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OPERATION AND MAINTENANCE MANUAL REHABILITATED CANALS

GENERAL INSTRUCTIONS

PRC ENGINEERING/CHECCHI
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FOREWORD

Section 1: Purpose

The purpose of this manual is to provide general instructions and guidelines that are required to operate and maintain rehabilitated canals, small systems or sub-systems within a larger system. The guidelines presented herein cover the normal conditions involved in operating and maintaining these canals. No manual can cover solutions to all the potential combinations of problems that someday could occur from operating the canals. This is the role of the canal officer.

The manual was prepared with the intent of introducing some applicable modern technology into the operation and maintenance of the canals under the current organization of the Irrigation Circle and Provincial Irrigation Department, and its policies and guidelines. The manual was prepared for use at the sub-division level. Therefore, references are made primarily to the Sub-division Officer (SDO) but it is fully understood and intended that the Executive Engineer (XEN) retains his authority and responsibilities as the SDO's supervisor and in the control of the allocation (distribution) of water.

Section 2: Authorization

This manual has been prepared under the direction of USAID to meet the requirements of Task V-a. of the approved PRC Engineering/Checchi Work Plan, 1986-87. Task V-a requires; "Preparation of a detailed O&M manual for each USAID-funded canal rehabilitation scheme", rehabilitated under Task I.

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

A. Background

In agricultural production, water is one if not the most important element. Thus, the role of an irrigation system and the system's operators can not be over emphasized. Water is such a precious commodity that it needs careful, efficient and effective management.

In order to overcome the deteriorated condition of the irrigation systems, the Government of Pakistan has embarked on a large scale program of rehabilitation of many existing irrigation systems. The upgrading of the Provincial Irrigation Department's management has accompanied this program. Many of these rehabilitation projects, are being financed jointly by the Government of Pakistan, World Bank and United States of America Agency for International Development (USAID).

Operation and maintenance activities should not be achieved through trial and error methods as is sometimes the current practice. An O&M Manual prepared for each irrigation system is the most effective means of providing the Irrigation Department's personnel with the necessary information that allows them to operate their canals efficiently. The "Operation and Maintenance Manual of Rehabilitated Canals General Instructions" has been prepared by the consultant to meet this requirement.

The objective of this manual is to provide the canal officers and staff with a document that provides them with the necessary supporting instructions for the efficient operation and maintenance of a canal. It must be remembered that no irrigation O&M manual will provide all of the answers for all of the problems that will occur over a period of time. The basic management objective is to solve the problems as they occur.

B. Purpose

The purpose of this manual is to provide the necessary standards, guidelines and general methodology required to keep the canals in good operating condition. This manual is based on the old "Manual of Irrigation Practices", 1943. Government of Pakistan, Reprinted 1963 and current field conditions as much as possible. The deteriorated condition of most canals today, would not have occurred if the PID had not relaxed compliance with the original manual. This manual updates the "general" O&M methods and techniques applicable to smaller canals and places them under a single cover for ready reference.

This manual provides the general basis for operating and maintaining the canals as well as providing the standards by which inspections should evaluate its operating condition. The primary emphasis is on:

* Equitable distribution of water
* Maintenance of freeboard
* Embankment safety
* Canal prism
* Structural integrity

C. Performance Standards

Inspectors will seldom agree as to what condition a canal is in. Too much is in the eye of the beholder and the individual emphasis each person places on the various aspects of operation and maintenance. Performance standards have been established to provide the field staffs with the standards to which the rehabilitated canal must meet with respect to the equitable distribution of water and maintenance parameters. Inspections are made for the purpose of monitoring compliance to these standards. It must be remembered that canals must be judged on their specified function, not aesthetics or other functions.

D. General Instructions

The Executive Engineer (XEN), who is under the Superintending Engineer (SE), will have the general responsibility for operation and maintenance of any rehabilitated canal. The XEN delegates some of this responsibility to his Sub-Division Officers (SDO). The SDO is responsible for maintaining all

records on the canals in his sub-division as only a few records are kept by Sub-engineers (SBE). The XEN also maintains records on the canals under his jurisdiction. The records must be kept current on each rehabilitated canal. A copy of this manual must be available as part of the permanent records. The required O&M records are:

* Flow measurements into distributaries and other designated points in the system.
* Operation logs.
* Control point water surface records.
* H Register
* Annual inspection reports
* Monitoring program records
* Outlet register
* As-built long-section and cross-section drawings.

Inspections of existing canals, particularly distributaries and minors indicates that the majority of the damage to the canal banks is the result of animals, carts and tractors entering and exiting the canal. The major loss of freeboard and canal embankment safety occurs where water buffalo and other traffic entering the canal is concentrated. Concentrating usually occur at villages, and populated points adjacent to the canal as well as where local roads/tracks end at the canal where no bridge has been provided. The total loss of freeboard and canal safety, as illustrated in Figure I-1 can occur in as little time as one year.

Under current organization and staffing conditions within a sub-division, beldars are assigned a zone of responsibility on the order of 5 miles of canal. The routine patrolling duties assigned to the beldar require the majority of his time. Therefore, neither the beldar nor the Sub-engineer have sufficient time or resources to adequately maintain or repair those locations where canal embankments receive concentrated use.

Rules or regulations against entering the canal prism are not enforceable at this time. Therefore, multipurpose use of the canals by the farmers will

continue. Designs for permanent crossings and animal bathing facilities (ghats) are available with the PID but they are seldom constructed in the field. Construction is expensive as it must include the protection of the entire embankment to be effective. These structures would have low annual maintenance costs. Semi-permanent facilities have not been considered by the PID. These are facilities constructed of soil which in reality are a widening of the canal banks to accommodate the flat slopes required for animal use, see Chapter IV.

It is recommended that the SDO adopt the semi-permanent design as a standard on the rehabilitated canals. This can be achieved over a period of time at each access point using proper maintenance techniques. Over a period of time, the annual maintenance costs at these points will be reduced and the canal will continue to meet performance standards.

The use of the canal patrol roads for farm-to-market purposes or access to fields is the second most critical maintenance problem. The sandy-silty soils that constitute the canal embankment can not support sustained traffic where there is insufficient clay particles to bind the soil particles together. The result is a rapid deterioration into a deep powder, particularly under dry conditions. Improved compaction or the beldars throwing water on the roadway both reduce the problem but may still allow considerable annual loss of freeboard.

It is not practical to replace thin layers of soil on a freeboard every year. Therefore, the replacement of freeboard will be required on a periodic basis. For example, if one inch is eroded each year, five inches will be replaced every five years. The replacement of the gradually lost freeboard or eroded embankment must be coordinated by the Executive Engineer. The Division should have a master work plan that would allow the restoration of 20% of the division's freeboard each year.

The restoration of freeboard and eroded embankment can not be delayed nor ignored. This is the reason for the current deteriorated conditions and lack of freeboard.

E. Duties and Responsibilities of Field Staff

1. Duties

The general duties and responsibilities of the sub-division's field staff are presented in Tables I-1 through I-3. As time goes on, these should be expanded and made more explicit. It is the responsibility of the SDO to keep these instructions current. In all probability, each individual beldars job description should be modified slightly to fit the individual zone of responsibility.

2. Area of Responsibility

The sub-division is normally divided into three sections or areas of responsibility although the number may vary depending on the configuration of the particular sub-division and the length of canals to be covered. The section is supervised by a Sub-engineer (SBE). Each section is sub-divided into two or more beats in order to cover the canals assigned. The beat is supervised by a Daroga/Mate. The beat is divided into a number of zones of responsibility to which the beldar is assigned. Sections and beats may parallel the canal system (i.e. responsibility running from head to tail) or they may apply to areas in which case they will cross a series of canals.

Organization charts are prepared at the sub-division level to show where people are assigned. An example sub-division organization chart is presented on Figure I-2. At the section level a roster can be prepared to show individuals and their assigned zones of responsibility as presented on Table I-4 or by use of an organization chart as presented on Figure I-3. In addition, it is recommended that the zones of responsibility be shown on a schematic diagram of a canal or sub-system. An example for beat assignments is shown on Figure I-4 and for beldar zones on Figure I-5. Where the individual beldars assignments are varied from year to year the use of a roster as shown in Table I-4 is particularly useful.

TABLE I-1
DUTIES AND RESPONSIBILITIES OF THE SUB-ENGINEER

The duties and responsibilities of the Sub-engineer are provided as guidelines with respect to operation and maintenance procedures are the following:

1. Supervises the operation and maintenance activities within his Section.

2. Reports to the Sub-division Officer and coordinates with the Gate Tenders in charge of gated regulators serving one or more distributaries. Forwards to the SDO requests for an increase or reduction in water supply within his Section so as to improve its timely and equitable distribution.

3. Controls the use of logistics available in his Section, i.e., motorcycle, communication facilities, hand wheels, tools, etc.

4. Controls and supervises the operation of gates, discharge measurements, patrolling, maintaining water levels and maintenance of the canals.

5. Checks the daily discharge report, discharge records, and operations log and any other daily reports for his routine use and submits these and any special reports to the Sub-division Officer.

6. Prepares maintenance programs for his Section.

7. Plans and prepares improvement programs within his Section.

8. Performs such other duties that may be assigned to him from time to time.

9. Provides guidance on the proper maintenance of watercourses and ditches and coordination with the Water Users Associations.

TABLE I-1

DUTIES AND RESPONSIBILITIES OF THE SUB-ENGINEER
(Continued)

10. Makes the annual inspection of the canals under his jurisdiction and prepares the written report including completing all required inspection forms.

11. Checks to make sure the weekly control point monitoring measurements are correctly taken, processed and forwarded to SDO.

12. Supervises the annual cross section and other surveys required for various monitoring reports.

13. Supervises the H Registers preparation.

14. Prepares a weekly report on all maintenance activities including the quantities of any earthwork accomplished, raincut repairs, killa bushing, road work, etc.

15. Collects monthly and annual sediment samples as required.

TABLE I-2
DUTIES AND RESPONSIBILITIES OF THE DAROGA/MATE

The Daroga is under the direct and immediate supervision of the Sub-engineer and shall perform the following:

1. Supervise the cleanliness and capacity of all canals in his beat.

2. Patrols and supervises the repairs of damages or leakages in canal embankments.

3. Prepares and submits weekly work orders and accomplishment reports promptly as required.

4. Prepares and submits reports about damages, repair needs and illegally constructed or tampered turnouts.

5. Observes and records discharges in the canals as required.

6. Completes weekly control point monitoring measurements and report(s).

7. Supervises the Beldars in his assigned beat.

8. Performs such other duties that may be assigned to him from time to time.

9. Conducts surveys as required.

TABLE I-3

DUTIES AND RESPONSIBILITIES OF A GATE TENDER/GAUGE READER

The Gate Tender is under the direction and immediate supervision of the Sub-division Officer. The Gate Tender performs the following:

1. Operates canal regulator headgates and headworks gates within his area of jurisdiction as directed by Sub-division Officer.

2. Observes and records discharges in the branch and distributary canals and any minor canals. Prepares and submits daily discharge reports.

3. Operates and controls the canal cross regulator structure.

4. Cleans and removes floating debris in front of canal structure.

5. Lubricates gates during season, cleans and paints them in closure period.

6. Prepares and submits the operations log as required to the Sub-division Officer.

7. Performs such other duties as may be required.

TABLE I - 4

ASSIGNMENT OF PERSONNEL
(EXAMPLE)

Sub-Division: _____

Section : _____

Beat : _____

Approved by : _____

Form No. _____
Page ___ of ___
Date _____

No.	Persons Name	Job Designation	Canal Name	Assignment: Embankment From RD	Embankment To RD	Embankment Length RD	Structures Description	Structures Location RDs	Remarks
1.		Sub Engineer Soomerki Sec.	Almani Branch						HQ Soomerki Reg.
2.		Daroga Soomerki Beat							HQ Soomerki Reg.
3.		Tandel	Almani				Soomerki Reg.	22.6	
4.		Khalasi	Almani				Soomerki Reg.	22.6	
5.		Beldar Zone 1	Almani	0	12.0	12	Escape	12.0	3 outlets
6.		Beldar Zone 2	Almani	12.0	22.6	10.6	Drigh Minor	14.8	3 outlets
7.		Beldar Zone 3	Soomerki	0	25.7	25.7			21 outlets
8.		Beldar Zone 4	Soomerki	25.7	50.6	24.9			15 outlets
9.		Beldar Zone 5	Pharkara	0	8.3	8.3	Pharakara Headwork	25.7	On Soomerki 4 outlets

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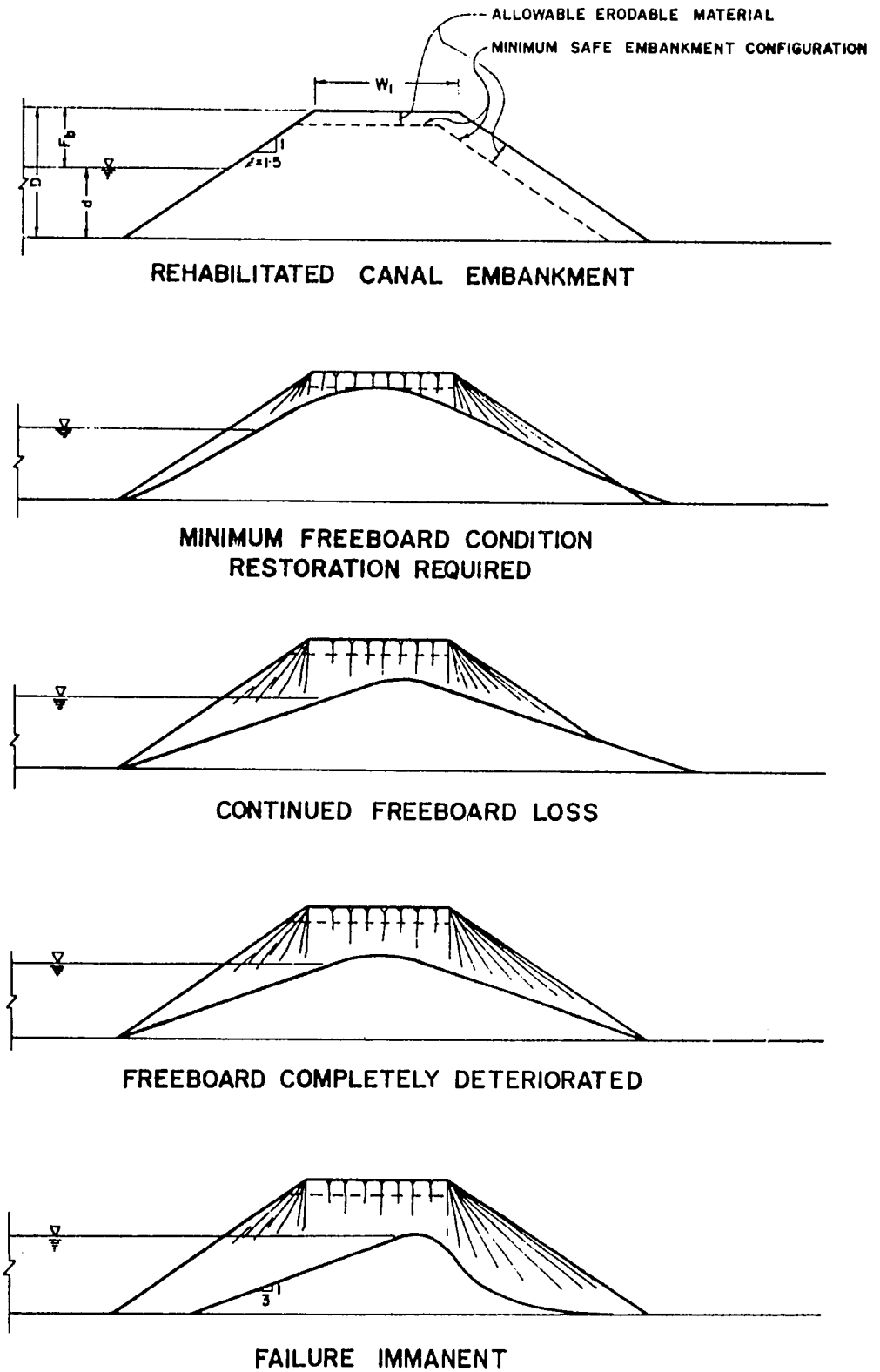
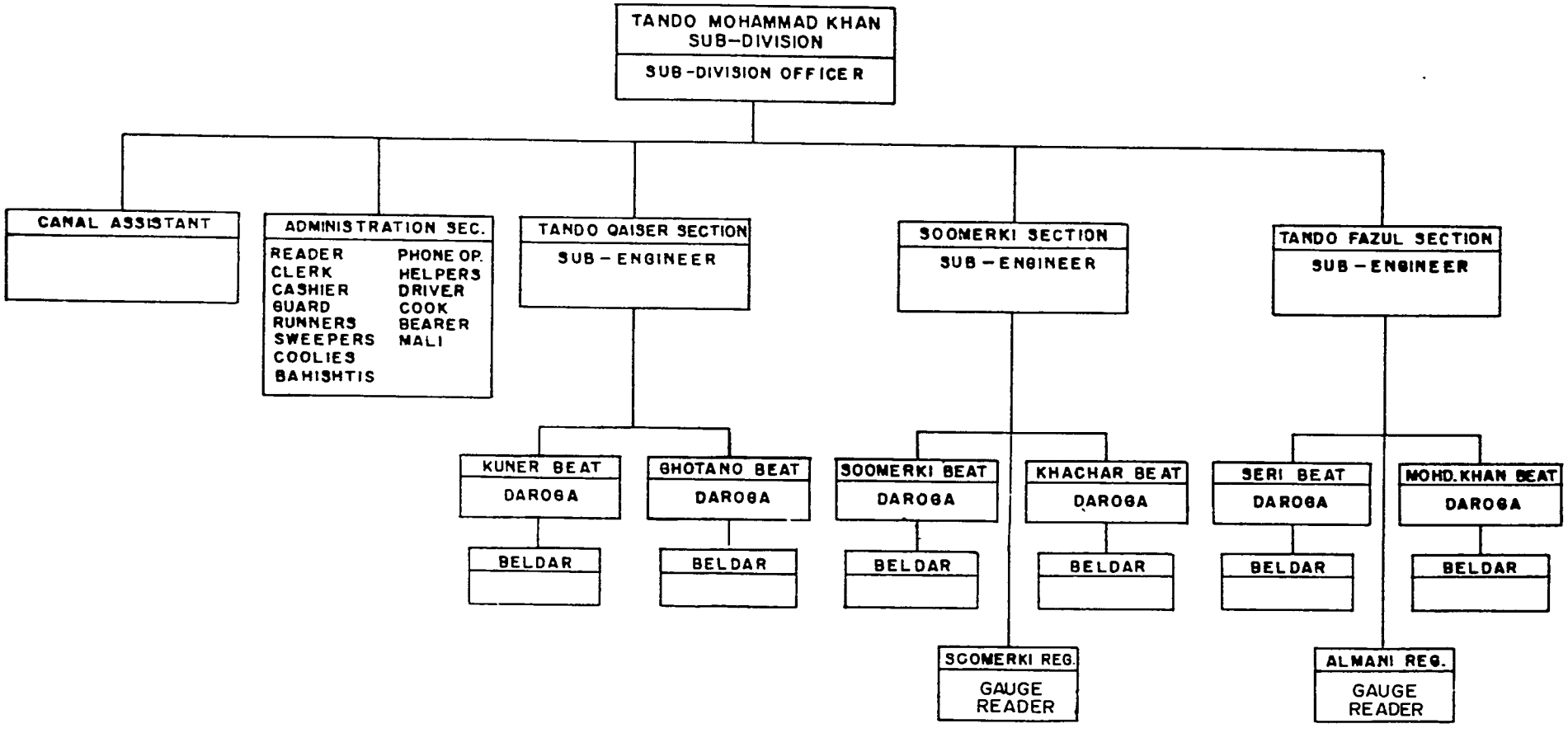
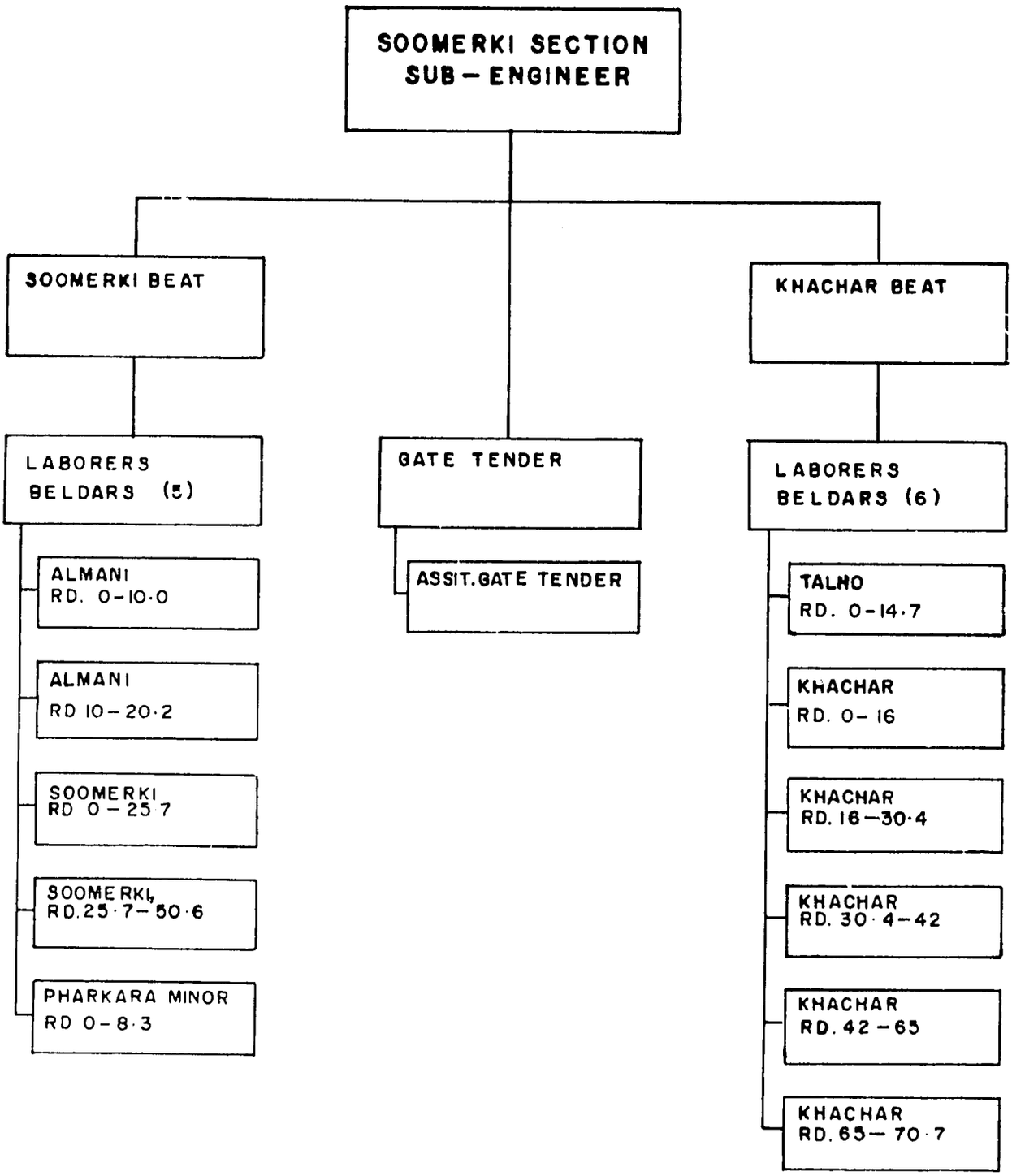


DETERIORATION OF CANAL BANK DUE TO CONCENTRATED CATTLE CROSSINGS

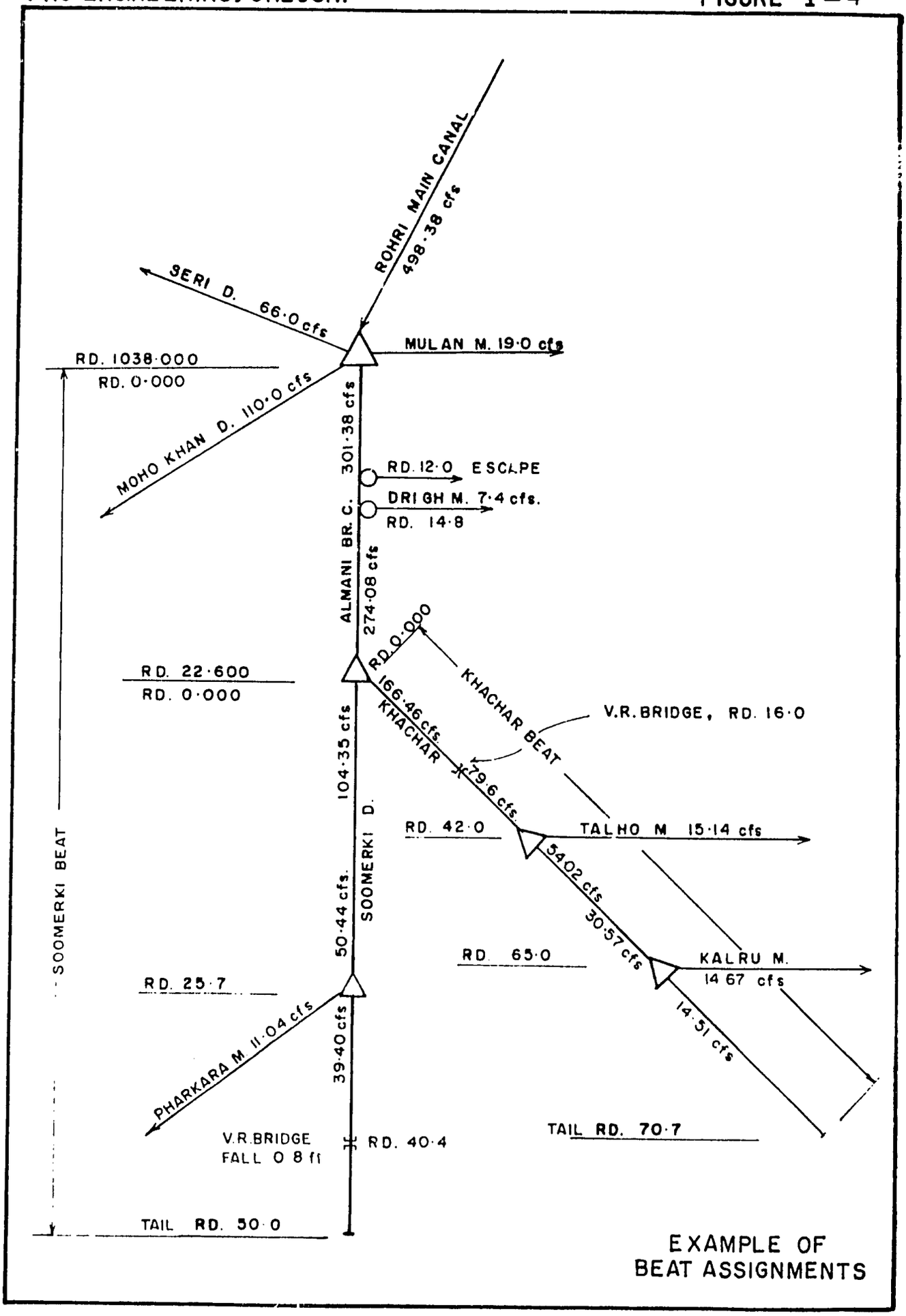


EXAMPLE
SUB-DIVISION ORGANIZATION CHART

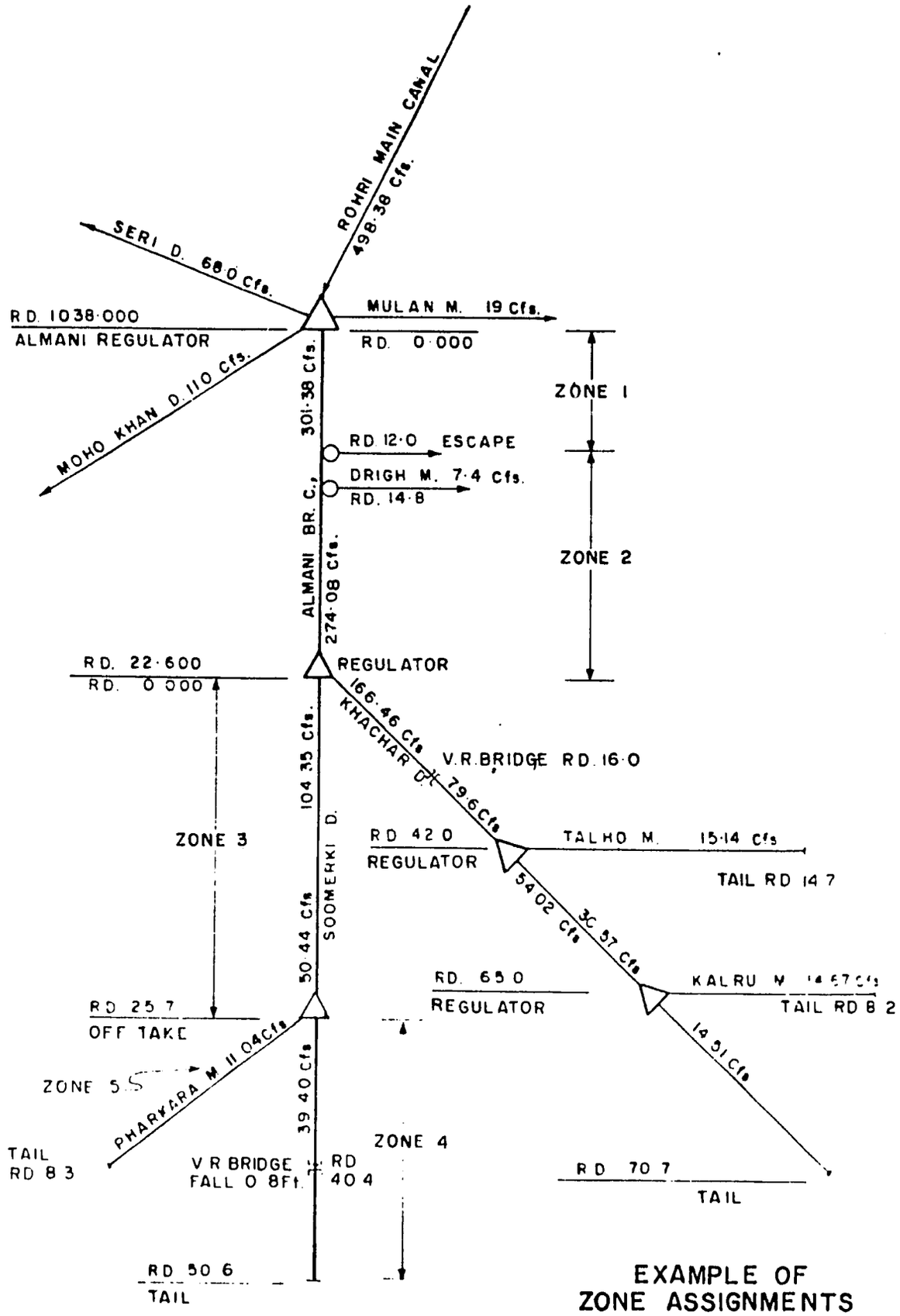
FIGURE I-2



EXAMPLE
SECTION ORGANIZATION CHART



EXAMPLE OF
BEAT ASSIGNMENTS



EXAMPLE OF
ZONE ASSIGNMENTS
FOR SINGLE BEAT

CHAPTER II

DISCHARGE AND SEDIMENT MONITORING PROGRAM

CHAPTER II

DISCHARGE AND SEDIMENT MONITORING PROGRAM

Section 1: Introduction

The calibration of an alluvial irrigation canal involves two components; 1) flow, and 2) sediment distribution. They can be made independent but the usual practice to save time, effort and cost is to combine the two. The equitable distribution of water to each watercourse is the ultimate goal of the irrigation system because this, in part, is what the farmers want. Sediment is an unwanted commodity as neither the farmer nor the system's management want it as both are required to desilt any channel that has an excessive amount.

It is cost effective for the conveyance system to confine sediment removal to a single location rather than to have it spread out along the length of a canal. A sediment trap does just that. An associated problem with a sediment trap is the storage space required over time if the material removed (spoil) is not used by the local population for one purpose or another as the cost of hauling and disposal can become quite a large problem.

Currently there are very few estimates of the seepage losses in the canals. The designs are all based of a rate of 8 cfs per million square feet of wetted perimeter. This is equivalent to 0.69 $ft^3/ft^2/day$. The actual seepage loss rate may be considerably different than this arbitrary design rate depending on soils, wetted surface, depth of water in the canal and the vertical distance from the canal water surface to the surface of the ground water table. One example for a canal reach of 6 RD showed seepage loss rates ranging from 0.03 to 5.35 $ft^3/ft^2/day$ a factor of 100 times the low rate (two orders of magnitude). Obviously this will affect the operation of the canal and the equitable delivery of water to the tail cluster watercourses. Therefore, when systems are rehabilitated it is absolutely necessary to calibrate the system and make the necessary adjustments in the actual canal water levels and the outlet invert elevations that will allow the sanctioned flow to reach the tail

cluster.

A shakedown period is the period of time a rehabilitated canal is operated during which the system is calibrated, that is, adjustments are made in outlet settings, water control levels established that provide the design outlet flows and adjusting base flows for the actual seepage losses in various reaches.

The shakedown period means that the canal is operated at the design discharge as much as possible. Initial observations at the tail cluster will probably indicate a problem and to some degree, the magnitude. The water surface level in the canal is then accurately surveyed with elevations taken at each watercourse turnout along with the outlet sill elevation. Initially the outlets are assumed to conform to design standards after rehabilitation. The surveyed water surface elevations are plotted on the long sections that contain the rehabilitated canal's designed water surface. The plot will reveal the extent and possibly the magnitude of any problems.

In that rare case when the flow of water reaching the tail end is greater than anticipated, no changes would be made unless safety is a problem. Any future sedimentation in upstream reaches of the canal would tend to cause the flows reaching the tail end to decrease. The more normal situation would be the condition where flow reaching the tail end would be considerably less than the required amount.

To increase flow at the tail end requires that the water surface level be lowered in the head reach of the canal or the sills of the outlet structures be raised. The plotted long section would indicate which reaches showed the surveyed water surface above the design level. This would be the area where the outlet sills should be raised to reduce inflows to the watercourses. Calculations can be quickly made to determine if adjusting these outlets would provide the necessary increase at the tail end. Care must be taken because increasing the discharge towards the tail would also mean that outlets located between the adjusted outlets and the tail structure would gain a slight increase in discharge due to the raising of the water level in the canal.

Control points are established along the canal at various outlets to allow canal water surface levels (WSL) to be monitored without having to continuously check the WSL's at each outlet. Control points should be established to coincide with the design reaches. A canal reach is designed with a constant bed width and depth until the discharge is decreased by 10% due to outlets and seepage. This length of a reach is somewhat arbitrary as it will normally coincide with a water control structure or outlet. Therefore, a canal with 40 or 50 outlets may have only 10 or 12 design reaches.

The flow control points would be used to determine which reaches removed more than their share of water. Once the cause of the excessive withdrawal is determined corrective measures would be taken. The most probable cause would be outlets discharging more than the sanctioned allocation. Excessive seepage losses could also be a cause. Where the magnitude of the seepage loss can be determined, it may be possible to increase the total or design inflow make up the difference. The actual seepage losses would be used to determine the sanctioned flow rather than the 8 cfs per million square feet used in design. Where the design inflow can not be increased, the actual losses must be prorated across all outlets which would. in fact, slightly reduce the sanctioned flow to each outlet. The outlets would then be reset to meet the new flow requirement plus making any other adjustments required to deliver water to the tail end.

During the calibration process, stage discharge curves are derived for each control point based on current meter measurements. Once this has been accomplished, and the canals are set with respect to all the outlets it is possible to derive a discharge curve for each control point based on flow entering the canal at the headworks and that which arrives at the control point. The total abstraction would be the sum of the intervening outlet discharges plus seepage losses. This curve can be equated to the rating curve for the control point.

This can be rather a costly process to make up for inadequacies in the design process in order to achieve equitability. The magnitude of the problem at the tail end determines the extent to which physical changes are made during the

calibration process.

Section 2: Flow Calibration

A. Discharge or Inflow

The calibration of flows throughout a canal or conveyance system requires an accurate measurement of discharges and water surface elevations. This includes the initial inflow and any branching flows within the system. Control of water requires a detailed knowledge of what is going where. It is basically a volume control or book-keeping system; i.e., what comes in must go out.

Discharge measurements are best made at a structure that controls the flow. Existing structures can usually be calibrated to provide a stage-discharge relation. Headwords, falls, siphons and bridges can be used. Particular care must be exercised during the calibration process to cover the range of expected flows and to be sure that submerged flow conditions are properly handled.

There are many water measurement structures that can be constructed in canals. The broad crested weir appears to be a good choice because it can provide accurate results with a high degree of submergence and is not as sensitive to construction problems, weeds and sedimentation as some other structures. In any event, some form of water measurement must be established. All water measurement structures must be calibrated by standard current meter measurement techniques.

B. Calibration of Water Surface Levels

The first step in the canal calibration process requires an accurate field survey be made for the canal or system being calibrated. Permanent metal bench marks are established at all water control structures to provide a readily available reference elevation. The next step is to determine the reduced level (temporary bench mark) at the top of each outlet structure that can be used as the reference elevation. This will facilitate the periodic measurement of the water surface elevation at a later time as shown in

Figure II-1.

The initial calibration of the water surface is made by operating the canal at design discharge and recording the exact elevation of the water surface at each outlet and other design locations. These will probably deviate somewhat from the designers FSL line. The deviations are due to the variable conditions of width and depth that exist in the field from the uniform prism configuration assumed by the engineer. Also, backwater conditions may affect the water surface elevation slightly. The actual water surface profile should be plotted on the "As built" drawings shortly after rehabilitation is completed and the canal is returned to service.

C. Control Point Discharge

Control points are established along the canal for the purpose of monitoring the operation of the system. The selection or setting of control points depends on their intended purpose. A flow monitoring program would require control points to be set at the ends of each "design reach" in the canal. This would provide information on cross-sections, discharge and depth of flow. Locating the control points according to the design reaches, allows a ready access to data used for design to be used to monitor conditions.

Initially a theoretical stage-discharge curve can be prepared for each control point. Current meter measurements made for a range of constant canal inflows at each control point would provide a calibration of the stage-discharge curve. Each control point discharge can then be related to the canal inflow discharge at the headworks. That is, if 300 cfs is entering the canal it means that at point A it will be 283 cfs, point B 251 cfs and on down through the system. Calibration makes it easy to check conditions within the system. If there a given amount of water coming into the system, the water surface will be at a corresponding elevation at each control point and hence at each outlet. Significant deviations (say 0.1 foot or more) would mean problems within the system and the possibility of loosing equitable distribution. A continuous monitoring of the tail cluster would quickly confirm this.

The main reason for calibrating each control point for discharge would be to determine seepage losses in each reach of canal. It is fairly apparent they will not be equivalent to the 8 cfs per million square feet of wetted perimeter used in design.

D. Outlet Discharges

The real need for outlet measurements can be made by observing conditions in the tail clusters. If water surfaces are near where they are suppose to be according to the design very little adjustment is required. If the arriving flow is much less, then it will be necessary to measure and survey each watercourse in order to reset the outlets as this is the only method that will achieve an increase in the amount of water reaching the tail cluster. Channel deepening is only a temporary measure since it flattens the slope.

A detailed calibration would require the measurement of water flows from each outlet at the canals design discharge. The summation of outlet discharges between control points would allow a comparison between sanctioned and actual diversions. It would also allow a relatively accurate determination of seepage losses.

It is suggested that calibration of outlets be made at three canal inflow discharge rates; 100%, 80% and 65% of design flow. This would allow an evaluation of proportionality of flow as well as providing three points to determine the discharge coefficients(s) from. The flow in each watercourse is measured using a portable measuring structure such as; cut-throat flume, long throat flume or broad crested weir.

The establishment of a rating curve for each outlet would provide the PID accountability of water. The farmers via a water user association would then be able to monitor the water they receive. The combination of water level data, discharge data and seepage loss data would be accurate enough for control purposes. Two other problems would still remain; (1) prediction or reliability of inflows by day or week and (2) affects of sedimentation during the irrigation season. Monitoring and a sediment trap should solve the second.

E. System Losses

Where water reaches the tail cluster so that field conditions are essentially the same as those used in the design (water level, outlet dimensions and sill level), the measured outflow to individual watercourses is not required to monitor the flows in a given reach of canal; it is only the total outflow or inflow to the downstream reach that must be monitored. The exact details of individual upstream extractions are not required so long as conditions closely approximate those used in design and full accountability is not required. Losses in any given reach could be estimated by subtracting the combined design outlet extractions as per the outlet register from the difference between the measured inflow and outflow of the reach. The inflow-outflow method is in reality a simple book keeping type of exercise and computation. The magnitude of the loss is only important in terms of providing information for system water management (distribution) and future design efforts. As long as when the design discharge enters the system, water arrives at each control point at the same elevation year after year and design flow reaches the tail cluster is it a stable regime canal operating equitably. When this is not the case, it will require the additional measurements discussed above in order to provide a complete calibration of the system.

F. Monitoring

As indicated above, as long as conditions remain stable or unchanging everything is operating correctly. But, as soon as they begin to deviate, it means changes are occurring and problems are starting. Except for conditions at the tail cluster, monitoring can not be left to memory and visual observation in alluvial canals because the changes are often subtle and occur gradually over a period of time. Numerical records must be maintained that can be reviewed periodically to ascertain where changes are occurring.

A monitoring program provides the means of keeping track of the water surface profile. It can also be used to verify and record flow data for accounting purposes. It is a very useful tool in isolating problem areas such as sedimentation, erosion and tampering. Observations made at the tail cluster indicate the existence of a problem but does not define it.

Monitoring can also be tied to inspections of the canal to ensure that the control points are visited as required. This could be on a weekly basis. Exhibit II-1 presents a form that can be used for this purpose. The method shown on Figure II-1 can be used to make the measurements as long as reduced levels are established at the measuring points. Exhibit II-2 is a modification of Exhibit II-1 in that records over a period of time are recorded on it. It can be set up to record either weekly or monthly entries. During initial shakedown periods it would be better to record weekly. Once it has been determined that conditions are reasonably stable monthly records should be adequate. Where tampering or theft of water appears to be a problem then daily observations or even more likely night time observations will be required to isolate the theft if other means are not successful. The use of the above to detect thefts has to depend on scale and the ability of the control point to monitor the change. The loss of 1 or 2 cfs from a supply of 200 cfs will not be noticed whereas if it is abstracted from 20 cfs it should be. This means that flow monitoring is more useful in determining long term changes than instantaneous.

Section 3: Monitoring for Sediment Management

A. Introduction

Rehabilitation also requires a shakedown period to determine sedimentation rates and locations. This would provide the XEN with a reasonable tool to estimate the annual desilting requirements and corresponding budget.

Where rehabilitation did not require an adjustment in the bed slope or other major changes to the wetted prism, historical records if available could provide the required information on desilting. Even a resetting of some outlets to increase or decrease sediment draw to achieve more equity, might not change the sediment deposition downstream to any great extent.

Where rehabilitation only required minor changes in slope or other features, sedimentation might be estimated from the hydraulic design statements and historic records. Monitoring would provide verification and improved accuracy.

The inclusion of a sediment trap in a canal to concentrate sediment deposition and facilitate cleaning would require a monitoring and calibration period. A sediment trap is designed and operated to remove only a fraction of the total sediment bed material over a years time. The canal must transport and distribute the remainder. Flowing water seeks to transport exactly the amount that its "stream power" will allow. Therefore, excessive desilting is not only expensive but there would be a tendency for the flowing water to scour enough downstream bed material to balance its potential transport capacity.

Once the system has been calibrated, and the operating rules established, only a nominal, long term, monitoring program is required to cover primarily those areas or points where a potential problem may form and to provide information on desilting.

Moving water has the ability to carry a certain amount of sediment based on water velocity, grain size and distribution, specific gravity and temperature. Depending on the velocities and depth in the canal the carrying capacity can change. In general, it can be stated that with higher velocities more sediment can be carried through the canal, a reduction in flow velocity introduces a reduction in carrying capacity. The hydraulic design of a canal is based on a uniform transport capacity along its entire length. This requires the bed slope to progressively steepen towards the tail end of the canal as water and sediment are withdrawn at the outlets; thus, the velocity remains nearly constant. Sediment traps are required when the incoming sediment load is greater than the transport capacity of the canal. For example, if the incoming load is 180 ppm and the transport capacity is only 145 ppm, 35 ppm must be removed by the sediment trap to prevent deposition in the canal.

For the sediment balance to be in equilibrium, the 35 ppm should be removed continuously. A sediment trap will not accomplish this directly. If the basin is empty, most of the bed material will drop out near the entrance so that the water exiting the trap will have a very low bed material concentration. Because the moving water has the capacity in this alluvial canal to carry 145

ppm, the water will immediately start to erode the canal bed downstream of the trap. This erosion process will continue as the water moves downstream until the transport capacity (145 ppm) is satisfied. Ultimately this could result in a flatter slope in the canal downstream of the sand trap.

The canal must be operated in such a manner that the downstream erosion is not allowed to continue for a long period of time because it may disrupt condition in the watercourses or within downstream channel(s).

A second consideration is that the bed load concentration does not remain constant for a given discharge. It appears to vary over relatively short periods of time. It also varies because of changes in discharge and the time of the year. Little is known about the variability of sediment concentration over time. This is another reason why monitoring is required.

B. Effects of Sediment Trap Location

The location of the sediment trap will have an affect on how the sediment trap will behave. The two typical locations are (1) located just downstream of headworks and (2) towards the middle reach of the canal where the slope can as longer be increased. The headend location would mean that the sediment trap would be located in a reach of canal that would be designed to operate with the same transport capacity as the last reach (say 145 ppm citing the above example). Therefore, even before the downstream end of the stilling basin was completely filled up sediment deposits would begin to occur above the design bed level in the front end because the incoming concentration continues to be 180 ppm. Deposition would still occur in the sediment trap and just downstream of it where the water depth causes a velocity reduction. Further downstream the bed would still continue to erode until the 145 ppm capacity was reached. The system is not quite in balance and might require considerable monitoring to make the adjustments that would approximate equilibrium. The amount of desilting, timing and possibly location would have to be determined in the field.

When the sediment trap is located towards the middle of the canal a different condition exists. In this case, the upstream reach of the canal would have

the capacity to carry the 180 ppm and it is only the downstream reaches that have the reduced capacity. Therefore, the sediment trap would be located at the end of the initial reach so that once it is filled it would carry the 180 ppm. Therefore, all of the excess bed material would deposit downstream of the stilling basin. In theory, the system would be balanced on a annual basis.

When sediment traps are located at the head end of a canal or system it is usually because there is insufficient slope to design a canal with a higher carrying capacity. A sediment basin could be designed to carry 180 ppm after it is filled but it would reduce the total head available for the design of the canal which reduces its carrying capacity; an example might be from 145 ppm to 140 ppm. This in turn means that the amount of sediment removed each year will increase and the sediment trap would have to be slightly larger. The design must be based on the most cost effective solution.

C. Effects of varying concentration

The day to day variation is sediment concentration is not known. Even at constant discharge, there are enough data to indicate that the rate changes with time. The rate of change is unknown. The reason for the daily (rate of change with time) variation is not known although part of it is related to change in the sediment inflow rate at the controlling barrage. Variations would also be due to changes in the upstream and configurations as well as the three dimensional affects of velocity. The design of the canal and monitoring are usually based on a one dimensional approach.

The variability of the incoming bed material sediment load will have an effect on the deposition pattern in the sediment trap, the annual amount of sediment entering the system and the processes and conditions affecting the erosion-sedimentation process downstream of the trap.

D. Monitoring Sediment Balance

The design values are only estimates and what occurs in the field will differ, not only in total volume but also from year to year. Since the system, in the example cited, will transport about 80% of the bed load, the desilting of more material than is necessary is an extra cost. Removal of too much

sediment may tend to cause the canal to scour downstream and may be drop out further on towards the tail. Since desilting is costly, operating rules should be devised to minimize this cost. The following describes some of the items that must be considered in setting up the sediment monitoring program and establishing the rules for operating and desilting:

(1) Annual sediment volumes will vary from year to year and sediment rates will vary from month to month depending on upstream conditions.

(2) The long term sediment transport capacity of the system must be determined as the designers estimate is an average value based on several assumptions.

(3) Excessive desilting may cause canal erosion to take place downstream if insufficient sediment is not available over the entire year to balance the canals transport capacity.

(4) The canal bed may degrade and/or aggregate periodically as the sediment load varies. The annual change, if any, is what must be controlled.

(5) The flow in the canal cannot be disrupted for desilting other than in the closure period; except possibly for a few days during kharif harvest or during rainy periods when the demand may be less.

(6) There are no experience factors to draw on.

The sediment management program is composed of two parts:

* Operation of the sediment trap.
* Monitoring sediment conditions or balance along the length of the canal.

A sediment monitoring program would be based primarily on observing/measuring conditions at various points along the profile of the canal. By

knowing what is occurring on the canal bed, changes can be made in operation of the sediment trap. The effect of these changes are then observed. This monitoring would be a more or less continuous program.

The sediment monitoring program is implemented in two stages:

* Startup - shakedown program.
* Operational program.

The startup or shakedown program would be implemented initially to determine what actually happens on the canal bed and how the system must be operated. It requires a large number of cross-section observations be made initially at short intervals. As the operating rules are developed and conditions in the canal tend to stabilize, both the number of observations and locations may be decreased.

Once the operating rules are established and fully evaluated, the operational monitoring program is implemented. This program would require periodic observations to be made only at those locations which are needed to monitor conditions. All other observation points used in the shakedown period could be eliminated. Both the location and the time between observations would be determined during the final phase of the shakedown period to allow a final evaluation of the proposed operational program.

The startup period would be flexible enough to allow more observation points to be added as well as additional measurements as conditions warrant. The first canal to receive and operate with a sediment trap will probably require a more extensive program than those installed later on. Experience factors should be applicable elsewhere.

The design of a canal for rehabilitation requires a cross section be prepared every 500 feet or 0.5 RD. Figure II-2 provides the cross section survey requirements. Figure II-3 indicates the survey requirements for each outlet. The cross sections are plotted and then the long sections prepared. All structures are located on the long sections with appropriate cross sections.

These are made part of the design and construction-contract drawings. Upon completion of the construction work and prior to operating the canal a second set of cross sections are prepared for the same locations as the original ones made for design. These are the "As-built" sections and should be plotted on a set of construction drawings and marked "As-built". All future references for conditions concerning the canal prism would be made to the "As-built" sections.

A startup monitoring program would require all the original sections to be resurveyed for two consecutive years following the canals return to operation. Exhibit II-3 presents the monitoring form for entering data for analysis and evaluation. A complete evaluation of conditions is made following the second year of operation to redefine the monitoring program. The selected monitoring control points established for flows will be also used for sediment. In addition, those points that appear to have sediment or erosion problems determined during the startup period evaluation will be retained and added to the control points for continued observation. At the end of 5 years, the monitoring program should be re-evaluated and adjusted accordingly.

A monitoring program is used to determine how much sediment will deposit in the canal, where it will deposit and how long it will take before the performance standards will require desilting. The program would then indicate how much would have to be removed. This still holds true when a sediment trap is included in the system. In this situation, the annual analysis and evaluation of the data will indicate how the sediment trap is preforming and what adjustments in operating the canal should be made to improve its performance. The stilling basin, in simple traps, can either be lengthened or shortened to control the total volume removed.

Any desilting that must be done during the irrigation season to improve sediment distribution may require closure of the canal. Removal of saturated sediments by mechanical means is difficult. It would probably require a backhoe with a solid bucket. The water level would have to be reduced considerably and the operator would have to be sure to go deep enough to fill the bucket before lifting it up and out. Dragline buckets will not work.

Clam shell buckets would require testing to determine performance. This tends to limit the size of canals that could be desilted during canal operations. The irrigation demands are usually lower during the harvest period so that cleaning could be scheduled by rotating flows or suspending inflows for a week to 10 days. Mechanical cleaning can be accomplished during rainy periods, particularly when the spoil is to be placed on the backslope of the embankment.

EXHIBIT II-1

FLOW MONITORING CONTROL POINTS

Canal: _____ Div. _____

Discharge: _____ Sub Division _____

_____ Date _____

Downstream W.S. elev. _____ Sub Engr _____

Control Points				Current Situation				
Reach RD No.	Structure Data			Dist. to W.S. (d) (in) (ft)	W.S. Elev	Stage ft	Est. Q cfs	Control Q cfs
	No.	Dir	RL					

W.S. = Water Surface

Q = Discharge

d = Distance from Reduced Level to Canal Water Surface.

LONG TERM FLOW MONITORING RECORD

Canal Name _____

Structure/Control point _____

Design dicharge _____

Calibrated Water Surface Level _____

Location (RD) _____

Reduced level _____

Division _____

Subdivision _____

Date of last Q Calibration _____

Date	Dist. to W.S. (d) (inch) (ft)	W.S. Elev. (ft)	Stage (ft)	Est. Q cfs	Control Q cfs

W.S. = Water Surface

Q = Discharge

d = Distance from Reduced Level to Canal Water Surface.

EXHIBIT II-3.

EMBANKMENT AND SEDIMENT MONITORING

Canal Name: _____ Division: _____

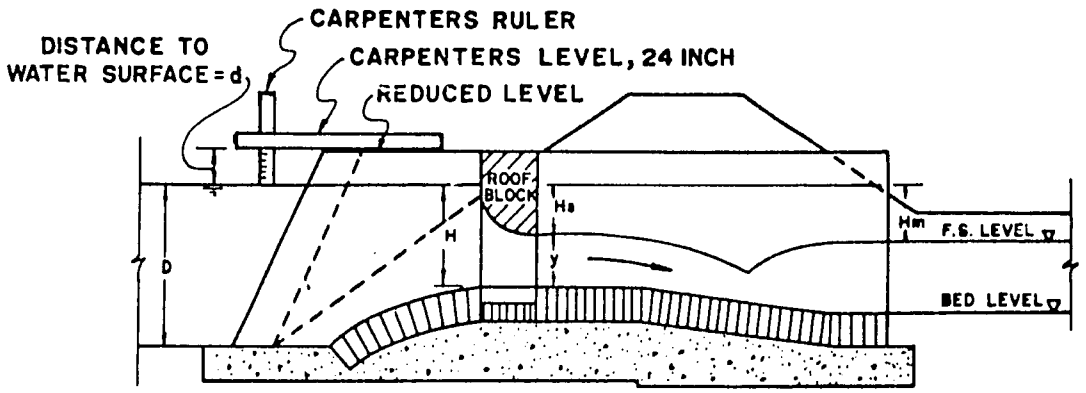
Design Discharge: _____ Sub Division: _____

Location RD _____

Structure/Name: _____

Average Sediment Concentration _____

Year	Ave. Max Q Cfs	Item	Point B (Ft)	Point C (Ft)			Point O (Ft)	Point P (Ft)
		Design Dist						
		Design Elev.						
		As built Dist.						
		As built Elev.						
		Meas. Dist						
		Meas. Elev.						
		Change Dist.						
		Change Elev.						

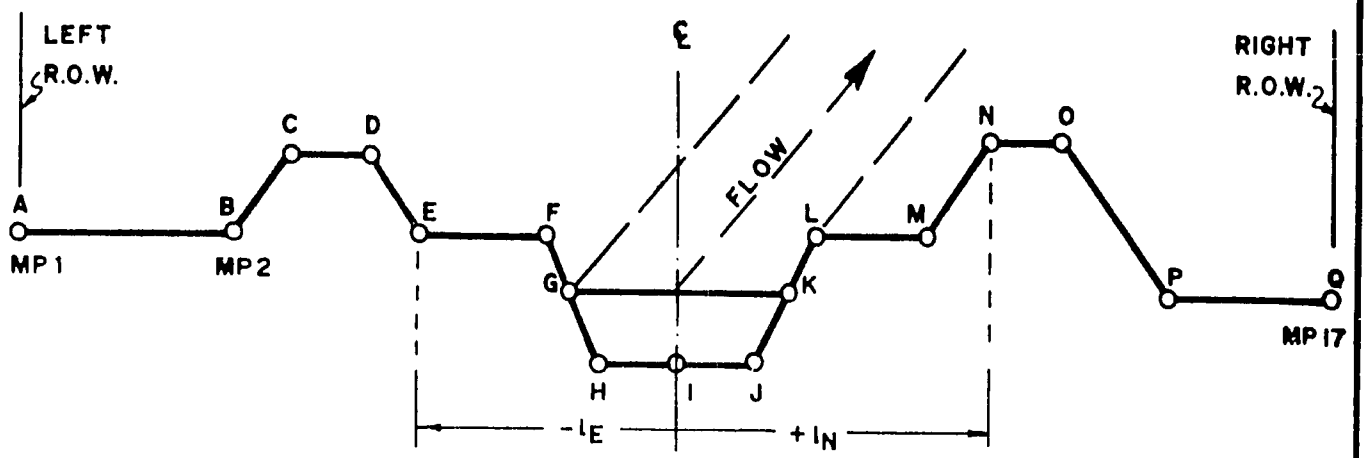


Note:

1. Reduced level set on outlet masonary cap.

2. Can substitute 6-foot steel tape for carpenters Rule.

MEASURING WATER SURFACE LEVEL AT CONTROL POINT

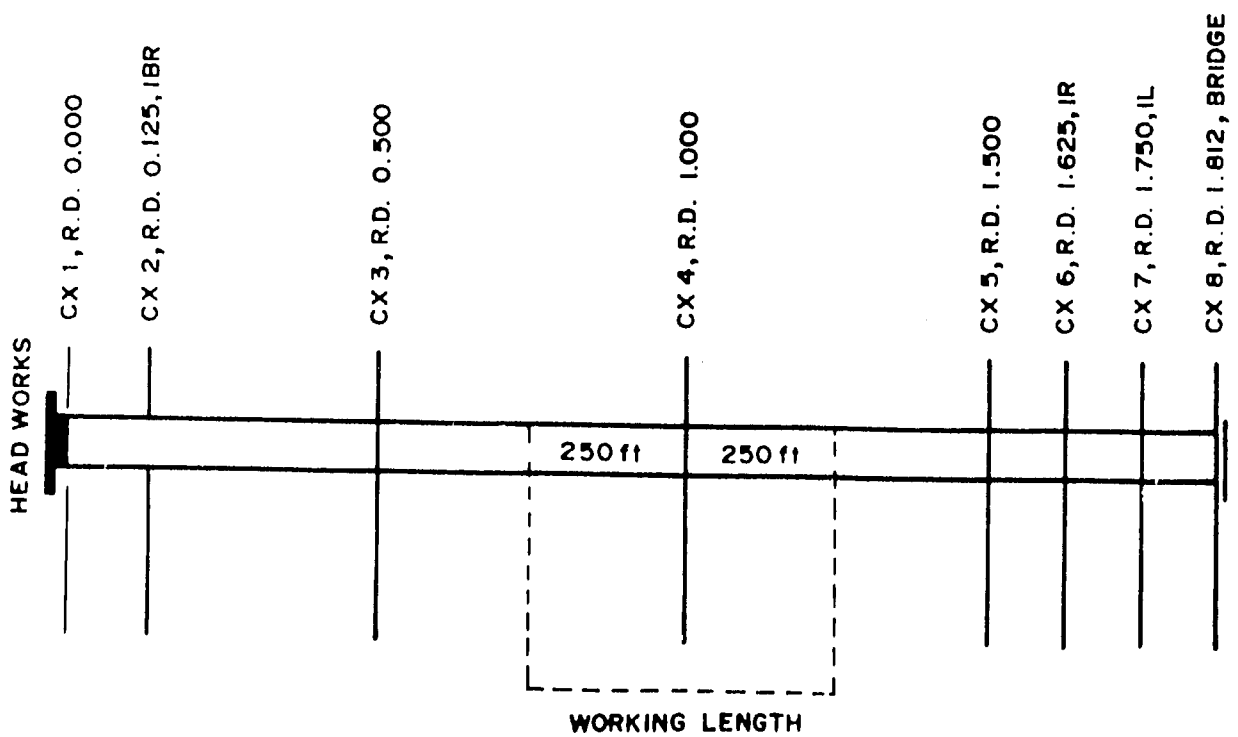


In each point A upto Q one number and two values are measured:

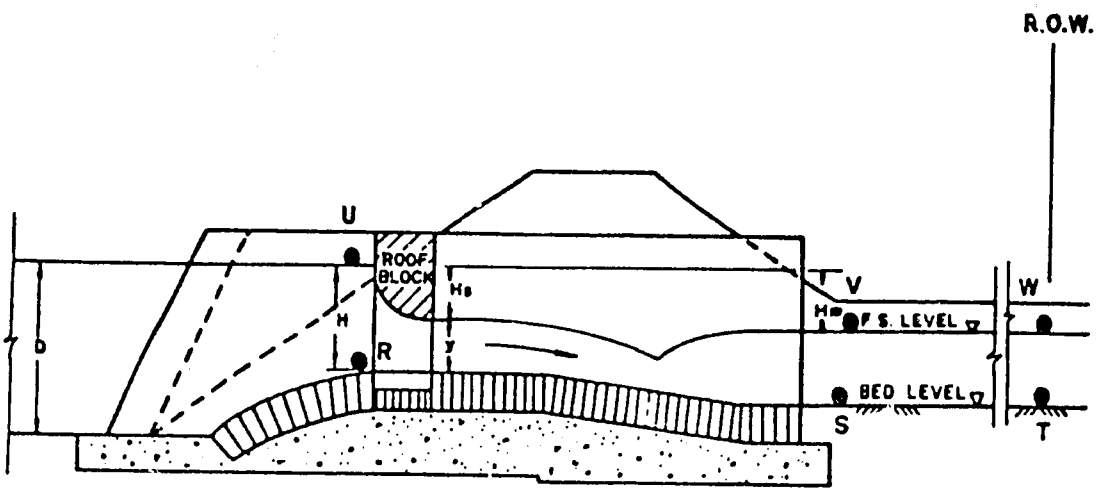
- measuring points in the cross-section, sequentially starting from point A
- level related to GTS
- distance to center line (negative or positive)
  points A - H negative
  points J - Q positive

The points A-Q are the minimum number points which must be measured in the cross-section. Additional points can be located between any two lettered points in order to define actual conditions.

In normal situations cross-sections will be measured every 500 ft, and at all structures.



SURVEY REQUIREMENTS
CANAL MONITORING PROGAM



Notes:

1. Estimate water surface level when watercourse is dry; points U, V and W.

2. Define outlet number and delivery side.

3. Define width of outlet.

4. Give canal stationing.

SURVEY REQUIREMENTS
OUTLET MONITORING PROGAM

CHAPTER III

OPERATION

CHAPTER III

OPERATION

Section 1: Introduction

The proper operation of any irrigation system is very essential in order to achieve optimum results; equity and productivity. So important is proper operation that even the most sophisticated system with the best facilities can not provide the expected results if the system facilities are not operated properly. Successful operation, therefore, will depend largely on the system operators as well as the operating procedures adopted and put to use. Operations activities should be closely supervised and well coordinated in order that the desired issues of water are made to the watercourses. The other requisite to good operations is to be able to keep the water level in the canals almost constant; thus to allowing uninterrupted delivery of water and maintaining proportionality.

Section 2: Performance Standards

A. Introduction

Performance standards have been established to provide the field staff with the standards to which a rehabilitated canal must be operated. The performance standards are defined in Table III-1 and relate to allocation of water to the watercourses, equitable delivery, maximum and minimum allowable flows and other operating functions.

B. Flows

The hydraulic design criteria, the basis of canal design, limited maximum discharges to 1.2 times the design discharge. This maximum discharge must be observed at all times. Following rehabilitation it is possible that sedimentation will reduce the maximum allowable discharge into the canal because the freeboard performance standard limits encroachment to 1/2 of the design freeboard which for most distributaries and minors is;

Design Depth	Maximum Encroachment
Less than 2.5 ft	6 inches
Between 2.5 ft and 4.99 ft	9 inches

C. Distribution of Water

The sanctioned outlet register defines the water allocated to each watercourse and is the basis for the equitable distribution. The outlets are designed to provide the sanctioned discharge based on the full supply level (FSL) in the canal. The design of the turnouts (mogahas) is such that the discharge to the watercourses is proportional to the flow in the canal. The nominal range of proportionality is 80 to 120% of design flow. Reasonable proportionality is maintained at discharges down to 60%. Therefore, the monitoring of equitability is done by monitoring the water surface elevation (level) at each outlet.

The discharge record for each canal provides information on the amount of water that was received and the water level record and the "H Register" provides information on distribution. Any deviations in these records (excluding minor fluctuations due to measurement inaccuracies) would indicate a change in the equitability of distribution. The change could be due to a change in the hydraulics, sedimentation for example, or tampering with the outlet itself.

Deviations of 0.1 foot or more from the calibrated water surface level requires the Sub-engineer to determine the cause and initiate corrective action. Variations of less than 0.1 foot in either direction are attributed to water bounce when reading the scale.

D. Distribution of Sediment

The distribution of sediment along a canal has been assumed to be equitable and that all outlets draw their proportional share. The sill levels of outlets must remain at the design level and cannot be raised. The exception to this rule may occur when the outlets have to be reset to obtain equitable distribution of water; i.e., the tail cluster must receive additional water. In

this case, it may be possible to narrow the existing outlet.

In those instances where the design of the canal is such that it will not transport the sediment bed load through the entire length of the canal, a sediment trap may be installed to trap that portion of the sediment load which cannot be transported. A monitoring program is used to evaluate the operation of a sediment trap, as explained in Chapter II.

E. Uninterrupted Delivery

The design of the canal is based on a continuous flow to all watercourse outlets. Except for periods of heavy rainfall or low demand, the canals should be operated with an uninterrupted delivery.

Section 3: Method of Operation

A. Introduction

The canal is operated to satisfy the performance standards as stated in Table III-1, i.e. continuous flow at the design discharge maintained at the FSL unless otherwise directed. The background and method of accomplishing this is described in the following subsections.

B. Equitable Distribution of Water

Equitable distribution of water is controlled by maintaining the canal water surface level (elevation) constant for a given discharge. This is accomplished by proper operation of the water control structures and constant monitoring of the water levels at the control points located along the length of canal and at the tail cluster. The watercourse outlets (mogahas) are designed and constructed in such a way that when the canal is at the full supply level (FSL), which represents the design capacity, each watercourse will receive exactly its sanctioned share.

The watercourse outlets are also designed to operate with modular flow, which means the head losses through the structure are less than the difference in water surface elevations between the canal and watercourse. Therefore, if the water level in the canal changes, the discharge to the

watercourse also changes in proportion to the change in water level. This allow each watercourse to continue to receive its proportionate share of the available flow in the canal.

Tampering with the outlet will cause that watercourse to receive more than its share and will cause the tail end of the system to receive less. All outlet tampering should be reported immediately to the SDO. It is a maintenance function to repair and reset the tampered outlet.

There are two conditions that may often occur in an alluvial canal operating with fluid sediment: deposition and erosion depending on local conditions. The rehabilitated canal was designed to minimize the occurrence of these conditions. The occurrence of either condition will affect the distribution of water as follows:

(1) Effects of Sedimentation - Sedimentation refers to a general deposition of bed load sediment in a reach of canal that causes the canal bottom to be raised. This sediment deposition will cause the water surface level in the canal to rise and encroach on the freeboard (assuming design discharge). This in turn causes a back-water curve in the upstream canal water surface which allows all affected outlets (mogahas) to discharge at a rate greater than the design discharge. The downstream outlets will receive less water. The problem tends to compound at the tail end.

(2) Effects of Erosion - Erosion is the loss of material on the canal bed or banks. This will tend to cause a lowering of the water surface level. Therefore, the outlets will discharge less than the original design called for.

Monitoring the water surface levels and the annual inspection and canal monitoring program provide the SDO and SBE with information on flow conditions in each canal.

C. Operating Modes

1. General

Water management within an irrigation conveyance system involves the technical procedure of operating the systems facilities in a competent manner that allows the system to serve all the outlets equitably. The major tool that allows the process to be accomplished in a relatively easy manner is water measurement. Discharges will be measured into all rehabilitated distributary and minor canals controlled by cross regulators. It is also important to measure the water that passes down the main channel so that the total inflow to the regulator can be accounted for.

The Executive Engineer determines the allocation of the available flow to each distributary and advises the SDOs. The SDO will then issue instructions to the appropriate Sub-engineers who inturn inform the gage reader. When inflows are less than the design flow, the SDO's may be given the authority to adjust flows between canals to improve equitable distribution and to meet irrigation demands.

2. Continuous Flow

Most irrigation systems in Pakistan were designed to operate continuously at the design flow. Therefore, the design discharge is maintained as much as possible to allow all canals to provide an equitable distribution of water. Distributaries tend to be located at the tail end of the irrigation system and are often subject to considerable variation of inflow. The amount of variation and how often the discharge changes depends on the operation of the barrage and adjustments made at the upstream regulators. The seasonal flow will most likely fit a pattern of some kind. This is where historical records can help the operating staff as they provide the basis for what can be expected in the future under similar circumstances. The variations in flow will most likely vary along a seasonal or monthly pattern. Harvest periods generally have low demands.

The travel time from upstream regulators determines the time of day that the changes in flow occur. This is important because it means that the gage reader must be available at this time of day or night in order to make any

necessary adjustments/changes. Whenever cross regulator gates are adjusted, it will take some time for the upstream flow conditions to settle down to equilibrium conditions. Rabbi season flows may be less than kharif season flows and therefore, care must be taken not to check the water surface up too high so as to loose equitability.

3. Rotation

Rotating flows between distributaries is the basic low flow operating strategy used in Pakistan. Flows are rotated when the incoming flows are between 55 and 60% of design flow. Flows less than 55% of design flow in small channels should be avoided because they cause increased sedimentation and poor proportionality between outlets. The SDO will notify the Sub-engineer or gage reader when to change to rotation distribution and the amounts to be sent to individual canals. Care must be taken not to exceed the downstream capacity of the receiving canal. The excess flow or the difference is released to the other canal. Rotation periods are 8 days with one day used to prime and dewater the respective canals.

4. Heavy Rainfall Situations

The Sub-engineer has no authority to change canal flows without the SDO's instructions. Under no circumstances are farmers allowed to close off headworks to watercourses, even when faced with drainage problems.

5. Flow Limits

There are three operating limits that must be observed at all times. First, the maximum inflow should not exceed 1.2 times the design discharge. Second, discharges greater than the design flow can not be run for more than two weeks and must be followed by a period of two weeks at normal flow. Third, under no circumstances will the design freeboard be encroached on more than 50% of its depth. Therefore, except for the tail reaches the maximum rise in the water level will be 9 inches. Canals where the depth of flow is less than 2.5 ft are limited to only 6 inches.

Operating under surcharge condition when flows are greater than design flows requires that the beldars be alerted. During surcharge operating conditions

the beldars should intensify their patrolling to ensure that the freeboard is not encroached on more than the allowed 6 or 9 inches specified above.

D. Water Control Structures

Water control structures are associated with cross regulators, proportional weirs and falls. They are used to control water surface levels and divide discharges. Gates or stoplogs (curries or needles) are used to regulate discharges and water levels on most control structures.

Falls or drops are placed in the canal to raise the water surface elevation and thereby reduce the velocity and scour potential.

The amount of water to be turned into a distributary canal is determined by the XEN and given to the SDO. His order is sent to the Sub-engineer who then orders the gauge reader to make the flow change as directed. This allows the SDO to balance the flows throughout the system.

The technical details of gate operations are presented in Table III-2. The Table details the opening and closing instructions. Under no circumstances will the water levels be allowed to encroach on the freeboard more than the maximum allowable, 9 or 6 inches.

When gates are not operated for long periods of time it is important to set up an exercise schedule to at least crack the gate, i.e. open and close the gate an inch or two to be sure it still works. The gates are to be exercised on the first day of the month. The escape gate(s) are a category that are included in the regular schedule. The Sub-engineer is responsible for this function. Exercise instructions are included in Table III-3.

E. Canal Filling and Drawdown (dewatering)

Except in emergency situations, the discharge in a canal should never be changed rapidly. A rapid rise or fall in the water level of a canal is a major cause of bank caving. A general rule is that a canal should not be raised or lowered more than one foot in a 24 hour period.

The major reason for a large change in canal discharge would be when the system must change the mode of operation from continuous flow to rotation flow. This means one canal must be increased to design discharge and the other decreased to near zero. An increase in flow from about 55 to 60% of design to 100% in a distributary will cause a rise in water level of about 1-foot. The decrease in the other canal will be on the order of two feet. The rapid drawdown condition is more serious than rapid filling. Drawdown would start with the first foot or so of the canal bank already unsaturated. Flows should be adjusted every six hours with the change limited to 20% of the total change in flow to be made. This will allow the complete change to be made at the head regulator in 24 hours. The alternative is to change at a rate of 10% of the total increased discharge every three hours. A second alternative exists wherein the change would be based on the percentage of depth that must be covered in a 24 hour period. This alternative would require a different change in discharge each time the change in gate opening is made. This method is better suited to large canals than small.

Section 4: Enforcement

The enforcement of the rules and regulations is an important part of good system operation. The enforcement has been difficult. It will require the complete cooperation and support of the PIDs, local officials and police. Without this support discipline will not be possible. Where political parties or individuals are able to exert sufficient influence to have individuals or groups excluded from the rules/regulations, enforcement will be difficult if not impossible.

TABLE III-1

PERFORMANCE STANDARDS FOR CANAL OPERATION

1. Allocation of Water

The latest Outlet Register used for rehabilitation provides the sanctioned allocation of water to each watercourse. This defines equity.

2. Equitable Distribution of Water

The full supply level, FSL, defines the condition for which the equitable distribution of water was designed to be made to each watercourse. Therefore, at the design discharge the water level in the canal must reflect the FSL at all times; i.e., a deviation indicates a non-equitable condition.

3. Equitable Distribution of Sediment

The design of the turnout includes the consideration of sediment draw. The design of a rehabilitated canal assume the equitable withdrawal of sediment by each watercourse turnout. Therefore, the sill level of an outlet cannot be raised.

4. Uninterrupted Delivery

The uninterrupted delivery provides equitable distribution of water in a continuous flow system. Rotation of flows between canals is required when canal flows are reduced to 55% of the design discharge. Flows can be reduced to watercourse(s) serving an area due to occurrence of heavy rainfall or a low crop water demand. All changes in distribution must be recorded on operations log.

5. Maximum-Minimum Flows

The maximum allowable flow in a canal under certain conditions is limited to 1.2 times the design flow (1.2 Qd).. The duration of a discharge greater than the design discharge cannot exceed two weeks under any circumstances. The canals should not be operated at flows less than 55% of design.

TABLE III-1

PERFORMANCE STANDARDS FOR CANAL OPERATION
(Continued)

6. Maximum Water Level

The maximum water level can never be allowed to exceed one half of the design freeboard (1/2 fb) under any circumstances.

7. Inspections and Reports

Inspections and accompanying reports must meet the following minimum:

(1) Sub-engineer must make a weekly inspection and report.

(2) Sub-division Officer is required to make a biweekly inspection and report.

TABLE III-2

GENERAL GUIDELINES FOR THE OPERATION OF CROSS REGULATORS

The control and delivery of irrigation water arriving at the cross regulators is the responsibility of the Executive Engineer. He is authorized to make all necessary adjustments to the flow to provide equal distribution of water to all distributaries and minor canals. Additional guidelines are as follows:

1. Every regulator gate should be provided with a locking device.

2. At the start of irrigation season, release only a small regulated flow, upto 20% of full capacity from the regulator(s) for canal priming purposes. This should be done a day or two immediately before the start of regular water deliveries. The flow can be gradually increased as the water wets the system. Be sure the flow can be passed through the system. The distributary headworks should all have the gates fully open to allow flow to pass through without raising water surface.

3. As soon as the priming water has reached the end of the main conveyance canal the check (cross) regulators should be partially closed to allow the water surface to slowly rise.

4. Release of water should be done slowly until the water level reaches the controlled water level at all the downstream regulators.

5. Water should be released into the branch and distributary canals as soon as the water level in the main canal will allow it.

6. Constant observation is necessary to be sure the water level does not rise too fast and the gates control the flow.

TABLE III-2

GENERAL GUIDELINES FOR THE OPERATION OF CROSS REGULATORS
(Continued)

7. When the conveyance system becomes fully primed the release (diversion) into the main canal should be increased to the required issue.

8. When the full release arrives at the regulators, the gates will be re-regulated and the appropriate discharges will be set for each distributary and water measurements made.

9. During low flow periods the Executive Engineer will check the available flows to determine when rotation irrigation should be initiated. Normally sufficient notification will be received so that he can notify the SDOs and some form of warning can be given to the farmers. The SDO has the same responsibility to check on when rotation should be started. The XEN should then inspect the system to be sure that the necessary adjustments have been made. He will also make sure that the standard operating procedures for rotation irrigation or other low flow scheduling strategies are understood and accordingly being carried out.

10. Except in an emergency, closing of the regulator should be regulated such that the water level in the canal does not change abruptly nor decrease more than one foot per day, thus minimizing slumping of the inside canal berms. The gate sill must be kept clean to avoid leakages when the gate is finally closed.

11. In closing a regulator or headworks gate, care should be exercised not to over manipulate the wheel in order to avoid bending the gate stem. Once the locking device is about 1/2-inch away from the horizontal braces of the gate, the wheel or crank should be turned very slowly until the gate rests on the sill. Stop turning the wheel at this point. Bending of the stem usually occurs when the gate keeper continues to on turn the closing mechanism not knowing the gate has already reached the gate sill. The gate is then locked.

TABLE III-2

GENERAL GUIDELINES FOR THE OPERATION OF CROSS REGULATORS
(Continued)

12. The travel time of flow to each regulator or between regulators varies and must be established if not known.

13. The losses in each canal reach should be estimated from preforming simple water balance studies at various discharges.

14. Under no circumstances should water be allowed to spill or flow over the top of gates.

15. Optimum stilling of water downstream of regulators and gated structures is produced when waterflow is distributed uniformly across the basin as it enters. A hydraulic control structure having more than one control gate produces flow distributed uniformly into the stilling basin when all gates are opened equally. Where all gates cannot be opened equally, the most desirable flow patterns usually are produced by equally opening gates symmetrically about the structure centerline. Gates must be operated in the above fashion at all times.

TABLE III-3

EXERCISING AND TESTING GATES

1. Safety of the structure, the canal system and good operation and maintenance practices require that each gate be tested to confirm that it will operate as designed.

2. All gates not subject to normal operations (periodic raising and lowering) must be tested once a year. This applies primarily to escapes.

3. Exercising and testing should be done by using normal power sources (nominally by assignment operator) to ensure the operation of each.

4. All exercising and testing results should be recorded and dated in the "operating log" or with the Sub-engineer. Copies should be forwarded to SDO.

5. A differential head test should be performed while subjected to the maximum normal head expected for the reason. Testing confirms the gates will open and close satisfactory. Testing should be conducted in the following sequence:

   (a) Barely open (crack) the gate so that it will produce additional leakage; then close.

   (b) Open the gate 1 inch; then close.

   (c) Open the gate 3 inch; then close.

   (d) Open gate 10 percent; then close.

Note: Percentage of gate open refers to percentage of normal full range of height gate would be operated in.

TABLE III-3

EXERCISING AND TESTING GATES
(Continued)

6. Caution: If, during any test, the gate will not close from any position or otherwise malfunctions, stop the test and determine the cause of the malfunction and correct it. If malfunction cannot be immediately corrected, contact SDO for assistance. Testing will not be resumed until malfunction is corrected.

7. An operational test shall be performed on emergency gates (escapes) once every six years. The gate(s) should be raised to the fully open position and closed. Gates can be opened sequentially unless known problem would occur. Operation of emergency facilities during the 6 year period may be substituted for this requirement.

8. All required lubrication and maintenance to the hoist equipment should be done prior to operational testing and exercising.

9. For safety reasons, two persons must be in attendance when exercising and testing of gates is performed.

CHAPTER IV

MAINTENANCE

CHAPTER IV

MAINTENANCE

Section 1: Introduction

A. General

Maintenance of the canal(s) or reaches of a canal assigned is the major concern of the Sub-engineer. It is his duty to supervise the performance of the beldars to maintain the canals and associated structures in good operating condition. This manual contains the maintenance standards necessary to keep the canal in good operating condition.

1. Maintenance Objective

Maintenance of an irrigation system in Pakistan is concerned with maintaining the channels capacity to deliver water. The objectives should to be:

* Keep the system in top operating condition at all times through proper maintenance.

* Obtain the longest life and greatest use of the systems facilities by providing good maintenance and timely replacements.

* Achieve the foregoing objectives at lowest possible cost.

Maintenance begins before the rehabilitation of a system or sub-system is completed and the system as a whole is placed back in operation. Keeping maintenance work current on all facilities in a system is the keystone of any successful irrigation maintenance program. Preventive maintenance not only pays dividends in the economical operation of a smooth working system, but also means the uninterrupted delivery of water to the watercourses.

2. Maintenance Program

All structures and facilities are subject to deterioration in varying degrees. Constant vigilance is necessary to identify and correct potential unsafe or unsatisfactory conditions as they develop. Cracks in lining, general erosion, settlement of embankment or structure, scour, seepage, and serve animal damage at crossings and in village areas, etc. can result in major failures if not corrected or repaired without delay. Breaches are an expensive failure, not only due to the cost of repair but for the loss or damage to crops of the farmers directly affected as well as those living downstream who are deprived of water.

Many problems that develop may not be of such a serious nature as to cause failure. The control of weeds, erosion of banks, seepage of water through banks, aggradation, degradation, loss of freeboard and minor localized animal damage may be less serious, but they are problems that must also be given attention. Frequently these problems are more time consuming and costly over the years.

The use of proper materials for repair or replacement is important. This can include adequate attention to the proper placement of earthfill including site preparation, moisture control, compaction, and other placement features; proper proportions and/or the constituents in masonry mortar, wetting bricks, site preparation and even the bricks or rocks themselves; suitable aggregates and other constituents of concrete. Sub-engineers should always be on the lookout for new materials or products and their adoption as well as better ways to use existing materials or improvements in construction techniques.

Maintenance in irrigation system is usually divided into four categories, namely:

* Regular routine maintenance
* Seasonal repairs
* Annual repairs
* Emergency repairs

Proper operation and an adequate annual budget are essential for a good maintenance program.

B. Permanent Bench Marks

The canal monitoring programs for flow and sediment require the resurveying of the rehabilitated canals at lease once a year. Therefore, considerable time will be saved as well as increased accuracy if permanent bench marks are established. The bench marks should be established during rehabilitation but if this is not done they should installed as soon as possible thereafter. The minimum would be to install a permanent metal disk at each canal headworks with the appropriate information engraved. Additional bench marks should be install about half way along the canal and at the tail cluster. The current bench mark standards for the Provincial Irrigation Department should be used.

The installation of bench marks will facilitate the establishment of reduced levels at each outlet and water control structure. It also facilitates periodic rechecking of these levels.

Section 2: Responsibilities and Standards

A. Responsibilities of the Sub-engineers

The Sub-engineer is responsible for supervising the mates/darogas and the beldars. He will implement work programs as instructed and will be responsible for carrying them out.

The Sub-engineer (SBE) should inspect his beats as often as transportation allows. The use of a motorcycle may allow him to cover one half or more of his area of responsibility each day. Bicycle transportation may limit it to twice a week. It is important that the Sub-engineer contact each beldar while traveling his beat. Additional responsibilities are contained in Table I-1. He will set priorities for the beldars when the work load is heavy.

The Sub-engineer will supervise any work gangs assigned to his beats to ensure that the work to be done is accomplished in a technical and professional manner. Short cuts in the work effort or procedures that will

not allow the work item to be completed according to specification will not be permitted.

Field inspection and field testing to assist the SDO in monitoring a contractors work effort must be done in a competent manner. The object is to have the work done to specification, not to cause a contractor problems by throwing ones weight/authority around indiscriminantly.

B. Inspection

1. Post Rehabilitation Inspection

As soon as the rehabilitation construction work is completed the SDO and SBE should make a very thorough inspection of the canal prism, structures and related facilities to ascertain that they meet the design and maintenance standards. All deficiencies should be noted and any remedial work required indicated. It is important that all deficiencies be corrected immediately. It is difficult to impose maintenance standards if excessive amounts of work have to be accomplished after rehabilitation to bring the canal into compliance.

The most difficult aspect of the post rehabilitation inspection will be the matter of resetting the outlets. The resetting should be done during the rehabilitation period because the social problems would be easier to handle. Trying to reset the outlets during the calibration of the canal will be more difficult.

2. Periodic Inspections

Inspections are made to ensure that the system is operating correctly and all features are maintained correctly. Inspections are also made in order to properly supervise the beldars in doing their work and to request additional help when the beldar is unable to keep up. Inspection trips allow the supervising officers to see what is happening and to take corrective action as required.

The spreading out of the beldars to cover several miles of canal minimizes the amount of work the individual can do if he is also expected to patrol his

zone of responsibility. Where problems become acute, the Sub-engineer will have to request additional help from the SDO to assign a work gang to make the necessary repairs. Particular care must be taken at locations where cattle concentrate on the canal banks to maintain freeboard and canal embankment standards. Figure IV-1 illustrate the problem.

The sight and knowledge that the Sub-engineer will visit a beldar's zone of responsibility at frequent intervals will tend to make him more responsible and keep his work upto normal standards.

3. Closure Period Inspection

A detailed inspection of all structures and canals must be made during the closure period by the SBE to determine what deterioration, if any, has taken place. The inspection should be performed by walking through the canal as the inspector is more sensitive to the problems. The inspector would be assisted by a technician who will help with measurements etc. Preventive maintenance procedures can be immediately taken to stop further deterioration. More extensive repairs would be programmed in the coming fiscal year to be accomplished during the next closure period. It is absolutely necessary that good records be kept and the results of each annual inspection be recorded in detail and kept on file. Exhibit IV-1 gives examples of annual inspection sheet forms.

Inspections should cover the following:

(1) Condition of gates. Each gate should be opened and closed to check the ease of operation. Gates requiring painting and repair should be noted. Replacement of rusted metal work should scheduled as soon a practical.

(2) Condition of the masonry. Damaged, cracked or loose masonry should be noted. Repairs should be scheduled to be completed prior to re-opening of the canal.

(3) Condition of upstream and downstream structural backfill. Leakages and piping should be noted. Piping conditions must be repaired as soon as practical after being observed, repair must not be deferred.

(4) Quantity of sediment upstream of the structure and in the canal sections upstream or in measuring structures.

(5) Condition of measuring structures and gauges. Verify occurrence of last rating check of the stage-discharge curve.

(6) Check freeboard available at each structure.

(7) Scour and other damage downstream of structures.

(8) Safety features.

(9) Rain gauge sites.

Upon completion of the annual inspection, a written report will be prepared and submitted to the SDO. The report should include recommendations on appropriate maintenance activities such as immediate or temporary repairs before the closure period ends; repairs that must be included in the next fiscal budget for completion during the next closure period and work that can be delayed and included in the annual program. The SDO should verify the SBE's inspections and evaluation by making spot checks.

Field inspections will also be carried out periodically by the SDO, XEN and other PID officials. The SDO's inspections will be on a relatively regular basis of at least twice a month whereas the XEN may be less often. These inspections must identify, assess and correct maintenance needs. Without corrective action, inspections do not contribute to meeting the maintenance standards.

The Sub-engineer must always be ready to conduct these officials on an inspection of his zone of responsibility. He is expected to make the operations log available for inspection.

C. Performance Standards

Performance standards refer to the thresholds of performance considered acceptable, tolerable or unacceptable. In canal maintenance, visual observations are often used to evaluate performance. Unfortunately, individuals will not evaluate a reach of canal the same unless a comprehensive rating criteria are used. In other words, a well maintained system is in the eye of the viewer; manicured banks are impressive and look good but it is the wetted section and overall bank condition that tell the real story. Standards are necessary to evaluate the true condition of the system, and determine if conditions are getting better or worse with time.

The performance standards for a rehabilitated canal are shown in Table IV-1, and Figure IV-2. These define the minimum conditions that can be tolerated. When any of the standards shown in Table IV-1 are reached, the Sub-engineer must take immediate action to prevent any additional deterioration of the embankments from occurring. The performance standards are based on the design standards shown on Table IV-2.

The major problem will be the loss of canal freeboard at unauthorized crossings and in heavily populated areas where water buffalo are allowed to enter the canal prism. These informal ghats can result in the complete loss of freeboard in as little as one year. Obviously, the wear on the embankment is due to the concentration of animals and the number of times each one has access to the canal. The construction of a permanent ghat would minimize maintenance problems.

A partial solution to the problem might be if the Sub-engineer can get the owners of the tractor-trollies who use the canal patrol roads to donate the tractors use one day a month to assist in canal maintenance. The Sub-engineer could then get a group of beldars together and utilize the tractor-trolley to haul fill to the worn spots in the embankment and/or to

raise or keep the patrol roads above the local ground level where water collects.

Section 3: Maintenance Categories

A. General

Maintenance work is divided into four categories to facilitate the work effort including; funding and accountability, responsibility, scale of work, who does what, equipment management, contract work and administration and other management related reasons. The regular routine maintenance efforts are done on a daily or weekly basis and must be performed by permanent staff. Seasonal or periodic maintenance or repairs are accomplished either on a fixed schedule or on a "as required" basis. Annual programs are those that are accomplished by outside contractors because they are performed only as part of a divisional work program; for example, the replacement of freeboard on 20% of the canals each year.

B. Emergency Repairs

Emergency repair refers to the repair of serious damages or failures which unless prompt action is taken, may entail even more catastrophic problems concerning canals and farmland. Damages are not always predictable either with respect to the time of occurrence or to their scale; therefore, the Sub-engineer in charge should always be ready to face the occurrence of an embankment failure or other major problems, preferably before they occur. Catastrophic damages of irrigation facilities may result from any or combination of the two or more of the following causes:

* Flood or heavy rainfall.
* Embankment failure due to sliding (shear) or piping.
* Careless operation of irrigation facilities.
* Human actions like stealing water through embankment, blocking canals, destroying gates, etc.
* Destruction of freeboard or embankment by animals like rodents, buffalos, etc.

Action needed to cope with emergency situations should be taken as soon as possible, and it is advisable to follow the procedures described in the special section located at the front of the system specific manual.

To prevent aggravation of damage, a report to the nearest office should be made immediately by the worker who first detects the situation. Prompt actions will be taken to shift the water from the damaged canal to an adjacent canal(s); and to partly or entirely close the damaged canal. Any system without adequate freeboard will have difficulties with closure if there are no escapes in the system.

C. Routine Maintenance

Routine maintenance refers to the day to day work items that must be accomplished to keep a system operating well. They are basically preventive maintenance functions that if done on a continuous basis prevent the problem from becoming larger and more expensive latter on. It is the first line of defense and is extremely cost effective if carried out in a competent and professional manner. Table IV-3 details some of these procedures.

Modern maintenance requires the complete absence of trees and brush from the canal embankment. Trees, brush, and other vegetative cover should be limited to the right-of-way beyond the toe of the embankment. Removal of trees is expected to occur during rehabilitation but may still require additional removal over a period of time. Soil compaction specifications must be maintained when restoring embankment freeboard and require that the embankments are tree and brush free. The material for killa-bush control must be grown in the right-of-way outside the toe.

Limiting water buffalo to designated reaches that have been lined and ramped to form ghats will go a long way to improve berm and bank conditions. Oxen and goats may continue to graze the embankments under controlled conditions as these animals seldom enter the canal prism. The rules for cattle control have been available for a long time. Enforcement has been lax and it has cost the irrigation system considerable added expense. Tree removal may make animal control easier as it removes a source of shade for the animals.

Many of the routine maintenance functions that Sub-engineers will have to supervise on a continuous basis are:

* Filling raincuts and rain-holes (gharas) when observed.
* Replacing missing stone or brick pitching as soon after it is sighted as possible to prevent additional material from being wasted away.
* Promptly removing trees that have fallen into canal.
* Repair cracks in walls or replace backfill material where water flows behind a structure.
* Clean weeds and other floating trash from in front of structures.
* Grease moving parts on gate hoist.
* Exercise gates monthly.
* Cut-off of new tree and brush sprouts.
* Filling rat holes.

D. Seasonal Maintenance

The difference between seasonal and annual maintenance refers primarily who is responsible. Seasonal maintenance is light maintenance work part of which has to be accomplished during closure. It is work that is classified as force account work meaning it is done by using permanent employees or casual labor hires. Annual work is heavy maintenance work that must be contracted out to private contractors or the Mechanical Circle.

Seasonal work is limited in extent because of the short time period available during closure and the availability of staff and casual laborers. It includes:

* Repair and resetting of outlets.
* Berm trimming.
* Repair lining.
* Repair structures.
* Complete temporary repairs.
* Riprap scour holes.
* Fill in low spots on freeboard; ghats or animal crossings.

Some of the seasonal repairs can be carried out throughout the year and are not dependent on closure; such as berm trimming, ripraping scour holes and filling in low spots in the freeboard. The last item is usually caused by excessive wear near settlements due to cattle coming in and out of the canal or at cattle crossings of the canal. Farmers tend to cross their cattle at the same general spot every day. The beldars, casual labor or contractors can be used during the rabbi season to accomplish this work. If seasonal work is carried out each year, the amount of earthwork required is not so great and it can postpone the more massive freeboard-embankment restoration program.

The SDO must prepare a detailed plan for the repairs to be performed during the closure period. Priorities must be set as to where the maximum effort will be expended. Canal lining and structure repair are primarily the replacement of missing or broken bricks and filling of cracks. Some of this may be apparent prior to dewatering. This work requires the use of craftsman not ordinary casual laborers.

Repair and resetting of outlets, completing temporary repairs and the ripraping of a few scour holes are known prior to dewatering for closure. Therefore, a repair program can be laid out ahead of time. In most cases, the location of small annual sediment deposits in and around structures is known and the removal can be programed for casual hire or contracted for ahead of time.

E. Annual Maintenance

The annual maintenance program is beyond the capability of the Sub-division. The annual maintenance program involves the extraordinary or extensive program of replacing the eroded freeboard and embankment slope. It also includes the grading of the patrol road 6 times a year, occasional large desilting work, and a comprehensive raincut repair program when required.

Section 4: Maintenance Procedures

A. General

Maintenance procedures describes the work that has to be done and how to go about doing it. There are often many ways to accomplish the same result. The fastest most cost effective way to complete a task is the procedure that should be used. It must meet the specification or intent of the task. Raincut repair calls for cleaning out the area and replacing the eroded soil with new compacted soils, therefore, the soil must be compacted with a tamping bar (durmat) not just dumped and lightly tamped with a foot. Work must be done in such a way that the repair will last.

There is no way a simple manual like this can list all the ways to do a job. The Sub-engineers will have to be innovative in order to accomplish all the work that needs to be done under the constraints of limited budgets. The money constraint will always be there and it should not be used as an excuse not to accomplish anything or to do it correctly.

B. Canal and Embankments Repairs

1. General

Cattle and vehicle damage are the two major problems concerning the canal banks. Cattle cause problems in three main areas: 1) the locations next to villages or farms where buffalo are driven into the canals to wallow around; 2) locations where both cattle and buffalo are driven across the canal; and 3) use of the canal by buffalo as a road. The use of canal right-of-way for grazing is limited so it does not cause a major problem.

The ability to keep the buffalo out of canals appears to be limited and difficult to achieve regardless of what the law and regulations state. The solution to the problem may lie in trying to achieve a working relationship with the farmers wherein they may help to restore canal freeboard near their villages or homes at the locations they use to bathe and cool the buffalo. Efforts should be made to limit access to as few locations as possible and then seek assistance in maintaining canal banks and freeboard at these locations.

2. Annual Canal and Embankment Monitoring Program

A monitoring program will be carried out each and every year to determine if the design configuration is still inplace and that performance standards are being met. This will require an accurate survey of the system's canals. Cross-sections will be taken every 500 feet and at all structures. Figure II-2 indicates the general requirements for the survey. This survey will allow a direct comparison to be made between current conditions with the design cross-sections.

The design sections would be part of the rehabilitation contract drawings along with the long-sections. A set of these must remain with the SDO. The data on the cross-sections can be tabulated numerically to facilitate comparisons.

The long-sections which are included in the system specific manual are the design long-sections which are the basis for the construction drawings. They provide data as bed and water surface elevations and the design depth and width. The design statements include controlling dimensions and elevations of each reach.

The information gained from the survey will allow the SDO to determine when the lost freeboard and embankment is such that it will have to be replaced. This information would allow the development of new improved yardsticks but more importantly it would the planning of detailed work programs and schedules for the coming year. Contractors or force account labor/equipment could then be procured and scheduled ahead of time. Budgets would be more realistic.

3. Berm

Width (b_1) is defined at bed level (see Figure IV-2) because the berm is designed to protect the embankment. This cannot be observed in the field. Therefore, for maintenance purposes the top width is used to monitor actual conditions. Top widths for embankment slopes of z_1 = 1.5 for various depths are as follows:

Depth of Flow (ft)	Berm Width (b_1) (ft)	Berm Top Width (t_1) (ft)
2.5	0	0
2.5 - 3.99	2	4.5 - 6.0
4.0 - 4.99	3	7.0 - 8.0
5.0 - 5.99	4	9.0 - 10.0
6.0 - 7.99	5	11.0 - 13.0
8.0 - 9.99	6	14.0 - 16.0
10.0 - 11.99	7	17.0 - 19.0

For slopes other than $z_1 = 1.5$ the equation $t_1 = b_1 + h(z_1 - z_3)$ may be used. The terms being defined in Figure IV-2. Similarly, $b_1 = t_1 - h(z_1 - z_3)$ which can be used to estimate present bed width (b) based on the design statement for given canal reach.

Canals with a design depth less than 2.5 feet do not require berms.

The berm width (t_1) may be used to monitor the width of the canal. The performance standards indicate that the canal width (b) Figure IV-2 can increase upto 10% with no action required. When it increases in width to about 20% of design width (1.2b), action must be taken to protect the berms and reduce the width to where it will be within the 10% leeway allowed. The change in berm width indicates what changes in bed width are taking place. Therefore, when the width of a berm decreases by the amount $t_2 = 0.1b$ the 20% limit has been reached and any further deterioration will require remedial measures. The Sub-engineer must immediately start remedial action, nominally killa-bushing. Since the retreat of a berm is generally not a rapid process there is sufficient time to initiate a work program after the value of $t_2 = 0.1b$ is observed.

The average width of the berm top, t_1, must be observed and measured to determine what the value of t_2 is. The minor scallops often observed are not considered in estimating t_2. These areas may be the first areas where remedial work is initiated. Particularly if the indentation is not due to animal access to the canal.

4. Sediment-Control

Unfortunately low velocities mean sediment deposition, particularly where the system can not transport all the incoming sediment through the system. Where the hydraulic design indicated sediment transport was limited to a value less than a 100%, a sediment trap was recommended. The trap would be located and constructed just upstream of the reach with limited transport capacity. The sediment trap collects sediment which can then be removed by hand basket or earthmoving equipment.

The exact timing and amount of sediment to be removed has not been determined. This will be determined during the a shakedown period of operation to finalize a set of operating criteria.

The performance standards (Table IV-1) indicate that sediment depositions upto 6 inches in depth are the acceptable maximum. When this depth is observed, the SDO must be notified so that a desilting program can be prepared for the next closure period. Under no circumstances would the canal be operated with a sediment deposition greater than 9 inches.

5. Erosion Control

Erosion in the canal prism may occur locally at a structure or along a canal. If it lowers the stream bed generally, it is called retrogression or degradation. Retrogression may be prevented by reducing the velocity of flow either by building check structures or by reducing the bottom grade. Rehabilitation should have eliminated most retrogression problems. Local scour at structures is controlled by cutoffs and wingwalls and by providing riprap or gravel protection. Broken brick can be substituted for both, being careful to watch gradation; so that finer material is laid against the bank and courser material on top. Riprap provided below a stilling pool or downstream of a bridge takes care of the erosion due to the residual eddies and waves present as the water leaves the pool or bridge. The size of the riprap protection is based on the velocity of flow. Unfortunately, there is no design principle yet evolved to indicate the length of protection required downstream of a structure. It is an unknown function of velocity and bank material; therefore, placement is always a compromise between safety and economy.

Hence, every Sub-engineer will have to watch this type of protection carefully and add more protection if actual operation shows it be required.

Riprap, gravel or broken brick may also be used to control local scour along a canal. This erosion may be due to bank instability caused by wave action, changes in discharge, changes in ground water level, animal ingress and egress or due to flow around bends. Riprap is recommended where velocities are above 2.5 to 3.0 feet per second or where the canal water contain little or no sediment.

Killa-bushing is recommended where velocities are under 2.5 feet per second and the water contains sediment. Killa-bushing, although used, is not recommended immediately downstream of structures because it is not a permanent solution whereas ripran is. Killa-bushing can be accomplished three ways:

(1) By longitudinal staking and bushing.
(2) By cross spurs.
(3) By hanging spurs.

The longitudinal staking and bushing is useful for channels upto 3 to 4 feet in depth, beyond which it becomes very expensive. Cross spurs are usually employed in channels of more than 4 foot depth and hanging spurs in very large channels, Figure IV-3 shows examples of killa-bushing techniques.

6. Control of Burrowing Animals

Distributaries and minors are particularly susceptible to burrows of rats. These are dug near the water line. The holes they burrow are points of weakness at which canal breaks/breaches may start. Such breaches are particularly liable to occur when the water surface is raised above the holes.

The beldars should open up and fill rat holes when they are spotted to reduce the potential of a breach. Rat holes are not easy to locate and the beldars can not be expected to spend a lot of time looking for them.

C. Canal Structure Maintenance and Repairs

1. General

The following list summarizes the major items likely to be involved in creating maintenance problems of one kind or another:

(1) Sediment accumulations.
(2) Local scour.
(3) Channel retrogression.
(4) Under seepage or piping
(5) Foundation settlement
(6) Mechanical or electrical equipment (missing stoplogs).
(7) Structural (cracks, spalls).

It is important to identify the problem correctly. Try to correct the basic cause of trouble rather than mitigate the effect.

Seepage losses at a structure are generally not important quantitatively. On the other hand, flow under or around a structure is a potential source of trouble and must be controlled. Piping failure around structures is a very real problem. Material may have to be excavated and repacked around structure.

2. Water-Control-Structures

Water control structures would normally include cross regulators, head works, falls and occasionally an escape. These structures should have been rehabilitated at the time the canal was rehabilitated. A complete inspection of each structure should be made as soon as the shakedown period starts. The exact condition of each structure should be noted and a request made for any necessary repairs to be made immediately so that they are completed during the shakedown period.

It is the responsibility of the Sub-engineer to keep these in good operating condition. Damaged gates, gate hoists and other metal works is accomplished by fixed procedures with the Mechanical Circle. The repair of the masonry structures is accomplished using normal contracting procedures with local

contractors.

3. **Outlets**

The type of outlets employed generally includes both open flow and orifice type. Plain orifice plates are sometimes installed. Orifice type outlets will often be installed at the head ends of distributaries and the open flume at the tail ends. Submerged flow conditions will sometimes exist on an outlet. This is unsatisfactory since it interferes with the control which modular flow provides and which in turn is required for proportional distribution. Since the water levels vary in any canal from time to time, the discharge of submerged outlets can vary from submerged to modular conditions. The resulting variations in watercourse discharge may affect canal discharges downstream and contribute to the discharge fluctuations at the canal tails.

The cross-sections made for the embankment monitoring program will also provide detailed records for each outlet. The extra data collected would show inlet invert elevation and conditions in the head end of the watercourse, bed levels and water levels. This along with the H Register will allow a complete and accurate record of the outlets to the watercourses to be kept. Any tampering should be spotted immediately and appropriate action can be taken up with the canal and civil authorities.

The major repair or resetting of outlets is normally contracted out to a local contractor. Early detection of tampering will allow the repair to be made during the next closure period. Non-perennial canals have an advantage in that they do not operate for a period of 6 months. Therefore, repair can be easily made. A single craftsman would be able to repair most minor damage in this period. The perennial canals present a different problem that can best be handled via local contractors.

Minor resetting can generally be accomplished by only removing one side of the outlet. The sill and head block can be set as required and the side of the structure replaced. In some instances, where the width is not changed, this may not require complete removal of outlet side. Standard drawings are available to be used in completely reset an outlet.

Cracks, missing or broken bricks should be repaired or replaced as soon as possible to reduce further damage and increased cost of future repairs. It is much more cost effective to fill cracks and replace the broken bricks as soon as possible. Care must be exercised to clean the cracks or area that will receive mortar of any loose material or salt deposits.

The area to receive mortar should be well soaked with water before placement to ensure adequate bond of the mortar to the brick surfaces. Every attempt should be made to fully fill the cracks with mortar. The excess can easily be cleaned off.

4. Bridges

Bridges should be inspected annually to determine if there are any structural faults. Cracks and spalling bricks should be repaired as soon as possible. Bridges tend to confine flows through the arches which causes an increase in velocity thur the bridge and may result in a scour hole downstream as the energy of the water is dissipated. Riprap may be need along the banks for bank protection.

5. Animal Control Facilities

Animal control facilities may be constructed as part of the rehabilitation program. These would be located near settlements and will require maintenance. The lined bank sections should not be allowed to deteriorate. It is much more economical to effect repairs as bricks loosen than to wait and replace an entire section of bank protection. Pucca bricks can be used to construct low fences to control access. Lining the top of the bank adjacent to the ghat or cattle crossing would help maintain the canal freeboard and reduce maintenance costs.

There is some question whether an illegal "ghat" is a structure or a destroyed canal bank. The water buffalo is the most destructive force of canal banks. The constant in and out of the canal of these animals causes most of the bank damage. The effort of moving in and out can remove sediment from the bank. This is particularly true in locations near villages where large numbers of animals are allowed to go in and out of the canals several times a day. In

most of these locations, both the berms and embankments are worn to very dangerous levels. Figure IV-1 shows what happens.

The performance standards for canal maintenance on rehabilitated canals are much more stringent than those used in the past and their enforcement may be monitored to a much greater degree than in the past. Animal trespass has been a major cause of canal embankment deterioration when it has been confined to short reaches of a canal. This usually occurs near settlements and where local roads/trails intersect the canal and where no bridge has been located. The problem is expected to continue after rehabilitation as few improvements to the described conditions may be incorporated.

The performance standards state that freeboard must be restored as soon as 5 inches of material are eroded off the embankment crest. Under concentrations of animals with access being made several times a day, it may only require a few months to wear of freeboard to endanger the safety of the embankment.

Both semi-permanent and permanent ghats are discussed as alternative methods of reducing canal maintenance costs. It acknowledges that water buffalo cannot be kept out of the canals and that the canals will continue to be used by farmers for various non-conforming practices including animal bathing.

a. <u>Installing a Semi-permanent Ghat</u>

A semi-permanent ghat is a widening of the canal embankment by flattening the slopes. Inspection of canal banks used by animals for access to canals indicates that they wear the slope back to 3H:1V or 4:1. It appears that most animals can negotiate an earth slope of 3:1 without excessive displacement of soil. Therefore, to reduce maintenance all that is required is to simply widen the embankments in the critical areas to accommodate these slopes and the top width.

A typical cross-section is shown in Figure IV-4. The top width has not been fixed. The minimum would be 5 feet based on design standards. It appears

reasonable to expect that if it was widened to 10-12 feet, the wear and tear on the freeboard would be less and material would be available to be pulled up to keep the crest elevation seasonally. Obviously, the wider the section the more right-of-way or land area required to accommodate it. This can be a problem where farmers have encroached on the canal right-of-way.

Widening the canal embankment will require adjustments be made in embankment configuration both upstream and downstream of the selected location as shown in Figure IV-4. The facility does not have to be constructed all at once but can be allowed to evolve as material is transported to the site to maintain the performance standards for rehabilitated canals. This would slowly push the location of the canal top away from the canal center line. Eventually things should stabilize so that a cross-section similar to that shown in Figure IV-4 will be obtained.

To control access to the semi-permanent ghat it would be necessary to construct pucca brick walls 2-1/2 to 3 feet high to guide the animals and to keep them off the normal canal embankment sections.

This solution would not be adaptable inside a built up area because encroachments of buildings would not allow the slopes to be developed and still maintain the canal top width. In this case, a permanent structure would be required or the location shifted.

b. Permanent Ghat

A permanent ghat is similar to the semi-permanent one except that the ramps and embankment crest are protected by pucca brick pitching. The ramp slope is 3:1 or 4:1 (H:V). A raised ridge composed of bricks set on edge provide additional support for the animals to maintain a footing. It would also trap soil which may provide traction. An alternative solution is to build stairs steps with a horizontal step of 2.5 feet and a rise of 0.5 feet on the 3:1 slope.

The access to the ghat should be controlled by pucca brick walls 2.5 to 3.0 feet high. These would guide the animals and prevent access to the regular

bank.

Access can be varied. A single ramp could be used for ghats upto 50-60 feet in length. For lengths on the order of 100 to 400 feet it would be more cost effective to use two or more ramps 20 to 30 feet in length. The canal banks between ramps would be protected by brick pitching on a 1:1 slope. This is sufficiently steep to prevent animals from climbing out of the canal. Access control would be even more important with multiple entries.

In villages or locations where entry is confined to access from only one side, the opposite side must be protected with brick pitching. The 1:1 slope is adequate.

In those villages where continued heavy traffic is expected, it might be cost effective to use brick masonry as it would have a lower maintenance cost and should stand up to the traffic better.

Figure IV-5 is a sketch of a permanent ghat constructed on only one side of a canal.

c. Cattle Crossings

Cattle crossings can be constructed in a manner similar to the ghats except that the width would be limited to 15 to 20 feet. Brick pitching would probably be more economical in the long run as maintenance cost should be lower. It might also be beneficial to cover the pitching with a 6-inch layer of soil to prevent damage from tractors or other vehicles.

TABLE IV-1

PERFORMANCE STANDARDS FOR CANAL MAINTENANCE

1. Freeboard

The freeboard (FB) is never allowed to erode or be worn off more than 5 inches. The freeboard must be replaced as soon as the minimum freeboard is reached at any point on the canal embankment.

2. Capacity

The canal capacity must never be allowed to become less than the design capacity.

3. Maximum Discharge

The maximum discharge allowed in the canal is 1.2 times the design discharge at full supply level (FSL). The duration of a discharge greater than the design discharge cannot exceed two weeks under any circumstances.

4. Maximum Water Level

The maximum water level can never be allowed to exceed one half the design freeboard (1/2 fb) under any circumstances. This standard fixes the siltation standard.

5. Siltation

Silt accumulation in a distributary or minor is not allowed to exceed 9 inches. When 6 inches of sediment is observed or measured above the design bed level of the canal desilting must be programed for the next closure period.

6. Canal Width

There are three separate conditions that govern the performance of a canal with regard to canal width; (1) a canal with berms, (2) a canal without berms with depth h greater than 2.5 feet and (3) a canal without berms with depth h less than 2.5 feet.

TABLE IV-1
PERFORMANCE STANDARDS FOR CANAL MAINTENANCE
(continued)

a. Canal with Berms

The average width of a canal will be allowed to vary between the design width (b) and 1.1 times the design width (1.1 b) without concern. No canal will be allowed to become narrower than the design width. A canal will not be allowed to widen beyond 1.2 times the design width without corrective action being taken.

b. Canal without Berms, h >2.5 ft

A canal without berms with a water depth greater than 2.5 feet does not conform to the design standards but may be allowed by the PID during rehabilitation to save cost on a distributary canal. Because of that eventuality the following criteria was established (It is equally valid for existing non rehabilitated distributary canals). Under no circumstances would the canal bank be allowed to erode above the intersection of the FSL and the embankment. This means the top width of the canal, t, cannot be allowed to increase at all. Only the toe of the embankment below the FSL is allowed to erode, thereby providing a steeper bank slope. When the canal starts to slough embankment material above the FSL killa bushing or other remedial measures are required.

c. Canal Without Berms, h <2.5 ft

The canal banks are allowed to erode to tbe point where the bank intersects the top of the embankment before remedial measures are required.

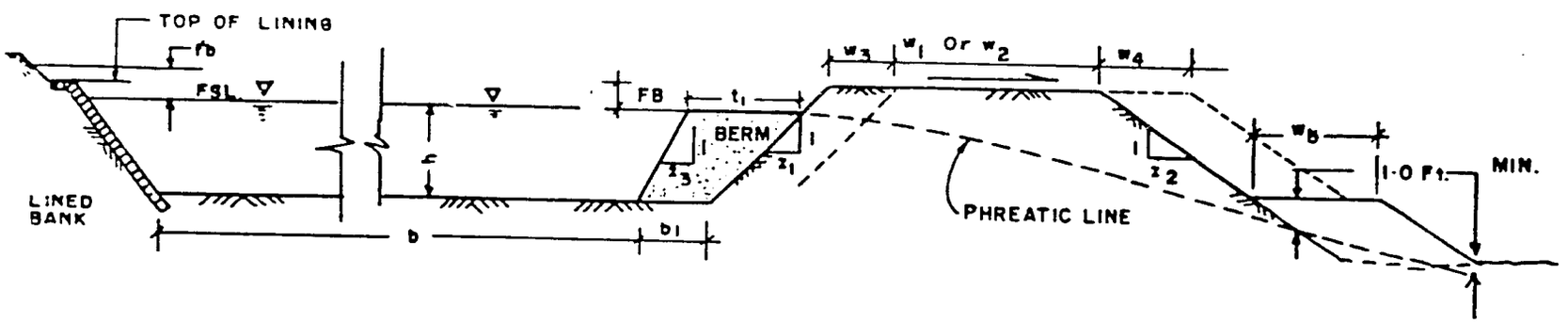
The bottom width is the critical dimension. The average top width is used to judge the condition of the canal. Minor scalloping due to animal ingress and egress, is not considered in evaluating the canal width as it does not affect hydraulic performance.

TABLE IV-2

REHABILITATED CANAL EMBANKMENT DESIGN STANDARDS

Depth of Flow h (ft)	Freeboard: Rigid Lining 1/ (ft)	Freeboard: Design f_b (ft)	Freeboard: Rehab. - FB: Earth (ft)	Freeboard: Rehab. - FB: Metalled (ft)	Min. top Width W_1 (ft)	Road Width - W_2: Equip Maint. (ft)	Road Width - W_2: Patrol (ft)	Road Width - W_2: Village (ft)	Road Width - W_2: Highway (ft)	Berm Width b_1 (ft)	Slopes: Inside (z_1)	Slopes: Outside (z_2)	Slopes: Berm (z_3)
2.50	0.5	1.0	1.5	1.0	4	5	0	18	30	0	1.5	1.5	1.5
2.5 - 3.99	0.5	1.5	2.0	1.5	5	7	12	18	30	2	1.5	1.5	0.5
4.0 - 4.99	0.6	1.5	2.0	1.5	6	7	12	18	30	3	1.5	1.5	0.5
5.0 - 5.99	0.75	2.0	2.5	2.0	8	9	15	18	30	4	1.5	1.5	0.5
6.0 - 7.99	1.0	2.5	3.0	2.5	10	9	15	18	35	5	1.5	1.5	0.5
8.0 - 9.99	1.5	2.5	3.0	2.5	12	12	20	20	40	6	1.5	2.0	0.5
10.0 -11.99	1.6	3.0	3.5	3.0	15	12	20	20	40	7	1.5	2.0	0.5
>12.0	Site Specific Study Required												

Notes:
1. Distance from FSL to top of lining (earth freeboard also required)
2. W_3 = Dowel and W_4 = Avenue; W_3 = W_4 = 5 foot; neither are required but may be retained if already on existing embankment.
3. W_1 = Minimum top width where maintenance road is not required.
4. W_5 = Outside berm required to cover existing seepage surface if necessary.
5. b_1 = Designed to protect toe; maintained using top width (t_1).
6. FB = f_b + 5 inches = Freed board established during rehabilitation.



SCHEMATIC DESIGN SECTION

TABLE IV-3
ROUTINE MAINTENANCE PROCEDURES

Item	Procedure
1. Remove Fallen Trees From Canal	The tree must be removed as soon as possible to limit scour damage to berm/bank. As many limbs as possible should be cutoff and removed to lighten the tree. A tractor with a chain a steel cable can be used to pull the tree up. Start near the top with the cable as the load will be lighter. As the tree comes out of the water, additional branch can be removed. Once the trunk is out and on the berm it can be cut up and removed.
2. Killa-bush Berm Repair	Killa-bush spurs can be placed 10 to 12 feet apart along reaches that require additional berm. In severe cases parallel revetment with branch laid behind it can be constructed.
3. Raincut Repair	Raincuts must be dug out and then the replacement material compacted in place. A hand tamper can be used. Soil material must be moistened before it is placed to obtain good compaction.
4. Rain Hole Filling and Repair	The rain hole must be fully opened up, cleaned and backfilled with compacted material. A hand tamper can be used. The soil must be moistened as it is mixed and placed.

TABLE IV-3

ROUTINE MAINTENANCE PROCEDURES
(Continued)

5.	Freeboard/Cattle Cut Repair	Same procedures as for raincuts or rain hole repair.
6.	Vegetation Control	Oxen and goats will keep grass cut. New brush or tree growth must be cutoff at ground level with a machete or other implement.
7.	Sodding Bare Spots	At the beginning of the monsoon season large bare spots on the embankment should sprigged or sodded with a drought resistant spreading type grass.
8.	Blow Sand Control	Fencing made of small vertical bamboo or reeds woven together and stood vertically will retard drifting sand. Post spaced about 12-feet apart buried 3-feet in the ground with a wire strung near the top of the post to hold up the woven fencing. The fence should be located about 100 feet on windward side of canal.
9.	Temporary Repair of Piping Around Structures	Piping around an outlet can be temporarily stopped by rodding or tamping material along the edge of the structure to reduce or close the opening through which water is moving. Additional earth may be required to help fill the void. Complete repair must be made during closure.

TABLE IV-3

ROUTINE MAINTENANCE PROCEDURES
(Continued)

10.	Painting Exposed Metal	Exposed metalwork should be painted work during the rabi season following closure. All loose paint must be chipped and wire brushed to remove all rust and loose particles. The cleaned area should receive a prime coat of paint; iron oxide or similar type. The outer protective coat is applied as soon as prime coat in dry so that dust or other extraneous materials do not coat the surface.
11.	Grease and Oil	Exposed gears, gate slides and other equipment must be greased periodically. Normally every three months or as otherwise instructed.
12.	Exercise Gates	Gates should exercised at least once a month. This applies primarily to escapes or other gates which are not used for water control.
13.	Remove Floating Trash From Infront of Structures	A long handled rake can be used to help pull trash out of the canal.

ANNUAL CANAL INSPECTION

1. Canal Name: _____ Sub Division: _____

2. Date: _____ Time; Start: _____ Finish: _____

3. Inspector: _____ Signed: _____

CONDITION OF CANAL

RD	Embankments	Prism	Partrol Road	Bank Seep

Remarks: _____

OUTLET INSPECTION CHECK LIST

1. Canal Name:_____ Sub Division:_____

2. Date:_____ Time, Start:_____ Finish:_____

3. Inspector:_____ Signed:_____

RD	Outlet Designation	Side	Condition

Remarks:_____

_____

_____

_____

REGULATOR INSPECTION AND MAINTENANCE RECORD

FILE NO. _____

EQUIPMENT _____

FACILITY _____ LOCATION _____ INSPECTIONS FREQUENCY _____

EQUIPMENT DATA

Specification/Solicitation _____ Date Furnished _____

Supplier _____ Type _____

MFR _____ Size _____

Model or Style No. _____

INSPECTION AND MAINTENANCE RECORD

DATE	INSPECTED BY	CONDITION FOUND OR DESCRIPTION OF WORK DONE

REPORT OF DAMAGE TO DISTRIBUTION SYSTEM FACILITY

Canal Name: _____

1. Date: _____ Time: _____
2. Facility: _____
3. Location: _____
4. Description of Damage: _____

_____

_____

_____

_____

5. Damage caused by: _____

_____

_____

6. Proposed Method of Repair: _____

_____

_____

_____

7. Are Emergency repairs required: _____
8. Action taken on role violation(s) if any: _____

_____

_____

9. Remarks: _____

_____

_____

_____

10. Inspector/Reporting Officer: _____ Signed: _____

MAINTENANCE WORK REQUEST

Work Action No._____ Priority Code:_____

(1) Emergency:

(2) Urgent; within one week:_____

(3) Normal; Date required:_____

(4) Next Closure Period:_____

Work Name and Location

Describe Work Requested, Recommended and Justification

_____

_____

_____

_____

_____

_____

Work Authorized by_____ Date:_____

Maintenance action taken, recommendation, Problems encountered

(include people, hours works, craft used etc.)

_____

_____

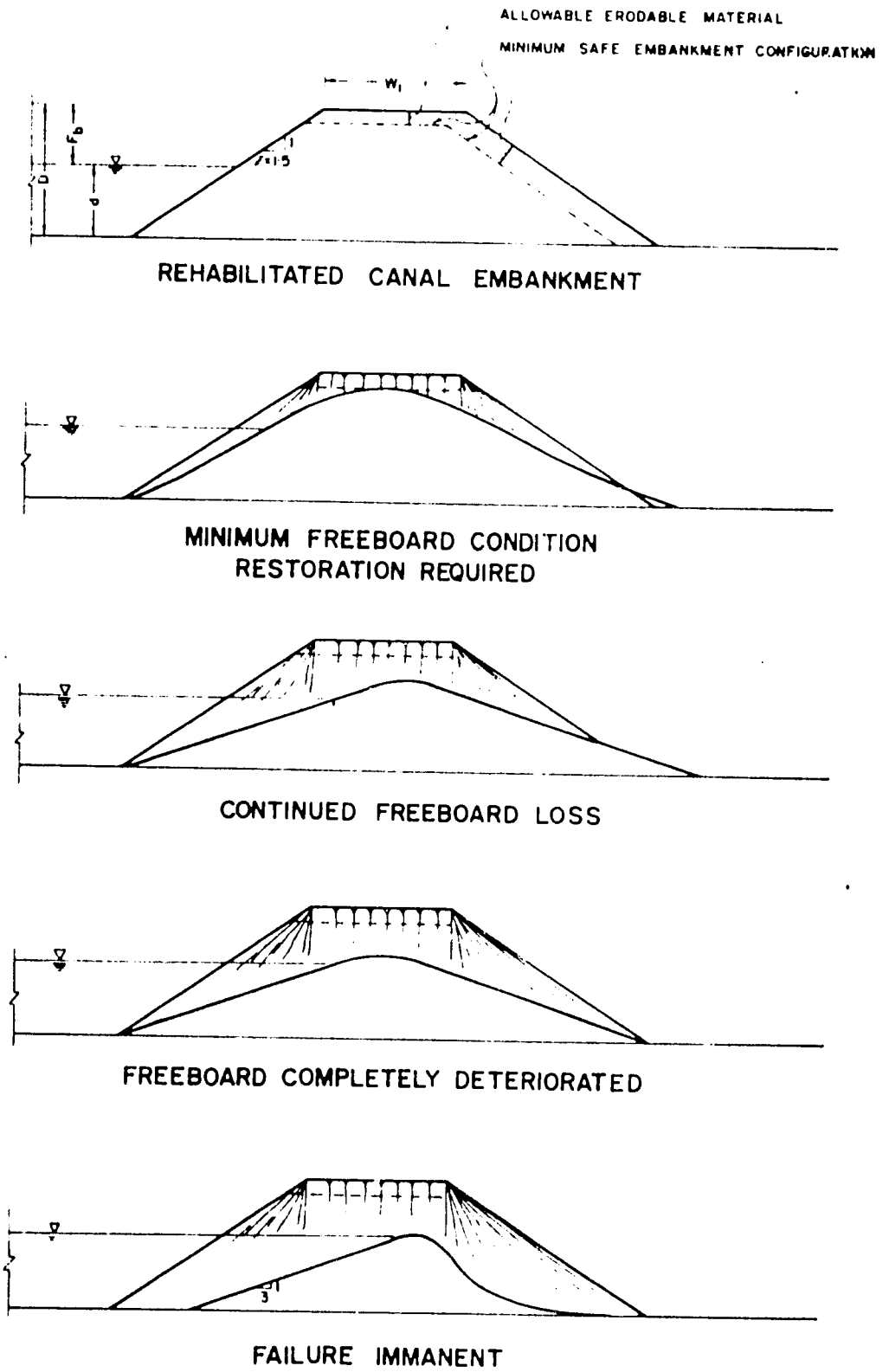
_____

_____

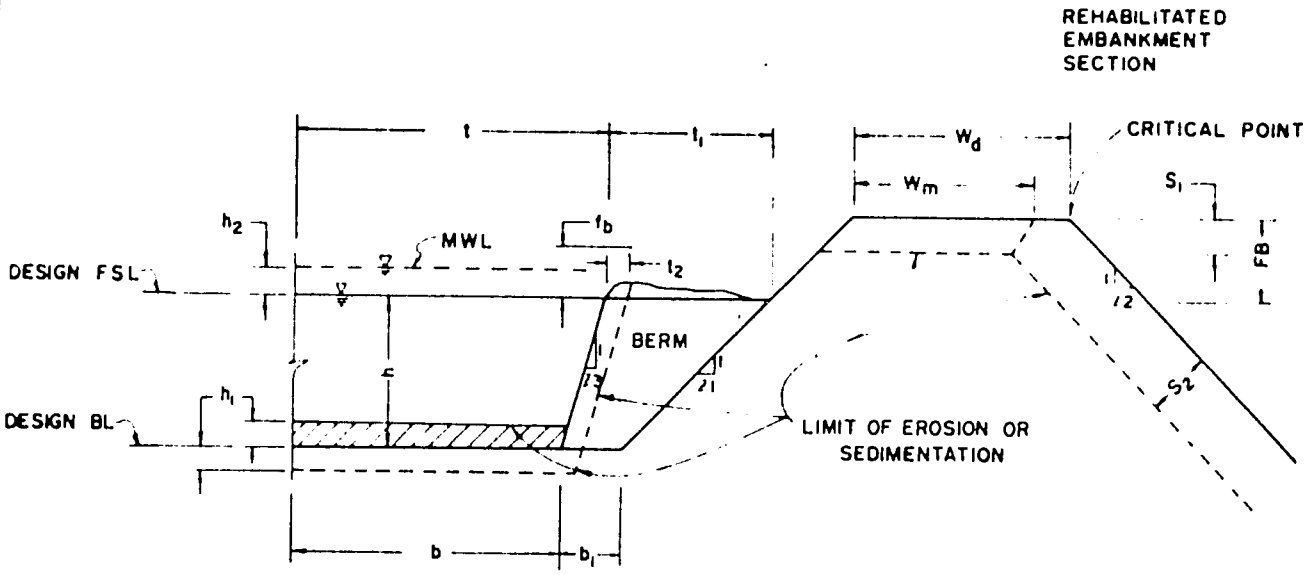
_____

_____

Completed by:_____ Date Completed_____



DETERIORATION OF CANAL BANK DUE TO CONCENTRATED CATTLE CROSSINGS

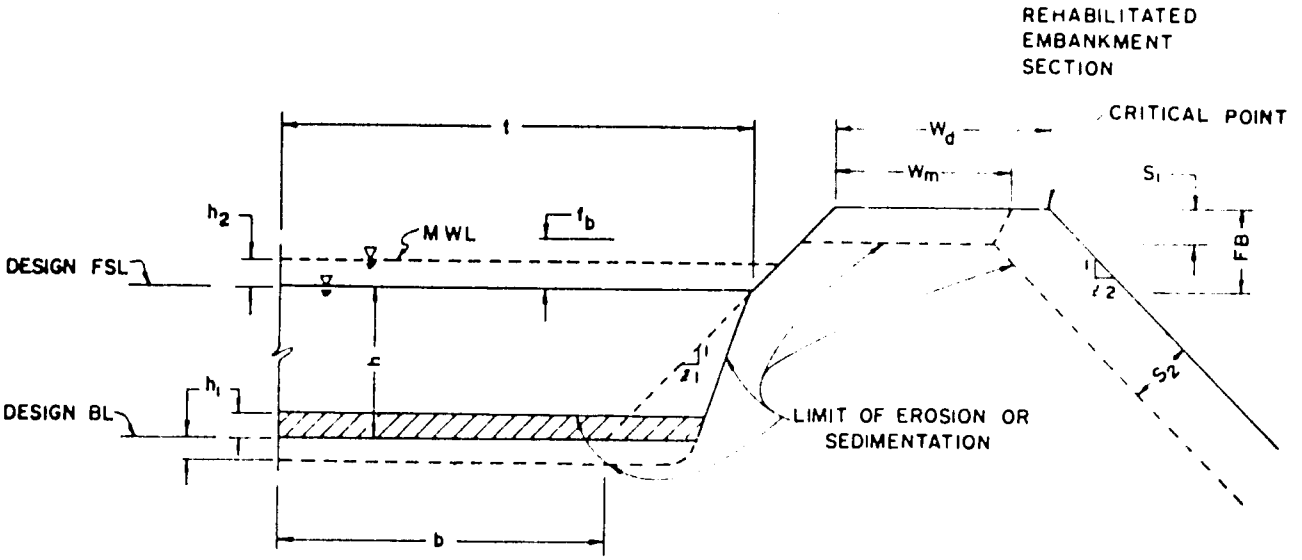


CANAL SECTION WITH BERMS

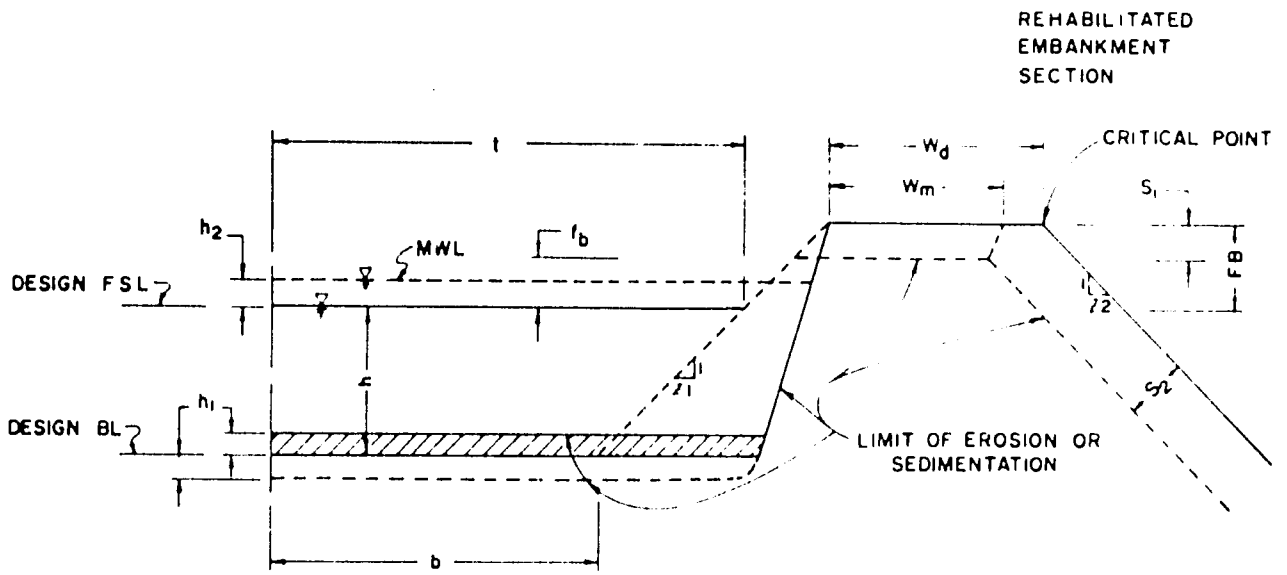
Legend

- b = Design width of canal.
- b_1 = Design berm width.
- h = Design depth.
- f_b = Design freeboard.
- h_1 = Maximum allowable depth of sediment accumulation/bed erosion.
- h_2 = Maximum water level encroachment on design freeboard = 0.5 fb.
- FB = Constructed freeboard = fb + 5 inches.
- S_1 = Maximum allowable freeboard erosion = 5 inches.
- S_2 = Maximum allowable embankment erosion = 10 inches.
- W_d = Design top width of embankment.
- W_m = Minimum top width of embankment = W_d - 0.875 (ft).
- t = Top width of canal prisum.
- t_1 = Berm top width corresponding to b_1.
- t_2 = Maximum allowable bank erosion = 0.1 b
- FSL = Full supply level.
- BL = Bed level.
- MWL = Maxinim allowable water level.

PERFORMANCE STANDARDS
CANAL MAINTENANCE

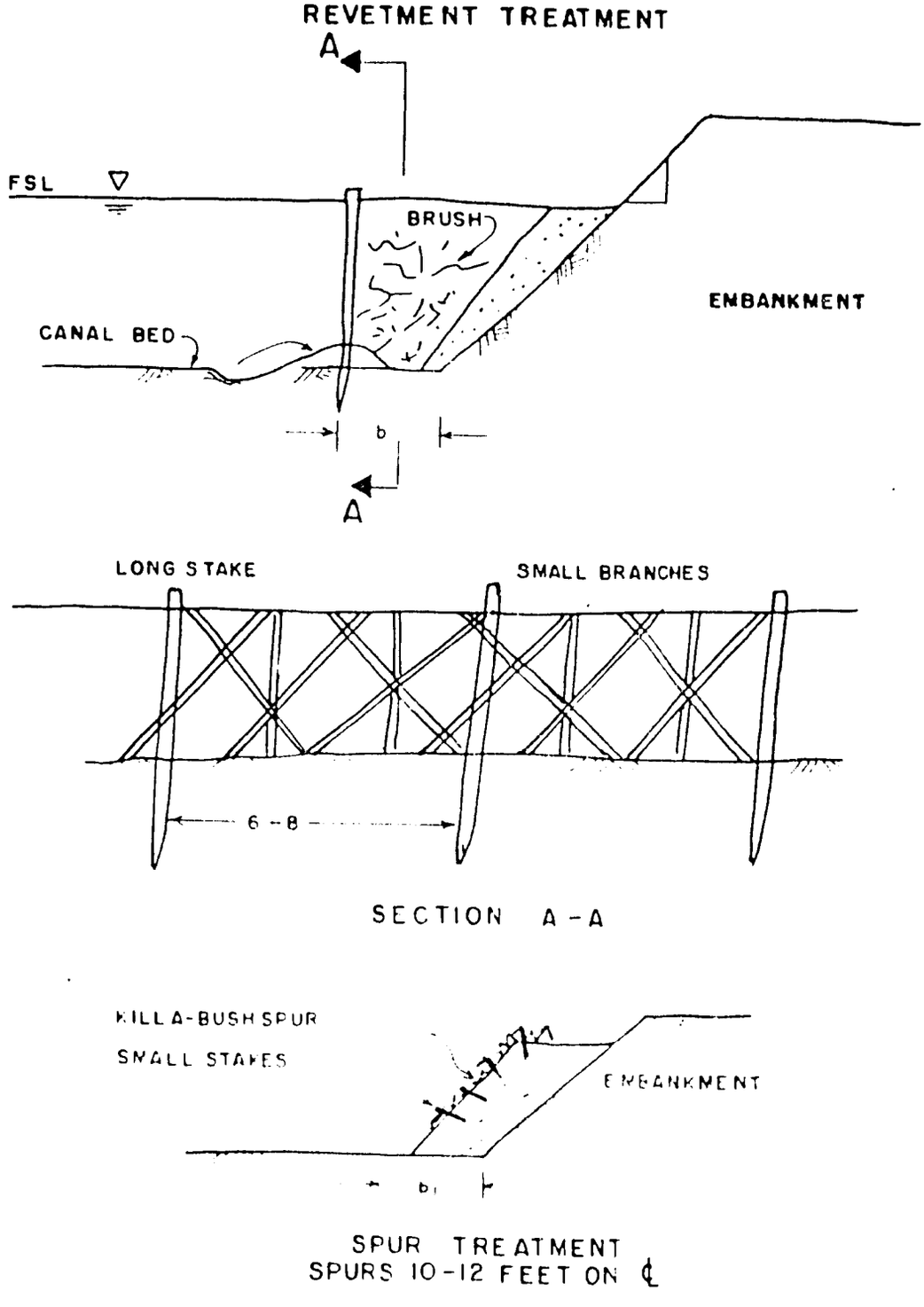


CANAL SECTION WITHOUT BERMS
(h > 2·5 Feet)

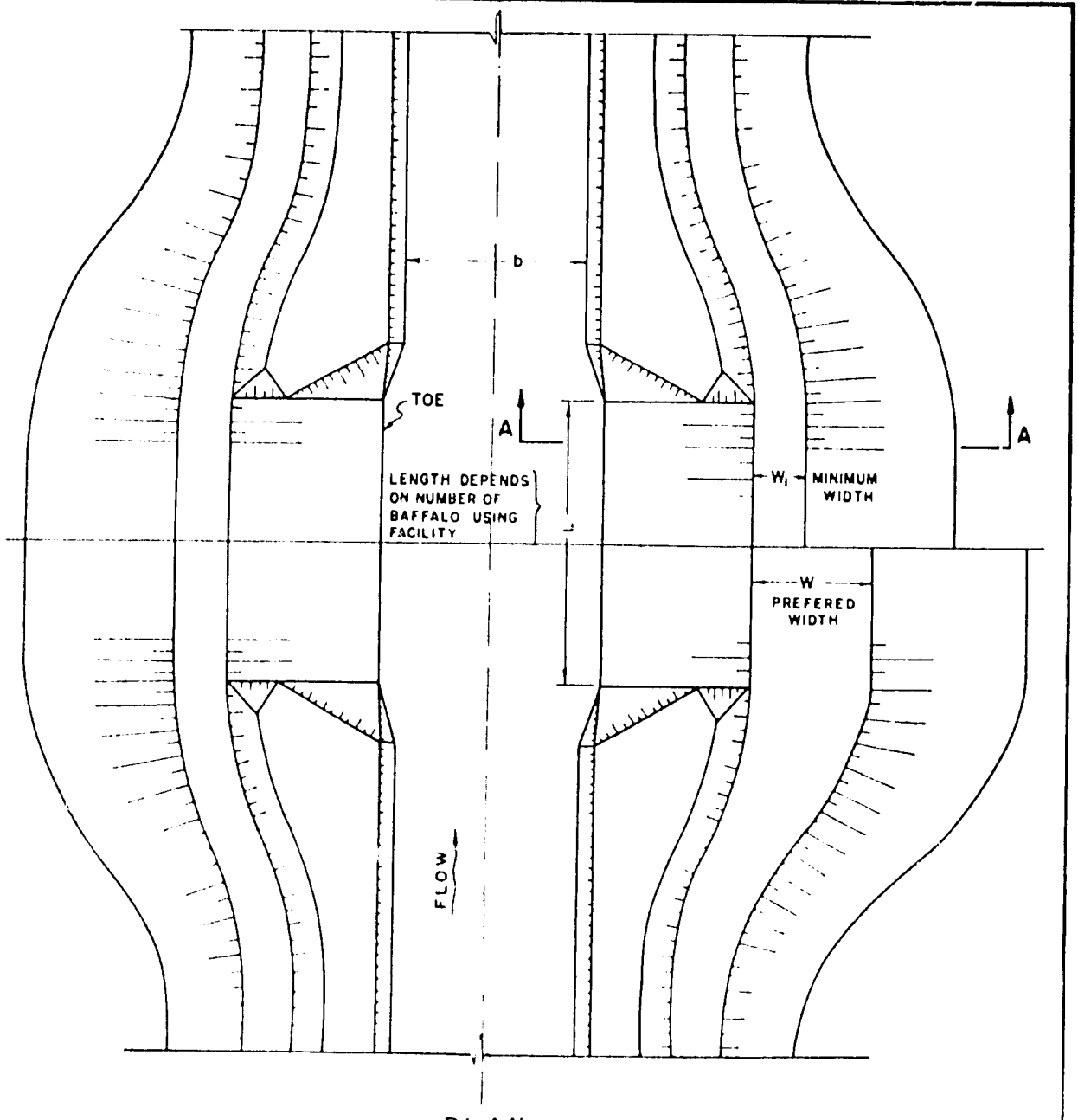


CANAL SECTION WITHOUT BERMS
(h < 2·5 Feet)

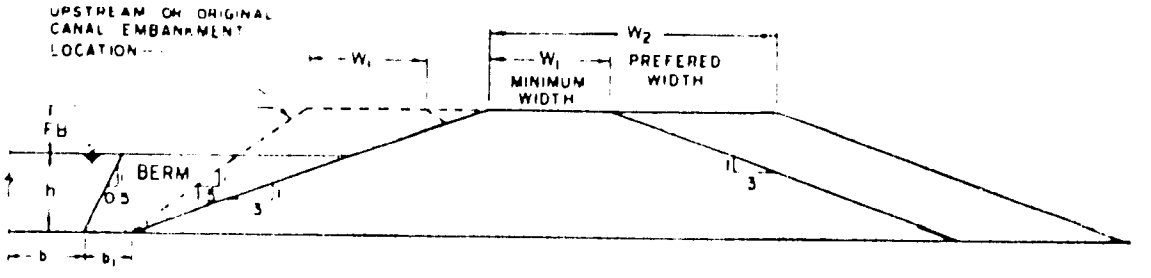
PERFORMANCE STANDARDS
CANAL MAINTENANCE



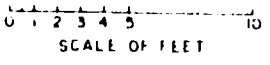
KILLA-BUSHING TECHNIQUE



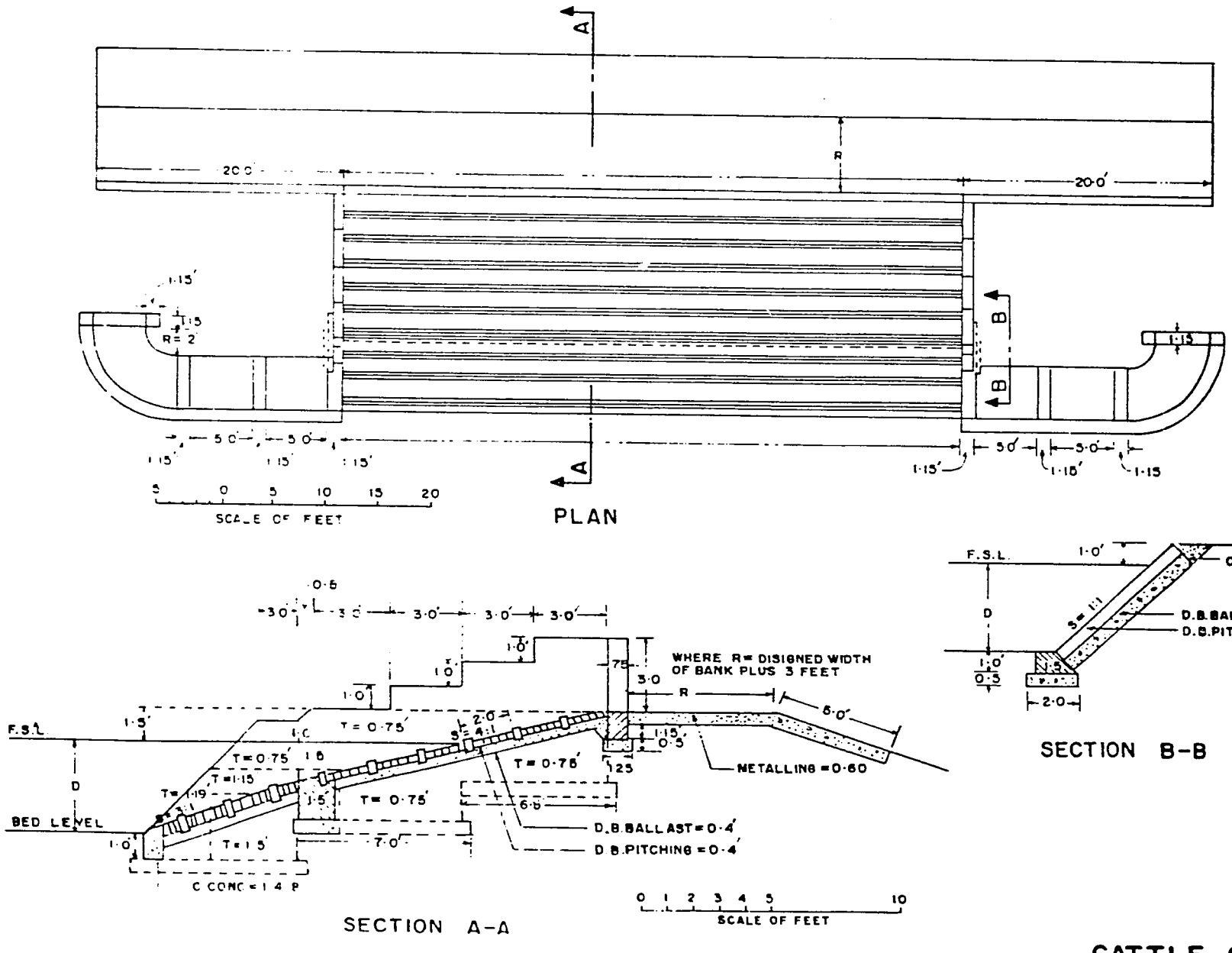
PLAN



SECTION A-A



SEMI-PERMANENT GHAT OR CANAL CROSSING



CATTLE GHAT

PRC ENGINEERING/CHECCHI

FIGURE IV-5