidable adverse environmental effects of the proposed project; and

(d) the steps proposed to be taken by the project proponent to minimise adverse environmental effects.

(3) The Agency may prescribe guidelines for the preparation of environmental impact statements and, where such guidelines have been prescribed the proponents of projects shall prepare environmental impact statements according to the said guidelines.

(4) The Agency may itself or through the appropriate Government agency review the environmental impact statement and, where it deems appropriate, it may also involve public participation in the assessment of the environmental impact statement.

(5) After the review under sub-section (4), the Agency may either approve the environmental impact assessment or recommend to the Federal Government that the project be modified or rejected in the interest of environmental objectives.

<u>9.</u> <u>Agency to assist local councils, etc. in disposal of wastes.</u>-The Agency shall assist the local councils, local authorities or other Government agencies and persons to implement schemes for the proper disposal of wastes in line with the standards and procedures prescribed by the Agency.

<u>10.</u> <u>Funds of the Agency</u>.- The funds of the Agency shall be derived from the following sources, namely:-

(a) grants made and loans advanced by the Federal Government or the Provincial Government;

(b) grants, loans advances and other moneys received from local or international agencies;

(c) fees, rates and charges received by the Agency under the provision of this Ordinance; and

(d) all other sums received by the Agency.

11. Audit and accounts.

(1) The Agency shall submit its annual budget estimates for approval of the Federal Government through the Council.

(2) The Agency shall maintain proper accounts and other relevant records and prepare annual statement of accounts in such form as may be prescribed by rules.

(3) The accounts of the Agency shall be audited i such manner as may be directed by the Federal Government.

12. Penalty

(1) Whoever contravenes or fails to comply with any provision of this Ordinance or of any rule or regulation of any direction issued by the Agency thereunder, shall be punishable with imprisonment for a term which may extend to two years, or with fine which may extend to one hundred thousand rupees, or with both, and in the case of a continuing contravention or failure, with an additional fine which may extend to ten thousand rupees for everyday after the first during which such contravent or failure conditions.

(2) The Director General or an officer generally or specially authorized by him in this behalf may compound any offence under this Ordinance.

13. Indemnity. No suit, prosecution or other legal proceeding shall be against the Council, the Agency, the Director General, or the members, officers, employees, experts or consultants of the Agency, for anything in good faith done or intended to be done under this Ordinance or any rule or regulation.

14. Bar of jurisdiction.- No Court shall take cognizance of any offence punishable under this Ordinance except on a complaint in writing made by the Agency.

15. Dues of Agency recoverable as an arrear of land revenue. Any dues recoverable by the Agency under the provisions of this Ordinance or any rules or regulations shall be recoverable as an arrear of land revenue.

16. Power to make rules. - The Federal Government may, by notification in the official Gazette, make rules for carrying out the purposes of this Ordinance.

17. Power to make regulations.- (1) The Agency may, by notification in the official Gazette with the approval of the Federal Government, make regulations, not inconsistent with the provisions of this Ordinance or the rules, for carrying out the purposes of this Ordinance.

(2) In particular and without prejudice to the generality of the foregoing power, such regulations may provide for the levy of fees, rates and charges in respect of services rendered, action taken and schemes implemented by the Agency.

General
M. ZIA-UL-HAQ
President.

C.A. RAHMAN
Secretary.

SALT TOLERANCE OF CROPS (ASCE, 1990)

Table 1. Salt Tolerance of Fibre, Grain and Special Crops[a]

Crop: Common name	Crop: Botanical name[b]	Electrical conductivity of saturated soil extract: Threshold dS/m[c]	Slope %/dS/m	Rating[d]
Barley[e]	Hordeum vulgares	8.0	5.0	T
Bean	Phaseolus vulgaris	1.0	19.0	S
Broadbean	Vicia faba	1.6	9.6	MS
Corn[f]	Zea Mays	1.7	12.0	MS
Cotton	Gossypium hirsutum	7.7	5.2	T
Cowpea	Vigna unguiculata	4.9	12.0	MT
Flax	Linum usita-tissimum	1.7	12.0	MS
Guar	Cyamopsis tetragonoloba	8.8	17.0	T
Kenaf	Hibiscus cannabinus			MT
Millet, foxtail	Setaria italica			MS
Oats	Avena sativa			MT*
Peanut	Arachis hypogaea	3.2	29.0	MS
Rice, paddy	Oryza sativa	3.0[g]	12.0[h]	S
Rye	Secale cereale	11.4	10.8	T
Safflower	Carthamus inctorius			MT
Sesame[i]	Seasamum indicum			S
Sorghum	Sorghum bicolor	6.8	16.0	MT
Soybean	Glycine max	5.0	20.0	MT
Sugarbeet	Beta vulgaris(h)	7.0	5.9	T
Sugarcane	Saccharum officinarum	1.7	5.9	MS
Sunflower	Helianthus annuus			MS*
Triticale X	Triticosecale	6.1	2.5	T
Wheat	Triticum aestivum	6.0	7.1	MT
Wheat[j] semidwarf	Triticum aestivum	8.6	3.0	T
Wheat, durum	Triticum turgidum	5.9	3.8	T

Table 1. Salt Tolerance of Fibre, Grain and Special Crops (cont.)

Footnotes:

[a] These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending on climate, soil conditions, and cultural practices.

[b] Botanical and common names follow the convention of Hortus Third (Liberty Hyde Bailey Hortorium Staff 1976), where possible.

[c] In gypsiferous soils, plants will tolerate electrical conductivities about 2 dS/m higher than indicated.

[d] Ratings and references are further discussed in Manual Number 71 (ASCE. 1990). Ratings with an * are estimates.

[e] Less tolerant during seeding stage, EC_e at this stage should not exceed 4 dS/m or 5 dS/m.

[f] Grain and forage yields of DeKalb XL-75 grown on an organic muck soil decreased about 26% per Ds/m above a threshold of 1.9 Ds/m (Hoffman et al, 1983).

[g] Because paddy rice is grown under flooded conditions, values refer to the electrical conductivity of the soil water while plants are submerged. Less tolerant during seeding stage.

[h] Sensitive during germination and emergence, EC_e should not exceed 3 dS/m.

[i] Sesame cultivars, Seasaco 7 and 8, may be more tolerant than indicated by the S Rating.

[j] Data from one cultivar, "Probred".

Table 2. Salt Tolerance of Grasses and Forage Crops[a]

Crop: Common name	Crop: Botanical name[b]	Electrical conductivity of saturated soil extract: Threshold dS/m[c]	Slope %/dS/m	Rating[d]
Alfalfa	Medicago sativa	2.0	7.3	MS
Alkali grass Nuttall	Puccinellia air oides			T*
Alkali sacaton	Sporrobolus airoides			T*
Barley[e] (forage)	Hordeum vulgare	6.0	7.1	MT
Bentgrass	Agrostis stolo-nifera palustris			MS
Bermuda[h]	Cynodon dactylon	6.9	6.4	T
Bluestem, Angleton	Dichanthium aristatum			MS*
Brome, mountain	Bromus marginatus			MT*
Brome, smooth	Bromus inermis			MS
Buffalo grass	Cenchrus ciliaris			MS*
Burnet	Poterium sanguisorba			MS*
Canary grass, reed	Phalaris arundinacea			MT
Clover, alsike	Trifolium hybridum	1.5	12.0	MS
Clover, Berseem	T. alexandrinum	1.5	5.7	MS
Clover, Hubam	Melilotus alba			MT*
Clover, ladino	Trifolium repens	1.5	12.0	MS
Clover, red	T. pratense	1.5	12.0	MS
Clover, strawberry	T. fragiferum	1.5	12.0	MS
Clover, sweet	Melilotus			MT*
Clover, white Dutch	Trifolium repens			MS*
Corn[f] (forage)	Zea mays	1.8	7.4	MS
Cowpea (forage)	Vigna unguiculata	2.5	11.0	MS
Dallis grass	Paspalum dilatatum			MS*
Fescue, tall	Festuca elatior	3.9	5.3	MT
Fescue, meadow	F. pratensis			MT*
Foxtail, meadow	Alopecurus pratensis	1.5	9.6	MS
Grama, blue	Bouteloua gracilis			MS*
Harding grass	Phalaris tuberosa	4.6	7.6	MT

Table 2. Salt Tolerance of Grasses and Forage Crops[a] (cont.)

Crop: Common name	Crop: Botanical name[b]	Electrical conductivity of saturated soil extract: Threshold dS/m[c]	Slope %/dS/m	Rating[d]
Kallar grass	Diplachne fusca			T*
Love grass[i]	Eragrostis sp.	2.0	8.4	MS
Milkvetch, Cicer	Astragalus cicer			MS*
Oat grass, tall	Arrhenatherum danthonia			MS*
Oats (forage)	Avena sativa			MS*
Orchard grass	Dactylis glomerata	1.5	6.2	MS
Panic grass, blue	Panicum antidotale			MT*
Rape	Brassica napus			MT*
Rescue grass	Bromus unioloides			MT*
Rhodes grass	Chloris gayana			MT
Rye (forage)	Secale cereale			MS*
Ryegrass, Italian	Lolium italicum multiflorum			MT*
Ryegrass perennial	L. perenne	5.6	7.6	MT
Salt grass desert	Distichlis stricta			T*
Sesbania	Sesbania exaltata	2.3	7.0	MS
Sirato	Macroptilium atro-purpureum			MS
Sphaerophysa	Sphaerophysa sulsula	2.2	7.0	MS
Sudan grass	Sorghum sudanese	2.8	4.3	MT
Timothy	Phleum pratense			MS*
Trefoil, big	Lotus uliginosus	2.3	19.0	MS
Trefoil, narrowleaf bird's foot	L. corniculatus tenuifolium	5.0	10.0	MT
Trefoil, broadleaf bird's foot	L. corniculatus arvenis			MT
Vetch, common	Vicia angustifolia	3.0	11.0	MS
Wheat[g] (forage)	Triticum aestivum	4.5	2.6	MT
Wheat Durum (forage)	T. turgidum	2.1	2.5	MT

Table 2. Salt Tolerance of Grasses and Forage Crops[a] (cont.)

Crop: Common name	Crop: Botanical name[b]	Electrical conductivity of saturated soil extract: Threshold dS/m[c]	Slope %/dS/m	Rating[d]
Wheat grass, standard crested	Agropyron sibiricum	3.5	4.0	MT
Wheat grass, fairway crested	A. cristatun	7.5	6.9	T
Wheat grass, intermediate	A. intermedium			MT*
Wheat grass, slender	A. trachycaulum			MT
Wheat grass, tall	A. elongatum	7.5	4.2	T
Wheat grass, western	A. Smithii			MT*
Wild rye, Altai	Elymus angustus			T
Wild rye, beardless	E. triticoides	2.7	6.0	MT
Wild rye, Canadian	E. canadensis			MT*
Wild rye, Russian	E. Junceus			T

[a] Same as Table 1.
[b] Same as Table 1.
[c] Same as Table 1.
[d] Same as Table 1.
[e] Same as Table 1.
[f] Same as Table 1.
[g] Data from one cultivar, "Probred".
[h] Average of several varieties, Suwannee and Coastal are about 20% more tolerant, and common and Greenfield are about 20% less tolerant than the average.
[i] Average for Boer, Wilman, Sand, and Weeping cultivars; Lehmann seems about 50% more tolerant.

Table 3. Salt Tolerance of Vegetables and Fruit Crops[a]

Crop: Common name	Crop: Botanical name[b]	Electrical conductivity of saturated soil extract: Threshold dS/m[c]	Slope %/dS/m	Rating[d]
Artichoke	Helianthus tuberosus			MT*
Asparagus	Asparagus officinalis	4.1	2.0	T
Bean	Phaseolus vulgaris	1.0	19.0	S
Beet, red[e]	Beta vulgaris	4.0	9.0	MT
Broccoli	Brassica oleracea botrytis	2.8	9.2	MS
Brussel sprouts	B. oleracea gemmifera			MS*
Cabbage	B. oleracea capitata	1.8	9.7	MS
Carrot	Daucus carota	1.0	14.0	S
Cauliflower	Brassica oleracea botrytis			MS*
Celery	Apium graveolens	1.8	6.2	MS
Corn, sweet	Zea mays	1.7	12.0	MS
Cucumber	Cucumis sativus	2.5	13.0	MS
Eggplant	Solanum melongena esculentum	1.1	6.9	MS
Kale	Brassica oleracea acephala			MS*
Kohlrabi	B. oleracea gongylode			MS*
Lettuce	Lactuca sativa	1.3	13.0	MS
Muskmelon	Cucumis melo			MS
Okra	Abelmoschus esculentus			S
Onion	Allium cepa	1.2	16.0	S
Parsnip	Pastinaca sativa			S*
Pea	Pisum sativum			S*
Pepper	Capsicum annum	1.5	14.0	MS
Potato	Solanum tuberosum	1.7	12.0	MS
Pumpkin	Cucurbita pepo pepo			MS*
Radish	Raphanus sativus	1.2	13.0	MS
Spinach	Spinacia oleracea	2.0	7.6	MS
Squash scallop	Cucurbita pepo Melopepo	3.2	16.0	MS

Table 3. Salt Tolerance of Vegetables and Fruit Crops[a] (cont.)

Crop: Common name	Botanical name[b]	Electrical conductivity of saturated soil extract: Threshold dS/m[c]	Slope %/dS/m	Rating[d]
Squash, zuchhini	C. pepo melopepo	4.7	9.4	MT
Strawberry	Fragaria sp.	1	33	S
Sweet potato	Ipomoea batatas	1.5	11	MS
Tomato	Lycopersicon lycopersicum	2.5	9.9	MS
Turnip	Brassica rapa	0.9	9	MS
Watermelon	Citrullus lanatus			MS*

[a] Same as Table 1.
[b] Same as Table 1.
[c] Same as Table 1.
[d] Same as Table 1.
[e] Sensitive during germination and emergence: EC_e should not exceed 3 dS/m.

Table 4. Salt Tolerance of Woody Crops[a]

Crop: Common name	Botanical name[b]	Electrical conductivity of saturated soil extract: Threshold dS/m[c]	Slope %/dS/m	Rating[d]
Almond[e]	Prunus duclis	1.5	19.0	S
Apple	Malus sylvestris			S
Apricot[e]	Prunus armeniaca	1.6	24.0	S
Avocado[e]	Persea americana			S
Blackberry	Rubus sp.	1.5	22.0	S
Boysenberry	Rubus ursinus	1.5	22.0	S
Castorbean	Ricinus communis			MS*
Cherimoya	Annona cherimola			S*
Cherry, sweet	Prunus avium			S*
Cherry, sand	P. besseyi			S*
Currant	Ribes sp.			S*
Date Palm	Phoenix dactylifera	4.0	3.6	T

Table 4. Salt Tolerance of Woody Crops[a] (cont.)

Crop: Common name	Crop: Botanical name[b]	Electrical conductivity of saturated soil extract: Threshold dS/m[c]	Electrical conductivity of saturated soil extract: Slope %/dS/m	Rating[d]
Fig	Ficus carica			MT[*]
Gooseberry	Ribes sp.			S[*]
Grape[a]	Vitis sp.	1.5	9.6	MS
Grapefruit[a]	Citrus paradisi	1.8	16.0	S
Guayule	Parthenium argentatum	15.0	13.0	T
Jojoba[a]	Simmondsia chinensis			T
Jujube	Ziziphus jujuba			MT[*]
Lemon[a]	Citrus limon			S
Lime	C. aurantifolia			S[*]
Loquat	Eriobotrya japonica			S[*]
Mango	Mangifera indica			S[*]
Olive	Olea europaea			MT
Orange	Citrus sinensis	1.7	16.0	S
Papaya[a]	Carica papaya			MT
Passion fruit	Passiflora edulis			S[*]
Peach	Prunus persica	1.7	21.0	S
Pear	Pyrus communis			S[*]
Persimmon	Diospyros virginiana			S[*]
Pineapple	Ananas comosus			MT[*]
Plum; Prune[a]	Prunus domestica	1.5	18.0	S
Pomegranate	Punica granatum			MT[*]
Pummelo	Citrus maxima			S[*]
Raspberry	Rubus idaeus			S
Rose apple	Syzygium jambos			S[*]
Sapote, white	Casimiroa edulis			S[*]
Tangerine	Citrus reticulata			S[*]

[a] These data are applicable when rootstocks are used that do not accumulate sodium or chloride rapidly, or when these ions do not predominate in the soil.

[b] Same as Table 1.

[c] Same as Table 1.

[d] Same as Table 1.

[*] Same as Table 1.