# HANDBOOK FOR IMPROVING IRRIGATION SYSTEM MAINTENANCE PRACTICES

## WATER RESOURCES MANAGEMENT AND TRAINING PROJECT

IRRIGATION MANAGEMENT AND TRAINING PROGRAM

Irrigation Research and Management Improvement Organization
Central Water Commission

United States Agency for International Development

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Irrigation Management and Training Program

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# HANDBOOK FOR IMPROVING IRRIGATION SYSTEM MAINTENANCE PRACTICES

Louis Berger International, Inc.
Water and Power Consultancy Services (India) Limited

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# FOREWORD

This handbook on "Improving Irrigation System Maintenance Practices" has been prepared on behalf of the Irrigation Research and Management Improvement Organization, Central Water Commission, Government of India, and the United States Agency for International Development under the Irrigation Management and Training Program of the Water Resources Management and Training Project (WRM&T) No. 386-0484, by Louis Berger International, Inc. and Water and Power Consultancy Services (India) Ltd.

The WRM&T Project is jointly sponsored by the Government of India, the United States Agency for International Development, and several state governments in India. The goal of the project is to achieve increased production from irrigated agriculture through improved performance of irrigation systems. The primary means to be adopted are training, research, information and technology transfer, and organizational and procedural changes.

A major component of the project is developing interdisciplinary training and management capabilities in irrigation management. This calls for substantial training efforts to train the trainers and through them the inservice personnel at the State Training Institutes (STIs).

The importance of timely maintenance and repairs of the irrigation systems for efficient and productive irrigation needs to be fully recognized. Enormous irrigation potential has been created in India at considerable cost under a large number of major, medium and minor irrigation projects. In order to achieve optimal benefits from the created potential, the physical system needs to be kept in good working condition. Irrigation systems are subjected to rainfall, floods, high wind velocities, burrowing animals, and cattle encroachments, etc., which cause recurring damage, erosion, deposition of silt, vegetative growth, seepage losses, etc. In addition, human interference like cutting of banks, putting obstructions in the bed, unauthorized/oversized outlets, etc., also create maintenance problems. Thus, natural and artificial causes create maintenance problems and disturb the design parameters and impair the operational efficiency of the systems. Therefore, adequate and timely maintenance of an irrigation system is a pre-requisite for efficient irrigation water management.

Curriculum development and preparation of course and other training materials are important means for providing required training to in-service personnel. In this direction, LBII/WAPCOS is assisting STIs in organizing national level curriculum development workshops on selected topics. Irrigation System Maintenance is one such topic identified for development of curriculum and training materials.

Irrigation Management and Training Institute (IMTI) Tamil Nadu took up this subject for organizing the Workshop. The Workshop was held at the IMTI headquarters at Trichi from 22-27 August, 1988 and was participated by various STIs and Universities under the WRM&T Project and Tamil Nadu Irrigation Department officers.

Two short-term consultants were engaged by LBII/WAPCOS to assist IMTI Tamil Nadu to conduct this workshop on Irrigation System Maintenance Curriculum Development. Dr. Gaylord V. Skogerboe, Director and Professor at the International Irrigation Center, Utah State University, Logan, USA, and Mr. G.C. Kanjolia, former Chief Engineer-cum-Additional Secretary, Irrigation Department, Rajasthan were engaged to assist the IMTI. Both the consultants are highly experienced in irrigation system management.

Mr. O.P. Mehta, Irrigation Engineer with the LBII/WAPCOS Resident Team assisted by Mr. Tom Kajer, Training Specialist designed the workshop. Mr. Mehta coordinated the efforts of the specialists and also contributed portions of the text under the overall guidance and supervision of Mr. J.I. Gianchandani, Team Leader, WAPCOS.

In this handbook four maintenance plans, namely (a) essential structures maintenance, (b) normal maintenance, (c) "catch-up" maintenance, and (d) preventive maintenance, have been developed to provide guidelines to identify problems, develop solutions and implement the same for improving irrigation systems. A flow chart illustrating the sequence of the scientific approach has been provided. A 'walk-thru' diagnostic survey rather than a 'drive-thru' survey for ascertaining the maintenance needs has been proposed as it provides field personnel with a greater understanding of the causes of maintenance problems and provides them with valuable experience in the application of remedies to these problems. The maintenance learning process has also been devised to bring senior administrative level officers to appreciate the need for improving the present normal maintenance programs and issues associated with its funding and implementation and to gain their administrative support. The training materials are intended to impress upon the trainees that there are many issues to be considered in undertaking improved irrigation system maintenance practices. It also provides an insight as to how the existing maintenance funds being provided to the projects could be used in a more cost effective manner for better results and to avoid the heavy cost of deferred maintenance.

This handbook will be followed by other training materials, including course schedules, lesson plans and audiovisuals. We trust that this publication would prove helpful to the STIs in improving their training efforts and to the field professionals and others in better management of irrigation systems.

Jan Stofkoper
Team Leader
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Team Leader
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## SUMMARY

### Chapter 1 **Maintenance Learning Process**

Adequate and timely maintenance of an irrigation system is imperative for proper irrigation management. Water management cannot be effective unless the infrastructure for water conveyance and delivery is in a reasonably good condition to retain its operational efficiency.

For increasing agricultural productivity from existing irrigation systems, evaluation of maintenance deficiencies and their rectification along with improved operational practices to provide more reliable, predictable and equitable water deliveries to the outlets, is an imperative requirement.

The maintenance learning process has been developed to provide guidelines to (a) **identify problems** (diagnostic analysis), (b) **develop solutions** and (c) **implement solutions** for further improvement in the irrigation system. A flow chart illustrates the sequence of the M & O Learning Process. A table provides the three phases of the Scientific Approach for Improved M & O. The concept of this process emphasizes (a) maintaining rather than rehabilitating; (b) documenting maintenance needs to improve financial management and accountability; (c) using existing flow control structures for water measurement; (d) developing more detailed physical knowledge about what is occurring within the system; (e) increasing sensitivity about operating the system to meet the needs of farmers; and (f) documenting the needs and costs for irrigation system improvements.

Four maintenance plans have been developed under the maintenance phase of the learning process - (a) **essential structure maintenance** is considered to be the minimum level of investment that should be made in order to improve water delivery; (b) **the normal maintenance program**, if not provided with sufficient resources, results in accumulation of deferred maintenance; (c) the **"catch-up" maintenance** plan is devised to take care of the accumulated deferred maintenance; (d) **preventive maintenance** provides insight for avoiding the cases creating maintenance needs at the initial stages. Ideally a normal maintenance program should be provided with **sufficient** resources that will allow the preventive maintenance program to be followed. The most important aspect is **to involve the farmers** in developing and understanding all the maintenance needs in a project. This will not only create a sense of ownership in them but inculcate willingness to provide many details about the maintenance and operation problems in the system to be improved.

The maintenance learning process has been devised to gain administrative support from senior administrative level officers, to create awareness about the types of maintenance problems being confronted in the field, to appreciate the need for improving the present normal maintenance program, and to understand the various maintenance plans and the resources required for implementing a program of improved maintenance practices.

## Chapter 2 **Hydraulic and Maintenance Surveys of the System**

Efficient water management practices are essential for increasing agricultural productivity. Water can be efficiently managed only if it can be accurately measured. Thus, it is important to identify the flow control structures (essential structures) that can be calibrated for measuring discharge. The intent is to properly fix and repair flow control structures required for the improved hydraulic operation of the system so that these can function both as flow control and flow measurement structures. This activity is a crucial linkage between the Maintenance Phase and the Operations Phase of the M & O Learning Process.

There is a considerable amount of engineering survey work required in evaluating the maintenance requirements of channels in order to develop maintenance plans. Hydraulic surveys of the channels are required for ascertaining the quantum of desilting required from the canal bed to bring the bed gradients as per regime section and for ascertaining the quantum of earth work to be filled in the eroded banks or bed to bring the canal embankment to proper slope and shape.

In order to equitably distribute water in an irrigation delivery system, a knowledge of the variation in the seepage losses in various reaches of the canal is essential to calculate the amount of seepage, and to identify seepage areas to determine the lining that may be required. This section describes methodology for calibration of flow control structures, discharge measurements and measuring irrigation channel losses.

## Chapter 3 **Development of Maintenance Plans**

The State government funnels money to each irrigation system annually for normal or routine maintenance. Unfortunately, most irrigation systems are deteriorating under a combination of insufficient funds and unwillingness to work by many salaried labourers. This is why the degree of deferred maintenance is increasing. An important question is how existing funds being provided to the project could be used in a more cost effective manner to accomplish better maintenance and how much of the deferred maintenance might be alleviated with existing project funds by various means. This chapter describes methodology for development of various maintenance plans such as essential structure maintenance plan, normal maintenance program, catch-up maintenance plan and preventive maintenance plan along with the requirement of manpower, equipment, the present status and costs thereof with the purpose of achieving "regime" in the irrigation channel, eliminating sediment sources, minimizing seepage losses, reducing deterioration of channel lining and estimating annual maintenance costs. The chapter helps in understanding the difference between each type of maintenance plan, and the background information and field data required for preparing each type of maintenance plan, and provides necessary guidance to the field staff in preparing various maintenance plans and documenting the same.

## Chapter 4 Administrative Arrangements

This chapter describes various categories of work-charged and regular staff usually engaged for M&O of an Irrigation System and their present job related functions in Normal Maintenance Organizational norms. The routine functions may undergo some changes to suit the various functions for implementing improved Irrigation System Maintenance Practices. It identifies and assigns modified job related functions for the existing M & O staff for assessing the maintenance needs and process for preparing various maintenance plans. The chapter further describes administrative arrangements, funding for improved Irrigation System Maintenance Practices and the responsibilities of various officers starting from Junior Engineers to Chief Engineer's level. Diagnostic 'Walk-thru' maintenance survey rather than 'Drive-thru' has been emphasized for more precise documentation of maintenance needs. It provides an insight to the functions of different functionaries in the maintenance process, the administrative aspects in implementing an effective and improved maintenance program and the importance of accountability in developing credibility with higher officers.

## Chapter 5 Physical & Social Phenomena Causing Maintenance Problems and Their Solutions

A general description of the physical phenomena occurring and causing maintenance problems has been presented in detail under various components of the Irrigation System such as catchment area, reservoir, dams, lined/ unlined canals, structures, communication & ancillary works as well as the tertiary system. More serious problems of sedimentation, erosion, formation of cavities behind the lining, heavy seepage losses, vegetative jungle & aquatic growth, and other maintenance problems have also been discussed.

In addition to physical reasons, many maintenance needs are created because of social causes such as cutting of banks, putting obstructions in the canal bed, unauthorized/oversized outlets, tampering of outlets/structures/ gates, etc. Understanding the causes helps in developing solutions and can result in applying an appropriate remedy. This chapter deals at length with the various solutions and appropriate remedies to the physical and social phenomena causing maintenance problems.

The causes and solutions have been presented in detail in order to understand the relationship between the field maintenance inventory and the proposed solutions. It further helps in understanding the variety of maintenance activities associated with sustaining an irrigation system in good operating condition.

Chapter 1

# MAINTENANCE LEARNING PROCESS

## 1.1 Introduction

Water is a prime natural resource, a basic human need and a precious national asset. Principle consumptive use of water has been for irrigation. The total cultivable area of India is 186 m ha and net sown area is 143 m ha. The ultimate irrigation potential from the major, medium, minor projects and ground water is estimated to be 113.5 m ha which is planned to be created by 2010 A.D. or so. The ultimate irrigation potential would not be able to serve the entire cultivable area. The country's population, which is over 750 million at present, is expected to reach a level of around 1000 million by the end of this century.

Water is one of the most crucial elements in developmental planning, therefore earnest efforts to develop, conserve, utilize and manage this important resource have to be made. Improvement in irrigation management of a substantial order is necessary if the food and fibre needs of a growing population are to be met. Adequate maintenance of an irrigation system/project is a precursor to any irrigation management. No water management is possible unless the infra-structure to deliver water is in a reasonably good condition, to retain its operational efficiency.

Irrigation structures and systems, created through massive investment, should be properly maintained in good health. Appropriate annual provisions should be made for this purpose in the budget. A well established maintenance programme in any water delivery system is therefore a must before any significant water management is accomplished.

In most of the States in India in general, both the construction and the maintenance works are entrusted to the same irrigation division. As a result, it has been seen that the staff remains mostly busy in looking after the construction work only and the maintenance work receives lesser or no attention, resulting in the gradual deterioration of the irrigation system year after year. It is therefore necessary that suitable organizational changes/adjustments are made in the irrigation departments so as to have separate construction and maintenance divisions. This would bring about significant improvement both in the construction as well as maintenance of the projects.

There is a common feeling among the engineers that there is nothing much to be done in maintenance. They argue that most of the budget allocated for maintenance is used for work-charged staff salary and very little remains for the maintenance work. This is, as a matter of fact, not a correct conception. Proper assignment of duties to the various work-charged staff for work on canals, dividing them into suitable beats, would result in productive work from them. The remaining budget after paying the salaries of work-charged staff could be beneficially utilized on the maintenance of the canal system by preparing a roster of the whole maintenance programme and taking up the same as per fixed priority year to year.

However, the fact remains that the budget provisions for maintenance and operation of irrigation systems are far too low. Due to revision in pay and increases in their dearness allowance and other allowances, as well as increases in minimum wages and the cost of building materials, the net savings for M & O works have been gradually reduced, resulting in gradual deterioration of the maintenance standards. This aspect needs very serious consideration by the various State Governments. The M & O provisions should be adequately raised to compensate for the increase in wages and cost of materials.

Maintenance of a system is very complex and time consuming and is not as simple as it may at first seem. It needs a lot of thinking, a lot of personal visits/inspection of the sites by the Junior Engineer/Assistant Engineer, contacts with the farmers to have detailed information of the various minor snags in the system, regular hydraulic surveys, discharge measurements both above and below the outlets and maintenance of both a minor and major nature throughout the distantly scattered reaches of the system.

## 1.2 Maintenance & Operation (M & O) Learning Process

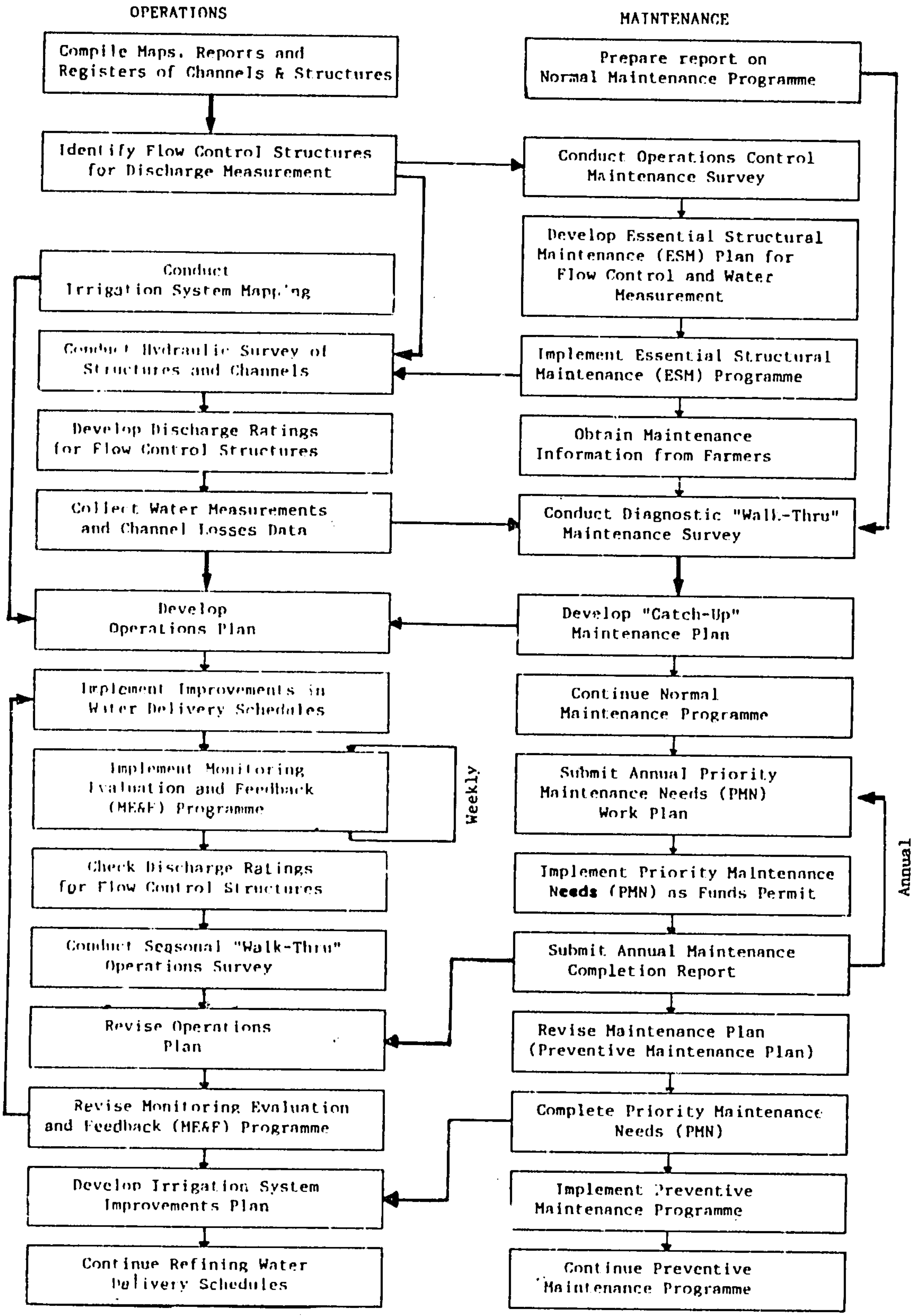
Most countries in the world have already constructed the most economical irrigation projects. Consequently, the major focus for these countries in the future will be on improving management practices in order to increase crop production on existing lands. However, deteriorating irrigation channels and inadequate operating procedures often preclude any significant improvement.

An important **strategy** for increasing the agricultural productivity of existing irrigation systems is, first of all, to evaluate the maintenance deficiencies on any particular irrigation system and then **correct all maintenance deficiencies** that interfere with the proper operation of the irrigation channels. Secondly, **improved operations practices should be developed** that will provide reliable, predictable and equitable water deliveries to each outlet structure (tertiary system). Finally, when operations practices have been improved, then **technical assistance should be provided to the farmers** so they can improve their water management practices in order to increase crop production.

> STRATEGY
> for Improving
> Existing Irrigation Systems
>
> 1. Correct maintenance deficiencies;
> 2. Improve operations practices to provide more reliable, predictable and equitable water deliveries to outlets; and
> 3. Provide technical assistance to farmers for enhancing tertiary system management.

The flow chart shown on the next page illustrates the essence of the Irrigation Maintenance and Operations (M & O) Learning Process. As shown, this process has two major phases: the Maintenance Phase and the Operations Phase. Although both phases will be discussed, the **initial emphasis** will be on **Implementing Improved Irrigation System Maintenance Practices.**

## IRRIGATION M & O LEARNING PROCESS



This Maintenance and Operations (M & O) Learning Process has been developed to provide guidelines that will: (a) **identify problems** which commonly prevent irrigation systems from delivering reliable and equitable supplies; (b) **develop solutions** which on implementation would be able to treat the causes of these problems, rather than just the symptoms; and (c) **provide field experience** and insights for further improvements in the irrigation system. It is also meant to develop appreciation, create awareness, and equip the senior officers of the department with the background of the maintenance process.

A scientific approach for improving maintenance and operations of irrigation systems consists of three phases: Problem Identification (Diagnostic Analysis); Development and Testing of Solutions; and Implementation of Solutions. Activities related to Operations and activities related to Maintenance are detailed in the accompanying table.

## Scientific Approach

## for Improving Maintenance and Operations of

## Existing Irrigation Systems

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### Problem Identification (Diagnostic Analysis)

| Operations | Maintenance |
|---|---|
| • Compile Maps, etc. | • Prepare Report on Normal Maintenance Programme |
| • Identify Flow Control Structures | • Conduct Operations Control Maintenance Survey |
| • Conduct Mapping | • Obtain Maintenance Information from Farmers |
| • Develop Discharge Rating<br>• Measure Channel Losses | • Conduct Diagnostic "Walk-Thru" Maintenance Survey |

### Development and Testing of Solutions

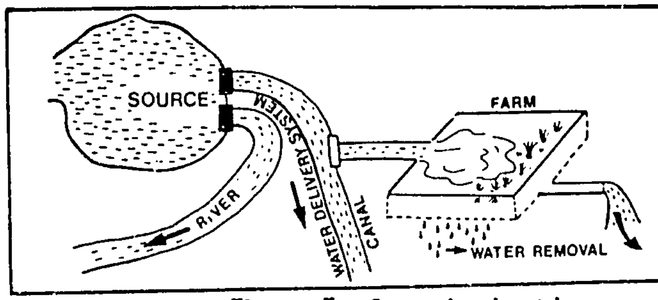
| Operations | Maintenance |
|---|---|
| • Develop Operations Plan<br>• Check Discharge Ratings | • Develop Essential Structural Maintenance Plan |
| • Conduct Seasonal "Walk-Thru" Operations Survey<br>• Revise Operations Plan | • Develop "Catch-Up" Maintenance Plan |
| • Revise Monitoring, Evaluation and Feedback Programme<br>• Develop Irrigation System Improvements Plan | • Prepare Preventive Maintenance Plan |

### Implementation of Solutions

| Operations | Maintenance |
|---|---|
| • Implement Improvements in Water Delivery Schedules | • Implement Essential Structural Maintenance<br>• Continue Normal Maintenance Programme |
| • Implement Monitoring, Evaluation and Feedback Programme | • Implement Priority Maintenance Needs as Funds Permit<br>• Complete Priority Maintenance Needs<br>• Implement Preventive Maintenance Programme |
| • Continue Refining Water Delivery Schedules | • Continue Improving Preventive Maintenance Programme |

### 1.3 Conceptual Approach

An **irrigation system** can be divided into four major subsystems:

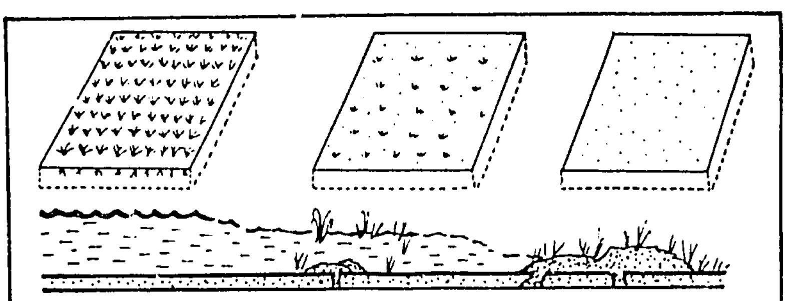



1. **Water Source(s);**
2. **Water Delivery;**
3. **Farm; and**
4. **Water Removal.**

The **Farm subsystem is** considered to be the **"heart"** of an irrigation system; it performs the system's primary function, that of food growth for humans and animals. The **Water Delivery** and **Water Removal** subsystems **support** the **Farm** subsystem.

Even if all four irrigation subsystems have been properly designed, the lack of an adequate technological and institutional framework for operating the system in accordance with the design criteria will likely lead to failure of the system, or low agricultural production levels. Generally, operating conveyance facilities have not been related to sustaining long-term productive agriculture.

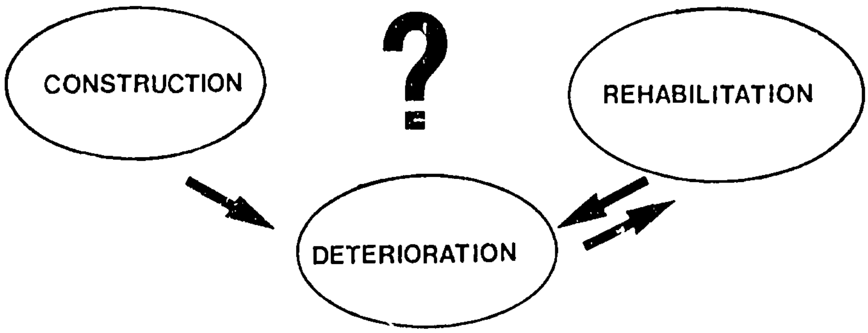
There is a growing awareness world-wide that improved farm water management practices can be cost-effective in achieving increases in crop production. But, in so many cases, improved maintenance practices and improved operating procedures in the water delivery subsystem are required before any significant improvements in farm water management practices can be attained.



DETERIORATING IRRIGATION CHANNELS
PRECLUDE GOOD CROP PRODUCTION

A **common problem** in irrigation systems **is** the continual **cycle of** irrigation system **construction,** followed by **deterioration** of the system because of inadequate maintenance, **and** then **rehabilitation** (which ends up being major reconstruction), **followed again by deterioration.** This significantly inhibits the development of irrigated agriculture. As the irrigation channel network deteriorates, there is a decreasing capability for equitably delivering water throughout the system. The adequacy and dependability of the irrigation water supply decreases for some farmers, depending upon their location; thus, they are less likely to risk other expensive agricultural inputs such as fertilizer, etc. In some cases, a portion of the lands has to be abandoned for lack of water. The consequence is very slow progress in agricultural production.

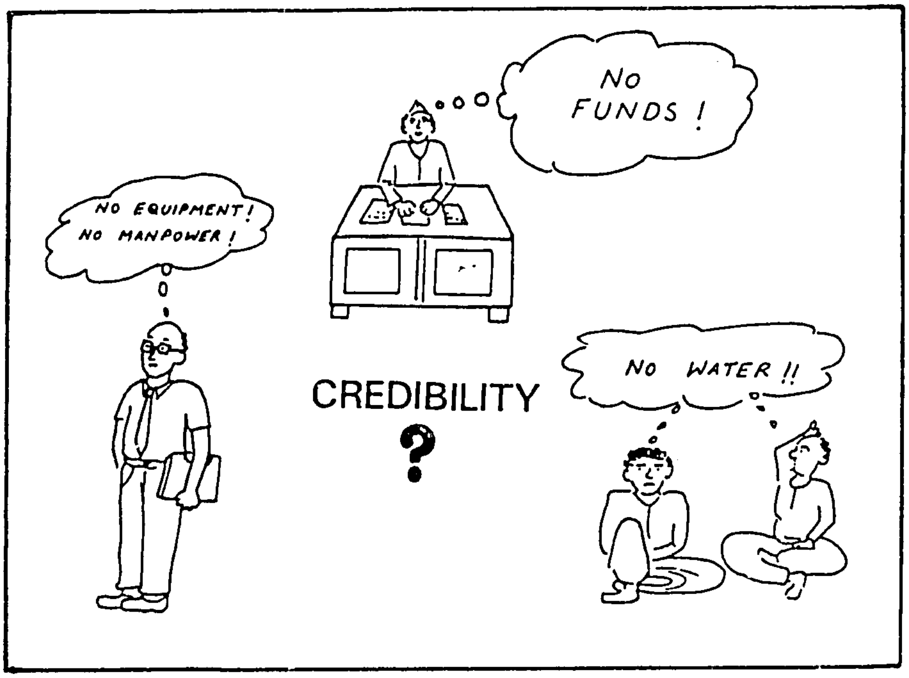
ISN'T THERE A BETTER WAY




The recurring cycle of construction-deterioration-rehabilitation (construction) - deterioration usually precludes the timely and equitable distribution of irrigation water supplies. Besides resulting in stagnant growth in agricultural production, the construction phase adds to the national debt burden, which has now become a painful problem for many countries. In general, the economic benefits resulting from irrigation investments in recent decades have been dismal. Not only donors are questioning irrigation investments, but senior officials in a number of countries are raising the question, **"Isn't there a better way?"**

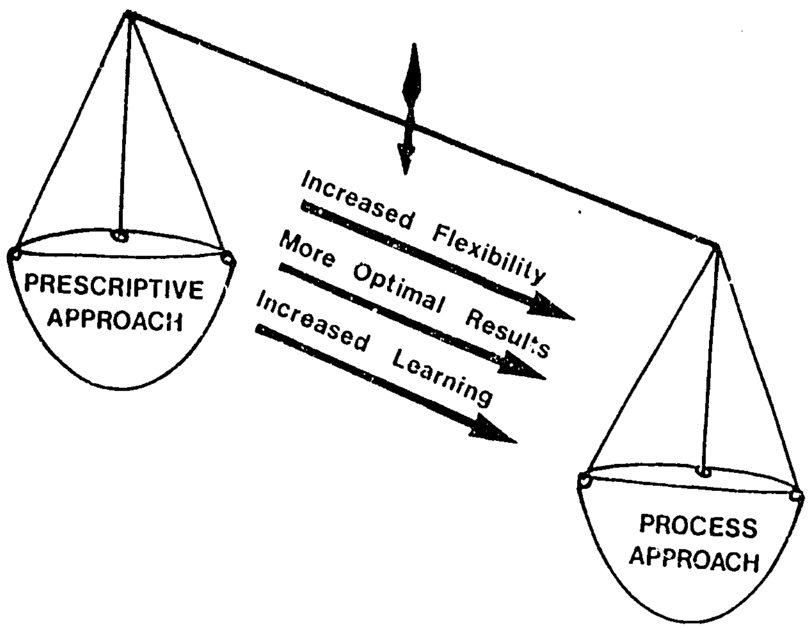
As mentioned, the emphasis in the future will be improving water management practices and increasing crop production on existing irrigated lands. Technology alone will not bring about the necessary improvements. Instead, both technological changes and institutional modifications are usually required to help existing irrigated lands become more productive.

For example, it is not sufficient to rehabilitate a network of irrigation channels; the **channels must be maintained season after season** so that a dependable water supply can be delivered to every farmer. Likewise, it is not sufficient to just fill the channels with water; **flow measurement** devices are needed **so** that **irrigation supplies** are **equitably delivered** to each outlet. First of all, in order to operate and maintain an irrigation system on a sustained basis, high ranking government officials need to provide the necessary manpower, equipment and budget. Secondly, the personnel responsible for operations and maintenance must provide farmers with timely and equitable water deliveries.




Recognizing the "site specific" nature of irrigated agriculture, where **each project area is uniquely different**, an effective **approach must be process oriented**, rather than an approach which emphasizes technology alone, or a "prescriptive" approach that lists step-by-step procedures that are to be used on every irrigation project. Although a "prescription" is usually preferred by most irrigation officials, the disadvantages are: (a) the procedures will lead to less than optimal results for most projects; and

(b) project field personnel do not "learn" how to accommodate the unique characteristics within their project area in order to improve the performance of the system. Instead, a process (or a series of processes) is required that is capable of being adapted to each "site specific" situation in order to be transferable.




**The maintenance and operations "learning process" provides one technological approach** for effectively sustaining an irrigation network over a long time period. This process emphasizes:

**(a)** **maintaining rather than rehabilitating;**

**(b)** **documenting maintenance needs to improve financial management and accountability;**

**(c)** **using existing flow control structures in irrigation channels for water measurement;**

**(d)** **developing more detailed physical knowledge about what is occurring within the system;**

**(e)** **increasing sensitivity about operating the system to meet the needs of farmers; and**

**(f)** **documenting the needs and costs for irrigation system improvements.**

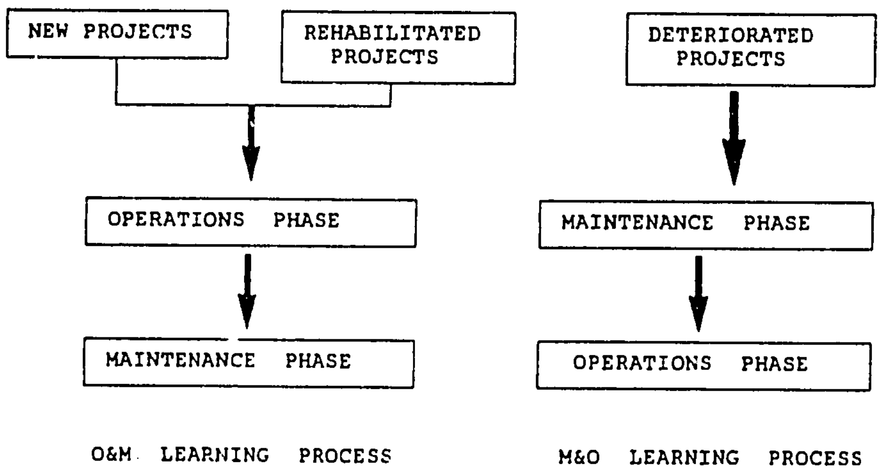
In discussing maintenance and operations (M & O) issues, it is useful to subdivide the water delivery subsystem into the main canal, the secondary system consisting of distributaries and minors, and the tertiary subsystem, which is watercourse or Unit Command Area (UCA). The tertiary system or UCA is the land served by the last flow control structure (outlet) along the secondary system. An irrigation project consists of a main and secondary system channel network (called main system) that serves many UCAs. Many irrigation projects around the world have a division of M & O responsibilities between the main system and the UCA. Usually, a government agency is responsible for M & O activities in the main system, while the farmers below an outlet are responsible for M & O activities in their tertiary channel network.

IRRIGATION WATER DELIVERY SUBSYSTEM

| MAIN SYSTEM | TERTIARY SYSTEM |
|---|---|
| ↓ | ↓ |
| M&O by Government | M&O by farmers |

This process is focused upon the water delivery subsystem, but the same principles would apply to the water removal subsystem (surface and subsurface drainage channel network). Most likely, the farmers would be responsible for maintaining the drainage channels in the tertiary subsystems, while the appropriate government agency would maintain the main drains and the branch drains flowing into each main drain. Presently, the maintenance of drainage channels is not being attended, in general, as no special funds are provided for this purpose.

For new irrigation projects, and recently rehabilitated systems, the initial emphasis would be the operations phase followed shortly afterwards with initiating activities under the maintenance phase, which would then be termed an O & M Learning Process. In contrast, for irrigation systems that are deteriorating, the term M & O Learning Process would be more appropriate, because the initial emphasis should be the maintenance phase, followed by an increasing emphasis on the operations phase as more and more of the maintenance needs are corrected. This is particularly true for lined irrigation channel networks that have deteriorated. However, for earthen channel networks, much of the data generated by implementing the Operations Phase is needed in order to make decisions about maintenance requirements (particularly the reconstruction of earthen embankments).




For implementation of the M & O programme to a reasonable degree of satisfaction, it is essential that O & M divisions & Construction divisions in the Irrigation Department have separate identities with separate cost accounts. M & O generally gives more attention to staff costs, with the result that the M & O of the existing system suffers because there is only a small amount of funds for doing field maintenance activities.

## 1.4 Maintenance Phase of the Learning Process

The application of the M&O Learning Process for undertaking the maintenance phase is shown in the accompanying flow chart. Note that some of the activities under the operations phase, notably developing discharge ratings and measuring channel losses, are also done to provide more background information that will enhance the effectiveness of conducting the Diagnostic "Walk-Thru" Maintenance Survey. Commonly used terms are explained in the following page.

There are **four maintenance programmes** shown in the flow chart and the diagram, which are also defined in the **definitions of irrigation system maintenance** on the following page. **Essential Structural Maintenance** is considered to be the minimum level of investment that should be made in order to improve water deliveries. The purpose of **"Catch-Up" Maintenance is** to take care of the accumulated deferred maintenance, which in most cases allows deterioration of the system. The **Preventive Maintenance** takes care of the causes creating maintenance needs at the initial stage. Its purpose is to avoid the need for costly rehabilitation. Ideally, a **Normal Maintenance** Programme should be provided with sufficient resources that will allow a Preventive Maintenance Programme to be followed.

The **first step** in both the operations and maintenance phases of the learning process is to do a field survey of required **Essential Structural Maintenance** (ESM) **for flow control** (e.g., replacing gates) **and water measurement** (e.g., repairing damaged structures or installing new flow measuring devices). If there is structural damage, then it becomes important to assess the cause(s) of the damage, so that appropriate remedies can be applied; otherwise, the damage may recur in a very short time period. This Operations Control Maintenance Survey can be done separately or simultaneously with the Diagnostic "Walk-Thru" Maintenance Survey. In either case, the results of the Operations Control Maintenance Survey are incorporated into the Diagnostic "Walk-Thru" Maintenance Survey to develop a "Catch-Up" Maintenance Plan.

A number of terms have been used to describe various approaches to maintenance. Definitions of some commonly used terms are given below:

## Normal or Routine Maintenance

Normal and Routine are synonymous terms referring to the usual (normal) maintenance activities that are conducted annually for an irrigation system. Normal Maintenance involves those activities commonly done (rather than "should be done") every year.

## Emergency Maintenance

When unusual conditions occur that jeopardize the safety of the dam, head works, or the irrigation channels, then the required maintenance is termed Emergency Maintenance because of the urgent need to take immediate action.

## Essential Structural Maintenance

Essential Structural Maintenance is the required maintenance for flow control structures that will also allow the structures to be used for discharge measurement after calibration.

## Deferred Maintenance

Deferred Maintenance is the accumulation of maintenance needs being accrued under the Normal or Routine Maintenance Programme; most likely because of a shortage of funds, and other reasons.

## Catch-Up Maintenance

Catch-Up Maintenance is a programme for taking care of the accumulated Deferred Maintenance needs in order to upgrade the hydraulic performance of the system.

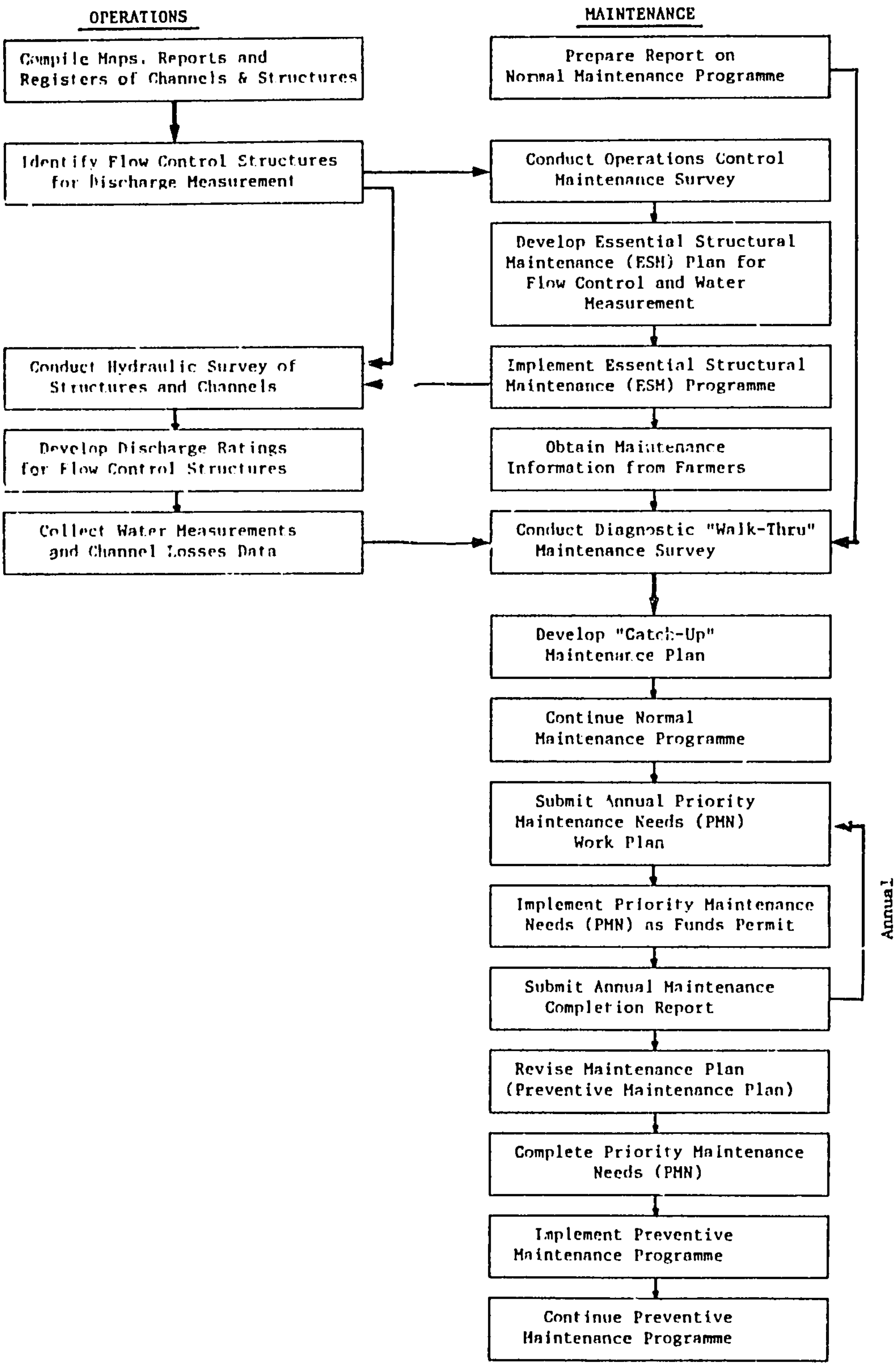
## Preventive Maintenance

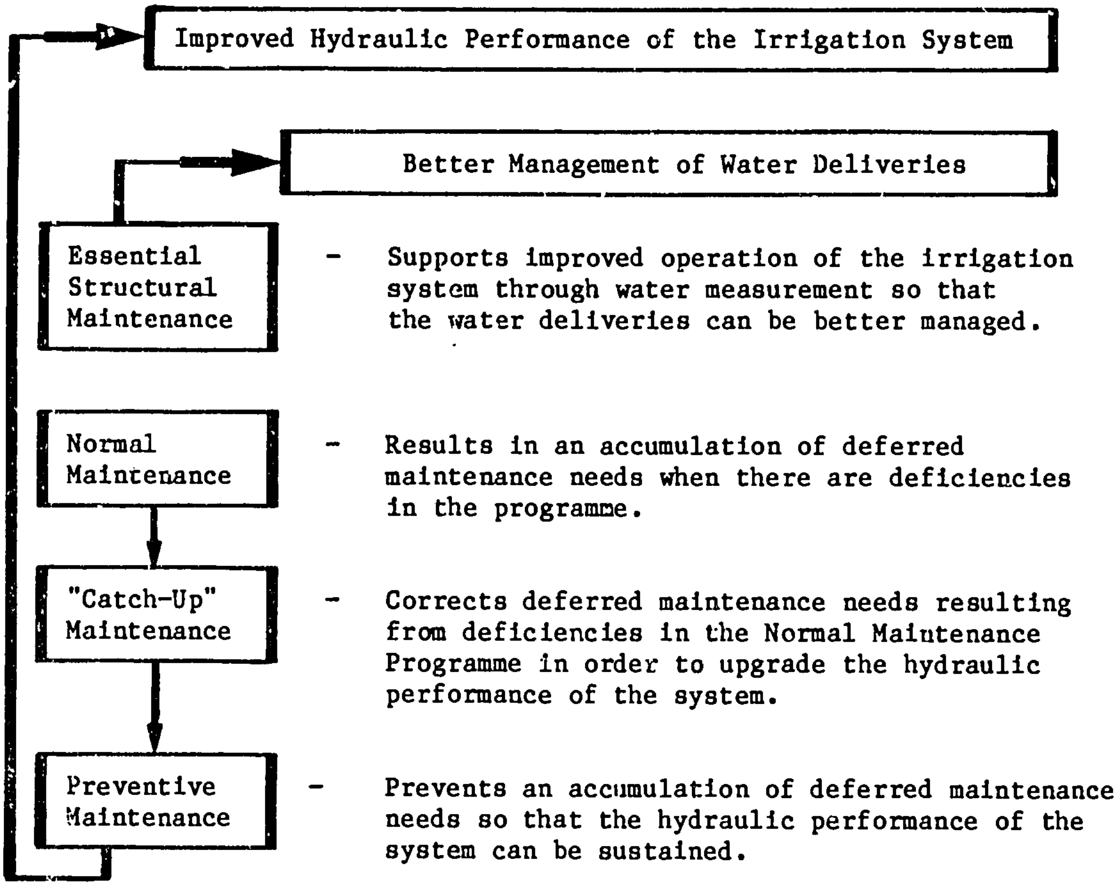
Preventive Maintenance is a programme for taking care of the causes creating the maintenance needs when they are only a minor problem, rather than allowing such maintenance needs to go unattended until they become a major expensive problem.

## Rehabilitation

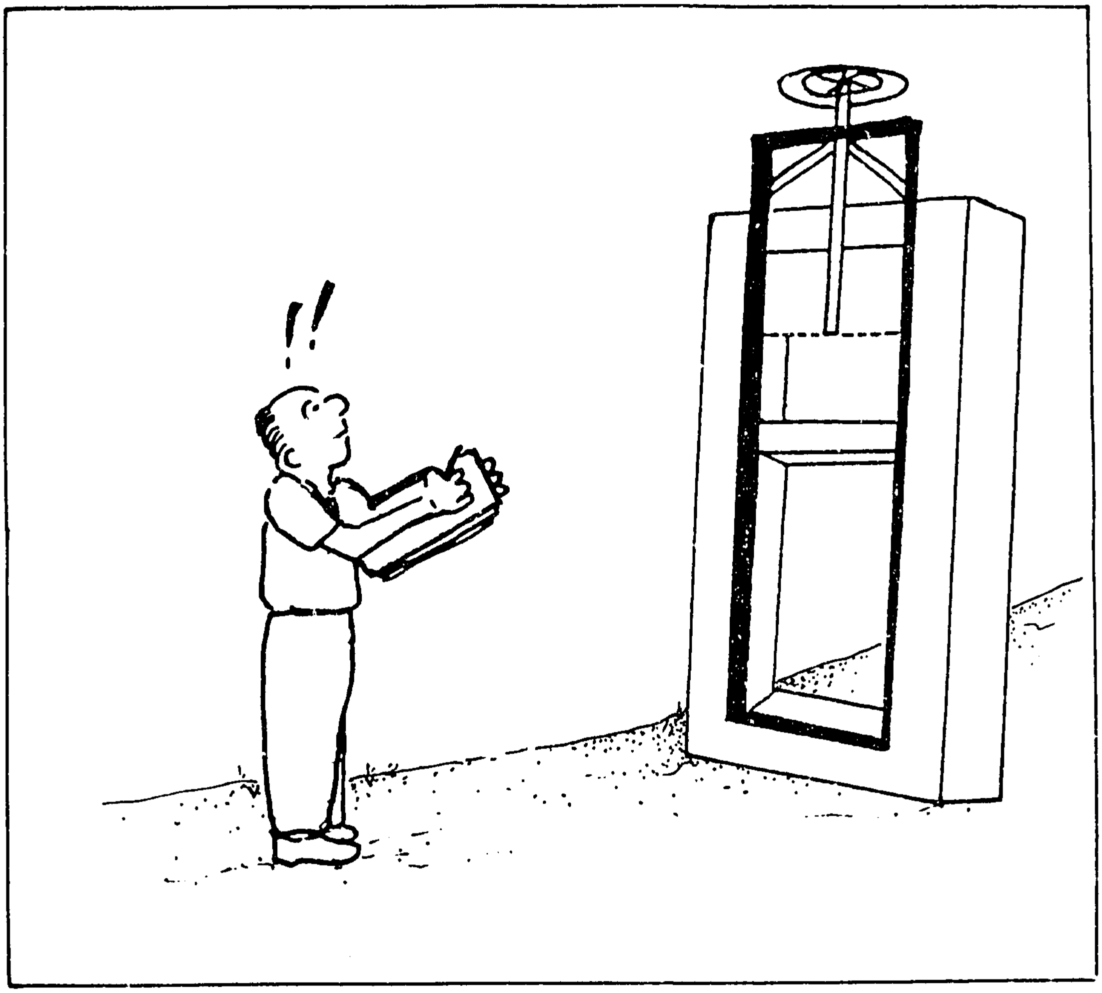
In most cases, Rehabilitation is required because the accumulation of Deferred Maintenance needs has become so great that the operation of the irrigation system is also significantly hampered. If an effective Preventive Maintenance programme has been followed, then Rehabilitation should only be required to replace aging structures.

## MAINTENANCE LEARNING PROCESS






The **Operations Control Maintenance Survey** is conducted after identifying the flow control structures in the irrigation system and deciding if all, or only some, of these structures will be used for discharge measurement. Of particular importance is each division point in the channel network because these are locations where water is diverted from a larger channel into a smaller channel, and the smaller channels' discharge rate should be measured. These division structures should be inspected for necessary cleaning, repairs and replacement (e.g., gates, bricks, etc.). The field inspection results for each structure should be recorded in a field book with sufficient detail so that a good cost estimate can be prepared later; then, the necessary maintenance should be done in order to have the structure function for both flow control and water measurement.



In many irrigation systems, **numerous open channel constrictions can be used for measuring water** such as drop structures, check structures, or flow regulating structures. Many of these structures should be improved (ESM) so that they can function as water measurement devices. Then, the **channel losses between two structures can be measured.** Sometimes, such measurements will require special operating procedures for 1/2-2 days so that water is not diverted between the two structures (unless the water diversions can also be accurately measured).

A detailed "Essential Structural Maintenance Plan" should be prepared.

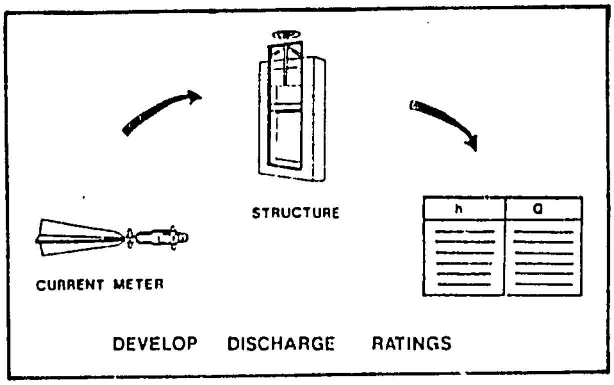
**ESSENTIAL STRUCTURAL MAINTENANCE PLAN**

1. **Physical Description of Irrigation System**
2. **Proposed Flow Measurement Program for Equitably Distributing Water Supplies**
3. **Proposed Flow Measurement Program for Evaluating Channel Losses**
4. **Essential Structural Maintenance (ESM)**
5. **Costs of Essential Structural Maintenance**
6. **ESM Implementation Plan**
7. **Field Notes and Sketches**

Once the ESM Plan has been approved, then **detailed cost records should be kept** of actual expenditures during ESM implementation. This is important for planning similar investments in other irrigation networks because these costs reflect the minimum investment that should be made in upgrading the irrigation channels' operation. Accumulating this information for many irrigation systems will allow planners to allocate more realistic funding for upgrading other irrigation projects in their region.

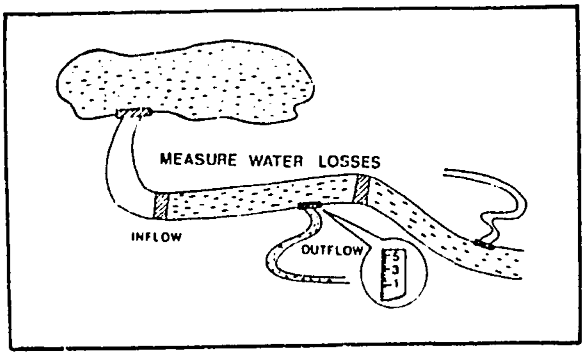
The first step in the Operations Phase begins when the structures in the irrigation system that are important for controlling the flow discharges in the system are identified. These structures are inspected under the Maintenance Phase in order to prepare an ESM Plan.

After doing the necessary Essential Structural Maintenance (ESM), a concerted effort will be needed to **develop discharge ratings** for all of the flow control structures. For the large main canals and branch canals, a current meter could be used to calibrate each structure, whereas portable flow measuring flumes can probably be used to calibrate the inlet structures for smaller irrigation channels (e.g., watercourses or minors). Distributary or branch channel structures could be rated using portable flow measuring devices wherever feasible; otherwise, a current meter could be used.




Periodically, the discharge ratings should be checked and adjusted, if necessary, which should become a routine operations procedure. Also, detailed field books should be kept to describe the physical condition of the structure and nearby channel each time a discharge rating is made. With periodic maintenance, the discharge rating for each structure will change very little with time. Although this technology is simple, periodic maintenance and attention to details are important in order to have discharge measurements that are accurate within five percent.

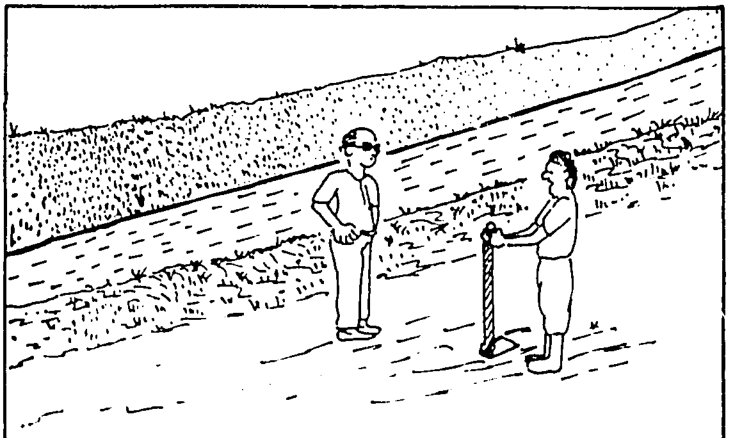
After discharge ratings have been developed for each flow measurement structure, **channel losses can be evaluated** for most of the reaches in the irrigation network using the inflow-outflow method.




In fact, stage readings collected at each structure prior to developing a discharge rating can be converted to calculated discharge rates that will be fairly accurate provided there have been no significant changes in channel sedimentation or vegetative growth, both of which are problems in many irrigation systems. Channel losses should be measured periodically throughout each irrigation season to determine the effects of channel water depths and water table depths on seepage rates. There will usually be some reaches where ponding tests will need to be conducted prior to or after the irrigation season, or perhaps before and after a scheduled rotation period, in order to accurately measure the conveyance losses.

A most important aspect is to **involve the farmers** in developing an understanding of the maintenance needs in a project. This will not only create a sense of ownership in them, but will also provide many details about the maintenance and operations problems in the system to be improved. For this, a Maintenance Committee should be formed in each irrigation subdivision, headed by the concerned Assistant Engineer, which could meet periodically during each crop season at a fixed place and fixed dates and time. The places should be so decided so that the farmers do not have to walk more than 5 km to attend the meeting in the village. The shortcomings pointed out by the farmers in such meetings should be recorded in a register and an attempt made to redress them before the next meeting at the same place, say after 4 weeks or so. This would create farmer confidence in the Government officials and also create in them a sense of nearness and responsibility for the project.

Another **important step** in the Maintenance Phase is to **conduct** a detailed **Diagnostic "Walk-Thru" Maintenance Survey** that lists all maintenance needs along each main canal, branch canal, distributary, and minor including the outlet structure to each tertiary system (UCA). The survey requires 2-3 individuals (e.g., irrigation engineer and technical assistant) walking

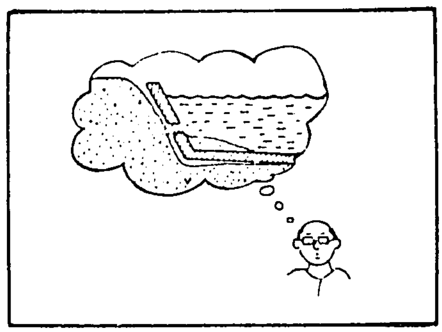


"WALK-THROUGH" MAINTENANCE SURVEY

along the irrigation channels, taking notes on each maintenance need (**e.g.** removal of sediment, repair of canal bank, repair of damaged structure, etc.). These notes must provide sufficient details for preparing a cost estimate for correcting each maintenance need.

The concept of a "walk-thru", rather than driving, is for field personnel to gain more sensitivity about maintenance problems, not just major problems, but also **minor problems that often develop into major maintenance problems** in another year or two. Many of these minor problems are overlooked when driving, even slowly, along a canal bank.

The term "diagnostic" is very important in all aspects of irrigated agriculture, including maintenance. The majority of maintenance problems are easily observed in the field. Unfortunately, on many irrigation projects around the world, **only** the **major maintenance problems** are **corrected,** so that **minor problems** that could be corrected inexpensively **are ignored** until they grow into major expensive problems. Even more importantly, often only the **symptoms of the problem are treated rather than the cause** of the problem. This is done sometimes purposefully because of less expense, and sometimes because the causes are not recognized. By developing an understanding of the causes (diagnosis), an individual attains **"maintenance eyes"** wherein **minor defects are readily perceived** and analysed as growing into a major problem unless remedial maintenance measures are implemented.

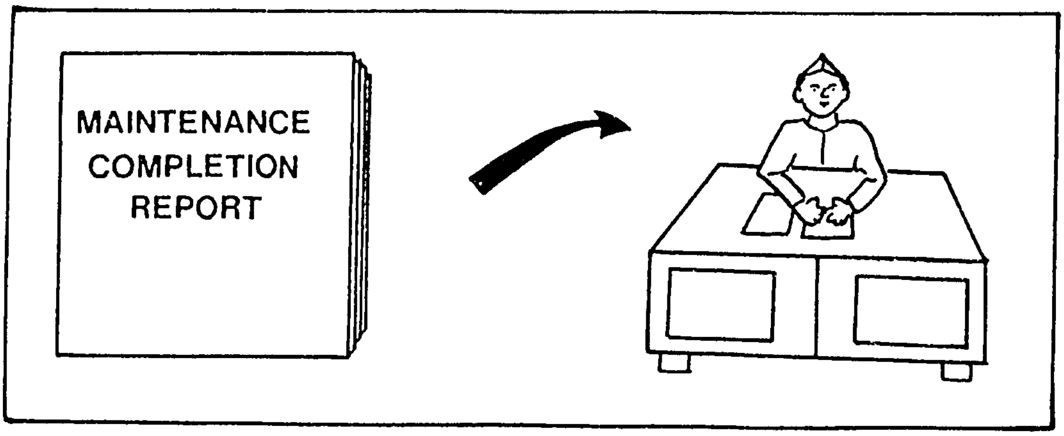


A report should be prepared for each irrigation project that describes a "Catch-Up" Maintenance plan to be implemented and completed within a reasonable time period, preferably 3-5 years for large projects and 1-2 years for small projects. The deferred maintenance needs identified during the Diagnostic "Walk-Thru" Maintenance Survey should be listed and then prioritized so that they become Priority (Deferred) Maintenance Needs (PMN).

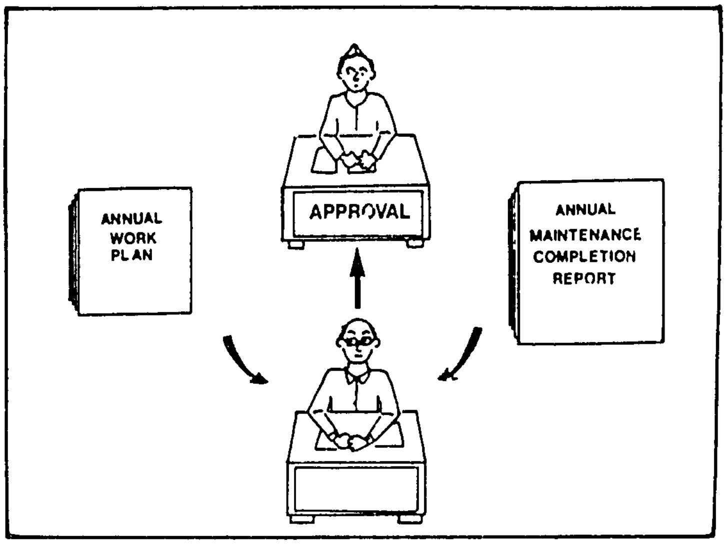
## "CATCH-UP" MAINTENANCE PLAN

1. Physical Description of Irrigation Project
2. Essential Structural Maintenance (ESM)
3. Status and Costs of ESM Plan
4. Inventory of Required Maintenance
5. Maintenance Costs
6. Priority Maintenance Needs (PMN) and Costs
7. Maintenance Equipment Requirements
8. Maintenance Manpower Requirements
9. Maintenance Plan
   a. Maintenance Issues
   b. Method of Implementation
   c. Implementation Schedule
10. Field Notes and Sketches

For each budget year, an Annual Work Plan containing both Priority Maintenance Needs and the Normal Maintenance Programme would be forwarded to appropriate authorities for approval and funding. At the end of each year, the Executive Engineer for each project area would prepare an Annual Maintenance Completion Report that lists each maintenance need that had been corrected and its actual cost. This report would be forwarded to appropriate authorities for their information and review.



**Accountability** is a key factor in this annual cycle of preparing a work plan and filing a completion report. Irrigation project personnel must develop **credibility** with the Chief Engineer that the provision of manpower, equipment and funds will be used appropriately to correct Priority Maintenance Needs (PMN), as well as doing Normal Maintenance. In turn, this documentation allows the Chief Engineer or Superintending Engineer to **monitor and audit** the effectiveness of the field maintenance program, as well as provide essential data for planning of future maintenance funding requirements.




Some funds will already have been expended for Essential Structural Maintenance (ESM), while additional funds will need to be allocated to correct PMN. The allocated funds to the project may not be sufficient to correct all maintenance needs, so the highest priority maintenance needs should be corrected first, then the next highest priority, etc., until all allocated maintenance funds have been expended, or all PMN have been corrected.

When the operations phase has proceeded to the point where channel losses (including the tertiary systems) are being measured, along with field evaluations of irrigation application efficiencies on cropped fields, then the maintenance plan should be refined. A revised maintenance plan should be prepared that includes a section on maintenance requirements for tertiary systems, which would be undertaken by the farmers' organization for each UCA with technical assistance provided by appropriate government agency personnel. As a minimum, the Junior Engineer, farmer representative for the particular UCA being inspected, and the technical assistant responsible for delivering water to the UCA should walk along the tertiary (watercourse) channel network and collectively prepare detailed notes on maintenance needs. At the same time, **revisions in the previous "Catch-Up" Maintenance Plan can be made based on new information and experience gained during implementation.** One of the more valuable insights that should have been gained by this time is an understanding of the causes of the maintenance problems, rather than just the symptoms.

Before completing PMN, and after gaining experience and credibility with farmers, a Preventive Maintenance Plan should be prepared that would be the basis for continued long-term maintenance activities.

**PREVENTIVE MAINTENANCE PLAN**

1. **Physical Causes of Maintenance Problems**
2. **Anticipated Extent of Maintenance Problems**
3. **Maintenance Equipment Requirements**
4. **Maintenance Manpower Requirements**
5. **Maintenance Requirements for Farmers' Organizations**
6. **Estimated Annual Maintenance Costs**
7. **Preventive Maintenance Plan**
   a. **Maintenance Issues**
   b. **Preventive Maintenance Activities**
   c. **Preventive Maintenance Requirements**

This document should be forwarded for appropriate review and approval.

## 1.5 Activities for Improving Irrigation System Maintenance Practices

The maintenance phase of the learning process was described in the previous section. In this section, all of the activities listed in the Maintenance Learning Process flow chart (in 1.4) will be briefly discussed in chronological order. This summary of activities provides a checklist of each activity in sequence.

### A. Compile Maps, Reports and Registers of Channels and Structures

The first step in this process is to compile existing information about the irrigation system. There should be some general maps of the project area as well as detailed design maps. Some reports may have been written regarding the project, either technical studies or economic evaluations, or both. There may be important information in the files that has never been placed in a report, such as short evaluation of either operations or maintenance problems. In addition, each project should have Registers that list the various structures in the system and the various channel reaches. These Registers should supply a history of changes, including maintenance, that have occurred with time over the entire irrigation system. All of this information is valuable in providing background about the project and to assist in the organization of the field work and the preparation of the various maintenance plans.

### B. Identify Flow Control Structures for Discharge Measurement

The second step in this Learning Process is to identify which flow control structures would also be desirable for water measurement. The most important flow control structures are the gates at the dam that regulate the flow rate into the main canals, or the river diversion structure; the Head Regulators for the branch, distributary and minor canals; and each outlet structure serving a tertiary sys'em (water course). In addition, check structures are valuable for flow control, while falls, drops and culverts can also be calibrated.

## C. Conduct Operations Control Maintenance Survey

The second step is to Conduct an Operations Control Maintenance Survey. The Maintenance Survey should be conducted at each structure that has been identified as being important for flow control and water measurement. Any necessary repairs, such as malfunctioning or leaky gates, should be written in detail in a field book. Any maintenance needed on existing flow control and/or water measurement structures should be adequately described in the field book. All deficiencies should be noted. In some cases, structures may need to be replaced or additional structures constructed.

## D. Develop Essential Structural Maintenance Plan

Foremost priority is given to the flow control structures, because their use for both flow control and water measurements is considered the minimum level of investment, and most cost-effective investment, for improving the operation and hydraulic performance of the irrigation system.

A detailed "Essential Structural Maintenance Plan" should be prepared that includes: (1) Physical description of irrigation system; (2) Proposed flow measurement programme for equitably distributing water supplies; (3) Proposed flow measurement programme for evaluating channel losses; (4) Essential Structural Maintenance (ESM); (5) Costs of Essential Structural Maintenance; (6) ESM Implementation Plan; and (7) Field Notes and Sketches.

## E. Implement Essential Structural Maintenance (ESM) Programme

Once the Essential Structural Maintenance Plan has been approved, then detailed cost records should be kept of actual expenditures during implementation. This is important for planning similar investments in other irrigation networks because these costs reflect the minimum investment that should be made in upgrading the operation of the irrigation channels. Accumulating this information for many irrigation systems will allow planners to allocate more realistic funding for upgrading other irrigation projects in their region.

## F. Conduct Hydraulic Survey of Structures and Channels

A network of accurate benchmarks must be established along each channel, including a benchmark at each structure. For some projects, a network of benchmarks will already exist. The benchmarks on structures are needed when developing discharge ratings, in order to relate gauge readings to invest elevations. Along channels they are needed for determining the vertical elevation for cross-sections when measuring channel water losses and the amount of sediment deposition that must be removed.

## G. Develop Discharge Ratings for Flow Control Structures

Discharge ratings should be developed in the field for all the flow control structures. In the canal, branch canals, and distributaries, a current meter will be used to measure discharge, which will be combined with water level measurements upstream and downstream from the structure in order to develop the calibration. For outlets, a standardized flow measuring device, such as a cutthroat flume, located downstream in the water course, can be used for the discharge measurement. This can be combined with upstream, or upstream and downstream, water levels (whichever is appropriate depending on whether modular or non-modular flow conditions exist in the outlet constriction) to develop the calibration.

## H. Collect Water Measurements and Channel Losses Data

After discharge ratings have been developed for each flow control structure, channel losses can be evaluated for most of the reaches in the irrigation network using the inflow-outflow method. In fact, stage readings collected at each structure prior to developing a discharge rating can be converted to calculate discharge rates that will be fairly accurate provided there have been no significant changes in channel sedimentation or vegetative growth, both of which are problems in many irrigation systems. Channel losses should be measured periodically throughout each irrigation season to determine the effects of channel water depths and surrounding groundwater table depths on seepage loss rates.

In addition, it is advisable to use the Ponding Method at numerous locations as a check on the inflow-outflow measurements and for channel reaches where sufficient accuracy cannot be obtained by discharge measurements. A combination of inflow-outflow and ponding measurements are used to evaluate the channel losses throughout the main system from the head works to all of the outlets feeding the tertiary systems.

## I. Obtain Maintenance Information from Farmers

Information should be obtained from many groups of farmers scattered throughout the project area as to their difficulties with the irrigation system. Certainly, not all of the problems will be related to maintenance. However, many of the problems about operation of the system that might be cited by farmers will also be related to difficulties with maintenance. Experience has shown that much can be learned from farmers.

## J. Prepare Report on Normal Maintenance Programme

Prior to preparing a "Catch-up" Maintenance Plan, the Normal Maintenance Programme for the irrigation system should be documented. A suggested outline for this document would be: (1) General description of irrigation system; (2) Available maintenance manpower; (3) Available maintenance equipment; (4) Present maintenance activities; and (5) Major maintenance difficulties. This report should be prepared by the project staff most familiar with the normal maintenance programme.

## K. Conduct Diagnostic "Walk-Thru" Maintenance Survey

The next step in this Learning Process is to Conduct a Diagnostic "Walk-Thru" Maintenance Survey, which is a detailed field survey that lists all maintenance needs along each canal, branch, distributary or minor, including the outlet structures to each tertiary (water course) system. This survey requires two to three individuals, such as an Assistant Engineer and Junior Engineer, walking along each irrigation channel, taking notes on each maintenance need.

There are three previous activities that provide considerable background information for diagnosing, or determining, the causes of maintenance problems. These activities are : (1) Hydraulic survey of channels; (2) Measuring irrigation channel losses; and (3) Obtaining maintenance information from farmers. All of this information should be readily available in convenient format for use by the field team conducting the Diagnostic "Walk-Thru" Maintenance Survey.

"Walk-Thru" rather than "drive-thru" is very important to be sure that all of the maintenance needs are actually seen. With "drive-thru," only the major maintenance problems are observed. A "walk-thru" will allow observations of minor maintenance problems that can readily be corrected at low level costs before they become expensive major problems.

It is important to understand the physical phenomena "causing" the problems. This allows the observers to "diagnose" the maintenance problems as to their actual causes so that recommended maintenance needs will correct the "cause" of the problem rather than treat the "symptoms." In this manner, the causes of maintenance problems can be eliminated so that they do not recur year after year.

Typical detailed field notes during a diagnostic "walk-thru" survey would include: (1) reaches of channel requiring sediment removal, including an estimate of the volume of sediment in cubic meters and the causes of the sediment deposition; (2) reaches of channel experiencing scour, and the causes; (3) area of vegetative growth to be removed; (4) grading of roadway; (5) repair or replacement of structures; (6) cavities at structures such as bridge abutments and gate structures; (7) cavities along concrete lined reaches that need to be filled, along with an estimate of the cavity volume; (8) repair of holes in brick or concrete lining panels; and (9) replacement of failed lining panels.

## L. Develop "Catch-up" Maintenance Plan

A report should be prepared that describes a "Catch-Up" Maintenance Plan that will correct all deferred maintenance needs within five years for large projects, or only one to two years for small projects. This report should include: (1) Essential Structural Maintenance for water control and flow measurement; (2) costs of Essential Structural Maintenance; (3) inventory of required maintenance; (4) maintenance costs; (5) Priority Maintenance Needs and costs; (6) maintenance equipment requirements; (7) maintenance manpower requirements; and (8) maintenance plan. The maintenance plan should include: (a) maintenance issues such as achieving "regime" in the irrigation channels, eliminating sediment sources, minimizing seepage losses, and reducing deterioration of channel lining; (b) method of implementation, such as departmental maintenance, or through contractual agency, or through a contract with the water users; and (c) implementation schedule including the first-year priority maintenance needs work plan and proposed work plans for the second, third, fourth and fifth years.

## M. Contimue Normal Maintenance Programme

The Normal Maintenance Programme needs to be continued every year throughout this process for improving irrigation system maintenance practices. In the next activity, Submit Annual Priority Maintenance Needs Work Plan, normal maintenance funds also need to be requested to take care of the usual normal maintenance needs that accrue each year, while funds for priority maintenance needs will be used to remedy deferred maintenance needs that have accumulated over a number of years because of deficiencies in the Normal Maintenance Programme. This will be continued until the Preventive Maintenance Plan is implemented, which will then replace the Normal Maintenance Programme.

## N. Submit Annual Priority Maintenance Needs Work Plan

For each fiscal year, a Priority Maintenance Needs Work Plan would be forwarded to appropriate Irrigation Department authorities for approval and funding. Priority maintenance needs are the prioritized deferred maintenance needs resulting from deficiencies in the Normal Maintenance Programme. Although most maintenance work is done between irrigation seasons, this work plan should also describe which maintenance activities can be completed during each irrigation season.

## O. Implement Priority Maintenance Needs as Funds Permit

The allocated funds may not be sufficient to correct all of the maintenance needs listed in the Annual Work Plan, so the highest priority maintenance needs should be corrected first, then the next highest priority, until all allocated maintenance funds have been expended, or all priority maintenance needs have been corrected.

## P. Submit Annual Maintenance Completion Report

At the end of each fiscal year, the Executive Engineer for each project would prepare an Annual Maintenance Completion Report that lists each maintenance need, both under the annual maintenance programme and the Priority Maintenance Needs, that had been corrected and its actual cost. This procedure will provide experience and documentation for more reliable estimates of maintenance costs in the future.

Documenting the maintenance phase with a Maintenance Plan, an annual Priority Maintenance Needs Work Plan, and an Annual Maintenance Completion Report allows for accountability between the project and the central offices. This documentation provides the necessary information for properly monitoring and evaluating the improvement in the main system and the effectiveness of the expenditures.

## Q. Revise Maintenance Plan (Preventive Maintenance Plan)

Before completing the Priority Maintenance Needs, a Preventive Maintenance Plan should be prepared that would be the basis for continued maintenance activities after completion of the Priority Maintenance Needs. This plan should discuss: (1) physical causes of maintenance problems; (2) anticipated extent of maintenance problems; (3) maintenance equipment requirements; (4) maintenance manpower requirements; (5) maintenance requirements for water users (farmers); (6) estimated annual maintenance costs; and (7) preventive maintenance plan that discusses maintenance issues, preventive maintenance activities, and preventive maintenance requirements. This document should be forwarded to the Chief Engineer for review and approval.

## R. Complete Priority Maintenance Needs (PMN)

While the Preventive Maintenance Plan is being reviewed, the Priority Maintenance Needs Work Plan (PMN) should be completed. This implies that all of the deferred maintenance has been done, so that only preventive maintenance is required in the future, except for emergency maintenance and the eventual replacement of some structures due to aging.

## S. Implement Preventive Maintenance Programme

Upon approval of the Preventive Maintenance Plan, including the provision of necessary resources, a Preventive Maintenance Programme should be initiated. This programme will likely require more resources than normal maintenance, which had previously resulted in deferred maintenance, unless means are found to make existing resources more cost-effective. Most likely, a combination of greater cost effectiveness in the employment of existing resources, plus having additional resources provided, will be required for an effective Preventive Maintenance Programme.

## T. Continue Preventive Maintenance Programme

The field experience gained while implementing the "Catch-Up" Maintenance Plan and the Preventive Maintenance Programme should prove to be extremely beneficial in sustaining the irrigation system in good working order. However, field personnel are rotated in their assignments and new officers may lack field experience, so there is a risk that the system might again deteriorate. The best safeguards against this occurring is adequate field training and experience, along with good administrative procedures. Even then, there is always the danger of political interference that makes sustaining of the physical system extremely difficult. Even if none of these problems occur, there will always be a need for field personnel and administrators to be alert to necessary changes that will further enhance the agricultural productivity from the fields served by the irrigation system.

# Chapter 2

# HYDRAULIC AND MAINTENANCE SURVEYS OF THE SYSTEM

## 2.1 Maintenance Survey for Flow Control Structures

### A. Identifying Flow Control Structures

There is a growing awareness that agricultural productivity needs to be increased on existing irrigated land. Efficient water management practices are essential in order to accomplish this goal. It has been said that water can be managed only if it can be accurately measured. Thus it is important to identify the kinds of flow control structures that can be calibrated for measuring discharge as a part of a general procedure for improving the hydraulic operation of the irrigation system.

Water can be utilized effectively for the production of food and fiber only when its quantity is known. Ideally, the discharge should be measured at every division in the irrigation system. In many projects, however, discharge measurements are taken only at the headworks of a canal. The headworks may be an outlet from a dam or other structure which diverts water from a river. While the technology for measuring irrigation water is comparatively simple and readily available, it has not been incorporated into the routine operations practices of many irrigation systems.

A variety of irrigation system structures can be calibrated to measure water. Generally, the most common constrictions are canal sluices (gate structures), open channel flow measuring flumes, falls, check structures, outlets, etc. Some systems have hundreds of gate structures for flow control. The outlet structures which are usually uncontrolled are most commonly free orifice flow structures, pipe outlets, or open channel flume outlets. Other irrigation structures which can be calibrated are culverts, inverted siphons, and escapes. Any type of structure that constricts the flow of water can be field calibrated for discharge measurement (e.g., a bridge where the abutments constrict the sides of the irrigation channel). By developing field discharge calibrations for existing irrigation structures, irrigation water management will be improved.



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For each main canal, identify the flow control structures. First, the Head Regulator at the dam or river diversion will be the primary flow control structure. Then, there may be some check structures in the main canals that are used to regulate water levels. Finally, the Head Regulator for each distributary is a flow control structure. Also, there may be some outlets along the main canal, as well as the distributaries and minors. In addition, there may be some other structures that affect the control of water in the main canals, such as escapes, that may also be important.

The inventory of flow control structures for each canal and branch canal should list all available known information, such as:

1. Location of the structure;
2. Dimensions of the structure;
3. Elevations; and
4. Existing hydraulic data.

Next, a similar inventory of flow control structures should be prepared for each distributary and minor. The primary structure is the Distributary Head Regulator, followed by the Head Regulator for each minor. There will also be some check regulators and other control structures that need to be included. The most common structure will be the outlets, where each outlet serves a tertiary system. Most of these outlets are uncontrolled orifices and flumes but some are single gate structures, some are adjutable proportional modules (APM), and some are gated culvert outlets but most culverts are open pipe outlets.

## B. Approach for Undertaking Field Work

Before discussing the Benchmark Survey of Flow Control Structures (Section 2.2) and the Discharge Calibration of these flow control structures (Section 2.3), some thought should be given to prioritizing the work. If there are two main canals, then probably the largest canal serving the most irrigated land will be of primary importance. However, it may be wiser to undertake the calibration of the smaller canal initially, because: a) it is important for the project staff to gain experience and develop sensitivity about what is occurring in the system; b) the work will be completed sooner so that there is a feeling of accomplishment; and c) the mistakes made on the first canal will provide valuable insights for minimizing errors in the larger canal and result in better quality work.

Undertake the field work first of all on the smallest distributaries and minors, thereby leaving the largest distributary, which is also probably the most important distributary, for last. Again, sensitivity will be gained under the smaller distributaries, particularly with respect to serving individual tertiary systems.

Also, for the smaller canal, after completing the necessary field work for the distributaries and minors, then begin field work on the smaller branch canal until all of the branch canals are completed; then, do the field work on the smaller main canal so that all of the field work for the entire smaller canal network is completed.

Also, in organizing the work, since many of the structures are standard Irrigation Department designs, it may be advisable to begin calibrating identical structures to determine if the results are compatible. If not, then the reasons for such incompatibilities must be investigated, such as checking dimensions and elevations, and even more importantly, the accuracy of the discharge measurements during calibration. Another common difficulty is obtaining accurate measurements of openings, whether gates or cutlets.

The above discussion places the emphasis on doing the Operations Control Maintenance Survey beginning at the lower end (distributaries and minors) of the smaller canal network (if there is more than one main canal) and working upstream until the canal headworks have been inspected. Afterwards, the Operations Control Maintenance Survey would be conducted on the larger canal network. Likewise, the benchmark survey (Section 2.2) should preferably be done first for the smaller canal network and then afterwards for the larger canal network. The same approach would be followed in developing discharge ratings (Section 2.3).

### C. Operations Control Maintenance Survey Procedures for Flow Control Structures

In this portion of the Maintenance Survey, the intent is to properly fix, repair or replace all flow control structures required for the improved hydraulic operation of the irrigation project so they can function both as flow control and flow measurement structures. This activity is a crucial linkage between the Maintenance Phase and the Operations Phase of the M & O Learning Process. The Operations Phase will identify the flow control structures that need to be calibrated for discharge measurement. The Maintenance Phase will conduct a maintenance survey of the identified flow control structures to determine what is required to have these structures in good condition prior to developing discharge ratings.

Ideally, the maintenance survey of flow control structures should be done twice, once when the channels are operating and once during canal closure. Most of the flow control structures in the major channels will be gate structures, while the outlets are usually fixed openings.

During channel operation, each structure should be inspected for visible damage and leakage. The gate structures should be operated to determine if there are any difficulties. In particular, each gate should be completely closed to determine if it can be completely seated and view the amount of leakage. In addition, since the flow conditions can be seen during normal or usual operating conditions, decisions should be made regarding where staff gauges, benchmarks, or piezometers should be located for measuring water levels later when developing the discharge ratings, and for use in operating the system afterwards. All of this information should be recorded in considerable detail in a field book, including sketches.

During canal closure, each structure should be carefully inspected for required maintenance. For gate structures, the gate and gate frame should be very carefully inspected. The condition of the gate lip should be noted in the field book -- are the edges square or rounded? are there any dents or encrustations? is scraping and painting required? can the maintenance be accomplished in-place or does the gate have to be removed? or, does the gate have to be replaced?

The gate frame needs to be just as carefully inspected as the gate. Again, the condition of the edges of the gate sill on the gate frame is important -- are the edges square or rounded? is any of the metal bent? are there any encrustations? are there any obstacles to prevent full closure of the gate? is scraping and painting required? can the required maintenance be done in-place or does the gate frame have to be removed? or, does the gate frame have to be replaced? Also, the condition of the gate seat should be especially noted in the field book -- is the seat of the gate frame smooth and level? are there any encrustations? is there any loose material that can easily be removed? is scraping and painting required? Finally, measurements should be made of the vertical depth between the gate sill and the gate seat; this should be done at both inside edges and in the middle (3 measurements) and should be repeated at both ends of the gate opening and at the one-fourth, half and three-fourths of the width, giving a total 15 measurements (3 measurements at 5 locations). This last information is extremely important in interpreting the field measurements when developing discharge ratings later.

For overflow structures, such as falls, drops and check structures, the elevation of the crest should be measured at five locations (both ends, middle, and one-fourth and three-fourths) as a minimum. In this manner, an appropriate crest elevation can be established for use later when developing the discharge ratings. If there are severe irregularities in the crest elevation, then a decision must be made whether or not to repair the crest as a part of the Essential Structural Maintenance Programme.

For outlets, the flow constrictions must be carefully inspected for cross-sectional area and compared with the sanctioned opening. If there is occasional tampering, then this should be noted in the field book and appropriate remedies recommended. If there is extensive tampering (more than 25 percent of outlet structures), then repairs or resetting is not a plausible solution because the outlets will again be tampered with in a very short time period; instead, it would be advisable to calibrate these outlets without doing any Essential Structural Maintenance and then distribute the findings among all farmers in the irrigation system.

## 2.2 Hydraulic Survey Of Structures and Channels

There is a considerable amount of engineering surveying work required in: (i) evaluating the maintenance requirements for earthen channels in order to develop a Maintenance Plan; or (ii) developing an Operation Plan. This survey work would have originally been done during the design and construction of the irrigation project, some of which may still be readily available such as benchmarks and station locations for structures, as well as station markings along the channels. A decision needs to be made whether existing benchmark elevations and station markings are still correct, or whether they should be resurveyed to ensure their correctness.

### A. Benchmark Survey of Flow Control Structures

The first step in surveying is having a network of benchmarks along each channel, including a benchmark at each structure. A network of benchmarks may already exist. If so, the records should be checked to determine how many years ago it was established and when it was last checked. If more than 10 years have elapsed since the benchmark elevations were checked, then it would be wise to do a resurvey. It is advisable that the benchmark elevations are true elevations, not based on an assumed elevation at some location. Also, it is important that the elevation survey be closed to assure that the elevations of the benchmarks are accurate.

After completing the Essential Structural Maintenance (ESM) programme, and during canal closure, or whenever distributaries are closed during rotation periods, the elevations pertinent to the hydraulics of flow control structures can be established. For example, the sill elevation of each gate frame can be measured at 3-5 locations across the width of each gate sill. In addition, the crest elevation on each drop structure or other

overflow structure (e.g.. falls or escapes) could be measured at 3-7 locations across the crèst width. Also, the sill elevation for each outlet structure should be established. If staff gauges have been located at flow control structures, then the elevations corresponding to the zero reading on each staff gauge should be measured.
For each outlet structure, the cross-section of the hydraulic constriction should be measured, which may or may not require a series of width measurements with height above the sill. If the constriction is an orifice, such as an Adjustable Proportional Module (APM), then a series of height measurements, say three, should be made across the width of the orifice (at both sides and in the middle). For pipe outlets, the inside diameter of the pipe should be known. Also, the invert elevation for each outlet must be established using the Benchmark Survey.

## B. Hydraulic Survey of Channels for Scour and Sedimentation

Sufficient advance notice is required whenever closure of the main canal and branches is scheduled to occur. Whenever any canal system is closed, it should be inspected by a 'walk thru' rather than 'drive thru' and the details of maintenance needed for the structures should be listed in the closure register by the Assistant Engineer.

For ascertaining the quantum of desilting required from the canal bed to bring the bed gradients as per regime section, surveys of longitudinal elevations and channel cross-sections are undertaken once in two years. The criteria listed below on Survey for Channel Loss Measurements can be used for determining the frequency of survey measurements along the channel reaches. The quantity of silt to be removed, or the quality of earth to be filled in the eroded banks or bed, is determined by marking the design slope in the longitudinal direction on a large piece of paper which has the actual bed elevations marked.

For ascertaining the earthwork needed to bring the canal section and embankments to proper slope and shape, cross-sections of the canal at suitable intervals are taken and the quantum of earthwork required is assessed by superimposing the designed sections on the cross-section based on this survey. The minimum width and freeboard of the bank has to be ensured. By studying the behavior of the canal for some time, the parameters in some reaches may be readjusted, if necessary, to ensure that the channel attains its regime section. In the case of channels where regime is yet to be attained, a regular periodic watch is needed; this can be accomplished by conducting regular hydraulic surveys at regular intervals (e.g., every two years).

### C. Survey for Channel Loss Measurements

Whether measuring channel losses by either the Inflow-Outflow Method or the Ponding Method, the same survey data is needed. In fact, the Hydraulic Survey of Channels described above can be used to satisfy the surveying needs for conducting channel loss measurements, provided these needs are anticipated in advance. Cross-sections are needed periodically along each channel in order to calculate wetted perimeter (see Section 2.4). For irregular shaped earthen channels, cross-sections are needed every 15 meters, while every 30 meters of channel length is satisfactory for more uniform shaped channels. For lined channels, very few cross-sections are needed, but the longitudinal bed profile should be surveyed every 30 meters. All of this work should preferably be done using true elevations above mean sea level.

## 2.3 Calibrating Flow Control Structures

### A. Discharge Calibration

Calibration is the process by which stage (gauge)-discharge relationships are established. With this process, the hydraulic functioning of constrictions in either the main channel or elsewhere in the system is determined. Standardized primary flow measurement devices (structures that have previously been calibrated in a hydraulics laboratory such as rectangular sharp- crested weirs, Parshall flumes and cutthroat flumes) can be installed if field conditions permit. While these devices are convenient, they are expensive to purchase and difficult to permanently install in an existing irrigation system. Field calibration becomes necessary: (a) if control structures rated in the laboratory are not identical to structures and conditions existing in the field; or (b) if the dimensions of the field control structures appear incorrect. Under such circumstances, the structures in question need to be recalibrated to correctly describe their hydraulic functioning. When doing field calibration on any of the control structures previously mentioned, water discharge rates corresponding to one or two flow depths are recorded. In order to make a meaningful data analysis, a minimum of four or five readings are necessary. Each reading will contain appropriate upstream, or upstream and downstream depth measurements and corresponding flow rate information. The manual on "Field Calibration of Irrigation Structures for Discharge Measurement" should be consulted for detailed procedures. When the appropriate data have been collected, a graphical technique is used in analyzing calibration data for establishing gauge (stage)-discharge relationships. Afterwards a rating table is prepared that is preferably contained in a glass case or plastic case that is located at the structure.

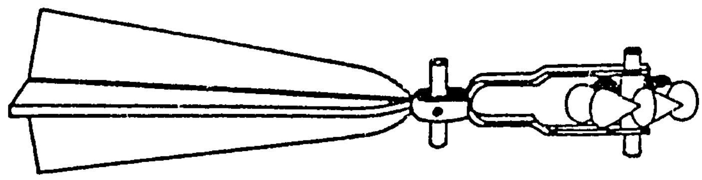
Classification of control structures is based both on their function and their operational nature. Gates, culverts, overflow structures, etc., are designed to operate essentially under either modular (free) flow or non-modular (submerged) flow conditions. The terms modular flow, free flow, and critical depth flow have identical meanings wherein a change in downstream flow depth does not affect the upstream flow depth because critical depth occurs in the vicinity of the constriction. Likewise, the terms non-modular flow, submerged flow and drowned flow have identical meanings. A non-modular flow condition exists when the downstream flow depth is raised to the extent that flow velocity at every point through a constriction becomes less than the critical value so that an increase in the downstream flow depth results in an increase in the upstream flow depth. Control structures designed to operate under modular flow conditions frequently become non-modular (submerged) in response to unusual operating conditions, or with the accumulation of aquatic and vegetative growth. Care should be taken to note the operating conditions of the control structure in order to determine which flow rating should be used.

Calibration data is collected differently, depending on whether modular flow or non-modular flow conditions exist. In a modular flow condition, a reading taken at each upstream stage (or gauge depth) must have a corresponding flow rate measurement. In a non-modular flow situation, two readings are required, one upstream and one downstream stage (or gauge depth) for each discharge measurement.

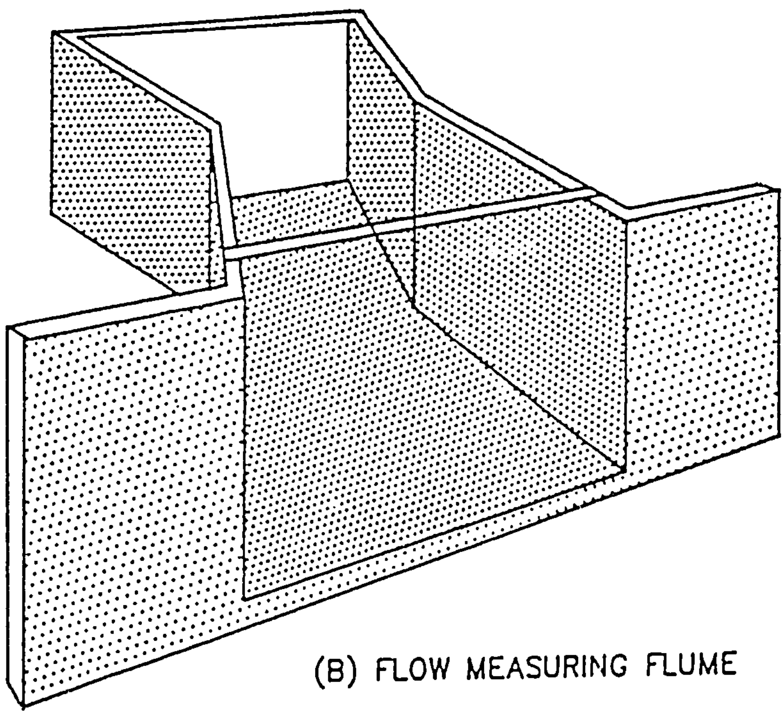
## B. Discharge Measurement

There are a number of methods which are commonly used to collect discharge measurements in an irrigation network (Figure 2.3-1).

A current meter is generally used for discharge rates greater than 500 liters per second and often for flow rates greater than 200 liters per second. When discharge rates are roughly less than 300 liters per second, flow measuring flumes -- such as the Parshall flume or cutthroat flume-- are temporarily installed. For larger discharge rates, the dye dilution method can be used. With improved dyes and instruments that measure in parts per <u>billion</u> rather than in parts per million, this method is becoming increasingly useful. Another useful method for measuring discharge rates is to make volumetric measurements (Figure 2.3-2). For example, a small volumetric pan can be used to determine the discharge rate over a small portion of a weir overflow structure. By taking a series of such measurements over the crest width, the total discharge rate can be determined. When needing to measure very small flow rates where the quantity is less than one liter per second, a plastic bag can be used. After collecting the water, it can be repeatedly poured into a graduated volumetric container until the total volume of water has been measured. This is a very helpful method for measuring leakage from gate structures when they are closed.



(A) CURRENT METER



(B) FLOW MEASURING FLUME

Figure 2.3-1 Typical Methods of Collecting Discharge Measurements in Irrigation Channels

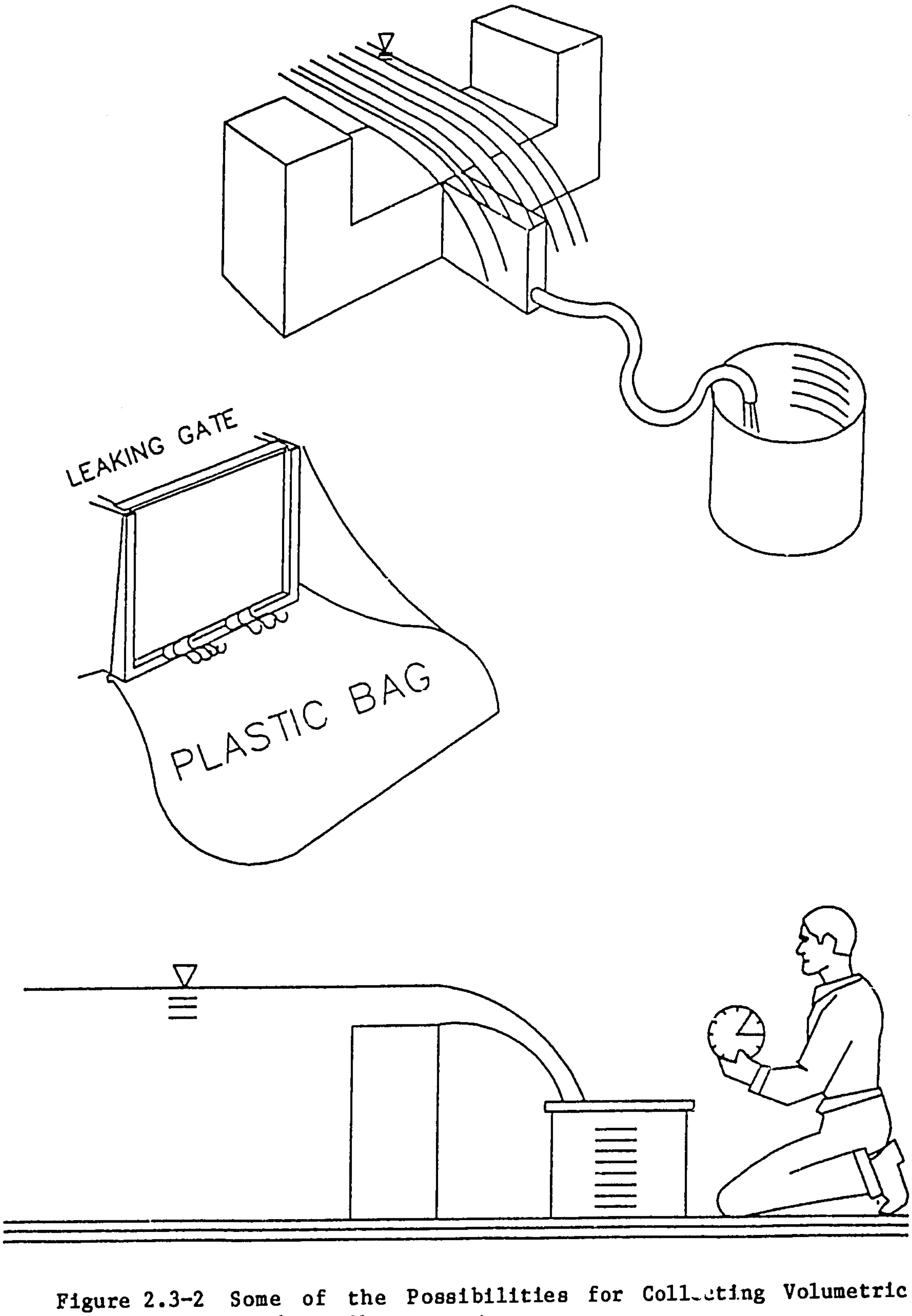
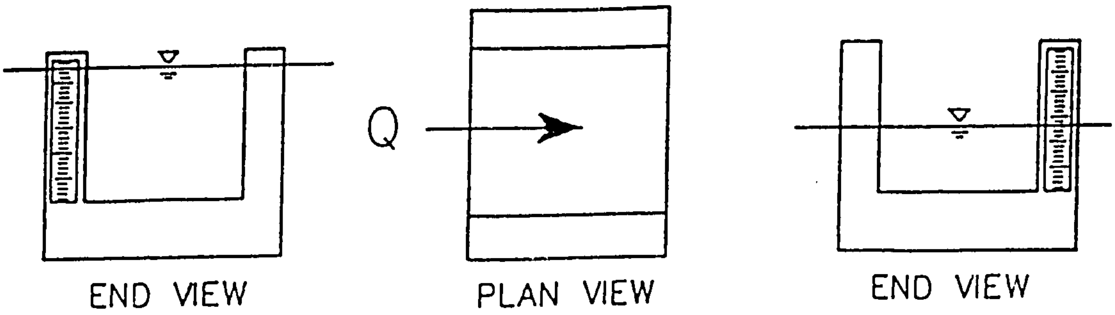



Figure 2.3-2 Some of the Possibilities for Collecting Volumetric Discharge Measurements

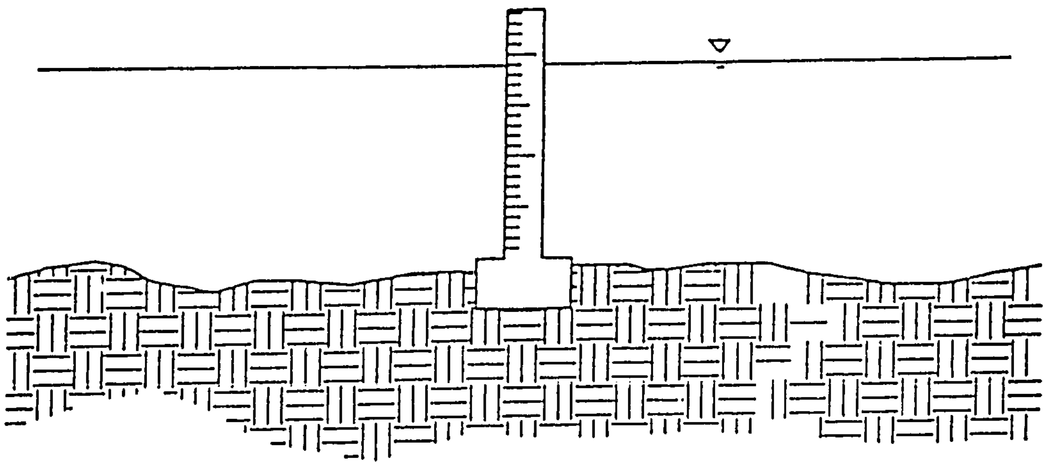
## C. Gauge (Stage) Measurement

Three techniques for gauge depth or stage measurement are commonly employed. With the first technique, a staff gauge is placed against the wall of an irrigation structure or on a post located in the middle of an irrigation channel (Figure 2.3-3). (Under non-modular flow conditions, more than one staff gauge is used -- one upstream and one downstream from the constriction.) The primary advantage of a staff gauge is that everybody can read it, including the farmers. The primary disadvantage of a staff gauge is that it has to be repainted each year because the markings below the surface of the water become obliterated.

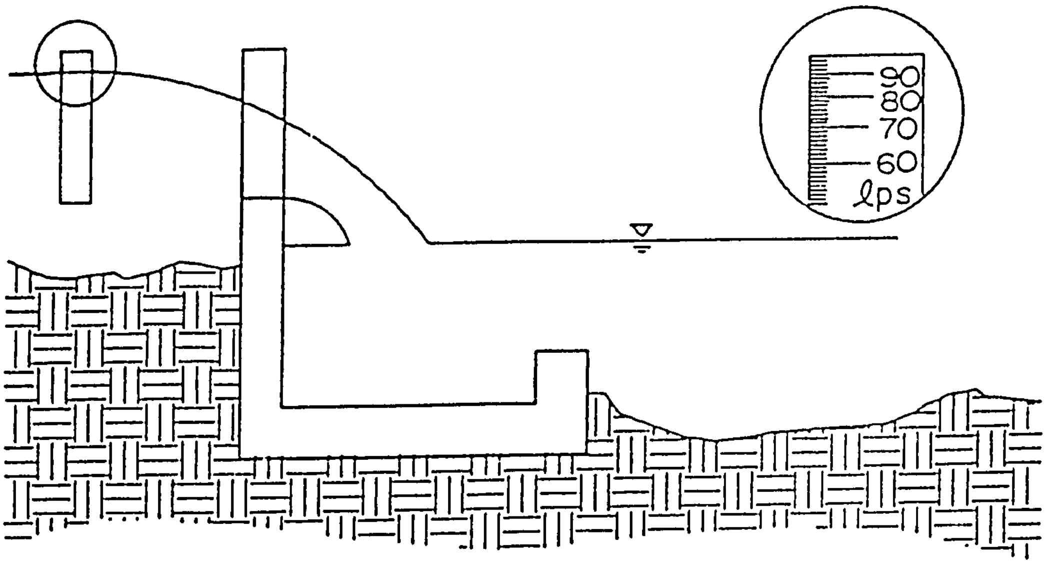
If a staff gauge is either too expensive to install or is unavailable, the benchmark technique may be used. A mark is drawn on the wall, or top of the wall, of an irrigation structure and the reading is made by using a tape measure to find the distance from the mark to the water surface below. This mark, known as a benchmark, establishes a reference point from which future readings can be taken. It must be referenced to the appropriate zero flow depth level for the irrigation structure being calibrated. Once the benchmark has been established, it should be etched into, or painted onto, the irrigation structure for preservation. Field notes should include an accurate sketch of the location of each benchmark. If field notes have been carefully prepared, anybody reading them in the future (say 10 years later) should be able to easily understand the procedure which was followed and to locate the benchmark.




(a) STAFF GAUGE ON UPSTREAM AND DOWNSTREAM WALLS
OF AN OPEN CHANNEL CONSTRICTION



(b) STAFF GAUGE IN AN IRRIGATION CHANNEL




(c) STAFF GAUGE READING DISCHARGE IN LITERS PER SECOND (LPS)

Figure 2.3-3 Various Uses of Staff Gauges

When the water surface is especially turbulent, the use of a piezometer is helpful (Figure 2.3-4). With this technique, a piezometer pipe is placed through the wall of an irrigation structure and connects a stilling well to the irrigation channel. Piezometer openings are commonly 5 to 10 millimeters in diameter. If piezometer pipe openings are used which are too small, there may be problems with clogging of the openings or slowresponse time within the stilling wells.

## D. Backwater Effects

A simple open channel constriction is shown in Figure 2.3-5. The flow through such constrictions is most often in the tranquil range, and produces gradually varied flow far upstream and a short distance downstream, although rapidly varied flow occurs at the constriction. The effect of the constriction on the water surface profile, both upstream and downstream, is conveniently measured with respect to the normal water surface profile, which is the water surface in the absence of the constriction under uniform flow conditions, and is calculated using Manning's formula. Upstream from the constriction, a backwater profile occurs. The maximum backwater effect, denoted by $y^*$ in Figure 2.3-5, occurs a relatively short distance upstream. For flat gradient irrigation channels, the backwater effect may extend for a considerable distance in the upstream direction, sometimes a few hundred meters in watercourses to more than 10 kilometers in large canals. Immediately downstream from the constriction, the flow expansion process begins and continues until the normal regime of flow has been reestablished in the channel, which occurs in a relatively short distance of 5-50 meters.

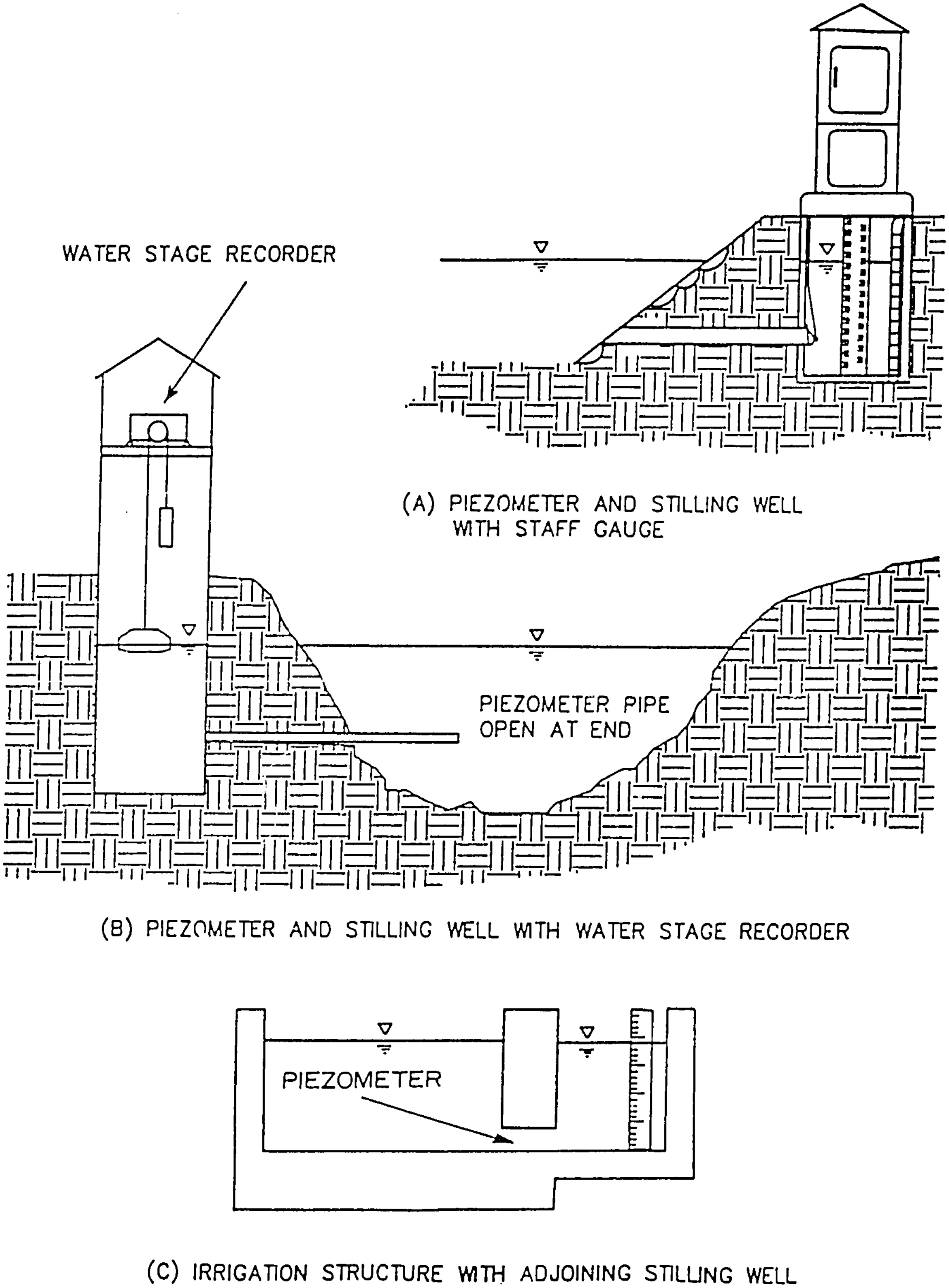
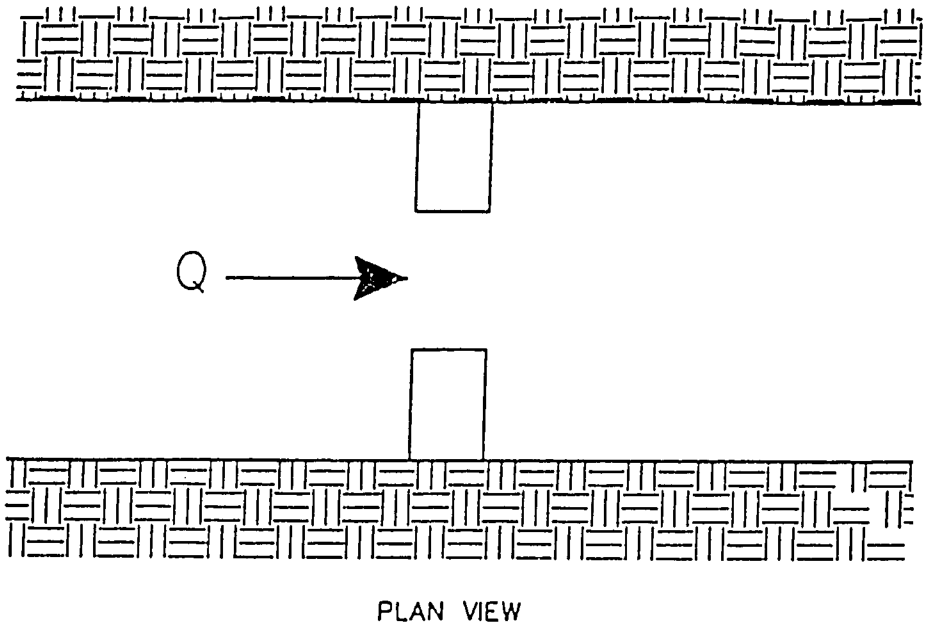



Figure 2.3-4 Typical Piezometer Installations



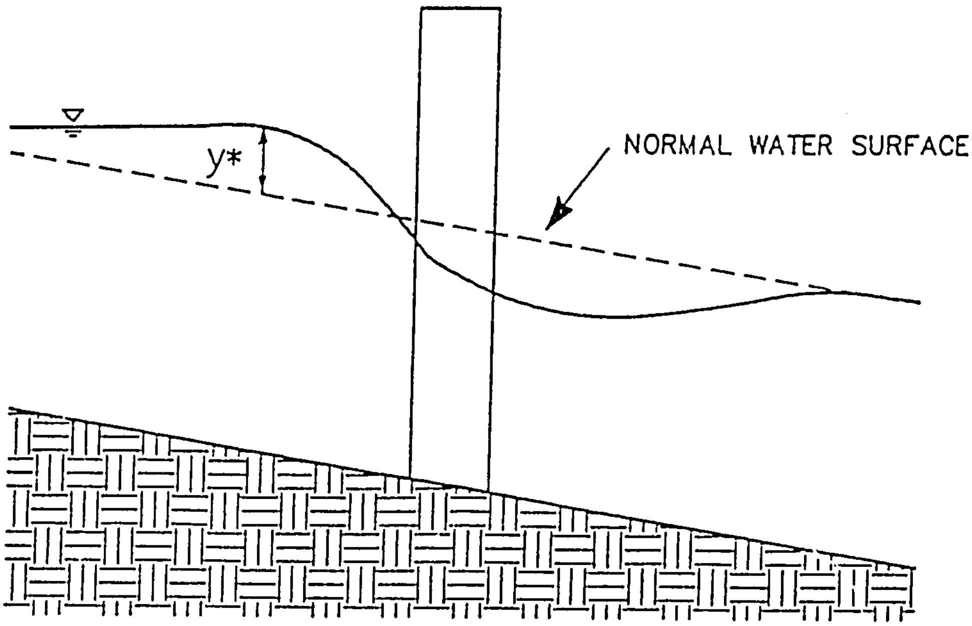




Figure 2.3-5 Definition Sketch for Backwater Effects from an Open Channel Constriction

## E. Orifice Structures

Any type of opening in which the upstream water level is higher than the top of the opening is referred to as an orifice. In this case, if the jet of water emanating from the orifice discharges freely into the air or downstream channel without backwater or tailwater effects, then the orifice is operating under modular (free) flow conditions. If the upstream water level is below the top of the opening, then the opening is hydraulically performing as a weir structure. For modular flow conditions in an orifice, the discharge equation is:

$$Qf = Cd\ Cv\ A\ (2g\ hu)^{0.5} \qquad (2.3\text{-}1)$$

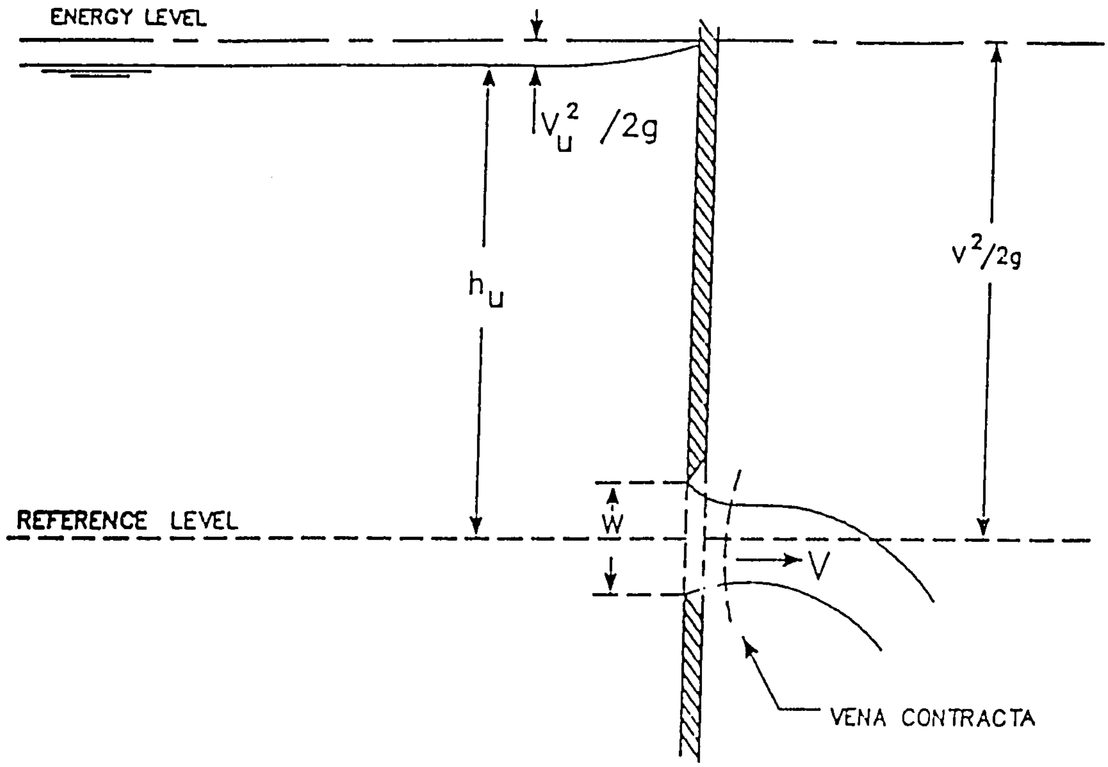
where Cd is a dimensionless coefficient of discharge, Cv is a dimensionless velocity head coefficient, A is the cross-sectional area of the orifice, g is the acceleration due to gravity, and hu is measured from the centroid of the orifice to the upstream water level as shown in Figure 2.3-6a.

If the downstream water level is also above the top of the orifice (Figure 2.3-6b), then non-modular (submerged) conditions exist and the discharge equation becomes:

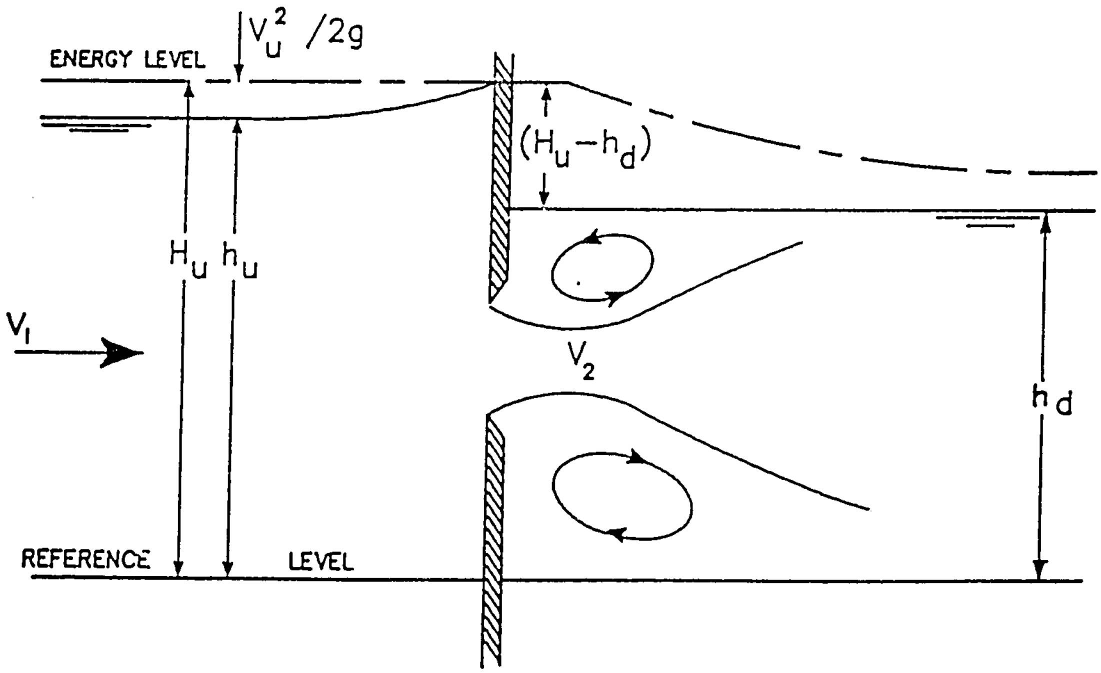
$$Qs = Cd\ Cv\ A\ [2g\ (hu - hd)]^{0.5} \qquad (2.3\text{-}2)$$

where, hu - hd is the difference in water surface elevations upstream and downstream from the submerged orifice.

The velocity head coefficient, Cv, approaches unity as the approach velocity to the orifice decreases to zero. In irrigation systems, Cv can usually be assumed as unity since most irrigation channels have very flat gradients and the flow velocities are low (usually less than 1 m/s).




(a) FREE FLOW




(b) SUBMERGED FLOW

Figure 2.3-6 Definition Sketch of Orifice Flow

An orifice can be used as a highly accurate flow measuring device in an irrigation system. If the structure has not been previously rated in the laboratory, then it can easily be rated in the field. The hydraulic head term, hu or hu - hd, can be relied upon to have the exponent 1/2, which means that a single field rating measurement, if accurately made, will provide an accurate determination of the coefficient of discharge, Cd. Generally, orifices have Cd values of about 0.6 to 0.8 depending on the geometry of the orifice structure, but values from 0.3 to 0.9 have been measured for various gate structures.

A definition sketch for a rectangular gate structure having submerged orifice flow is shown in Figure 2.3-7. For a rectangular gate having a gate opening, b, and a gate width, W, the non-modular flow discharge equation can be obtained from Equation 2.3-2, assuming that the dimensionless velocity head coefficient is unity:

$$Qs = Cd\ (b\ W)\ (2g)^{0.5}\ (hu - hd)^{0.5} \qquad (2.3\text{-}3)$$

where b W is the area, A, of the orifice.

The upstream flow depth, hu, can be measured anywhere upstream from the gate, including the upstream face of the gate. The value of hu will vary a small amount depending on the location chosen for measuring hu. Consequently, the value of the coefficient of discharge, Cd, will also vary according to the location for measuring hu. This would also be true regarding the location for measuring hd. The principal criterion for selecting the locations for measuring hu and hd is that the water surface is smooth, not turbulent and surging, or bouncing up and down. The second criterion would be to use the same locations for hu and hd for similar types of structures so that the Cd values can be compared.

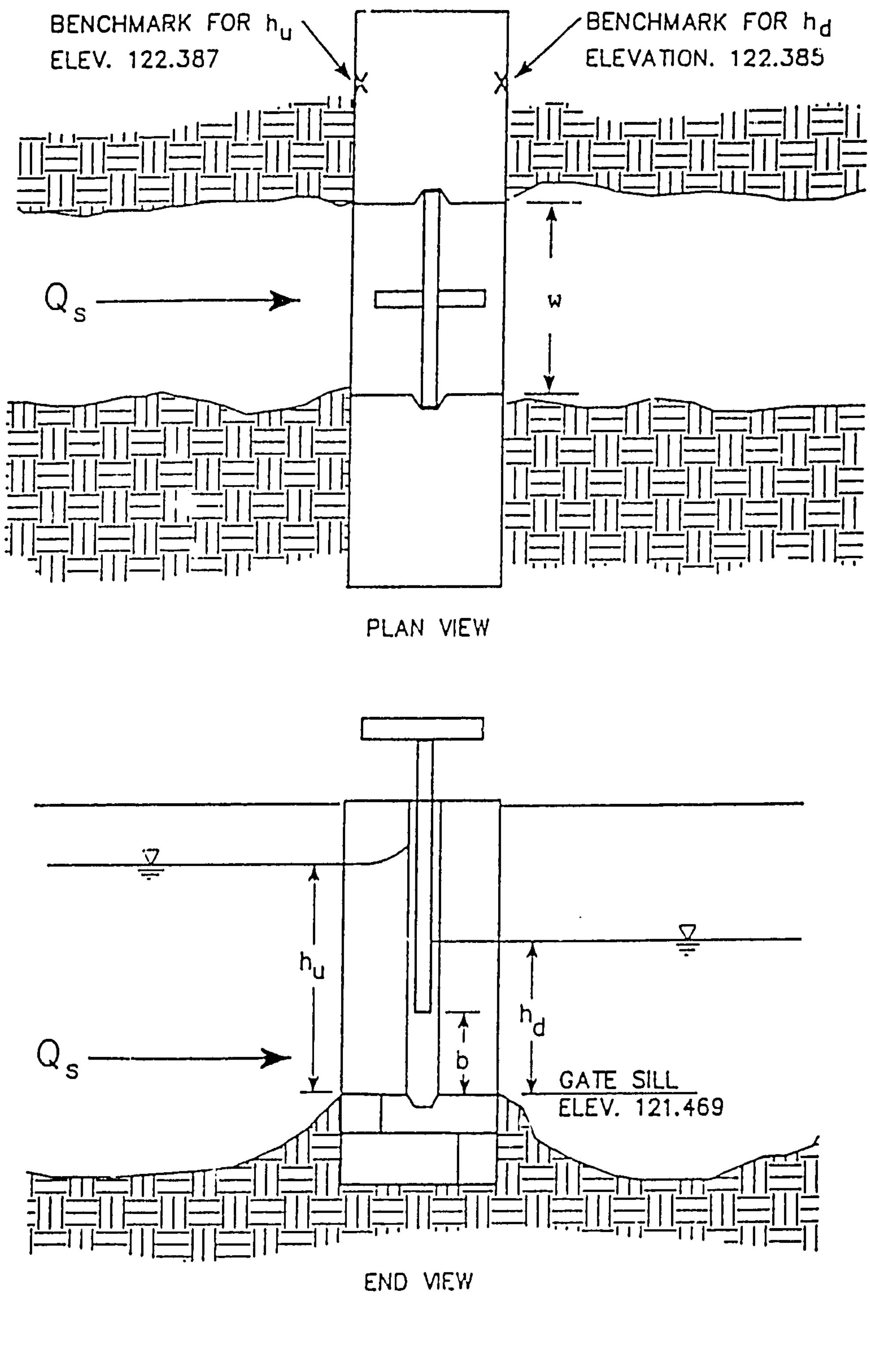



Figure 2.3-7 Definition Sketch and Example of a Rectangular Gate Structure Having Submerged Orifice Flow

The greatest difficulty in calibrating a gate structure is obtaining a highly accurate measurement of the gate opening, b. For gates having a threaded rod that rises as the gate opening is increased, the gate opening is read from the top of the handwheel at the top of the rod with the gate closed and when set to some opening, b. This very likely represents a measurement of gate opening from where the gate is totally seated, rather than a measurement from the gate sill; therefore, the measured value of b from the threadrod will usually be greater than the true gate opening, unless special precautions are taken to calibrate the threadrod.

Likewise, when the gate lip is set at the same elevation as the gate sill, there will undoubtedly be some flow or leakage through the gate. This implies that the datum for measuring the gate opening is below the gate sill. In fact, there is often leakage from a gate even when it is totally seated (closed) because of inadequate maintenance. Thus, Cd will vary with the gate opening, b. One methodology for analyzing this problem is presented in the manual on "Field Calibration of Irrigation Structures for Discharge Measurement".

Orifices are the most common type of flow control structure encountered in irrigation systems. First of all, the Head Regulator for each main canal is a gate structure having a variable orifice size depending on the height of the gate opening. Sometimes, there are Check Gate Structures in the canal also. The Head Regulators for branch canals and distributaries are also gate orifice structures (Figure 2.3-8). Then, the outlets from the main system to the tertiary system are usually uncontrolled orifices (have no gates). In most cases, these structures operate as modular orifices, or sometimes non-modular orifices, so they are ideal flow measurement structures (Figure 2.3-9). Also pipe outlets (Figure 2.3-10) are used, and their calibration is discussed below since the hydraulic behaviour of pipe outlets is the same as culverts, which is very complex.

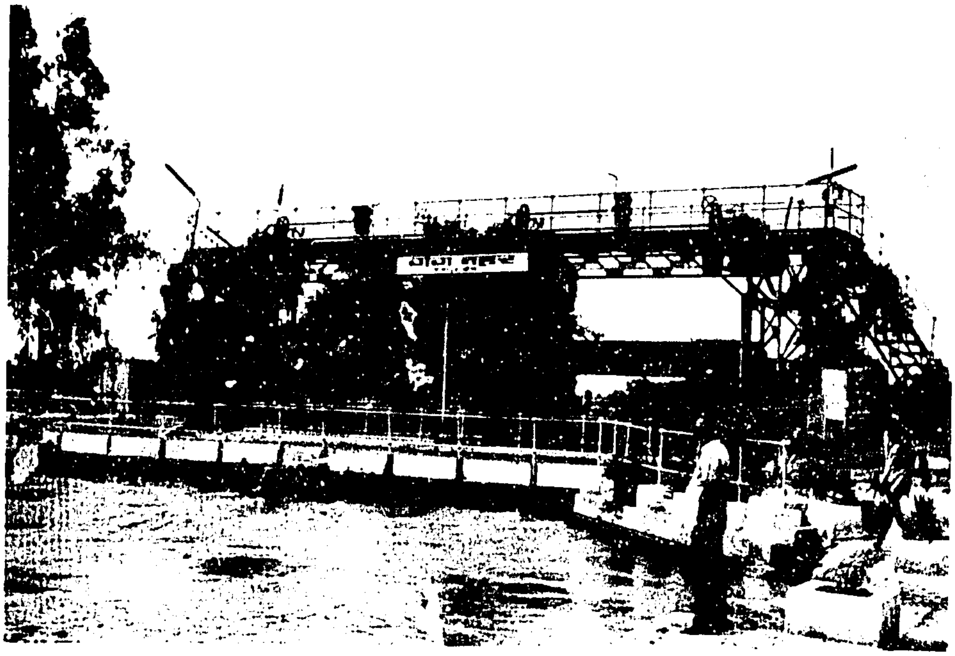
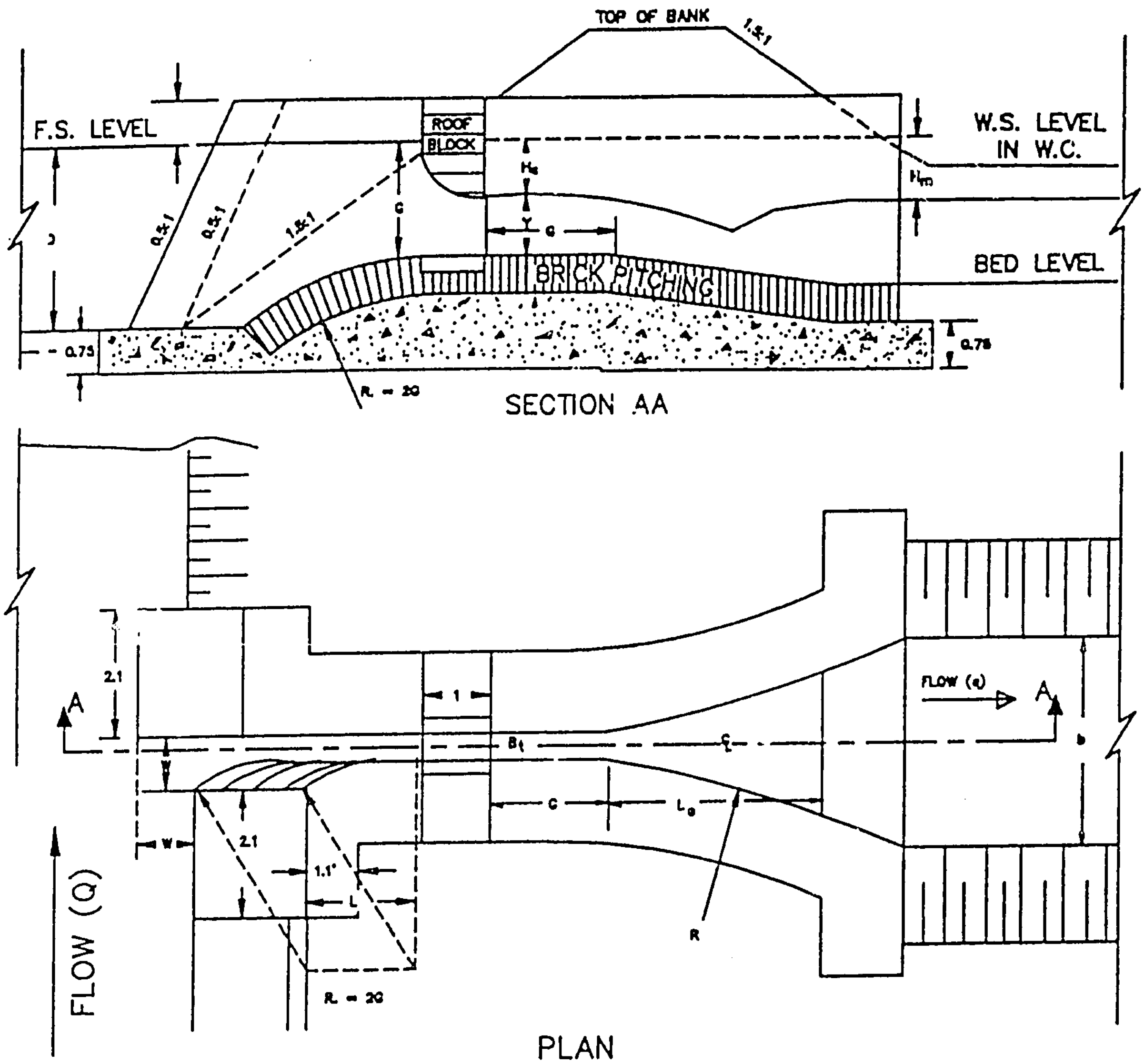


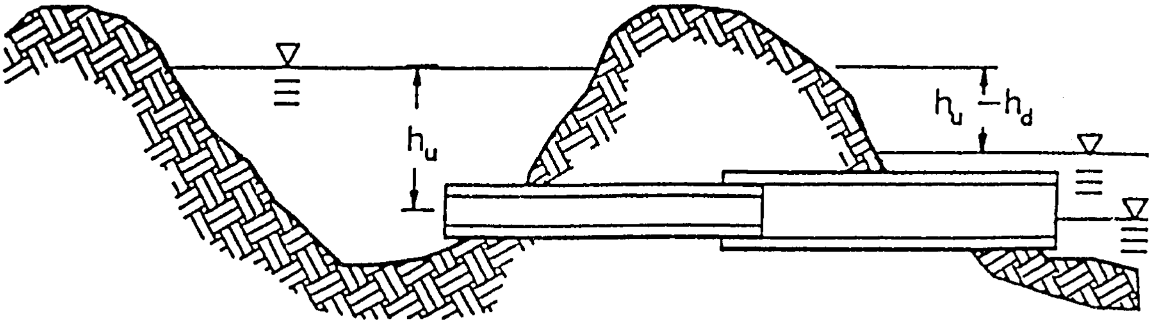
Figure 2.3-8 Example of Head Regulator for Distributaries



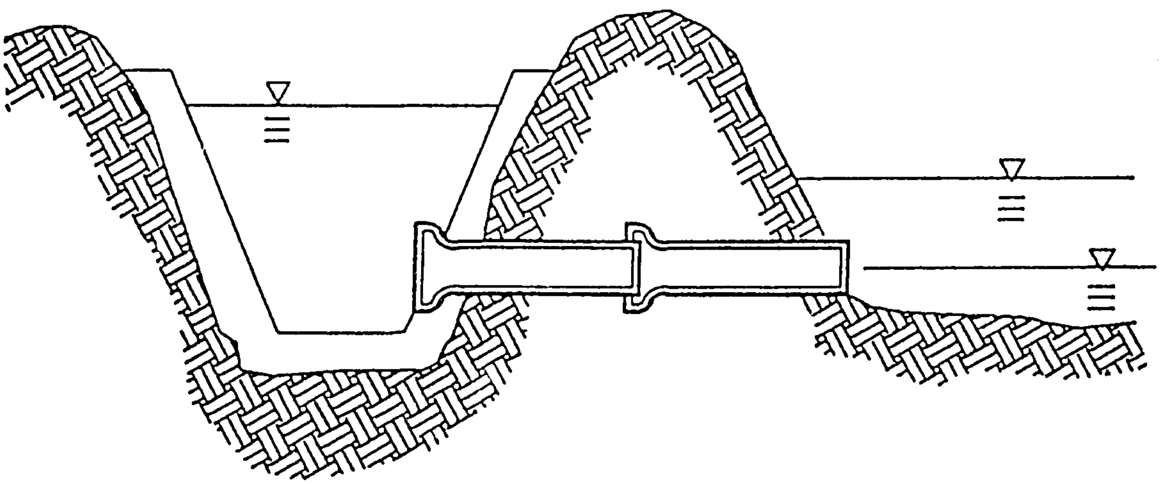

NOTES:

| | | | |
|---|---|---|---|
| B | = | BED WIDTH | UPSTREAM OF OUTLET |
| D | = | FSL DEPTH | |
| Q | = | FLOW IN CANAL | |
| C | = | F.S. DEPTH OF CREST | |
| q | = | DISCHARGE OF OUTLET | |
| $B_t$ | = | THROAT WIDTH | |
| b | = | BOTTOM WIDTH, WATERCOURSE | |
| W | = | $b/Q(B+D/2)$ | |
| L | = | $\sqrt{(W-B_t)(4C-W-B_t)}$ LENGTH OF APPROACH CURVE | |
| L | = | LENGTH OF OUTFALL | |
| R | = | $\frac{q-B_t}{4}+\frac{Lo^2}{q-B_t}$ RADIUS OF OUTFALL CURVE | |

Figure 2.3-9 Typical Orifice Structure as Outlet from the Main System Serving a Tertiary System




(A) OPEN PIPE OUTLET FROM AN EARTHEN CANAL



(B) OPEN PIPE OUTLET FROM A CONCRETE–LINED CANAL

Figure 2.3-10 Pipe Outlet Structures

## F. Culverts and Inverted Siphons

Culverts can serve as a combination open channel and closed conduit flow measurement structure depending upon the type of flow condition in the culvert. Most of the research involving the hydraulics of culverts has been concerned with the use of such structures under highways. Most frequently, a highway culvert is designed to operate with full flow (closed conduit) at the design discharge. Much of this research has been concerned with inlet control (free orifice flow) and submerged outlet control (submerged orifice flow).

For culverts placed in an irrigation conveyance channel, free surface (open channel) flow often occurs in the culvert. In addition, downstream conditions will likely control the depth of flow in the culvert. For this particular condition of free surface subcritical culvert flow, the analysis for non-modular (submerged) open channel constrictions would apply.

### 1. Hydraulics of Culverts

The classification of the hydraulic performance of culverts can take several forms. Three primary groupings will be used to describe the hydraulics of culverts. The primary groups are based on the three parts of the culvert that exert primary control on the culvert performance and its capacity: the inlet, the barrel, and the outlet.

#### Inlet Control

Inlet control means that the discharge capacity of the culvert is controlled at the culvert entrance by the depth of headwater, hu, and the entrance geometry, including the barrel shape and cross-sectional area and the type of inlet edge. With inlet control, the roughness and length of the culvert barrel, as well as outlet conditions (including depth of tailwater), are not factors in determining culvert capacity. An increase in barrel slope reduces headwater to a small degree.

Barrel Control

Under barrel control, the discharge in the culvert is controlled by the combined effect of entrance, length, slope and roughness of the pipe barrel. The characteristics of the flow do not always identify the type of flow. The usual condition for this type of flow at design discharges is one in which the pipe cross-section flows full for a major portion of the length of the culvert. The discharge in this case is controlled by the combined effect of all hydraulic factors.

Outlet Control

Culverts flowing with outlet control can flow with the culvert barrel full, or part full, for part of the barrel length, or for all of it (Figure 2.3-11). If the entire cross-section of the barrel is filled with water for the total length of the barrel, the culvert is said to be in full flow or flowing full, as shown in Figure 2.3-11. The flow condition in Figure 2.3-11 is called submerged outlet control flow.

2. Method of Flow Analysis

For culverts in irrigation systems placed on a mild slope and having a short length, three flow conditions should describe the types of flow to be encountered. Beginning with free surface inlet control, the downstream flow depth can be increased until the headwater is increased just slightly. Free surface flow will still exist, but flow conditions are now affected by changes in tailwater. This flow condition can be described as free surface outlet (non-modular) control. Finally, the tailwater can be raised sufficiently to submerge the outlet. For a short culvert installed on a mild slope, a submerged outlet should result in a submerged inlet, with the flow condition being submerged outlet control.

The method of flow analysis is different for each of the three flow conditions mentioned above. The technique for developing the discharge equation describing each of the flow conditions is presented in the manual

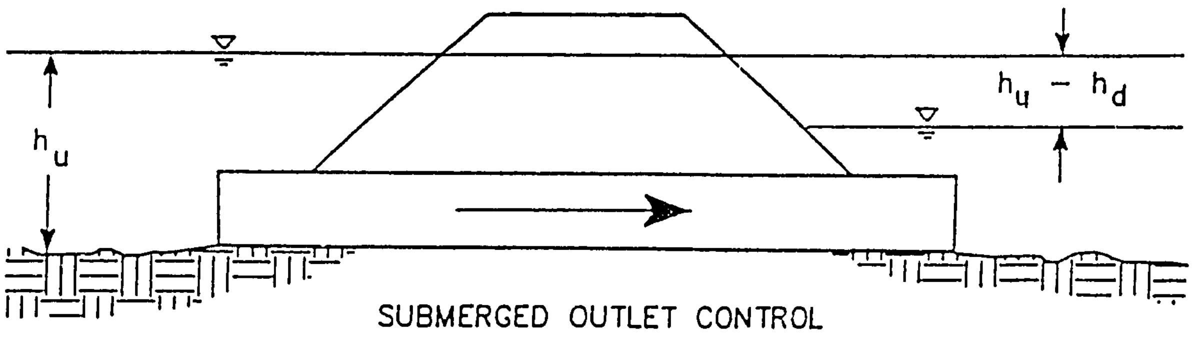



Figure 2.3-11 Outlet Control - Flow Conditions for a Culvert

on "Field Calibration of Irrigation Structures for Discharge Measurement". However, only the simplest case of submerged outlet control is presented below.

When the flow conditions are such that the downstream flow depth, hd, is raised to the extent that the culvert is completely full throughout the culvert length, resulting in a change in the upstream depth, hu, then the culvert is operating under submerged outlet control, as shown in Figure 2.3-11. The culvert operating under submerged outlet control flow conditions also requires that two flow depths be measured, one upstream (hu) at the culvert invert, and one downstream near the end of the culvert (hd). The reference elevation must be the same for hu and hd, and preferably, true elevations should be used. For this hydraulic condition, the absolute values of the flow depths are not important, but rather the difference in water surface elevation, hu - hd.

For the submerged outlet control flow condition, the submerged orifice equation is valid.

$$Qs = Cso\ A\ (2g\ H)^{0.5} \qquad (2.3\text{-}4)$$

where: Qs = submerged flow rate;

H = difference between upstream and downstream flow depths, hu-hd;

Cso = submerged outlet control flow coefficient; and,

A = cross sectional area of the culvert barrel.

The coefficient Cso contains the effects of inlet, barrel, and outlet geometry. However, the discharge rating will be affected by the accumulation of sediment or debris in the barrel of the culvert, or in the vicinity of the inlet or outlet.

A culvert with submerged outlet control represents the most ideal case for undertaking a field discharge rating. A single field discharge measurement, accurately done, is sufficient to calibrate the discharge equation so that the culvert can then be used as a flow measuring device by only measuring hu - hd.

This is also the case for inverted siphons wherein both the inlet and outlet are submerged. However, there is a greater concern about accumulating sediment, gravel and debris at the bottom of an inverted siphon. Such accumulation would reduce the discharge capacity of the inverted siphon which would result in a lower value of the submerged outlet flow coefficient, Cso. Thus, periodic discharge measurements at an inverted siphon, using a current meter, would indicate if Cso has been reduced; if so, then maintenance is required to remove the accumulated materials within the inverted siphon.

## G. Overflow Structures

### 1. Examples

The most common overflow structures used for discharge measurement are weirs. Whereas flumes are open channel structures with the flow constricted from the sides (walls), weirs are open channel structures with the flow constricted from the floor so that the flow must pass over the top of the floor constriction.

In order to prevent the overflow of a canal section and its subsequent failure, canal overflow escape structure are often used. If the water level in the canal becomes too high because upstream turnout structures have been closed, or because of excessive rainfall, then the excess flow will pass over the escape structure. A typical canal escape structure is shown in Figure 2.3-12. The length of overflow structure is the weir crest length (or width), Ww.

Another common type of overflow structure is a drop structure, such as curvilinear crest drop structures (Figures 2.3-13a and 2.3-13b), inclined drop structure (Figure 2.3-13c), or a vertical drop structure (Figure 2.3-13d). In these examples, the flow is passing through critical depth in the vicinity of the crest, so modular flow is occurring.

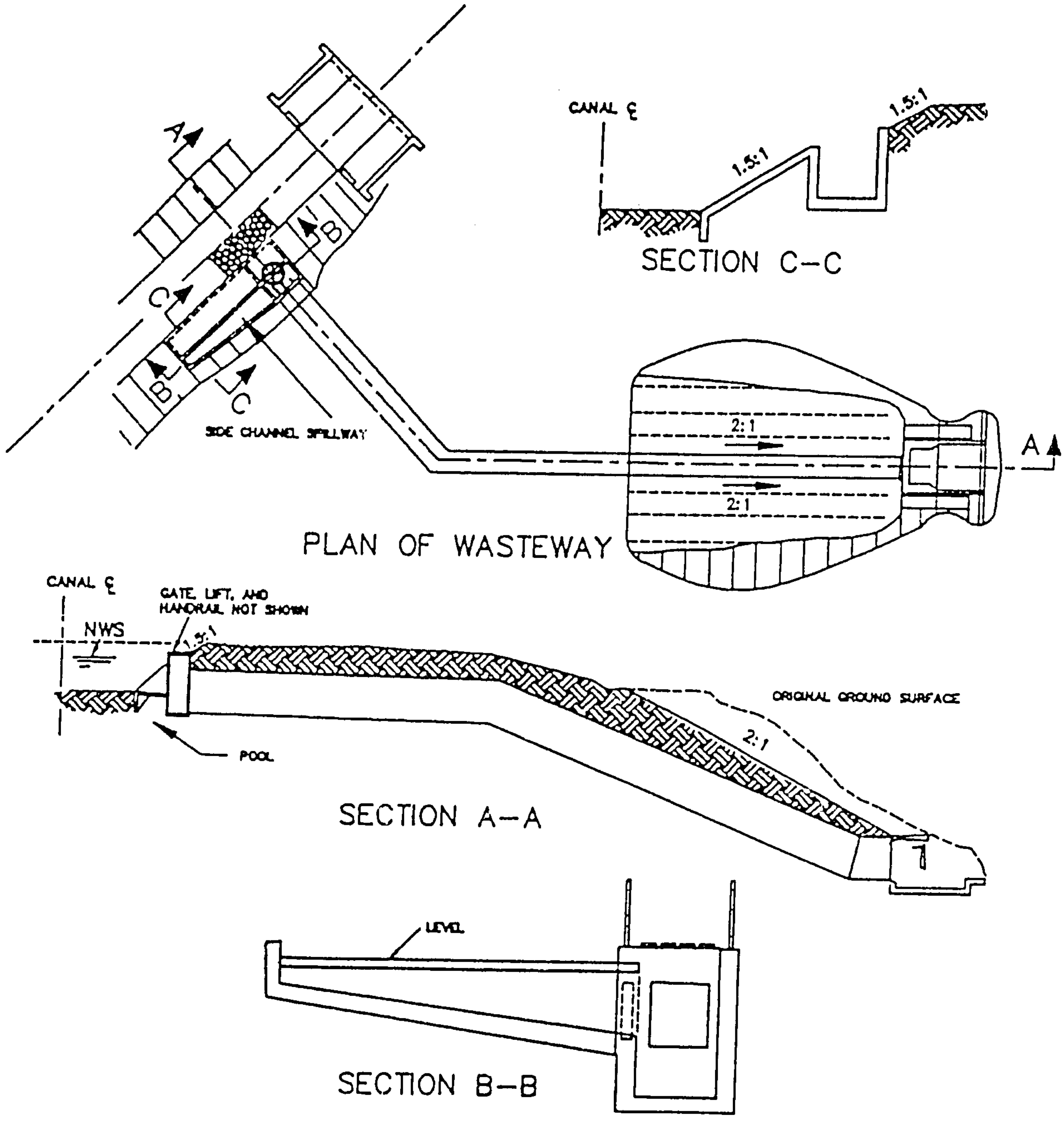



Figure 2.3-12   A Typical Canal Escape Structure (Wasteway)

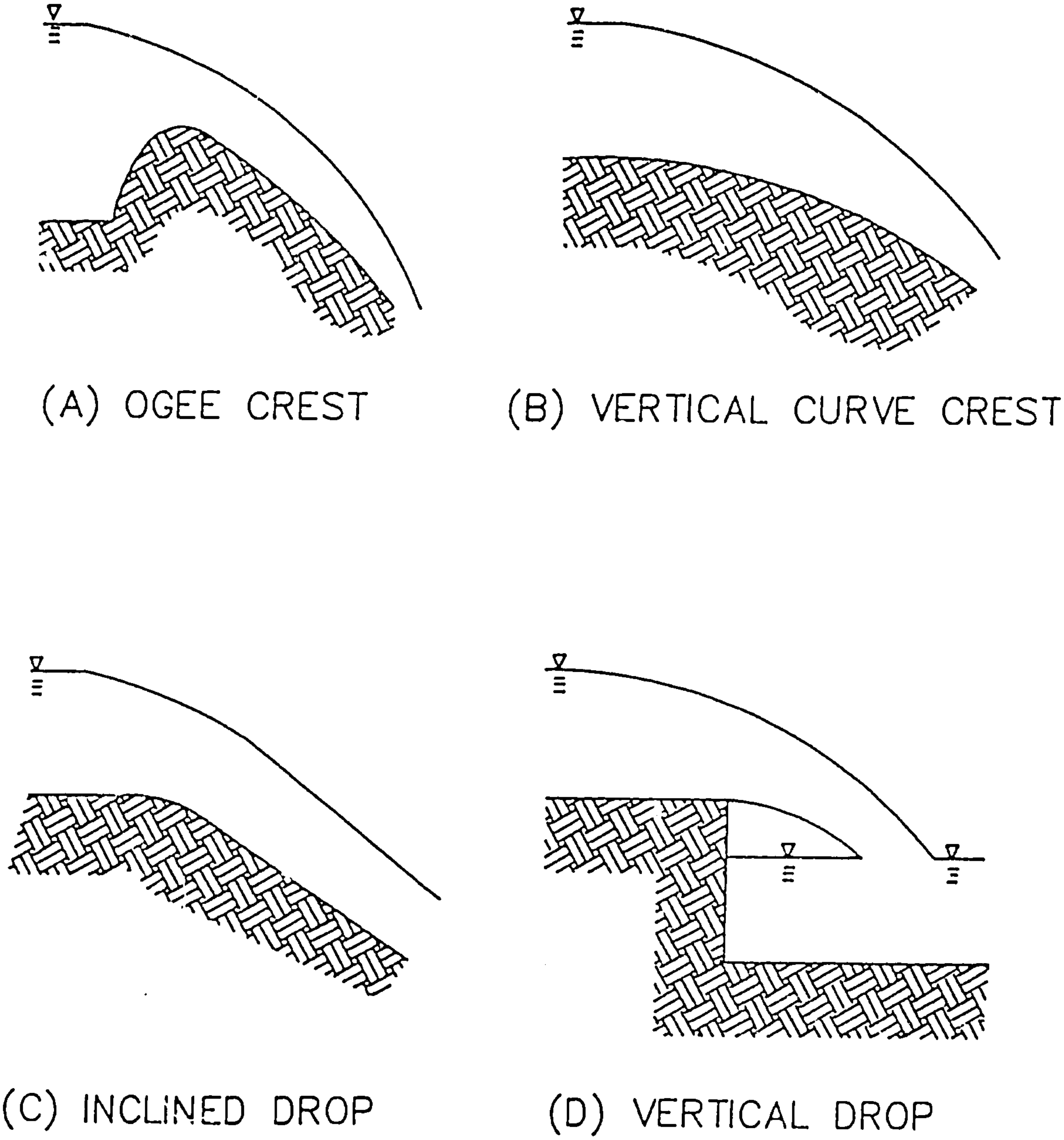



Figure 2.3-13 Examples of Drop Structures

Check structures are commonly used in irrigation systems. These structures are used to control the water level in the irrigation channel upstream from the check structures. This is often necessary in order to raise the upstream water levels so that there will be sufficient head (hu) to allow an adequate discharge to flow through the upstream structure(s). In some cases, a check structure has no flow passing downstream. More frequently, there will be flow passing over, or through, a check structure to satisfy downstream water delivery requirements.

In many irrigation projects, check structures are installed with a slide gate to control the upstream water level. There is a wide variety of flow conditions that can prevail at such a structure. Most commonly, the gate will perform as an orifice with either free orifice flow (Equation 2.3-1) or submerged orifice flow (Equation 2.3-2). In some cases, the structure is not used to control upstream water levels during certain periods of time, so the gate is raised in order not to constrict the flow. If the downstream bed elevation is about the same as the upstream bed elevation, then the check structure becomes an open channel constriction with either modular flow or more likely, non-modular flow. If immediately downstream from the gate there is a vertical curve crest (Figure 2.3-13b), inclined drop (Figure 2.3-13c), or vertical drop (Figure 2.3-13d), then the check structure performs hydraulically as an overflow (weir) structure.

## 2. Measuring Discharge

For large irrigation channels, usually a current meter is used to measure the discharge when rating an overflow structure. For smaller irrigation channels, a flow measuring flume would likely be used; however, in this case, it may be possible to use a standard calibrated weir, such as a rectangular thin-plate weir or a V-notch weir to measure the discharge at a location downstream from the overflow structure. Also, for some overflow structures, such as those shown in Figures 2.3-12 and 2.3-13d, volumetric methods (Figure 2.3-2) can be used to measure the discharge over a small portion of the crest; a series of such measurements can be made in order to determine the variation in discharge across the entire crest width, Ww, which will provide an accurate measurement of the total discharge flowing over the crest.

3. Modular Flow

The general form of the modular flow equation for an overflow (weir) structure is:

$$Qf = (Cd)f\ Ww\ hu^{nf} \qquad (2.3\text{-}5)$$

where Qf is the free (modular) flow discharge rate in cubic meters per second, (Cd)f is the free (modular) flow coefficient of discharge, Ww is the crest width of the overflow section, and nf is the free (modular) flow exponent. The upstream flow depth, hu, must be measured at some location upstream from the overflow crest (the exact location will affect the value of (Cd)f and must have the zero reference elevation correspond with the overflow crest elevation).

The variation in (Cd)f will increase only slightly for increasing crest widths if the geometry of the structures is similar. Excellent examples are vertical or inclined drop structures that are used in an irrigation project; usually, the geometry will be very similar and only the width of the structure will be changed according to the design discharge. Certainly, the expected values of (Cd)f for different values of Ww will be known after field calibration of similar structures at two or three irrigation projects; but, there will always be some variation from the expected value for each individual structure because of slight differences in construction or approach conditions.

The procedure for developing the free flow discharge rating for an overflow structure is preferably to collect three to five measurements of Qf and hu to verify whether or not nf = 3/2 or a number slightly higher. However, it is a relatively safe assumption that nf will be equal, or very nearly equal, to 3/2, particularly for overflow structures commonly found in the main system of an irrigation project. If nf is assumed equal to 3/2, then a single field measurement of Qf and hu will provide a good estimate of the value of (Cd)f.

## H. Canal Outlets

### 1. General Situation

There are numerous small structures used to convey water from a canal into a tertiary (watercourse) channel. Generally, these small canal outlets will convey 10-250 lps (0.3 - 8 cfs or cusecs). For this flow range, portable flow measuring flumes are usually the most convenient device for measuring discharge when developing a rating. Either a flat-bottomed trapezoidal flume, or a Parshall flume, or a cutthroat flume can be temporarily installed downstream from the small canal outlet structure. Another possibility is to install a temporary trapezoidal broad-crested weir. Although all of these devices have the disadvantage of increasing the water surface elevation upstream from the flow measuring device, this does not affect the accuracy of the discharge rating for the canal outlet structure, except they do not take into account the channel losses between the canal outlet structure and the flow measuring device.

Another common method of measuring the discharge rate in the tertiary irrigation channel is to use a pygmy current meter mounted on a wading rod. This method is not as accurate as using standard flow measuring flumes, but is sufficient if the equipment has been properly maintained.

### 2. Types of Small Canal Outlets

There are two basic design philosophies used for canal outlets. First of all, many irrigation systems around the world have manually operated gates that are used to control the discharge rate through the canal outlet. Secondly, many irrigation systems have been purposefully designed without gates on the canal outlets, such as in India; the discharge rate through the canal outlet is a function of the water surface elevation (hu) in the canal if modular flow exists, or a function of the difference in water surface elevation between the canal and tertiary channel (hu- hd). For the latter systems, each outlet is to receive a proportion of the available flow in the canal, as well as a proportion of the sediment load, during times of both water scarcity and water surplus.

The types of small canal outlets that will be discussed below are:

i. Flume outlets;
ii. Fixed orifice outlets;
iii. Open pipe outlets; and
iv. Gated orifice outlets.

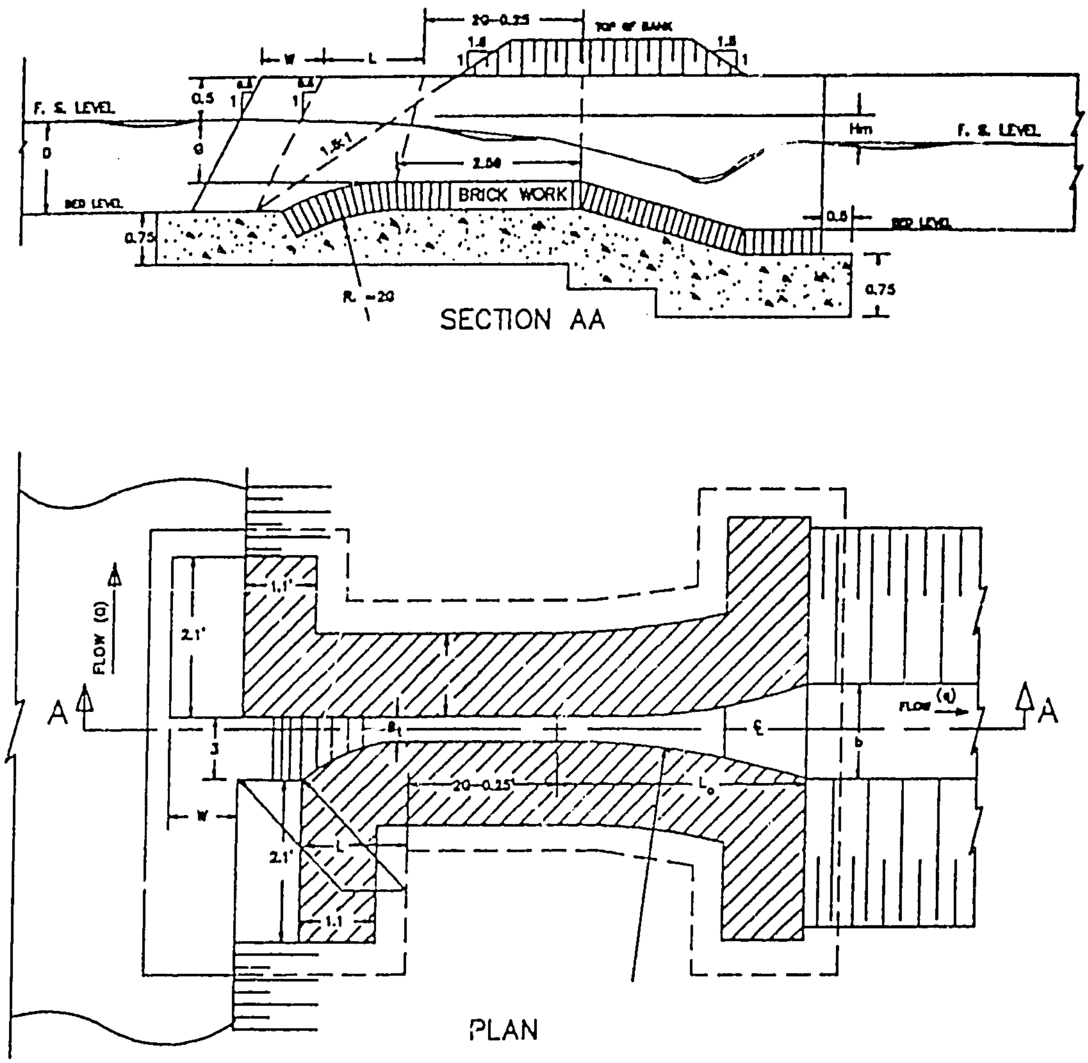
The discharge rate through flume, fixed orifice, and open pipe outlets is a function of the water level in the canal for modular flow conditions, or the difference in water surface elevations upstream and downstream from the outlet for non-modular flow conditions. Thus, the design discharge will only be satisfied when the design water surface elevations occur. Only the gated orifice outlet provides a mechanism for accurately controlling the discharge rate.

Flume Outlets

A flume outlet is an open channel constriction that can operate with either modular (free) flow or non-modular (submerged) flow conditions. A commonly used flume outlet is illustrated in Figure 2.3-14, and is frequently seen in the Indian subcontinent. For any open channel constriction, the modular flow rating is given below:

$$Qf = Cfhu^{nf} \qquad (2.3\text{-}6)$$

where Qf is the modular flow discharge rate, hu is a flow depth measured upstream from the throat and using the flume floor or sill as the zero reference datum, Cf is the modular flow coefficient and nf is the modular flow exponent.




NOTES:

B = BED WIDTH } UPSTREAM OF OUTLET
D = FSL DEPTH } UPSTREAM OF OUTLET
Q = FLOW IN CANAL } UPSTREAM OF OUTLET
C = F.S. DEPTH OF CREST
q = DISCHARGE OF OUTLET
$B_t$ = THROAT WIDTH

b = BOTTOM WIDTH, WATERCOURSE
W = b, (B+D/2)
L = $\sqrt{(W-B_t)(4C-W-B_t)}$ LENGTH OF APPROACH CURVE
L = LENGTH OF OUTFALL
R = $\frac{q-B_t}{4} + \frac{Lo^2}{q-B_t}$ RADIUS OF OUTFALL CURVE

Figure 2.3-14 Typical Flume Outlet Frequently Used in the Indian Subcontinent

The free flow, or modular flow, discharge equation for the flume outlet illustrated in Figure 2.3-14 is written in the literature as:

$$q = K\ Bt\ G^{3/2} \qquad (2.3\text{-}7)$$

where q = Qf, Bt is the throat width W, and G = hu. Therefore, Equation 2.3-7 can be rewritten as:

$$Qf = K\ W\ hu^{3/2} \qquad (2.3\text{-}8)$$

The non-modular flow rating for a flume outlet would be represented by

$$Qs = \frac{Cs\ (hu - hd)^{nf}}{(-\log S)^{ns}} \qquad (2.3\text{-}9)$$

where Qs is the submerged (non-modular) flow discharge rate, hd is a flow depth measured downstream from the flume throat but using the throat floor or sill as the zero reference datum, S is the submergence hd/hu, Cs is the submerged (non-modular) flow coefficient, and ns is the submerged (non-modular) flow exponent.

An important consideration in using flume outlets is that the discharge rate is a function of either hu or hu - hd to the exponent 3/2 theoretically, and possibly the exponent will be slightly greater than 3/2. Thus, the discharge rate increases rapidly with increasing flow depths in the canal. Consequently, this type of outlet is best used in the vicinity of the lower end of the canal, so that if the canal discharge increases (e.g., as a result of rainfall) then the discharge through the flume outlets will rapidly increase.

## Fixed Orifice Outlets

The primary advantage of a fixed orifice compared with a flume outlet is that the discharge rate is a function of the canal water level to the exponent 1/2 (rather than 3/2). Thus, the discharge rate increases with increasing water levels in the canal, but not nearly as rapidly compared with flume outlets. Consequently, fixed orifice outlets are used in the upper and middle reaches of a canal, whereas flume outlets would be used in

For a fixed orifice outlet, the free flow discharge rating would be given by Equation 2.3-1, which can be rewritten as:

$$Qf = Kf\ A\ hu^{0.5} \qquad (2.3\text{-}10)$$

The submerged flow discharge rating for a fixed orifice outlet is given by Equation 2.3-2, which can be rewritten as:

$$Qs = Ks\ A\ (hu - hd)^{0.5} \qquad (2.3\text{-}11)$$

A typical fixed orifice outlet commonly used in the Indian subcontinent, particularly in the Punjab, is shown in Figure 2.3-9. This was originally introduced by E.S. Crump in 1922 as the Adjustable Proportional Module (APM). Later, when the sill level was lowered from 0.6 depth for the APM to 0.9 depth, in order to convey more sediment load through the outlet, the name of the outlet structure was changed to Adjustable Orifice Semi-Module (AOSM). Then, the discharge equation was also modified to:

$$Qs = K\ BtY\ Hs^{0.5} \qquad (2.3\text{-}12)$$

where Qs is the submerged (non-modular) flow discharge rate, K is a coefficient having a value of 7.3, Bt is the width of the orifice (standard widths of 0.20, 0.25, 0.32, 0.40, 0.50 and 0.63 foot have been adopted), Y is the height of the orifice, and Hs is the difference in elevation between the canal water level and the crown of the orifice (Figure 2.3-14).

A value of K = 7.3 in Equation 2.3-11 corresponds with CdCv = 0.909 in Equation 2.3-2.

<u>Open Pipe Outlets</u>

An open pipe outlet is the simplest of all outlet structures in terms of fabrication and installation, but the most complex hydraulically. Some typical examples are shown in Figure 2.3-10. The discharge rate will, in most cases, be a function of the water depth in the canal, hu, to the exponent 1/2, or the square root of the difference in water surface elevation between the canal and tertiary channel (Figure 2.3-10a).

Most of the complexities described in an earlier sub-section on "Culverts" pertains to open pipe outlets. First of all, there is the question of free orifice flow (inlet control) or submerged orifice flow. Secondly, the geometry of the inlet has a pronounced effect on the inlet flow. Thirdly, there is the question of pipe slope; the design may have called for zero slope, but the installation during construction may result in a slope which will have a highly significant effect. Fourthly, the length of the pipe outlet will also affect the discharge rate being conveyed to the tertiary channel. Thus, there are many parameters to be evaluated in designing an open pipe outlet.

When developing the field discharge rating for an open pipe outlet, the first question is whether free orifice flow (Equation 2.3-1) or submerged orifice flow (Equation 2.3-2) is occurring. Then, a single discharge measurement combined with the measured value of hu, or hu and hd, whichever is appropriate, will allow the coefficient of discharge, Cd, to be calculated, depending on the flow condition. This calculated value of Cd based upon field measurements will be affected by all of the parameters described in the paragraph above.

Gated Orifice Outlets

The canal outlets described above have the discharge rate controlled by the water level in the canal, or the difference in water level between the canal and tertiary channel. The advantage of placing a gate at the upstream (inlet) end of a canal outlet is to allow more precise regulation of the discharge rate. Thus, if water levels change, the gate opening can be changed in order to maintain a more constant discharge rate through the canal outlet. Field calibration of these structures is identical to the procedures described in the sub-section, "orifice structures."

## 2.4 Measuring Irrigation Channel Losses

### A. Units for Expressing Seepage Loss Rate

Seepage losses from canals and tertiary irrigation channels are a significant problem for many of the irrigation systems in India. With the increasing emphasis upon improved irrigation water management practices, accounting for the movement of water through a system, including seepage losses, becomes increasingly important. In order to equitably distribute water in an irrigation delivery system, a knowledge of the variation in seepage losses throughout the system is required.

Seepage loss studies answer such questions as: (a) How much does a given canal or canal reach seep? (b) Where are the major seepage areas? (c) Should a channel be lined? (d) Is an existing irrigation channel lining effective?

Some of the more obvious factors that affect the rate of seepage loss from an irrigation channel include: (1) permeability of the soil traversed by the channel; (2) surface seal in the channel by silt and clay; (3) depth of water (which is affected by the channel roughness, backwater from downstream structures, vegetative growth, aquatic growth, inadequate maintenance, etc.); (4) wetted surface area; (5) location of groundwater table relative to channel invert; and (6) soil and water chemistry.

Three common methods for representing seepage loss rates will be presented. The first method calculates the seepage loss rate, Ql, in liters per second per 100 meters of channel length, as the difference in discharge rates in liters per second between the upstream Qu location and the downstream Qd location, divided by the length L in increments of 100 meters. Thus, if the length of channel between the Qu and Qd measurements is 450 meters, then L would be 4.50.

$$Q = \frac{Qu - Qd}{L} \times 1000 \qquad (2.4\text{-}1)$$

where Q = seepage loss rate (lps/100 m);

Qu = reach inflow rate ($m^3/s$);

Qd = reach outflow rate ($m^3/s$);

L = reach length (100's of m).

The second method calculates the seepage loss rate Ql p in percent per 100 meters of length, which is Q divided by Qu to represent the seepage loss as a ratio of Qu, then multiplied by 100 to change from a ratio to percent.

$$Qlp = \frac{Qu - Qd}{Qu \times L} \times 100 \qquad (2.4\text{-}2)$$

where Qlp = seepage loss rate (%/100 m);

Qu = reach inflow rate ($m^3/s$);

Qd = reach outflow rate ($m^3/s$);

L = reach length (100's of m).

The third method is the most universally acceptable representation of the seepage loss rate Qslr in cubic meters of seepage loss per square meter of wetted surface area per day, denoted by the abbreviation cmd. Likewise, Qslr can be calculated as cubic feet of seepage loss per square foot of wetted surface area per day, which can be abbreviated as cfd. Since there are 3.28 feet in a meter, one cmd equals 3.28 cfd. Often, the seepage loss rate is expressed in millimeters per day (1 cmd = 1000 mm/day).

$$Qslr = \frac{Qu - Qd}{WPavg \times L} \times 24 \text{ hr/day} \times 3600 \text{ sec/hr} \qquad (2.4\text{-}3)$$

where Qslr = seepage loss rate ($m^3/m^2/day$);

WPavg = average wetted perimeter (m);

Qu = reach inflow rate ($m^3/s$);

Qd = reach outflow rate ($m^3/s$);

L = reach length (m).

All three methods of representing the seepage loss rate can be used with the Inflow-Outflow Method for measuring irrigation channel seepage, whereas only the third method using Qslr, can be calculated from the Ponding Method. The Inflow-Outflow and Ponding methods are described below.

## B. Inflow-Outflow Method

### 1. Description of Methodology

The most accurate technique for measuring seepage losses in an irrigation channel is the Inflow-Outflow Method using existing irrigation structures for discharge measurement. The manual on "Field Calibration of Structures for Discharge Measurement" provides the necessary information for developing ratings for various types of structures. The seepage loss rate can be evaluated for each reach between two structures. A single structure provides Qd for one reach and Qu for the next reach. By having developed discharge ratings for a series of structures along a canal, the seepage losses for the entire canal can be evaluated. In addition, it is very easy to take a series of discharge readings at various times throughout each irrigation season in order to determine the variation in seepage loss rates over time for each reach.

Another technique for using the Inflow-Outflow Method is to install temporary flow measuring devices, such as weirs or cutthroat flumes. This is usually only satisfactory in small tertiary channels. Also, if a canal outlet or other structure has been field calibrated, then it can be used to obtain Qu, and a temporary flow measuring device could be installed downstream to provide Qd. The primary disadvantage of installing an additional flow measuring device is that the water surface level upstream is raised, which increases the seepage losses.

Current meter measurements can be made for using the Inflow-Outflow Method. The only difficulty is that the seepage losses have to be much greater than the error in the current meter discharge measurements, about 5 to 10 times greater, or more. Thus, if the seepage loss rate is low, then very long reaches must be used. If this is not feasible, then the "Ponding Method" should be used.

## 2. Example of Main Canal Inflow-Outflow Test

### Introduction

The Inflow-Outflow Method adapted to measuring seepage in the canal is by using a series of control structures in the branch canal as the boundary of each reach.

This method can be used rather easily and does not interfere with the operation of the branch canal, but the results depend upon the accuracy of the water measurements. Current meters are generally used to measure the flow rate in large canals. The stage of the canal should be kept constant during the test period in order to eliminate the effect of unsteady flow and channel bank storage. Failure to take this factor into account may introduce large errors into the results. The seepage loss rate should be measured in all reaches of the canal system. The seepage loss rate may have a negative value if the canal reach is in a cut section in which saturated soil conditions cause water to seep into the canal. The leakage that cannot be eliminated can be best measured volumetrically with a container of known volume. The time required to fill the container is measured; therefore, the leakage rate can be determined. If the test is made during periods of precipitation, the rainfall must be measured and considered when computing seepage losses.

### Classroom Lectures

The participants can be taught, the hydraulic theory of calibrating irrigation flow control structures. These included check structures, head regulators, culverts, inverted siphons, overflow structures, and outlet structures. The participants are instructed on how to use a current meter, a cutthroat flume, and how to perform seepage loss measurements before going to collect the field data.

## Field Work

The trainers may demonstrate the use of a current meter and cutthroat flume in the field. After that, individual groups should be assigned to practice session using the equipment on the real canal system in order to become familiar with the use of the equipment and learn how to apply the field data to calibrate the control structures. Each group of about four participants are assigned to calibrate one or more control structures by using a current meter in the branch canal and large distributary sections, and using a cutthroat flume in the smaller channels. It is important that the trainers check the data very carefully after each day of field work to make sure that the information is valid and that no obvious mistakes have been made. When groups are assigned to do the field work in adjacent canal sections, the data from each group can be cross-referenced and any errors can be more easily identified. Also, each group should make all discharge and seepage loss computations at the field site as the data is collected. The true water level elevations at the upstream and downstream ends of each reach are recorded for reference as a datum relating all of the data throughout the system. The gate opening of the control structure should also be precisely measured in the field. This may mean that the person making the measurement will have to dive into the water and use a scale to accurately measure the height of the gate opening; or if this is too dangerous, the gate opening should be carefully calibrated during closure of the branch canal.

## Conducting Inflow-Outflow Test

The branch canal, and its distributaries, are divided among the groups by using control structures as a boundary between each group. Before the group starts measuring the water by using the current meter, they had to make sure that steady-state flow conditions existed by observing the water level at the staff gauge. When the stage is no longer changing, the group can start the field work.

The individual groups should make a current meter measurement at every important structure, such as sluice gates, check structures, drop structures and every Distributory Head Regulator. This is necessary to determine how much water is going into and out of the reach. The outflow from the Distributary Head Regulator, or the leakage through a closed Distributory Head Regulator, is measured. A very important task is the accuracy of current metering because the seepage loss in the reach sometimes is very small compared with the discharge; therefore, the group must make the discharge computations immediately in the field to make sure that there is nothing wrong with the data. If they fin something wrong, they should recompute or perform the measurement again. This strategy helps to assure that meaningful and consistent data will be collected for the entire system.

The seepage loss rate in millimeters per day requires that the average wetted perimeter in the reach be measured. The group should measure the side slope, top width, and bottom width (on the top of the silt) at a couple of stations along the reach. This should have already been done under the Hydraulic Survey of Channels. After the computation of wetted perimeter at each station, the average wetted perimeter can be calculated.

The leakage through the closed gates is also considered to be a loss from the branch canal. The leakage should be measured volumetrically with a calibrated can.

## Results

The final procedure is to make a summary report. After every group calculates the seepage loss, the data is compared. The reasonable results are compiled. If some question or argument is raised, then the group would be sent to re-do the field work at the particular structure in question.

So during a couple of days of inflow-outflow measurement, the discharge at every Central structure should not be changed (thus, steady state conditions are maintained). When all the results are satisfactory, the individual groups would write their summary report in a clear and easily understood manner. These reports are put together and finalized for the entire inflow-outflow test. The results can be summarized as illustrated in Table 2.4-1, (Example of a previously conducted Training). It shows that the average seepage loss rate for the branch canal was 851 mm/day (32.3 cusecs/10,00,000 ft.). The total seepage loss for the branch canal was 1,820 lps, compared to an inflow of 5,993 lps, which gives a total loss of 30 percent.

Now everybody in the project knows how much loss exists in this conveyance system. This allows the operation schedule to take into account measured seepage losses, rather than assuming the seepage loss by pulling some number out of the air. Of course, this process needs to be repeated for every canal reach, branch canals, distributaries, and minors.

**Table 2.4-1 Summary of Seepage Loss Rates for the Branch Canal and Some Distributaries**

| Group | Canal | Branch | Distri-butory | Reach Begin | Reach End | Length L in m | (W.P.)L m^2 | Seepage loss lps/100m | Seepage loss %/100m | SLR in mm/day | Seepage loss, lps |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | – | ZHD | – | 0+210 | 2+700 | 2490 | 17805.3 | 26.060 | 0.435 | 3149.26 | 649.0 |
| 2 | – | ZHD | – | 2+700 | 6+000 | 3100 | 28782.0 | 9.450 | 0.204 | 879.55 | 293.0 |
| 3 | – | ZHD | – | 6+212 | 10+798 | 4586 | 44567.0 | 0 | 0 | 0 | 0 |
|  | – | ZHD | – | 11+000 | 16+000 | 5000 | 49273.0 | 5.944 | 0.225 | 521.14 | 297.2 |
| 4 | – | ZHD | – | 16+060 | 16+700 | 640 | 2519.0 | 15.516 | 1.174 | 3405.92 | 99.3 |
|  | – | ZHD | – | 16+782 | 18+800 | 2064 | 8502.0 | 2.370 | 0.211 | 497.91 | 49.0 |
| 5 | – | ZHD | – | 18+883 | 20+240 | 1357 | 4979.0 | 7.440 | 0.819 | 1752.32 | 101.0 |
|  | – | ZHD | – | 20+290 | 23+981 | 3691 | 17319.8 | 3.736 | 0.479 | 687.92 | 137.9 |
| 6 | – | ZHD | – | 24+000 | 26+245 | 2245 | 7845.2 | 4.285 | 0.675 | 1059.46 | 96.2 |
|  | – | ZHD | – | 26+280 | 26+995 | 715 | 3196.7 | 13.678 | 2.752 | 2643.33 | 97.8 |
|  |  |  |  |  |  |  | 184790.7 | Average SLR =851 |  | mm/day | 1820.0 |
| 9 |  | – | KJL | 5+958.75 | 8+600 | 2701.25 | 9315.0 | 3.370 | 0.264 | 844.06 | 91.0 |
|  |  | – |  | 0+000 | 1+041 | 1041 | 4441.1 | 9.827 | 0.010 | 1990.21 | 102.3 |
|  |  | – | PNR | 0+000 | 0+550 | 550 | 888.2 | 1.000 | 1.433 | 535.02 | 5.5 |
| 7 |  | – | SNG | 0+020 | 1+507 | 1487 | 6503.6 | 4.035 | 0.456 | 797.00 | 60.0 |
| 8 |  | – | PTL | 0+000 | 4+148 | 4148 | 13866.0 | 3.156 | 0.494 | 599.48 | 130.9 |

## C. Ponding Method

### 1. Description of Methodology

Several factors will determine the sites selected for conducting ponding tests, such as visual evidence that adjacent fields are suffering high groundwater levels, evaluating the seepage loss rates for various soil types, or evaluating various irrigation channel lining materials. Ponding sites are preferred that have a minimum of canal outlets, unless they can be either accurately measured or plugged without any leakage.

The length of a pond is dictated mostly by the slope of the irrigation channel, with the ponds being longer for flatter gradient channels. The primary disadvantage of the ponding method is having a level water surface, so that at the lower dike the pond water level should be above the normal water surface or full supply level and there should be a like amount below the normal water surface at the upper dike. Another guideline is that the wetted pond end areas should not exceed 3 per cent of the total pond wetted area.

For small channels, the dikes or dams may be built of canvas or plastic held in place by a timber at the top and dirt thrown along the edge. More commonly, earth dikes are constructed at each end of the pond; for large canals, the earthen dikes are constructed in layers of 15 to 20 centimeters and each layer compacted. A cutoff trench 30 centimeters deep is recommended. Sometimes, an existing check structure or check-drop structure can be used for one of the dikes by sealing with plastic and earth.

Leakage or seepage through the dikes can be eliminated by covering the pond side of each dike with sheet plastic. The edges can be held in place by excavating a shallow trench 30 centimeters deep with soil shoveled carefully over the plastic in order not to puncture the plastic sheet.

For canals having a water depth less than 1.5 meters, the water can be allowed to run over the upper dike if protected with plastic sheet. For large canals, a pump is frequently used for filling the pond. For a series of ponds along a canal, a pipe is placed through each dike with a gate, or some other mechanism for plugging the pipe, at the inlet.

The test equipment that is commonly used consists of one or two staff gauges, one or two hook gauges, a water stage recorder, stilling wells for the hook gauges and recorder, and in some cases, an evaporation pan. A ponding test can be conducted with only one staff gauge; however, if there is very much wind, then gauges should be used at both the upstream and downstream ends of the pond. Hook gauges should be used when seepage loss rates are low, such as in clay soils or lined channels.

Each staff or hook gauge should be referenced to true elevation so that depths of water in the pond can be compared with design operating depths. The gauges can be installed on vertical uprights that have been firmly positioned. The stilling wells for the hook gauges and recorder can be made from metal or plastic pipe, with small piezometer openings of 5 millimeter diameter to dampen water surface disturbances due to wind and wave action. An oil drum can be used for the recorder stilling well.

Good judgement must be exercised in deciding on the necessity for rain or evaporation measurements. If ponding tests are being conducted during the monsoon season, then there must be a capability for measuring precipitation. Evaporation needs to be measured if it will be significant, say 10-20 percent, or more, of the expected seepage loss rate.

An engineering survey to establish the shape of the pond is required before filling the pond. For irregular earthen channels, cross-sections should be measured every 15 meters, and elevations and widths measured to the closest centimeter. This is usually done with a surveyor's level and rod, along with a tape measure. The survey should establish the shape of the canal to an elevation of about 30 centimeters above the anticipated water test level or normal water surface elevation (full supply level). This should be done as part of the Hydraulic Survey of Channels.

For more uniform channels, such as well maintained earthen channels, cross-sections can be taken every 30 meters instead of 15 meters. For lined channels, only a few cross-sections will be needed.

From the survey of the pond cross-sections, calculations can be made to determine: (a) the variation in water surface width with elevation; and (b) the variation in wetted perimeter with elevation.

The first step is to plot the canal cross-sections to a scale that will allow the water surface widths and wetted perimeters to be measured within one centimeter. Beginning with an upper elevation of about 30 centimeters above the normal water surface at the downstream dike, the water surface width and wetted perimeter should be scaled from the drawings in increments of 3 to 10 centimeters. This data is placed on two separate tables, each with fixed predetermined elevations across the top of the table, and with each of the stations listed in the first column. One of the tables is for water surface widths, which are summed and averaged for each elevation. The other table lists the wetted perimeter for each elevation and station, which are then summed and averaged for each elevation. Having these tables completed prior to filling the pond allows the seepage loss rates to be calculated in the field during the ponding test.

Generally, a pond should be filled twice. If the test-reach proves to have very high seepage loss rates, such as greater than 0.5 cubic meters per square meter per day (cmd), then the pond should be filled three times.

When conducting a ponding test, a form for recording "Seepage Loss Data" should be used that gives the name of the irrigation channel, the stations for the axis of the upstream and downstream dikes, and the location of the staff gauges, hook gauges, and recorder. The hook gauges are read to the nearest 0.1 millimeter and the staff gauges to the nearest millimeter.

Initially, readings are taken quite frequently, say every 15 to 30 minutes, but the time between readings is increased after a few hours to every 1-4 hours according to the rate of fall of the water in the pond.

Between each set of readings, the seepage loss rate in cubic meters of seepage loss per square meter of wetted area per day can be calculated. For the example of a ponding test described in the following section, upon refilling a pond, readings are taken at 9:00 a.m. and noon, a time increment of 3 hours (Table 2.4-5). At 9:00 a.m., the water surface elevation in the pond was 82.445 meters, which had dropped to 82.415 at noon, a difference of 30 millimeters. Based on the pond survey, the interpolated values of the water surface width are 3.90 meters and 3.84 meters, while the wetted perimeter decreased from 4.39 meters at 9.00 a.m. to 4.27 meters at noon. The volume of seepage loss is the average water surface width of 3.87 meters multiplied by the drop in water surface elevation of 0.030 meter multiplied by the length of the pond of 270 meters, which results in 31.347 cubic meters of seepage loss. The wetted surface area is the average wetted perimeter of 4.33 meters multiplied by the length of the pond of 270 meters, which is 1169.1 square meters. The time period between 9 a.m. and noon is 3 hours, which is 0.125 day. Thus, the seepage loss rate is 31.347 cubic meters divided by the terms 1169.1 square meters and 0.125 day, which is 0.214 cubic meters per square meter per day (8.1 cusecs/1,000,000 $ft^2$). Note that the length of the pond is both in the numerator and the denominator, so it is not necessary in the computations.

The purpose of the ponding test is to measure the seepage loss rate. Low seepage loss rates are 0.009 to 0.03 cubic meters per square meter per day. A poorly lined canal or an unlined canal with significant losses would have a seepage loss rate of 0.15, or higher, cubic meters per square meter per day. Seepage loss rates greater than one have been measured.

## 2. Example of Main Canal Ponding Test

This sample problem has been taken from the training manual, "Measuring Seepage in Irrigation Canals by the Ponding Method". This is an unlined earthen canal that illustrates the methodology described above. Tables 2.4-2 and 2.4-3 represent the field survey of the pond prior to conducting the ponding test. Table 2.4-4 shows the actual field data measurements beginning with the first filling on September 16, and continuing through the second filling on September 18. Finally, the seepage loss rate computations are shown in Table 2.4-5.

Table 2.4-2 Table of Water Surface Widths in meters for the Example Ponding Test.

Canal High Line Pond No. AT STA 3 + 480 to 3 + 735

| Elevation / Station | Water Surface Widths for Various Elevations | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 582.13 | 582.19 | 582.25 | 582.31 | 582.37 | 582.43 | 582.49 | 582.55 |
| 3 + 480 | 2.62 | 2.81 | 2.96 | 3.17 | 3.32 | 3.54 | 3.69 | 3.90 |
| 3 + 495 | 2.65 | | | | | | | |
| 3 + 510 | 2.68 | | | | | | | |
| 3 + 525 | 2.74 | | | | | | | |
| 3 + 540 | 2.77 | | | | | | | |
| 3 + 555 | 2.84 | | | | | | | |
| 3 + 570 | 2.80 | | | | | | | |
| 3 + 585 | 2.74 | | | | | | | |
| 3 + 600 | 2.90 | | | | | | | |
| 3 + 615 | 2.93 | | | | | | | |
| 3 + 630 | 2.99 | | | | | | | |
| 3 + 645 | 3.05 | | | | | | | |
| 3 + 660 | 3.05 | | | | | | | |
| 3 + 675 | 2.96 | | | | | | | |
| 3 + 690 | 3.26 | | | | | | | |
| 3 + 705 | 3.35 | | | | | | | |
| 3 + 720 | 3.42 | | | | | | | |
| 3 + 735 | 3.32 | 3.35 | 3.38 | 3.42 | 4.15 | 4.30 | 4.48 | 4.73 |
| Total | 53.07 | | | | | | | |
| Average | 2.95 | 3.08 | 3.17 | 3.19 | 3.72 | 3.90 | 4.09 | 4.36 |

The figures in this table are used as an illustration. The table is not completely filled out. Interpolate for water surface widths not calculated.

Table 2.4-3 Table of Wetted Perimeters in meters for the Example Ponding Test.

Canal High Line Pond No. AT STA 3 + 480 to 3 + 735

| Elevation | Wetted Perimeters for Various Elevations | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Station | 582.13 | 582.19 | 582.25 | 582.31 | 582.37 | 582.43 | 582.49 | 582.55 |
| 3 + 480 | 3.35 | 3.54 | 3.66 | 3.69 | 3.75 | 4.06 | 4.57 | 4.73 |
| 3 + 495 | 3.38 | | | | | | | |
| 3 + 510 | 3.35 | | | | | | | |
| 3 + 525 | 3.51 | | | | | | | |
| 3 + 540 | 3.45 | | | | | | | |
| 3 + 555 | 3.42 | | | | | | | |
| 3 + 570 | 3.63 | | | | | | | |
| 3 + 585 | 3.72 | | | | | | | |
| 3 + 600 | 3.69 | | | | | | | |
| 3 + 615 | 3.57 | | | | | | | |
| 3 + 630 | 3.54 | | | | | | | |
| 3 + 645 | 3.42 | | | | | | | |
| 3 + 660 | 3.57 | | | | | | | |
| 3 + 675 | 3.63 | | | | | | | |
| 3 + 690 | 3.66 | | | | | | | |
| 3 + 705 | 3.54 | | | | | | | |
| 3 + 720 | 3.72 | | | | | | | |
| 3 + 735 | 3.66 | 3.69 | 3.75 | 4.06 | 4.57 | 4.73 | 4.94 | 5.31 |
| Total | | | | | | | | |
| Average | 3.55 | 3.60 | 3.72 | 3.87 | 4.24 | 4.39 | 4.82 | 5.00 |

The figures shown in this table are used as an illustration. Table is not completely filled out. Interpolate for wetted perimeters not calculated.

Table 2.4-4 Field Data Measurements for Seepage Loss in Example Ponding Test

NOTE: Assume two staff gages and a recorder used on this pond.

Canal High Line
Dike: sta. 3 + 480 and sta. 3 + 750

Hook gages: sta. NONE and sta. ____
Staff gages: sta. 3 + 495 ($S_u$) and sta. 3 + 720 ($S_d$)
Recorder: LMT

| DATE | TIME | HOOK $H_u$ | HOOK $H_d$ | STAFF $S_u$ | STAFF $S_d$ | TEMPERATURE AIR | TEMPERATURE WATER | add 581.823 to staff gage for elevation | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| 9/16 | 9.00am | | | 0.707 | 0.707 | 16 | 13 | 582.476 | Normal w.s. |
| | | | | | | | | | |
| 9/16 | 3.00pm | | | 0.654 | 0.651 | 29 | 14 | 582.476 | 582.44 at sta. 3 + 735 |
| 9/16 | 11.00pm | | | 0.567 | 0.567 | 21 | 18 | 582.390 | |
| 9/17 | 9.00am | | | 0.461 | 0.461 | 18 | 14 | 582.284 | |
| 9/17 | 5.00pm | | | 0.385 | 0.382 | 32 | 16 | 582.207 | |
| 9/18 | 1.00am | | | 0.321 | 0.318 | 18 | 18 | 582.143 | Refilled pond |
| 9/18 | 9.00am | | | 0.619 | 0.625 | 20 | 14 | 582.445 | During night |
| 9/18 | 12.00noon | | | 0.592 | 0.592 | 29 | 16 | 582.415 | |
| 9/18 | 5.00pm | | | 0.543 | 0.543 | 32 | 18 | 582.366 | |

Table 2.4-5 Seepage Loss Rate Computations for Example Ponding Test

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Time | Elapsed time, hours | Water surface elevation | Drop in water surface meters | Water surface width meters | Average water surface width meters | Product of columns 5 & 7 $m^3$ | Wetted perimeter meters | Average wetted perimeter m | Product of columns 3 & 10 m.hr | Seepage rate cmd $\frac{\text{col.8} \times 24}{\text{col.11}}$ |
| 9/16 | 9:00 am | | 582.530 | | 4.21 | | | 4.85 | | | |
| | | 6.0 | | 0.054 | | 4.135 | 0.223 | | 4.415 | 26.49 | 0.202 |
| 9/16 | 3:00 pm | | 582.476 | | 4.06 | | | 3.98 | | | |
| | | 8.0 | | 0.086 | | 3.920 | 0.377 | | 4.110 | 32.88 | 0.246 |
| 9/16 | 11:00 pm | | 582.390 | | 3.78 | | | 4.24 | | | |
| | | 10.0 | | 0.106 | | 3.490 | 0.370 | | 3.710 | 37.10 | 0.239 |
| 9/17 | 9:00 am | | 582.284 | | 3.20 | | | 3.78 | | | |
| | | 8.0 | | 0.017 | | 3.140 | 0.242 | | 3.690 | 29.52 | 0.197 |
| 9/17 | 5:00 pm | | 582.207 | | 3.08 | | | 3.60 | | | |
| | | 8.0 | | 0.064 | | 3.020 | 0.193 | | 3.553 | 28.42 | 0.163 |
| 9/18 | 1:00 am | | 582.143 | | 2.96 | | | 3.506 | | | |
| | ----Refill---- | | | | | | | | | | |
| 9/18 | 9.00 am | | 582.445 | | 3.90 | | | 4.39 | | | |
| | | 3.0 | | .030 | | 3.87 | 0.116 | | 4.330 | 12.99 | 0.214 |
| 9/18 | 12.00noon | | 582.415 | | 3.84 | | | 4.27 | | | |
| | | 5.0 | | 0.049 | | 3.735 | 0.183 | | 4.225 | 21.13 | 0.208 |
| 9/18 | 5.00 pm | | 582.366 | | 3.63 | | | 4.18 | | | |

BASIC EQUATION:

$$(\text{cmd}) = \frac{\text{Length of Pond} \times \text{Drop in Water Surface} \times \text{Average Width of Water Surface} \times 24}{\text{Length of Pond} \times \text{Average Wetted Perimeter} \times \text{Hours of Run}}$$

## 2.5 Obtaining Maintenance Information from Farmers

Involving the farmers and securing their participation in the maintenance of irrigation system is very essential. Sometimes, they know the problems in operation and maintenance of the system better than than the field staff. Some finer issues, which may not come to notice during the hydraulic surveys, can sometimes be identified through the farmers. Therefore, it is advised that 'Irrigation Maintenance Committees' should be formed at each sub-divisional level for the irrigation works under its control. The Committee may consist of the concerned Assistant Engineer as its convener, the concerned junior engineer of the section, and the farmers. The supervisor under that section should also attend the meetings.

A meeting should be convened every week during the Rabi (winter crops) season on fixed dates, and at a fixed place and fixed time notified in advance. Four such stations could be fixed in the sub-divisional jurisdiction to hold these meetings. Places of meeting should be such that farmers do not have to walk more than 5 km to attend the meeting. All suggestions put forth by the farmers during the meeting should be recorded in a register and entries should be made in the same register as soon as each problem is redressed or any action is taken. Efforts should be made to mitigate the minor problems, say within a month or by the time another meeting is held at the same place.

Another approach has been initiated in the State of Tamil Nadu. A former Chief Engineer, established an Irrigation Assessment and Action Programme on the Periyar Vaigai Irrigation System to enhance communication between the Irrigation Department and farmers. Each Section Officer is required to be in his office every Monday at 4:00 PM during the irrigation season to meet with farmers. Both operations and maintenance problems can be discussed, or any other issues important to the farmers.

Again such committees would be very helpful in seeking the farmers' advice and their involvement in the maintenance programme. This would also create in them a sense of ownership of the system and a confidence in the Irrigation Department. It will also enhance credibility between departmental officials and farmers.

## 2.6 Diagnostic 'Walk-Thru' Maintenance Survey

Before conducting the Diagnostic 'Walk-thru' Maintenance Survey, there are four other activities that provide valuable insights regarding the diagnosis, or determining the causes, of maintenance problems:

* Hydraulic Survey of Channels (Section 2.2)
* Calibrating Flow Control Structures (Section 2.3)
* Measuring Irrigation Channel Losses (Section 2.4)
* Obtaining Maintenance Information from Farmers (Section 2.5)

### A. Information from Hydraulic Survey of Channels

The primary information obtained from the Hydraulic Survey of Channels are: (a) the quantities of sediment to be removed from various reaches in the network of irrigation delivery channels; and (b) the locations where either the banks or the bed of the channels require fill material.

This information should be known and available when conducting the Diagnostic 'Walk-thru' Maintenance Survey. In this manner, the scour and sedimentation problems can be addressed during the 'walk-thru' in order to diagnose why scour has occurred at the various locations and why there are significant sedimentation problems at some locations.

### B. Information from Calibrating Flow Control Structures

By having developed discharge ratings for the flow control structures, recent actual discharge records will be available for the Head Regulators and the outlets. This information can be compared with design discharges so that the degree of compatability, as well as any discrepancies, will be known. This will allow some inferences to be made regarding regime conditions in various channel reaches. Also, this information will provide some insights about sedimentation.

## C. Information from Channel Loss Measurements

The information obtained from measuring Irrigation Channel Losses consists of channel reaches having high, intermediate, or low water losses. When conducting the Diagnostic 'Walk-thru' Maintenance Survey, particular emphasis should be given to those channel reaches having high water losses and those channel reaches having low water losses. By concentrating on the two extreme situations, it is more likely that an accurate diagnosis can be made regarding those physical conditions and environments that result in high water losses and those situations where low water losses occur. Some of the major parameters that will likely play a role in understanding the causes of either high or low water losses will be:

* soil type
* reaches in cut versus reaches in fill
* depth to adjoining groundwater levels
* biological activity in the embankments (look for leakage at the toe of the outside embankments)

## D. Information from Farmers

Certainly, it is difficult to anticipate maintenance problems that might be identified by farmers. However, experience has shown that extremely valuable insights can be gained if an individual can learn to listen to farmers. Often, the problems being discussed may be operational, but the causes are maintenance problems that need to be corrected. Again, it is extremely important that the field team conducting the Diagnostic 'Walk-thru' Maintenance Survey should have the information obtained from farmers. Preferably, this information should have been obtained by direct communication between the field team and the farmers.

## E. Conducting the Diagnostic 'Walk-thru' Maintenance Survey

The Operations Control Maintenance Survey and the Essential Structural

Maintenance Plan will have already been done prior to conducting the Diagnostic "Walk-Thru" Maintenance Survey. Thus, the flow control structures do not need to be inspected during this field survey.

A 'walk-thru' survey rather than 'drive thru' for ascertaining the minor maintenance needs by the Assistant Engineer/Junior Engineer with his supervisor is very essential. Sometimes, the field surveys may not provide minor details of the maintenance needs and so it is important to do the 'walk-thru' to provide detailed insights into the maintenance problems. This will help in their proper diagnosis as regards the causes and remedies for such problems.

Conducting the Diagnostic 'Walk-thru' Maintenance Survey provides the field personnel with a greater understanding and sensitivity regarding the causes of maintenance problems. Later, participating in the actual field maintenance activities by completing the Priority Maintenance Needs provides field personnel with extremely valuable experience in the application of remedies to maintenance problems.

This survey requires two to three individuals such as Assistant/ Junior Engineer and his supervisor walking along each irrigation channel and taking notes on each maintenance need. While 'driving thru' may highlight only the major maintenance problems, the 'Walk-Thru' survey will allow observation of minor maintenance problems which can be readily corrected at low cost before they become expensive major problems.

The supervisor should have already received field training prior to undertaking this activity, or he should be receiving supervised training while conducting this 'walk-thru' survey. If the supervisor has received training previously, then he can conduct this survey in conjunction with the Assistant/Junior Engineers under his supervision, thereby extending the training to these people. However, it must be strongly emphasized that the supervisor is expected to do this 'walk-thru' survey over every meter of canal, branch canal, distributary and minor under his jurisdiction. The

Assistant/Junior Engineers can participate by also walking along with the supervisor.

Prior to conducting this field survey, the supervisor should have compiled a complete listing of structures and their location for his area of jurisdiction. Also, stations should be marked along each channel, preferably every 100 meters, so that the field notes can fairly accurately describe the location of any particular maintenance problem.

In conducting a Diagnostic "Walk-thru" Maintenance Survey, both sides of the irrigation channel have to be carefully inspected. This is where the Assistant/Junior Engineers can help. Either one or two of them can assist the supervisor. Certainly, when conducting the 'walk-thru' in the area of operation for a Assistant/Junior Engineers, they should participate with the supervisor in this survey since it is their area of responsibility. Initially, when training the Assistant/Junior Engineer, the supervisor will have to walk along both channel embankments to be sure that all of the maintenance problems are being detected. Then, when the supervisor has a high degree of confidence in the capability of an Assistant/Junior Engineer, he can allow him to walk along one of the embankments, while the supervisor walks along the opposite bank.

All of the field notes should be written by the supervisor. A very important part of the field notes should be numerous sketches illustrating the maintenance problem being described, along with any proposed remedies. Another important point is to provide sufficient detail in the field notes so that quantities of materials can be calculated and cost estimates can be prepared for correcting the maintenance problems.

For earthen channels, the field notes during the 'walk-thru' survey may include:

* Reaches of channels requiring sediment removal, the quantum of sediment, and the causes of sedimentation;

* Locations where scour has occurred and an evaluation of the causes of scour;
* Channel reaches requiring weed removal and the area involved;
* Embankment erosion from rainfall and the volume of fill required;
* Channel reaches requiring service road grading;
* Channel reaches having high water losses and the causes for these losses;
* Channel reaches having visible signs of leakage at the toe of the embankment and the causes of this leakage;
* Channel locations where earth has been removed at the toe of the embankment and the volume of fill required;
* Erosion and cavities adjacent to concrete structures and the volume of fill required; and
* Damage to a structure, causes of the damage, and the required maintenance.

On lined channels, it should be ensured that the rate of drawdown is not more than what is provided in the design. The following points should be noted while carrying out the inspection of lined irrigation channels:

* Locations of any cavities or pockets that have been found behind the lining and the volume of fill required;
* Development of any cracks, displacement, or damage to the lining and the extent of repair or replacement required;
* Whether the filler material in the joints of the lining is sound, intact, leak proof and whether or not any weed growth in the joints has taken place;
* Evaluate whether or not pressure release arrangements function effectively;
* Determine if cavities at various structures are affecting the lining;
* Sediment deposits and their volume; and channel reaches having weed growth and the area.

For both carthen channels and lined channels, there can be many more maintenance requirements listed during the 'walk-thru' survey than indicated in the lists above. The variety of maintenance needs is a 'site specific' question that is also dependent on the degree of maintenance activities in recent years.

Some example field notes for a Diagnostic "Walk-Thru" Maintenance Survey are shown in Tables 2.6-1 and 2.6-2. As can readily be seen, using sketches along with written notes adds considerable information.

Table 2.6-1 Some Example Field Notes for an Earthen Channel while Conducting a Diagnostic "Walk-Thru" Maintenance Survey

| | |
|---|---|
| 0+300 to 1+100 | Channel looks very good in this area because land on both sides is lower than the distributary. |
| 1+857<br>1+870 | The inlet pipe (0.20 m diameter) at the left side extends into the distributary. The embankment has eroded partially, depositing soil in the canal. Total soil volume is 0.4 m x 1.4 m x 13 m length = 7.3 cubic meters. |
| 2+050<br>2+975 | In this reach there are 9 pipe outlets which discharge 20-80 percent more than the sanctioned discharge. Evidence of tampering at one outlet. Also, the measured channel losses are high (13.6 cusecs/10,00,000 square feet of wetted perimeter). The water surface elevation is approximately 8 cm above FSL, which is caused by backwater effects from downstream sedimentation. There are many leakage holes at the left embankment toe from 2+400 to 2+750. |
| 3+150<br>3+950 | The depth of sediment determined from the Hydraulic Survey of Channels is 17 cm at 3+150, 26 cm at 3+400 and 34 cm at 3+750. The discharge was measured at 3+400 as 1.62 cubic meters per second. The water surface elevation is very near FSL. The flow cross-section has been reduced by 16 percent, but the discharge is only 65 percent of design discharge. The channel losses in this reach are 9.7 cusecs per 10 lakh square feet of wetted perimeter. Moderate vegetative growth from 3+150 to 3+400 and then heavy vegetative growth to 3+750. There are many leakage holes at the left embankment toe from 3+250 to 3+400 and the rightembankment toe from 3+850 to 3+950. |
| 4+120 | Outlet on right embankment is receiving only 62 percent of authorized discharge. Water surface level is 7 cm below FSL. |
| 4+165<br>4+220 | Severe raincuts on left cutbank with erosion into distributary. Estimate 180 square meters of surface requiring soil removal and 140 cubic meters of compacted backfill required. Surface drain at toe of cutbank is over-filled with sediment and not functioning, lack of adequate maintenance in recent years has caused this condition. |

| | |
|---|---|
| 4+280 | Outlet on right embankment is receiving only 47 percent of authorized discharge. Water surface level is 11 cm below FSL. |
| 4+360 | Evidence of illegal cut in right embankment with leakage at toe of embankment. |
| 4+410 | Outlet on left embankment is receiving 42 percent of authorized discharge. Water surface elevation is 12 cm below FSL. |
| 4+450<br>4+750 | Evidence of 4 illegal cuts in right embankment and 3 illegal cuts in left embankment. Average sediment depth in this reach is 17 cm. Channel losses are 7.1 cusecs per 10 lakh square feet of wetted perimeter. Much of this loss would be leakage which can be reduced by removing soil in illegal cuts and placing compacted backfill. The 7 cuts would require 25 cubic meters of soil removal and the same amount of compacted backfill. |
| 4+810 | Outlet on left embankment is receiving 58 percent of authorized discharge because of bund constructed in distributary bed 5 m downstream. |
| 4+825 | Measured discharge in distributary is only 32 percent of design discharge at this location. |
| 4+885<br>5+160 | There are numerous illegal cuts and many bunds in the distributary bed to raise the water surface level. |
| 5+175 | There is ponded water in the distributary bed, but essentially no flow. |
| 6+240 | Tail cluster is passing no discharge. |

Table 2.6-2 Some Example Field Notes for a Lined Channel while Conducting a Diagnostic "Walk-Thru" Maintenance Survey

| | |
|---|---|
| 0+250 | Two failed right panels and next downstream panel will fail in one or two monsoon seasons because of cavities. Besides replacing these two panels, surface drainage on right berm is required for 200 m. Also, roadway grade must be changed for 130 m. |
| 3+200 - 4+650 | This part of the distributary is in a cut area and was constructed with concrete blocks. Vegetation is filling the joints of the concrete blocks, and in some places these blocks have collapsed. The silt in the canal is about 0.30 m deep. |
| 8+813 - 8+930 | The left embankment is too high. The farmer prepared the cropping area by placing the big boulders along the embankment, which caused the boulders to roll into the canal. There were two holes (size 0.2 x 6.0 x 2.0 m) along the concrete berm. The concrete is in good condition. The right embankment is lower than the top of the concrete lining, so fill is required of 1.8 m width x 0.25 m height x 117 m length = 53 cubic meters. Soil can be obtained from left embankment, which must then be properly graded and turfing provided. |
| 9+146 | A concrete panel is cracked at the left side of the canal. Soil volume = 0.15 x 3.00 x 2.70 = 1.215 $m^3$. Concrete volume = 0.05 x 3.00 x 2.85 = 0.428 $m^3$. |

KM 10 + 000 - 10 + 475

The concrete panels should be replaced due to 20 cavities at the berm of diameter size 0.30 m. The water table pressure has cracked the concrete panels and formed cavities underneath and at the connection of the old and the new concrete. There are 23 concrete panels that were damaged, 3 concrete beds were cracked. There are 60 holes in the concrete panels along the concrete joints which also have vegetation in the holes. The depth of weeds and silt is 0.05 m.

## Chapter 3

## DEVELOPMENT OF MAINTENANCE PLANS

### 3.1 Essential Structural Maintenance Plan

After completing the "Maintenance Survey of Flow Control Structures" (Section 2.1), a detailed "Essential Structural Maintenance Plan" (ESM) should be prepared that includes:

1. Physical Description of Irrigation System;
2. Proposed Flow Measurement Programme for Equitably Distributing Water Supplies;
3. Proposed Programme for Evaluating Channel Losses;
4. Essential Structural Maintenance (ESM);
5. Costs of Essential Structural Maintenance;
6. ESM Implementation Plan; and
7. Field Notes and Sketches.

**A. Physical Description of Irrigation System**

A general description of the irrigation project should be provided including a small location map and a larger map of the irrigation system showing the main canal(s), branch canals, distributaries, minors, and structures including outlet structures, each properly labelled. The lengths of each minor, distributary, branch canal and main canal can be provided in tables, along with their design discharge capacity and culturable command area (CCA).

**B. Proposed Flow Measurement Programme**

This section of the ESM Plan must show on the large map and list in a table the structures selected for flow control and water measurement. The listing of structures should state the type of structure, important dimensions pertinent to flow measurement, and the design discharge capacity. The role of the various structures in controlling the discharges in the system and equitably delivering water to the outlets serving the tertiary systems needs to be clearly presented.



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Next, the schedule for developing discharge ratings for the flow control structures should be presented. This phase should state how the system will be operated during discharge measurements, how many measurements are required for each type of flow control structure, and how many days will be required to complete the discharge ratings in each channel reach. The schedule for completing this work is, first, dependent on the qualified personnel available for doing the work and, secondly, the time lag involved in reaching steady-state flow conditions in the channel reaches where discharge measurements are to be made, which can vary from a few hours to a few days each time the discharge rate in the channel network is changed.

**C. Proposed Programme for Evaluating Channel Losses**

Assuming the completion of Essential Structural Maintenance and the Development of Discharge Ratings for the Flow Control Structures, state an operational programme for evaluating seepage loss rates in various reaches of the main canal, branch canals, distributaries and minors using the Inflow-Outflow Method (see Section 2.4). First of all, serious consideration needs to be given to operating the system at different water levels, either by adjusting gate settings, or varying the discharge rates, or a combination of the two. If there are some reaches of the irrigation channel network where there is some doubt as to whether the Inflow-Outflow Method will provide satisfactory data, then these reaches should be delineated, and consideration given to whether or not the Ponding Method will be used in these reaches (see Section 2.4). A time schedule for conducting the channel loss measurements should be given; this requires some thought as to how much of the system could be evaluated on a single day taking into account the availability of personnel. Also, for large-scale projects, it may be preferable to evaluate an entire distributary for one discharge on a single day, which would require three days for three discharges, not necessarily consecutive days, to collect the necessary field measurements, so that the variation in seepage loss rate with water surface elevation will be known.

**D. Essential Structural Maintenance**

The results from the "Operations Control Maintenance Survey of Flow Control Structures" (Section 2.1) provides all of the field data required to prepare this particular section of the ESM Plan. In this section, the results of the field survey will be summarized. The major categories of maintenance requirements could be listed under: (1) In-Place Maintenance Requirements; (2) Workshop Maintenance Requirements; and (3) Replacement of Gates, Gears, Gate Rods and Gate Frames. Then, under each of these three major categories, the specific maintenance activities can be listed with the quantities of maintenance required.

## E. Costs of Essential Structural Maintenance

This is a relatively short section that utilizes the lists of required maintenance activities, and the quantities from the previous section of the ESM Plan. Then, unit costs are applied to these activities to arrive at estimated total costs for each activity and the total cost for Essential Structural Maintenance. If there are any particular problems with some of the unit costs being used, they should be presented in the written Plan.

## F. ESM Implementation Plan

A proposed time schedule for completing the Essential Structural Maintenance should be presented. The discussion should state any particular problems that might disrupt the proposed time schedule. Also, a statement should be made as to the possibilities of completing the work in a shorter time period, and under what conditions. The proposed time schedule will dictate the cost schedule. Consideration should also be given as to how much of these costs could be met with present project resources, the remaining being a request for additional funds.

## G. Field Notes and Sketches

Preferably, a copy of the field written notes and sketches should be appended to the ESM Plan. To type the written comments and draft the sketches may be too much of an unnecessary burden on the project, so rewritten field notes and redrawn freehand sketches are very acceptable.

## 3.2 Normal Maintenance Programme

A department in each State, usually an Irrigation Department, but sometimes a Public Works Department or some other department, funnels money to each irrigation system annually for normal or routine maintenance. Unfortunately, most irrigation systems are deteriorating under a combination of insufficient funds and an unwillingness to work by many salaried labourers.

Prior to conducting a Diagnostic "Walk-Thru" Maintenance Survey (Section 2.6) the Normal Maintenance Programme for the irrigation system should be documented. The individual responsible for preparing this document would be the Executive Engineer. A suggested outline for this document would be:

1. General Description of Irrigation System
2. Available Maintenance Manpower
3. Available Maintenance Equipment
4. Present Maintenance Activities

    a. Watershed and Reservoir
    b. Masonry Dam
    c. Earthen Dam
    d. Earthen Channels
    e. Lined Channels
    f. Irrigation Structures
    g. Drain Network
    h. Communication System
    i. Ancillary Works

5. Major Maintenance Difficulties
    a. Physical
    b. Manpower
    c. Equipment
    d. Budget
    e. Administrative

## A. General Description of Irrigation System

A general description of the irrigation system should be presented including a small map showing storage facilities, main and branch canals, the major drains, and the command area. The amount of available storage and the discharge capacity at the canal head works should be cited. A table could be used to present the discharge capacity at the head and then the length for each canal, branch canal, distributary and minor.

## B. Available Maintenance Manpower

The different levels of staff and their numbers should be listed. In Section 4.1, there is a sub-section on Job-Related Functions in Normal Maintenance that can be used as a guide. Then, the level of effort in maintenance activities by these staff should be listed. Also, the number of temporary labourers employed throughout the year should be stated, as well as the total number of days of work, and how much of this effort is on maintenance activities.

## C. Available Maintenance Equipment

A listing of all equipment presently used for maintenance of the irrigation system should be listed. The number of hours or days that each piece of equipment is required to be used during a year should be given, as well as how much of this use is for maintenance activities. Finally, the condition of each piece of equipment should be stated.

## D. Present Maintenance Activities

This is an extremely important section that will also provide important guidance in developing the "Catch Up" Maintenance Plan and the Preventive Maintenance Plan. For each major activity listed below, it is important to indicate the quantity of maintenance work done and it's total cost, as well as listing unit costs for each maintenance activity.

1. Watershed and Reservoir

Any activities by other departments, such as Forestry or Agriculture, regarding the planting of trees or other vegetation in the catchment area, should be described. Maintenance problems in the reservoir area should be described, such as debris or vegetative and aquatic growth. Any maintenance activities associated with these problems should be listed, including quantities, costs and unit costs. Also, any problems associated with encroachment of the reservoir should be stated, along with any measures being taken to avoid or discourage encroachment.

2. Masonry Dam

The quantities, unit cost and total cost should be listed for any of the activities listed below that are included in Normal Maintenance:

- Maintenance for non-overflow and overflow dams, their bucket/apron, wing walls, head sluices, etc.
- Sluice gates - their maintenance, painting, greasing, etc.
- Inspection gallery - any maintenance needed for lighting, pumping, ventilation, etc.
- Maintenance to the spillway gates.

3. Earthen Dam

Some of the major maintenance activities for earthen dams are listed below. However, there may be other activities as well. List all maintenance activities, the quantities of work, unit costs and total costs.

- Jungle clearance and earthwork for earthen dam to bring its top to the designed top level and slopes as near to the designed parameters as possible, filling of rain cuts, rodent holes, etc.
- Maintenance, if any, needed for the upstream pitching and downstream filter toe.

- Maintenance, if any, needed for the head outlet sluices and gates, painting and greasing of gates, etc.
- Maintenance for the spillway including bucket and apron, wing walls, etc.

## 4. Earthen Channels

There are numerous maintenance activities associated with earthen channels. For each activity, list the quantities of work, unit cost and total costs. Some of the major maintenance activities are listed below:

- Jungle clearance, deweeding and desilting from the canal bed.
- Jungle clearance, deweeding and earthwork on canal slopes.
- Jungle clearance and earthwork on canal berms, dowels and service road, etc.

## 5. Lined Channels

Like earthen channels, there can be many activities associated with the maintenance of lined channels. For each activity, list the quantity of work, unit cost and total cost. Some of the major activities are listed below:

- Desilting of the bed.
- Filling of cracks, pockets in the concrete, or repairs to the masonry lining in the bed and slopes.
- Jungle clearance on canal berms, dowels, service road, etc.

## 6. Irrigation Structures

Maintenance needs of all structures should be listed. Such structures are bridges, aqueducts, syphons, falls, head and cross regulators, and measuring flumes. The quantities of work, unit costs and total costs should be cited in the report.

7. Drain Network

Any maintenance activities associated with the network of open drains should be listed. Mostly, this activity would involve the removal of vegetation, usually by labourers. List the hours or days spent on this activity, unit costs and total costs for various sizes of drains.

8. Communication System

Inspection roads, as well as the telegraph and telephone or wireless system, come under communication. Any repairs or other maintenance needed for these facilities should be listed in the report.

9. Ancillary Works

Buildings constructed on the project, both residential and non-residential, as well as tree plantations, are part of the ancillary works. These works should be listed and the annual maintenance costs cited.

**E. Major Maintenance Difficulties**

The primary value of this section of the report is to draw upon project experience in delineating the difficulties associated with trying to accomplish the annual maintenance activities. This will be of considerable value in preparing the various maintenance plans.

1. Physical

The previous portion of this report, Present Maintenance Activities, when combined with project experience, should prove ample to give an excellent description of the physical facilities and their degree of maintenance, including some indications of deferred maintenance. Notice that the emphasis is on MAJOR difficulties, not on small details.

2. Manpower

The emphasis should be upon the technical capability of the staff for doing maintenance work and whether sufficient staff are available. Also, if there are difficulties with the willingness of the staff to undertake the necessary maintenance work, this should be stated along with any suggestions for correcting the situation.

3. Equipment

Any difficulties associated with accomplishing Normal Maintenance with existing equipment should be reported. A distinction should be made between maintenance of existing equipment, expensive repairs, and replacement.

4. Budget

Almost every irrigation project suffers from a lack of funds for maintaining the irrigation system. This is why the degree of deferred maintenance is increasing. But an important question is, how can existing funds being provided to the project be used in a more cost-effective manner to accomplish much more maintenance. An indication should be given as to how much of the deferred maintenance might be alleviated by various means with existing project funds.

5. Administrative

Major difficulties with present staff and staffing conditions should be reported. Also, any constraints associated with higher levels of administration should be cited. Finally, any difficulties in doing the necessary maintenance work as a result of political interference should be ated in this report on the Normal Maintenance Programme.

### 3.3 "Catch-Up" Maintenance Plan

A "Catch-Up" Maintenance Plan should document a proposed programme for catching-up on deferred maintenance, so that afterwards the irrigation project can function properly on a Preventive Maintenance Programme. This plan should be prepared based upon: (a) the ESM Plan (Section 3.1); (b) the Hydraulic Survey of Structures and Channels (Section 2.2); (c) Calibrating Flow Control Structures (Section 2.3); (d) Measuring Irrigation Channel Losses (Section 2.4); (e) Obtaining Maintenance Information from Farmers (Section 2.5); and (f) the Diagnostic "Walk-Thru" Maintenance Survey (Section 2.6). Thus, there is a large amount of information used in preparing this plan. The proposed outline for preparing a "Catch-Up" Maintenance Plan is:

1. Physical Description of Irrigation Project
2. Essential Structural Maintenance (ESM)
3. Status and Costs of ESM Plan
4. Inventory of Required Maintenance
5. Maintenance Costs
6. Priority Maintenance Needs (PMN) and Costs
7. Maintenance Equipment Requirements
8. Maintenance Manpower Requirements
9. Maintenance Plan
    a. Maintenance Issues
    b. Method of Implementation
    c. Implementation Schedule
10. Field Notes and Sketches

**A. Physical Description of Irrigation Project**

The material contained in the first section of the Essential Structural Maintenance (ESM) Plan should be included here. In addition, more background about channel sizes might be provided in a list included in a table, or series of tables. Also, the number of outlets along different minors and distributaries should be listed, as well as those along various reaches of other channels if they exist.

**B. Essential Structural Maintenance**

The material for this section of the "Catch-Up" Maintenance Plan would be taken directly from the ESM Plan. If there have been any modifications to the original plan resulting from experience gained while implementing the essential structural maintenance for flow control structures, then this should be presented in this section of the report.

**C. Status and Costs of ESM Plan**

First of all, the present status of the ESM Plan should be presented. Has it been approved? If so, what fraction of the work has been completed ? Then, the costs of the ESM Plan can be presented; if the program is underway, or completed, then revised cost estimates can be presented.

**D. Inventory of Required Maintenance**

This section of the report is a summary of the field notes written during the Diagnostic "Walk-Thru" Maintenance Survey. All of the required maintenance can be summarized in tables similar to the forms presently used in preparing a funding request for maintenance Also, the topic listing for sub-sections in Section 5.2 of Chapter 5, particularly those on Maintenance of Head Works, Maintenance of Channels, Maintenance of Structures, and Maintenance of Communication and Ancillary Works can be used as a guide. In addition, if the drainage network is included in this "Catch-Up" Maintenance Plan, then Maintenance of Drains in Section 5.2 can be used as a guide.

**E. Maintenance Costs**

Each irrigation project has unit costs for various types of maintenance activities commonly used in preparing a Budget Request. In preparing the estimated costs for this section of the "Catch-Up" Maintenance Plan, there may be some difficulty if, for example, the project field staff are not experienced in certain maintenance activities. If this is the case, then the Executive Engineer of the irrigation project that has been doing this maintenance activity should be consulted. The unit costs are used in conjunction with the tables listing Maintenance/ Requirements to arrive at the estimated costs for catching-up on deferred maintenance.

## F. Priority Maintenance Needs and Costs

In most of the cases, the degree of deferred maintenance will exceed the capacity of the irrigation project to complete it in a single year. Thus, there is a need to prioritize the proposed maintenance activities, so that the highest Priority Maintenance Needs (PMN) are completed during the first year following approval of the "Catch-Up" Maintenance Plan, followed by the second highest PMN for the second year, and so on until all of the deferred maintenance can be alleviated. The same tabular format used in presenting the "Inventory of Required Maintenance" and "Maintenance Costs" should be used in this section.

## G. Maintenance Equipment Requirements

In general, most irrigation projects will have to undertake these deferred maintenance activities without receiving additional equipment. But, if it is obvious that the proposed maintenance activities cannot be economically done without some additional items of equipment, then a request for the required equipment should be presented and a strong justification provided.

All of the presently available equipment should be listed. Then, the capacity of this equipment for completing the PMN should be stated. For example, how much concrete can be placed in a year, how much sediment can be removed, how much turfing (sodding) can be accomplished, what percentage of the drains can be cleaned annually, etc.

## H. Maintenance Manpower Requirements

First of all, the capacity of the present irrigation project staff to undertake the deferred maintenance activities should be presented, including any deficiencies in staff capability or unwillingness to undertake the necessary maintenance activities. If certain staff vacancies exist that would seriously hamper the implementation of the "Catch-Up" Maintenance Plan, then this deficiency should be clearly stated and good justification provided for filling such vacancies. Finally, the amount of temporary labour usually employed by the irrigation project, and the annual capacity of this temporary labour to undertake the proposed maintenance activities, should be presented. If additional temporary labour will be required, then the number of man-days and costs should be presented for the first year, second year, and so on until the deferred maintenance is proposed to be completed.

## I. "Catch-Up" Maintenance Plan

### 1. Maintenance Issues

The "Catch-Up" Maintenance Plan should address, as a minimum, the following four issues:

- o Achieving "regime" in the irrigation channels;
- o Eliminating sediment sources;
- o Minimizing seepage losses; and
- o Reducing deterioration of channel lining.

For most of the irrigation channels in the Indian subcontinent, a key issue is the movement of sediment through the irrigation delivery subsystem onto the fields. This is a very complex hydraulic phenomena that is extremely difficult to evaluate. Certainly, large quantities of sediment deposition annually in a channel reach indicates the channel is not in "regime". Careful analysis is required in evaluating why an irrigation channel is not in regime. Sediment removal is treating the symptoms of the problem rather than the causes.

The second issue, eliminating sediment sources, should clearly come from the field notes while conducting the Diagnostic "Walk-Thru" Maintenance Survey. However, it is very important that the "Catch-Up" Maintenance Plan clearly describe this issue, so that when the deferred maintenance is completed, the quantities of sediment entering along the irrigation channels afterwards will only be a very small fraction of what is presently entering the channels.

The third issue, the problem of minimizing seepage losses, will become increasingly important with each passing year. Much can be accomplished with improved maintenance practices. Also, some seepage losses can be reduced by improved operation practices. However, if the seepage losses are very high, then Irrigation System Improvements may be required in order to significantly reduce these losses (see the Operations Phase of the M&O Learning Process.

The fourth issue, reducing deterioration of channel lining, should also clearly address how the completion of the "Catch-Up" Maintenance Plan will significantly decrease the degree of cavity formation behind lined channels and irrigation structures. Again, the intent is that, eventually, the level of required maintenance for lined channels and structures should be significantly less than the present situation.

2. Methods of Implementation

There are three primary methods that can be used in completing the proposed maintenance activities:

- o Departmental maintenance by the Irrigation Department;
- o Maintenance through contractual agencies; and
- o Contracting main system, distributary maintenance to the water users.

The method of implementation should be stated. Also, if a combination of methods will be employed, then the amount of maintenance to be accomplished by each method should be presented.

### 3. Implementation Schedule

The number of years proposed for completing the "Catch-Up" Maintenance Plan should be stated. Then, summarized versions of the proposed Work Plan for each year should be presented. The summary for the first-year Work Plan should be based on the preparation of a detailed Work Plan, which is a separate funding request document that could be forwarded following review and approval of the "Catch-Up" Maintenance Plan. The summarized Work Plans for the succeeding years would not be based on so much detail, but would be based on subdividing the total maintenance requirements and costs into annual workloads that can be accommodated by the irrigation project staff by any method of implementation, or combination, as discussed in the subsection above.

## J. Field Notes and Sketches

Based upon the original field notes and sketches, this work would be recopied and appended to the "Catch-Up" Maintenance Plan. This material can be recopied by hand, in order to save time, or the field notes can be typed, and the sketches drafted. In the future, it will be more common to place the field notes on a micro-computer, which will greatly facilitate the preparation of an Annual Maintenance Work Plan and the Annual Maintenance Completion Report. Although appending all of the field notes and sketches to the "Catch-Up" Maintenance Plan adds a lot of bulk, it is extremely important documentation for use during implementation of the "Catch-Up" Maintenance Plan.

### 3.4 Preventive Maintenance Plan

By the time that the Priority Maintenance Needs have been nearly completed under the "Catch-Up" Maintenance Plan, the irrigation project staff will have a very good knowledge about the causes of maintenance problems, as well as the most effective measures for minimizing or eliminating these causes. Because of the experience gained at this point in time, preparing a Preventive Maintenance Plan will be a relatively easy task.

This is a revised or updated maintenance plan that recognizes that the deferred maintenance is nearly implemented. Therefore, the irrigation project is ready to enter a new phase of maintenance activity that will require fewer resources. Another term commonly used is Routine or Normal Maintenance. If there is a distinction between Preventive Maintenance and Normal Maintenance, it would be that Preventive Maintenance represents a minimized form of Normal Maintenance because the deferred maintenance has already been done, and many of the causes of maintenance problems have been eliminated. However, since the present Normal Maintenance Programme commonly allows the irrigation system to deteriorate, then it can be expected that a Preventive Maintenance Programme will be more costly than the present Normal Maintenance Programme, unless greater cost-effectiveness can be achieved.

The greatest danger when implementing a Preventive Maintenance Plan is the field staff becoming lax in their maintenance procedures. If this occurs, then the maintenance requirements will begin to increase again. Thus, a Preventive Maintenance Plan should anticipate the procedures required to continue good maintenance practices. The level of required resources is expected to be minimized, but certainly kept adequate to maintain the irrigation project in good condition.

The Preventive Maintenance Plan should present and discuss:

1. Physical Causes of Maintenance Problems
2. Anticipated Extent of Maintenance Problems

3. Maintenance Equipment Requirements
4. Maintenance Manpower Requirements
5. Maintenance Requirements for Water Users (Farmers)
6. Estimated Annual Maintenance Costs
7. Preventive Maintenance Plan
    a. Maintenance Issues
    b. Preventive Maintenance Activities
    c. Preventive Maintenance Requirements

This document should be forwarded for appropriate review and approval. If adequate resources are made available and the programme is faithfully implemented, then it will greatly assist in avoiding deterioration of the irrigation system, facilitate improved operation of the irrigation system, and increase agricultural production.

## A. Physical Causes of Maintenance Problems

Again, at this point in time, all of the irrigation project field staff should know very well what the causes are for the maintenance problems that they see. The presentation in Section 5.1 can be used as a guide; however, the presentation in the Preventive Maintenance Plan should be very specific to the irrigation project.

## B. Anticipated Extent of Maintenance Problems

This section of the Preventive Maintenance Plan should describe what the anticipated, or expected, maintenance requirements will be for the project after completion of the Priority Maintenance Needs. The type of maintenance activities that will be required and the annual magnitude of these activities should be presented. The magnitude of each activity should be a quantitative listing for reaches of the main and branch canals, and for each distributary and minor.

## C. Maintenance Equipment Requirements

The maintenance equipment available for correcting Priority Maintenance Needs is expected to be sufficient for implementing the Preventive Maintenance Plan. However, some equipment may need special repair or replacement. Also, there may be some pieces of equipment that can be identified which would make the Preventive Maintenance Programme more cost-effective; if so, then the justification for purchasing such equipment should be presented.

## D. Maintenance Manpower Requirements

The expectations are that the Preventive Maintenance Programme will require less manpower. Certainly, all of the permanent Irrigation Department field staff will continue to function with the maintenance activities as before, but the amount of time that they spend will be slightly less, and the amount of time required for temporary employees will be less, and for part-time labourers much less. The manpower requirements and annual costs for the Preventive Maintenance Programme should be presented, and then compared with the manpower requirements for completing the Priority Maintenance Needs and previously required for Normal Maintenance.

## E. Maintenance Requirements for Water Users

Hopefully, at the time of preparing this Preventive Maintenance Plan, the irrigation project field staff will have spent some time collecting field data in the tertiary systems below some of the outlet structures. If not, then it is suggested that a Diagnostic "Walk-Thru" Maintenance Survey be conducted on a sample of tertiary system channels in order to make a preliminary evaluation of the extent of maintenance problems, along with requirements for alleviating these problems by the water users (farmers). The Preventive Maintenance Plan should discuss how the irrigation project field staff might provide technical assistance to the water users so they can do a better job, if required, in maintaining their tertiary channels. Since the tertiary channels are most likely unlined, field data from

Measuring Irrigation Channel Losses (Section 2.4) will be very helpful in assessing seepage and leakage losses, which would be indicative of the need for improved maintenance practices.

## F. Estimated Annual Maintenance Costs

An estimate of the annual maintenance costs under a Preventive Maintenance Programme should be presented. The format required in preparing a funding request should be used.

## G. Preventive Maintenance Plan

### 1. Maintenance Issues

The maintenance issues addressed in preparing the "Catch-Up" Maintenance Plan should also be addressed in the Preventive Maintenance Plan. These are:

- o Achieving "regime" in irrigation channels;
- o Eliminating sediment sources;
- o Minimizing seepage losses; and
- o Reducing deterioration of channel lining.

This section should state to what degree these issues have been accomplished as a result of completing the Priority Maintenance Needs. Then, the role of the Preventive Maintenance Programme in addressing these issues should be presented.

### 2. Preventive Maintenance Activities

A summary of Sub-Sections A, B and E should be presented. This would state in summary form the causes of maintenance problems in the irrigation project, the anticipated extent of preventive maintenance activities, and the proposed programme for project staff to provide technical assistance to water users for improving their maintenance practices in the tertiary channels.

### 3. Preventive Maintenance Requirements

A summary of Sub-Sections C, D and F should be presented. This would give a summary of the equipment, manpower, and annual budget required for the Preventive Maintenance Programme.

## Chapter 4

## ADMINISTRATIVE ARRANGEMENTS

### 4.1 Job Functions in Maintenance

There are differences in the organization for irrigation from one state to another; however, a generalized organization chart for an Irrigation Department is shown in Figure 4.1-1. Then, the numbers of work-charged staff associated with various sizes of irrigation project are indicated in Table 4.1-1.

### A. Job-Related Functions in Normal Maintenance

The normal maintenance programme needs the services of the following personnel:

| | | |
|---|---|---|
| 1. | Beldars/Chowkidars | Work charged |
| 2. | Mate/Munshi | |
| 3. | Gauge Readers | |
| 4. | Signallers | |
| | Telephone/Telegraph Operator | |
| 5. | Mistries/Supervisors | |
| 6. | Junior Engineers | Regular |
| 7. | Assistant Engineers | |
| 8. | Executive Engineers | |

Besides these individuals malis (gardeners), sweepers, cooks, mechanics pipe fitters, electricians, and masons, etc., are also needed.

#### 1. Beldars/Chowkidars

Most of the maintenance workers are unskilled labourers, called beldars and chowkidars. The basic unit is the gang consisting of 8 - 20 beldars under the supervision of a mate or munshi.

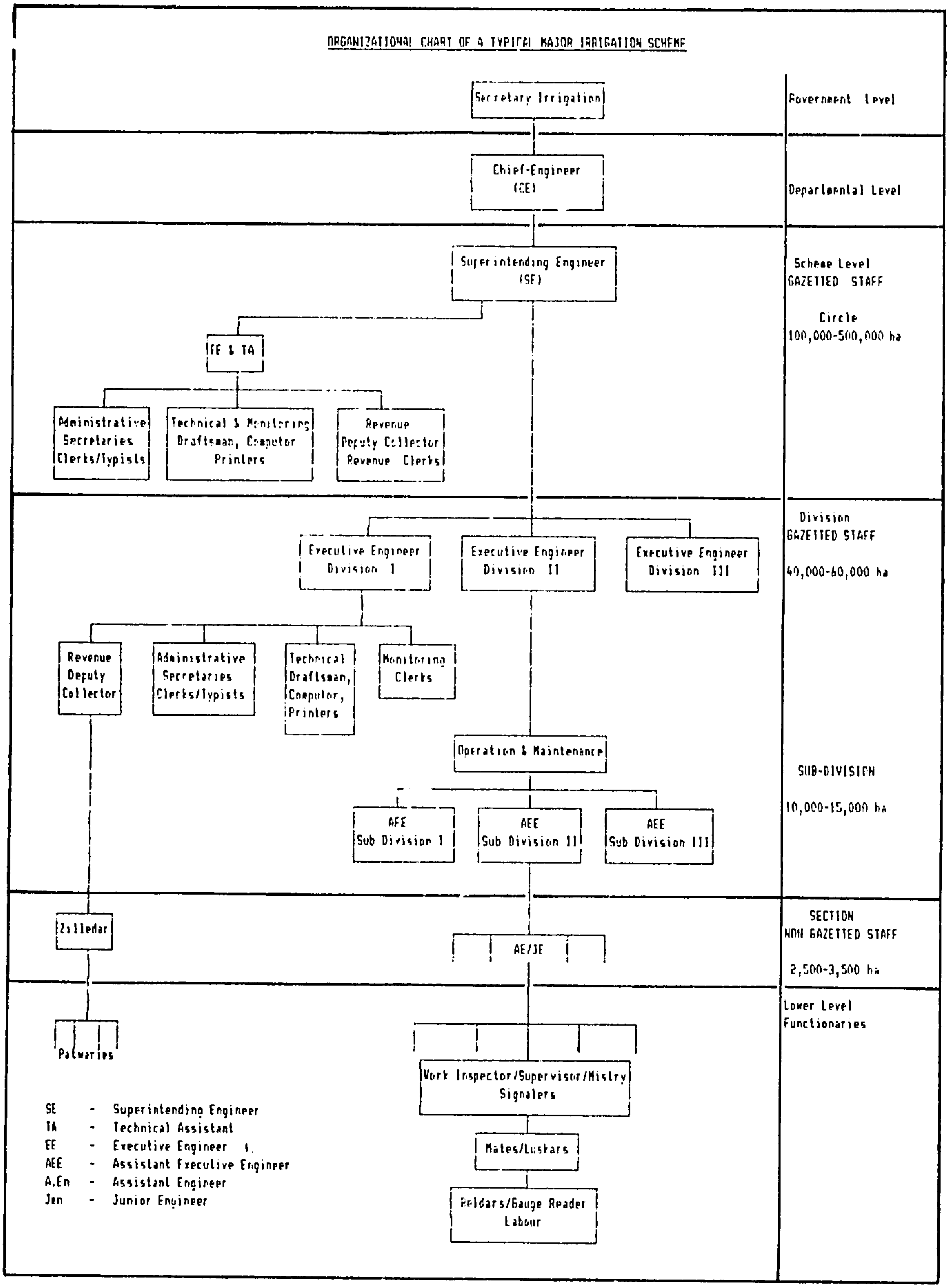



Figure 4.1-1 General Organisational Pattern of an Irrigation Department

Table 4.1-1 A Typical Norm for Deployment of Work Charged Staff on Maintenance

| S.No | Particulars | Staff Category | No | Remarks |
|---|---|---|---|---|
| A. | Minor Irrigation Works (CCA up to 2,000 Ha) | | | |
| 1. | Tanks up to 50 Mcft | Beldar | 1 | for both tanks and canals |
| 2. | Tanks above 50 Mcft | Beldar | 1<br>1 | for tank<br>for each canal |
| B. | Medium Irrigation Works (CCA from 2,000 Ha to 10,000 Ha) & Major Irrigation Works (CCA above 10,000 Ha) | | | |
| 1. | Medium Tanks | Beldar | 4 | For dam & appurtenant work maintenance and day and night watch |
| 2. | Major Tanks | Beldar | 6 to 8 | - do - |
| C. | Canal and Distribution System | | | |
| 1. | General Maintenance of canals | Mate | 1 | for 10 beldars |
| | | Beldar | 1 | for 10 kms up to 25 cusecs discharge |
| | | " | 1 | for 8 kms from 25 cusecs to 100 cusecs |
| | | " | 1 | for 5 km from 100 cusecs to 500 cusecs |
| | | " | 1 | for 3 km beyond 500 cusecs to 1000 cusecs |
| | | " | 1 | for 2 km beyond 1000 cusecs |

Table 4.1-1 (cont'd)

| S.No | Particulars | Staff Category | No | Remarks |
| --- | --- | --- | --- | --- |
| 2. | Regulation of canals | Gauge Reader | 1 | for discharge up to 50 cusecs |
| | | Gauge Reader | 1 | for discharge from 50 to 100 cusecs |
| | | Beldar | 1 | |
| | | Gauge Reader | 2 | for discharge from 100 cusecs to 500 cusecs |
| | | Beldar | 2 | |
| | | Gauge Reader | 3 | for discharge above 1000 cusecs |
| | | Beldar | 3 | |
| D. | <u>Telegraph/Telephone or Wireless Station</u> | | | |
| 1. | at Divisional Headquarters | Signaller/ Telegraph/ Telephone Operator | 2 | per instrument |
| | | Beldars | 2 | |
| 2. | at Sub-divisional | Signaller/ Telegraph/ Telephone Operator | 1 | per instrument |
| | | Beldar | 1 | |
| 3. | Other places | Signaller/ Telephone Operator | 1 | per instrument |
| E. | <u>Inspection Hut and Rest Houses</u> | | | |
| 1. | Inspection hut where no catering arrangements exist | Chowkidar | 1 | |
| 2. | Rest houses class II where arrangements for providing tea only exist | Chowkidar<br>Beldar | 1<br>1 | |

Table 4.1-1 (cont'd)

| S.No | Particulars | Staff Category | No | Remarks |
|---|---|---|---|---|
| 3. | Rest House Class I | Chowkidar | 2 | |
| | | Mali | 1 | |
| | | Beldar | 2 | |
| | | Sweeper | 1 | |
| | | Cook | 1 | |
| | | Receptionist/ Supervisor | 1 | |
| F. | <u>Irrigation Colonies</u> | | | |
| | 1 Colonies up to 25 houses with or without office complex | Chowkidar | 1 | |
| | 2. Colonies with 25 to 50 houses with or without office complex | Chowkidar | 1 | |
| | | Beldar | 2 | |
| | | Sweeper | 1 | |
| | | Artisan | 1 | |
| | 3. Colonies with 50 to 200 houses with or without office complex | Chowkidar | 2 | |
| | | Beldar | 4 | |
| | | Sweeper | 2 | |
| | | Gardener | 1 | |
| | | Mistry | 1 | |
| | | Mason | 1 | |
| | | Artisan | 1 | |
| | | Electrician | 1 | |
| G. | <u>Plantation Nurseries</u> | | | |
| | 1. Nurseries providing minimum 5000 plants per year | Gardener | 1 | |
| | | Beldar | 2 | |

Generally, a mate/munshi controls the work of 10 to 20 labourers. While the labourers may be illiterate, a mate/munshi will be a literate man. The number of beldars required for a maintenance job varies widely since it depends on many factors like type and location of work, labour substitution policy by machines, working conditions, etc. Table 4.1-1 provides some norms for labour, but actual requirements will depend on local conditions. While the labourer employed on maintenance of the dam and watch and ward of the inspection bungalow and site stores is called the chowkidar, the labour employed on canal maintenance is called a beldar.

The functions of a beldar in general are:

a) Jungle clearance, removal of floating weeds;
b) Plantation, pruning of trees;
c) Operation of regulation gates;
d) Watering of banks and service road on canal embankments;
e) Normal maintenance of the channel and its banks, service road, filling of rain cuts and patrolling of channels; and
f) Assisting in survey work and repair of structures wherever required in his beat.

2. <u>Mate/Munshi</u>

The mate/munshi is in charge of about 10-20 beldars. He is generally one among the workers. He enforces discipline, supervises the work of beldars, and ensures productivity. His normal duties are:

a) Marking attendence of the labour working under him;
b) Distributing the work among beldars and getting the same executed as per instructions;
c) Measuring and recording the progress of work and reporting to the supervisor or junior engineer;

d) Keeping watch and ward on the canal and other properties in his beat and reporting to his seniors about any causality, accident, damage, or encroachment upon Govt. property;

e) Keeping account of tools and plant and materials, trees in his beat; and

f) Assisting the junior engineer in taking measurements of works and survey.

3. Gauge Readers

Gauge readers read the gauges at regular intervals as decided by the authorities, at the head and tail of channels, at the head outlet sluice of the dam and at all the off taking points of the distributaries and minors. They maintain a register of gauges for each location. They communicate these gauge readings to the Junior Engineer, Assistant Engineer and Executive Engineer in a prescribed gauge slip every 3 hours or 6 hours or daily as instructed by the authorities. Gauge readers are minimum High School/Matriculate with experience.

4. Signallers/Telegraph and Telephone Operators/Wireless Operators

They are very important links for communicating the canal massages regarding gauges, increasing or decreasing the canal discharges etc to higher authorities. They are as a minimum High School Matriculate with training in telegraph service from the P & T department.

5. Mistries/Supervisors

A Mistry/Supervisor crganises and supervises the work of about 5 to 10 mates as per the type of work and is directly responsible to the Junior Engineer. He is one, who being senior, is promoted from the post of the mate, but he has to be a minimum of High School Matriculate with experience as mate. He ensures discipline and adequate output and quality of work. He collects the daily progress of works from mates and submits to the

Assistant Engineer. He maintains the discharge at the Head outlet and in the channels as per directories from the Executive Engineer by adequately regulating the gate openings. He also maintains the site stores and tools, and plant and field equipments, under the charge of the Junior Engineer. He assists the Junior Engineer in surveys and measurement of works.

The staff category from item 1 to 5 above are not part of the regular staff. They are called 'work charged' staff and are engaged for periods of time for particular work. After completion of one work, their services are generally utilized on the other works.

6. Junior Engineer

A Junior Engineer is an engineering degree holder in Civil Engineering or may also be a engineering diploma holder in Civil Engineering. He is the first step to the engineering hierarchy in the Irrigation Department and is in charge of one section in the irrigation division. The section generally covers an irrigation command area of 2500 ha to 3500 ha.

Within a maintenance unit, he is the key person upon whom depends the achievement of a good standard of maintenance. He is the man concerned with periodical supervision of items that may need maintenance, their surveys, preparation and estimation of works to be done, supervision of work, and measurements of the actual work done at the site for making payments.

He is in-charge of all stores, material and equipments at the site. Also, he maintains the accounts, both their receipts and issues, which he submits to his Assistant Engineer every month. He also maintains the muster/acquittance rolls of the daily-waged or work-charged labourers under his charge. At the close of the month, he submits the rolls to the Assistant Engineer with the progress of work done by that labourer for pass and payment orders. His job descriptions briefly are:

a) Periodic inspection of the system (dam, canals, roads, building, etc) for the command area under his charge and preparation of maintenance plan/estimates for this area;
b) Submission of the maintenance plan to the Assistant Engineer for arranging approval;
c) Organising the maintenance work to be done either with machines or manually;
d) Ensure proper technical standards while doing the maintenance work;
e) Ensure adequate safety measures during maintenance works; and
f) Measurements of the maintenance work completed.

7. Assistant Engineer

An Assistant Engineer is in-charge of a sub-division comprising of 4 to 5 Junior Engineers and controls an irrigation command area of nearly 10,000 to 15,000 ha. An Assistant Engineer may be a degree holder in Civil Engineering or a diploma holder with experience. He may be a direct recruit, if a degree holder through the Public Service Commission, but some posts are also filled by promotion from the post of Junior Engineer. The percentages and eligibility for direct recruitment and promotion vary from state to state.

Apart from general duties of organising and administering the maintenance works, he is responsible for the following jobs:

a) Evaluate annually the maintenance work needed;
b) Plan the maintenance work in order of priority so as to achieve maximum utilization of the available budget;
c) Prepare technical and economic specifications of the work to be undertaken by contract;
d) Arrange timely sanction of the maintenance estimates from the Executive Engineer;
e) Order and account for material and tools and plants;
f) Supervise the upkeep of equipments in his charge;

h) Issue instructions to the subordinates regarding the maintenance work to be done; and
g) Pass payment to labourers and contractors.

8. Executive Engineer

An Executive Engineer is in charge of an irrigation division comprising 3 to 4 subdivisions, i.e. he supervises the work of 3-4 Assistant Engineers and controls an irrigation command area of nearly 40,000 ha to 50,000 ha. An Executive Engineer is promoted among the Assistant Engineers based on seniority cum merit and has generally an experience record of 10 to 15 years as an Assistant Engineer before promotion.

An Executive Engineer is the head of all maintenance activities in the division and is competent to sanction all the maintenance estimates upto the budget provisions. Generally, he is responsible for the following jobs so far as maintenance is concerned:

a) Sanction the maintenance estimates as per budget provisions;
b) Decide the methods of implementation for the maintenance programme, whether departmentally or contractually;
c) Get the maintenance of the system done as per the programme and make payment for the work done;
d) Check same percentage of the work done quantitatively and qualitatively;
e) Make payment to the labourers (skilled and unskilled) employed on maintenance;
f) Plan proper regulation and distribution of water among the farmers as per availability of water, and convening water distribution committees;
g) Listen to the farmers' petition and give judgements as per provisions in the Irrigation Act and rules of the State;
h) In some states, he is also in-charge of assessment and collection of water charges and depositing them in the treasury; and
i) He is to function as per directions of the Government or his superiors from time to time and is responsible to them.

His superiors in the departmental hierarchy are a Superintending Engineer and a Chief Engineer. A general staffing pattern of an Irrigation Department, which is generally on a command area basis, is given as Figure 4.1-1.

## B. Job-Related Functions for Implementing Improved Irrigation System Maintenance Practices

The field maintenance activities are done by the Irrigation Division and sub divisions with 3 to 5 sections under each as described earlier under normal maintenance job functions. Each section, which is headed by a Junior Engineer, has a crew of mistry, mate, gauge readers and beldars. Their functions in relation to improved irrigation system maintenance practices are described below:

### 1. Maintenance Survey of Flow Control Structures

a) The Assistant Engineer in charge of operation, as well as maintenance, makes a list of flow control structures to be calibrated for discharge measurement in the operation plan;

b) The Assistant Engineer provides this list of structures to each Junior Engineer for the area under his charge; and

c) The Junior Engineer conducts the maintenance survey accompanied by the mistry/supervisor when in that portion of the reach serviced by that mistry/supervisor.

### 2. Essential Structural Maintenance Plan

a) Based on the Operations Control Maintenance Surveys, the Junior Engineers, each give their plan of works to be done with necessary explanatory notes and sketches to the Assistant Engineer;

b) The Assistant Engineer compiles and prepares a complete plan and submits it to the Executive Engineer;

c) The Executive Engineer technically approves the Essential Structural Maintenance Plan, or submits the plan to the Superintending Engineer if it is beyond his powers to approve.

3. Hydraulic Survey of Structures and Channels

a) The Executive Engineer issues a Memorandum to the Assistant Engineers to begin the Hydraulic Survey of Structures and Channels;
b) Each Assistant Engineer develops detailed work plans for the extent of the hydraulic survey and the required accuracy of the measurements, which are issued to the Junior Engineers under his supervision;
c) The Junior Engineer conducts the hydraulic surveys accompanied by the mistry/supervisor when in those channel reaches or at those situations serviced by that mistry/supervisor.

4. Develop Discharge Ratings for Flow Control Structures

Calibration is the process by which discharge ratings (stage-discharge relationships) can be developed. With this process, the hydraulic functioning of the structures in the main canal or other channels in the system is determined. Field calibration is necessary if the dimensions of the structures existing in the field differ from those required as per design or as rated in the hydraulic laboratories. For field calibration on any control structure, waterr discharge rates corresponding to one or two flow depths are recorded. Discharges can be measured by current meter if the channel is large, or by Parshall or cutthroat flumes if the channel is small. For meaningful data, at least four to five readings are necessary. Each reading will contain the upstream depth measurement and corresponding flow rate information. Based on this data, a discharge rating curve is plotted. Calibration data is collected separately for modular flow and non-modular flow conditions. In a modular flow condition, one reading upstream from the constriction with the corresponding flow rate is required, while for non-modular flow two readings are required for each discharge measurement - one upstream and another downstream of the constriction.

The Junior Engineer with the gauge reader under his supervision will be responsible for doing the discharge ratings in his area of responsibility. He will be responsible for ensuring that correct data is collected as he will be responsible for subsequent data analysis.

The Assistant Engineer will periodically participate in the field work to ensure that proper procedures are being followed.

5. Collect Water Measurements and Channel Loss Data

The Assistant Engineer will make out schedules for conducting the inflow-outflow tests to evaluate channel losses for various reaches in the irrigation channel network. This may have to be supplemented with ponding tests for some reaches.

a) The Executive Engineer should review and then approve the work schedules prepared by the Assistant Engineers for conducting the inflow-outflow and ponding tests.
b) While conducting these tests, the Assistant Engineer will coordinate the operation of the main canals, distributaries and minors in conjunction with the field data collection.
c) The Junior Engineer and supervisor will be responsible for the field data collection.
d) The Junior Engineer will be responsible for the data analysis
e) The Assistant Engineer will review the data analysis individually with each Junior Engineer and then compile the results.
f) The Executive Engineer will review the final data and ensure that field results are satisfactory; if not, he will state which measurements are to be repeated, or additional tests to be conducted.

6. Obtain Maintenance Information from Farmers

a) The Junior Engineers for their respective sections will be responsible for convening the maintenance committee meeting with farmers on a fixed day, fixed place and fixed time. The Assistant Engineer will be the convener of the committee.

b) Each Junior Engineer will enter: i) the problems/suggestions of the farmers in a page numbered based register on the left half of the page; and ii) record the action taken on each in the right half of the page by the time the next meeting takes place at the same station.

c) The Assistant Engineer will see to each item for the action taken and record his instruction, if any, for further action.

d) The Executive Engineer should also attend at least one such meeting in a month and watch for the actions taken on the farmers' problems/suggestions.

7. Diagnostic 'Walk Through' Maintenance Survey

a) The 'walk through' survey is conducted by the Junior Engineer who prepares all the field notes and sketches.

b) The mistry/supervisor should also accompany the Junior Engineer so that he gains experience about the maintenance problems and also the causes of such problems.

8. Normal Maintenance Programme Report

a) Each Junior Engineer will compile a listing of normal maintenance activities, and the cost of each activity, for the command area under his jurisdiction for the past 3 budget years. This compilation will be submitted to the Assistant Engineer.

b) The Assistant Engineer will compile and edit the materials received from the Junior engineer under his supervision. The compiled material will be submitted to the Executive Engineer.

c) The Executive Engineer will be responsible for preparing the Normal Maintenance Programme Report. He should consult with the Assistant Engineers for any additional information needed. The completed report should be forwarded to the Superintending Engineer for review and comment.

d) The Superintending Engineer should review the Normal Maintenance Programme Report and make comments to the Executive Engineer if any further improvements are necessary. When approved by the Superintending Engineer, the report should be forwarded to the appropriate Chief Engineer for information.

## 9. 'Catch-Up' Maintenance Plan

a) The Junior Engineer, based on the hydraulic surveys, maintenance committees' suggestions and the diagnostic 'walk through' survey, should prepare a listing of Priority Maintenance Needs for the portion of the system under his charge. He will also prepare the cost estimate for each Priority Maintenance Need. This material will be submitted to the Assistant Engineer.

b) The Assistant Engineer will compile the materials from each of the Junior Engineers under his supervision and prepare a single compilation of all materials.

c) The groups of Assistant Engineers will prepare a 'catch up' or system deficiency maintenance plan based on the above surveys and prepare the cost estimates for total project. In addition, they will write the other sections of the 'Catch-up' Maintenance Plan under frequent consultation with the Executive Engineer.

d) The Executive Engineer will advise the Assistant Engineers on the requirements for preparing a 'Catch-up' Maintenance Plan and will review each section of the plan as it is prepared. The Executive Engineer is responsible for final editing of the plan.

e) The 'Catch-up' Maintenance Plan should be forwarded to the Superintending Engineer for review and comments (if changes are required by the Executive Engineer). Upon approval, the plan should be forwarded to the appropriate Chief Engineer for information and arranging a budget.

## 10. Annual Maintenance Work Plan

a) The Executive Engineer should provide a directive to the Assistant Engineers giving guidelines for the following budget year for : (i) the Normal Maintenance Programme; and (ii) the Priority Maintenance Needs (PMN) under the 'Catch-up' Maintenance Plan.

b) Each Assistant Engineer should provide written guidelines to the Junior Engineer regarding the preparation of normal and 'catch-up' maintenance activities to be undertaken during the next budget year.

c) Each Junior Engineer would submit these plans with cost estimates to the Assistant Engineer who will compile them and review and suitably modify, if necessary.

d) The Assistant Engineer will then prepare separate plans for Normal Maintenance and Priority Maintenance Needs for the following budget year.

e) The group of Assistant Engineers will prepare a draft of the Annual Maintenance Work Plan in consultation with the Executive Engineer.

f) The Executive Engineer will do the final editing of the proposed cost estimates and implementation of the Normal and PMN works to be undertaken during the following budget year.

g) The Annual Maintenance Work Plan should be forwarded to the Superintending Engineer for his review and comments requiring correction by the Executive Engineer. Upon final approval, the document should be forwarded to the appropriate Chief Engineer for information.

## 11. Annual Maintenance Completion Report

a) Each Junior Engineer will submit a monthly progress report for his section to the Assistant Engineer for the completed maintenance works giving details of the men and material used with details of expenditures.

b) The Assistant Engineer would compile the details of expenditure for all the sections and submit the same to the Executive Engineer.

c) The Executive Engineer would compile the reports from all of the Assistant Engineers into a final Annual Maintenance Completion Report, which would be forwarded to the Superintending Engineer.

d) The Superintending Engineer will review the Annual Maintenance Completion Report, send comments to the Executive Engineer, and forward the report to the appropriate Chief Engineer for information.

12. <u>Preventive Maintenance Plan</u>

a) The Executive Engineer will issue written guidelines to the Assistant Engineer regarding the preparation of a draft Preventive Maintenance Plan.

b) The group of Assistant Engineers will prepare the draft Preventive Maintenance Plan in consultation with the Junior engineers and the Executive Engineer.

c) The Executive Engineer will determine when the Assistant Engineers have prepared a satisfactory draft document. Then, he will be responsible for the final editing of this plan in consultation with the Superintending Engineer.

d) The Preventive Maintenance Plan should be submitted to the Superintending Engineer for approval and forwarding to the Chief Engineer for information and budget arrangements.

## 4.2 <u>Administrative Approval and Accountability</u>

### A. Administrative Review and Approval

Although there would be some variation from one State compared with another State in India, in general, the process of preparation, review, approval and funding would be similar for: (1) the Essential Structural Maintenance Plan; (2) the "Catch-up" Maintenance Plan and the Annual Maintenance Work Plan associated with implementation and completion of Priority Maintenance Needs; and (3) the Preventive Maintenance Plan.

The procedures are described below.

1. <u>The Junior Engineers' Responsibilities:</u>

a) Preparation of the detailed cost estimates based on necessary plans- (longitudinal section, X-sections and other drawings, etc.) with details of the quantities of various items of work involved;

b) Preparation of the abstract cost estimate for the above quantities of the various items of work to be executed; and

c) Submission of the above estimates (both abstract and detailed) to the Assistant Engineer.

2. The Assistant Engineers' Responsibilities:

a) Review of the estimates --- if any additions and deletions are to be made, he would have it done by the Junior Engineers;

b) Checking of the estimates for quantities, unit costs, and total cost; and

c) Submission of these estimates to the Executive Engineer with his comments and recommendations

3. The Executive Engineers' Responsibilities:

a) Review of the estimates --- if any further modifications are required, he would have it done by the Assistant Engineers;

b) Checking of the estimates;

c) Approval of the estimates;

d) Ensuring that the estimates sanctioned for maintenance during the financial year are within the allocated budget for his division;

e) Conveying this sanction to each Assistant Engineer for execution during that very financial year; and

f) Planning all the maintenance works in his division according to priority, and if additional funds are required during that financial year, he makes out a complete case and requests the Superintending Engineer to arrange for additional funds.

4. The Superintending Engineers' Responsibilities:

a) Arranging additional funds if required by the Executive Engineers under his supervision; and

b) Preparing a complete case with his recommendations to the Chief Engineer for additional funds, or request for reappropriation of budgets from one division to the other, if it is possible.

5. <u>The Chief Engineers' Responsibilities:</u>

a) Considering the Superintending Engineers' request for additional budget;

b) Either recommending additional budget from the State Government, or arrange for reappropriation, if possible, from one division to the other after reviewing the overall budget needs of each division; and

c) Ensuring with the State Government that the budget to be provided for maintenance is quite adequate.

**B. Budget Control and Accountability**

In order to document the costs of various maintenance activities, it is very important for the Irrigation Department to have good records of the actual costs, including the variability that occurs for each type of activity. This provides the necessary records for obtaining appropriate levels of funding for maintenance at irrigation projects. This type of documentation is also very useful for future planning to improve the maintenance at other irrigation projects.

There are many advantages in conducting the Diagnostic "Walk-Thru" Maintenance Survey, one of them being the more precise documentation of actual maintenance requirements. One of the additional benefits is the accountability provided by listing each maintenance need. The items to be included in the Annual Maintenance Work Plan can be selected; when a maintenance activity is completed it can be moved to the Maintenance Completion List and the costs added.

This type of process documentation also facilitates inspection of the work by the Superintending Engineer and Chief Engineer to assure quality control in the maintenance procedures and by the Executive Engineer to quickly review the progress being made. The maintenance documentation also facilitates periodic evaluation by other Irrigation Department staff having a concern with improving irrigation system maintenance practices.

### C. Submittal of Annual Maintenance Completion Report

The Annual Maintenance Completion Report should list each maintenance need contained in the Field Notes appended to the "Catch-Up" Maintenance Plan that has been corrected during the year, along with the actual cost. Then, these results should be summarized onto the same forms used in preparing a request for additional budget for the Annual Maintenance Work Plan.

A discussion should follow on "Comparison of Actual Costs with Estimated Costs." The reason for variations if any should be given, including whether the reasons are "site specific" to the irrigation project, or more general in nature and would also apply to other projects.

The next section should be on "Lesson Learned" during implementation of this Learning Process for Improving Irrigation System Maintenance Practices. First of all, any improved techniques for accomplishing particular maintenance activities should be presented in sufficient detail that the information could be transferred to other irrigation projects that might benefit from such information. Also, the lessons learned might be with respect to administrative aspects of implementation.

The final section of this report should be "Recommendations for Improving the Implementation of Irrigation System Maintenance Practices." When completed, copies of the Annual Maintenance Completion Report should be forwarded to the Superintending Engineer and Chief Engineer by the Executive Engineer.

## Chapter 5

## MAINTENANCE OF THE SYSTEM

### 5.1 Physical and Social Phenomena Causing Maintenance Problems

A general description of the physical phenomena occurring in irrigation systems needs to be presented in order to understand the relationship between the field maintenance inventory and the proposed solutions contained in the form of maintenance needs, including activities, costs, and manpower.

The most serious problem in earthen channels is sedimentation, which is often the case for lined channels as well.

For lined channels, the most serious problem is the formation of cavities behind the lining panels which eventually leads to the actual failure of the panels themselves.

Third, erosion is a serious problem in some channels, but not others; the theoretical approach to this problem is to prevent erosion so that additional sediment cannot enter the irrigation channels.

Fourth, seepage losses from earthen channels can be quite significant in canals, branch canals, distributaries, minors and tertiary channels, particularly when operating at high water levels.

Fifth, vegetative and aquatic growth is a difficult problem especially as the present level of technology generally allows for such growth to be removed by hand or sometimes mechanically.

Many maintenance needs in an irrigation system are created because of social reasons in addition to the physical reasons given above, such as:

- Cutting of canal embankments or inserting extra unauthorized pipe outlets below the bank to draw more water than one's share.

- o Putting obstruction dikes in the canals to raise the water level for drawing more water into the outlets.
  Tampering with the outlets.

- o Lack of adequate maintenance within the tertiary system (water courses) including field drains and not following the "Warabandi".

- o Allowing the cattle to cross or to bathe in the canals.

- o Unauthorized use of the canal service road by carts, trucks, tractors, etc.

- o Unauthorized cutting of canal plantation.

- o Removal of lining blocks or panels for personal use.

- o Removal of the gauge strips from the gauge walls or gauge sites.

To provide further insight into solutions to the various maintenance problems, the role of drainage is also discussed. To complete the general picture about maintenance needs in an irrigation system, the impact of various structures upon maintenance requirements is also presented

## A. Catchment and Reservoir

The watershed or the catchment area which brings the runoff into the reservoir through the rivers and streams should be maintained in good condition. Any lack of attention and care to this sub-system would deteriorate the designed performance of the reservoir and the irrigation system as a whole. When reservoirs are formed, large areas of forest lands are submerged, trees are cut to form roads and colonies. The labourer also disturbs the sub-system of the catchment during construction. The denudation of forests on the hills causes phenomenal increases of sediment transport into the river and eventually the reservoir, thereby adversely affecting its useful life. Changes in land use practices also affect the hydrology and the transport of sediment and debris from the catchment.

Silt accumulation in the reservoir is a major problem. In some reservoirs the rate of siltation is alarming because of rapid reductions in the storage capacity. Encroachment in the foreshore areas for cultivation gives rise to accelerated soil erosion and silt accumulation. Aquatic weed growth in water submergence areas is a problem because some of this growth eventually reaches the canals. In the reservoir itself, this aquatic growth sometimes chokes the head sluice, thereby affecting its performance.

### B. Head Works

The headworks are usually earthen, rockfill, masonry or concrete dams with appurtenant works. They may be gated or also ungated. While the masonry and concrete dams have the least maintenance needs, the earthen and rockfill dams need a lot of timely maintenance; but timely inspection and watch is needed for all.

Causes of maintenance problems which may be common to all types of dams are:

- leakages from gates and shutters due to worn out seals;
- corrosion in gate parts;
- mechanical or electrical faults in the mechanism resulting in non-lifting of spillway gates at the time when excess flood is to be passed;
- similar faults in the head outlet sluices for release of water to the canals;

- erosion and retrogression of rocks below the bucket or apron of the spillways; and

- leakage through the body of the dam.

Other causes peculiar to the masonry or concrete dams may be choking of the drain pipes and impairing of ventilation arrangements.

As regards earth and rockfill dams, the causes may be:

- damage to embankment - its pitching due to excessive wave action;

- growth of jungle/weeds on the slopes;

- Rain cut on slopes and pot holes on the top of the bund;

- damage to or choking of the filter toe;

- lowering of the top of the bund at places by constant movement of man and animals over it; and

- settlement or seepage at junctions of masonry and earth.

## C. Earthen Channels

Though earthen canals in India are designed and constructed with nonsilting and nonscouring velocity in order to achieve their regime section, still excessive sedimentation and scouring is perhaps the most common problem affecting the performance of the entire system due to the following reasons:

- Excessive sediment entry from the reservoir into the main canal.
- Disproportionate withdrawals of sediment by branch canals.
- Disproportionate withdrawals of sediment by outlets.
- Improper side slopes and berms in high-cut reaches.
- Prolonged running of canals with discharges less than the designed full supply discharge, causing lower velocity and deposition of sediment.
- Excessive weed growth - choking of sections of canal, thereby reducing the velocity of flow and causing the deposition of sediment.
- Drifting of sand.
- Prolonged heading-up at control points.
- Haphazard desilting during maintenance.
- Re-entry of excavated earth/silt by rain and wind.
- Prolonged running of canals with excessive discharges causing higher velocities of flow and consequently eroding of the sides and bed of the canal.
- Improper regulation of control structures, which also causes erosion of canal banks and bed.
- Damaged structures, especially the falls, are mainly responsible for erosion.
- Canal banks get eroded from heavy rainfall and animal drinking.

The most significant problem with earthen channels is seepage losses. There are tremendous variations in seepage loss rates from one reach to another in an irrigation channel network. Also, as the depth is increased in an irrigation channel, the seepage loss rate will increase. Raising the water level in a channel just a few centimeters above the usual operating level may more than double the seepage loss rate, which is measured in cubic meters per day of water loss per square meter of wetted surface area.

The type of soil in which the irrigation channel has been constructed will certainly affect the seepage losses. Clay soils can be expected to have much lower seepage loss rates than sandy soils. However, the seepage loss rates can be greatly affected by surface sealing by sediment, particularly in more porous soils.

The nearby groundwater levels also play a major role in the seepage losses from earthen channels. The greatest losses will occur when the groundwater levels are far below the invert or bed of the channel, say five meters or more below. If the surrounding groundwater levels correspond with the water level in the irrigation channel, then there should practically be no seepage losses. For an irrigation channel constructed in a cut area, the nearby groundwater levels may be higher than the water level in the channel, so there may be groundwater flows into the channel and the reach is said to "gain" water; the primary difficulty with this situation is that the groundwater inflows may weaken the channel banks and result in sloughing and subsequent erosion of the banks.

The greatest contributing factor to high seepage losses in earthen channels is the biological life existing in the channel banks. This is particularly the case in the capillary fringe above the phreatic line, which by definition is the line demarcating saturated soil moisture flow from unsaturated flow. The capillary fringe immediately above the saturated soil provides an ideal living environment for many forms of biological life, including rodents, worms and insects. Excavation of a channel bank is likely to disclose small caverns and numerous very small diameter channels. In fact, careful inspections of the channel banks may show small leakage holes in the embankment. In some cases, there will be hundreds of these small leakage holes near the base of the channel embankments along a reach length of only one kilometer. Consequently, even irrigation channels constructed in clay soils may have very high seepage loss rates, particularly when the operating water levels in the channel are high.

Another problem, particularly in tertiary channels, is that farmers will cut the bank of the channel in order to take water. With time, this results in many cuts along the channel. Besides increasing seepage losses, some of these cuts also provide small holes through the channel bank that allow leakage. Without adequate maintenance, the seepage and leakage losses from earthen channels will continue to increase with time. Many times, the channel banks (or embankments) need to be rebuilt in order to decrease water losses.

When an irrigation channel is being operated below Full Supply Level (FSL), oftentimes farmers will construct a dike in the bed of the channel so as to increase the water level upstream. This is done in order to obtain water through their outlet, or to increase the discharge rate through the outlet structure. This situation creates two problems. First of all, the upstream velocities will be decreased so that more sedimentation occurs. Secondly, the seepage and leakage losses through the embankments will be increased. Also, the downstream channel below the dike will get eroded due to creation of a fall over the dike, which will also result in sedimentation further downstream.

In the vicinity of a village, or a cluster of houses, facilities need to be provided for human bathing and clothes washing, as well as animal bathing and crossing. Otherwise, erosion will occur at these locations during the monsoon rains, thereby increasing the flow of sediments into the channel. Bathing ghats (steps) are constructed of brick on the embankment at a slope of 3:1 or flatter to provide human access to the irrigation waters (Figure 5.1-1). A short distance downstream, a ramp will be constructed for animal access using a slope of 3:1 with bricks on-edge with some protruding bricks that allow the animals a foot-hold (Figure 5.1-2B).

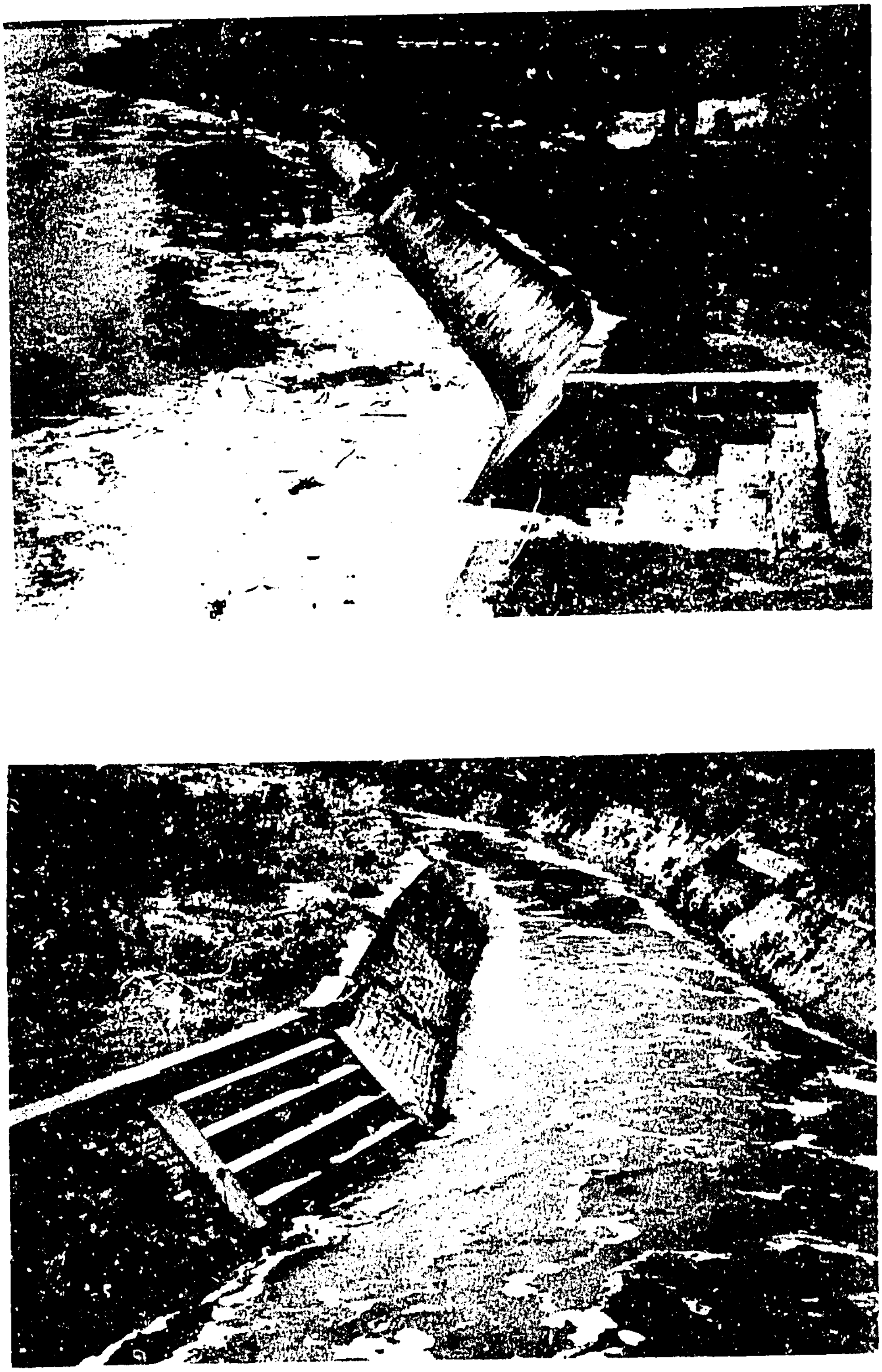
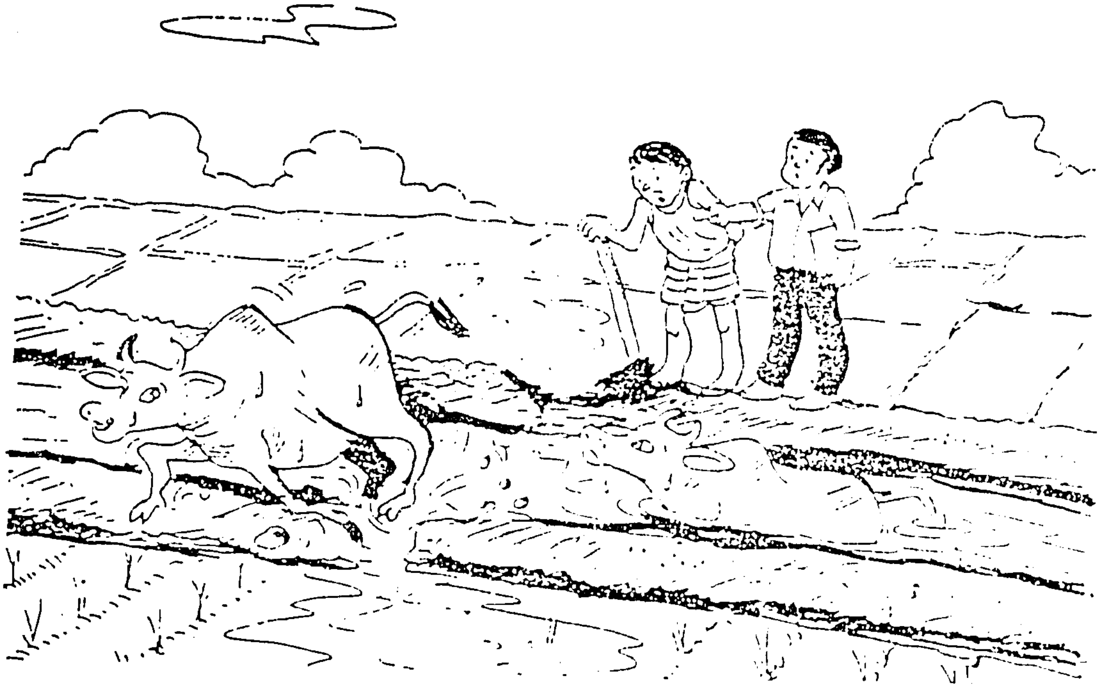


Figure 5.1-1. Bathing Ghats (Steps) to Provide Human Access to the Irrigation Channel for Bathing and Clothes Washing.



The Animals Are Yours

So Also Channel

"SAVE CHANNEL"

Figure 5.1-2 A.Save Channel

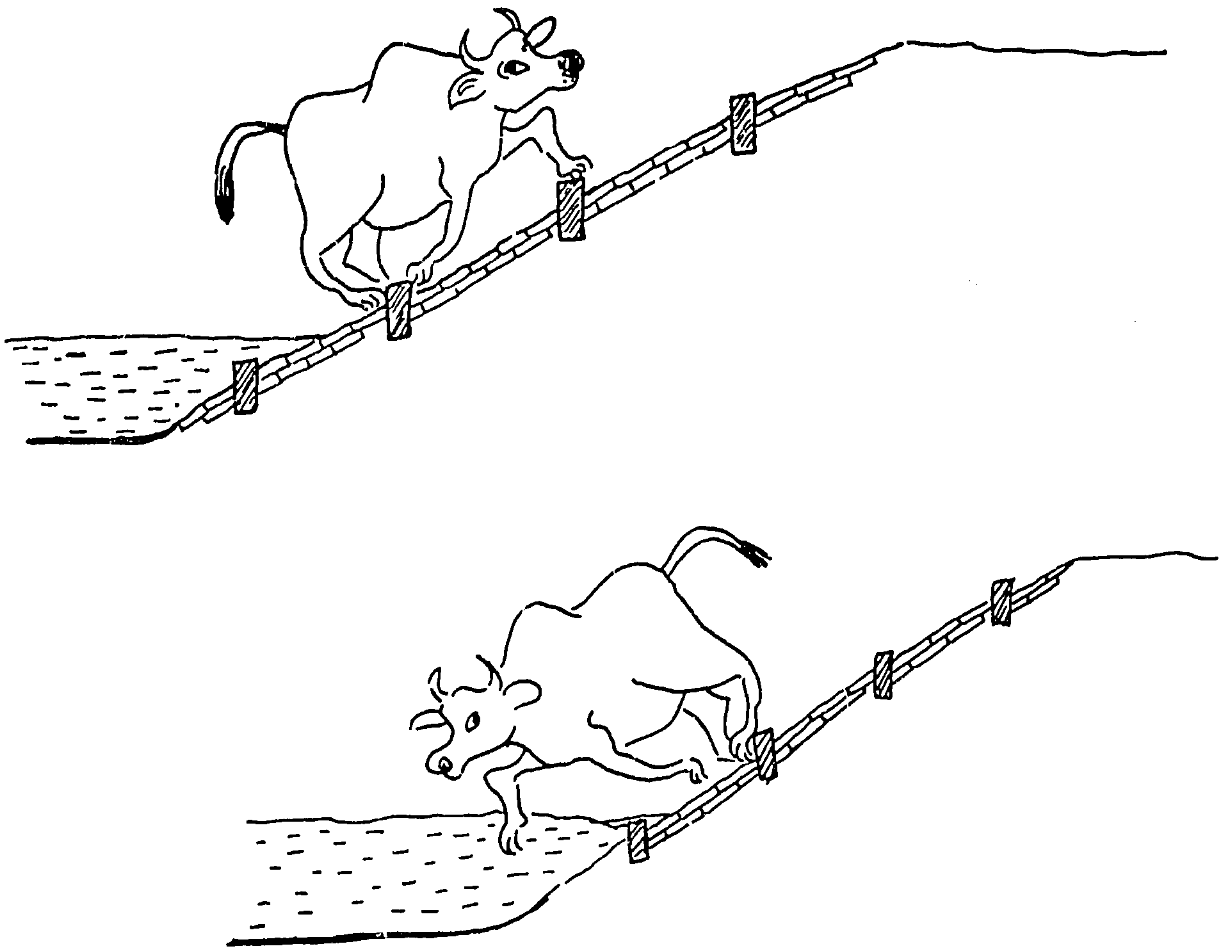


Figure 5.1-2 B. Brick Ramp for Animal Access to the Irrigation Channel for Bathing and Crossing.

## D. Lined Channels

Canals are lined to improve the coefficient of roughness for increasing the velocity of flow, and to have less absorption (bank storage) and seepage losses. Material used for lining is concrete (insitu or reinforced concrete slabs) or brick/ tiles, etc. Velocity of flow is such that it does not allow sediment deposition except near cross regulators. The lining material is strong enough to take care of erosion of the sides and bed. It, therefore, requires little maintenance, provided it has been properly constructed. The routine activities of maintenance are replacement of joints, slabs or tiles and weed control on joints.

However, if the lining is not properly designed and constructed, then it creates maintenance problems. Backwater or subsurface water pressure behind the lining can cause cracks and bulging/eruption of lining. Sometimes, the damage to lining is so extensive that its repairs cannot be done as routine maintenance. It can be properly repaired by providing subsurface drainage and pressure release valves during long closure periods, but the cost involved is also quite high.

Particularly for smaller channels lined with blocks, local people may very likely remove some of the blocks. The blocks are reused as steps on the embankment above the lining, for sitting, or for washing clothes.

The most serious long-term damage to the lined irrigation channels is the formation of cavities behind the wall panels such as shown in Figures 5.1-3 and 5.1-4. The systematic physical process of cavity formation followed by eventual failure of the lining wall panel(s) results from the combination of lining panel joints and monsoon rains, with many other contributing factors. This problem is further aggravated in locations having sandy soils.

Generally, the lining panels are constructed of bricks/ tiles, concrete, or reinforced concrete slabs. In some cases, there are periodic open joints to accommodate expansion and contraction, whereas in other cases, the joints are filled with either mortar or asphalt.

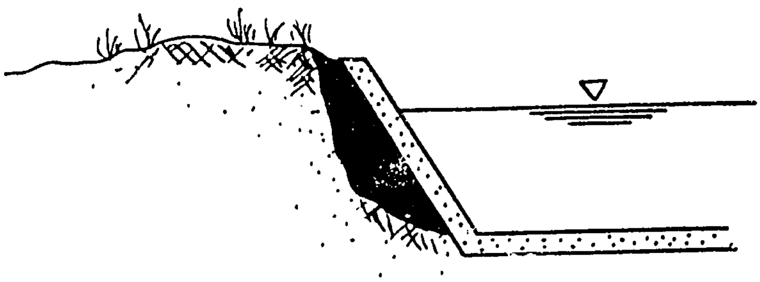


Figure 5.1-3. Medium-Sized Cavity Behind Concrete Lining.

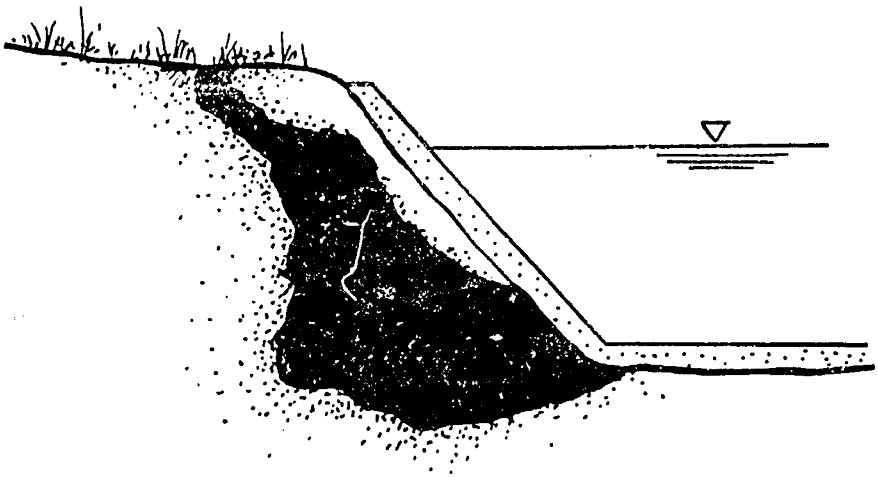


Figure 5.1-4. Huge Cavity Behind Concrete Lining.

The process of cavity formation most commonly begins with seepage through the joint into the irrigation channel. This seepage also carries some sediment into the channel, which results in a small cavity near the joint. Since the easiest path of the seepage water is vertically along the joint, it does not take too long for the cavity to progress upwards until there is an actual opening at the top of the lining wall panel. Then, as surface runoff during the monsoon rains starts running down the embankment into the open cavity, it enlarges even more.

During this process of cavity enlargement, the concrete panel begins to deteriorate. First of all, very small amounts of brick or concrete on the sides of the joint opening begin to break off, most commonly just above the floor level, but sometimes much higher, leaving a small hole in the lining (Figure 5.1-5). This small hole further aggravates the problem by allowing the cavity underneath to further enlarge, so that larger chunks of brick mortar, brick or concrete eventually break off (Figure 5.1-6). Hairline cracks will likely occur, first near the joint, but perhaps later across an extensive length of mortar between bricks or the full width or height of a concrete panel. At this point, water in the irrigation channel is also eroding the underlying soil. The filling and emptying of the irrigation channel, which occurs frequently, further aggravates this process of soil erosion. The eventual outcome of this physical phenomenon is the failure of the lining panel. This process is accelerated if surface runoff from the roadway or berm is allowed to flow towards the irrigation channel. If the cavity has formed an opening to the top of the lining, then some of the surface runoff will flow into the cavity, thereby increasing the seepage flow and sediment transport through the joint. Thus, the cavity becomes enlarged even more rapidly. If the soil surface is depressed below the top of a panel, then the surface runoff will pond behind the panel and is likely to move along the interface between the soil and concrete, eventually reaching a joint as an outlet.

Figure 5.1-5. Damaged Concrete Lining with Berm Surface Erosion.

Figure 5.1-6. Damaged Concrete Lining in a Cut Area.

Lined irrigation channels located in cut areas are highly susceptible to cavity formation and eventual failure of the lining panels (Figure 5.1-7). (In contrast, lining in fill areas, such as shown in Figure 5.1-8, are usually in excellent condition unless the fill was not properly compacted.) The cut banks are easily eroded and eventually surface runoff containing high sediment concentrations are being transported into the irrigation channel (Figure 5.1-9). Also, the soil is saturated to a height higher than the top of the panels; this results in seepage flow over the panels in some cases, as well as definitely increasing the seepage rate and sediment transport through the joints. In addition, seepage continues to occur for many more days after a rainfall event or canal closure because of the large volume of stored soil-water, (absorption or bank storage).

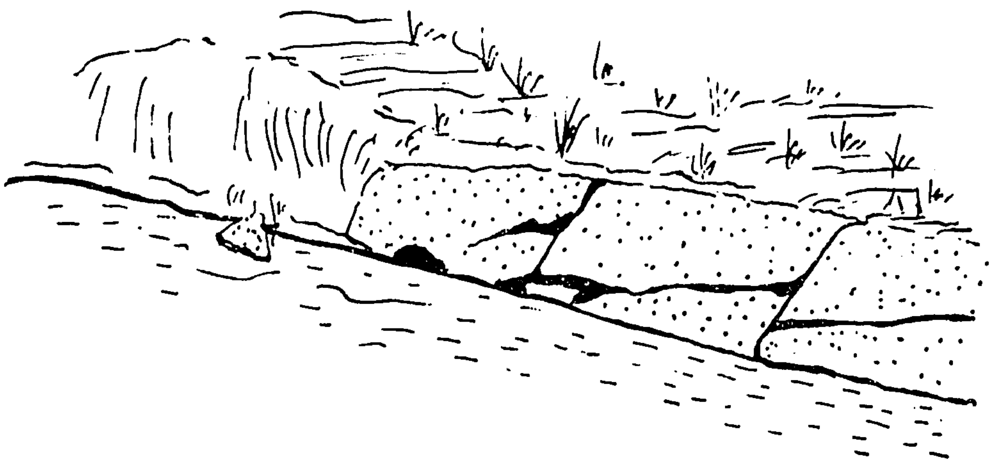


Figure 5.1-7. Damaged Concrete-Lined Canal in a Deep Cut Area.

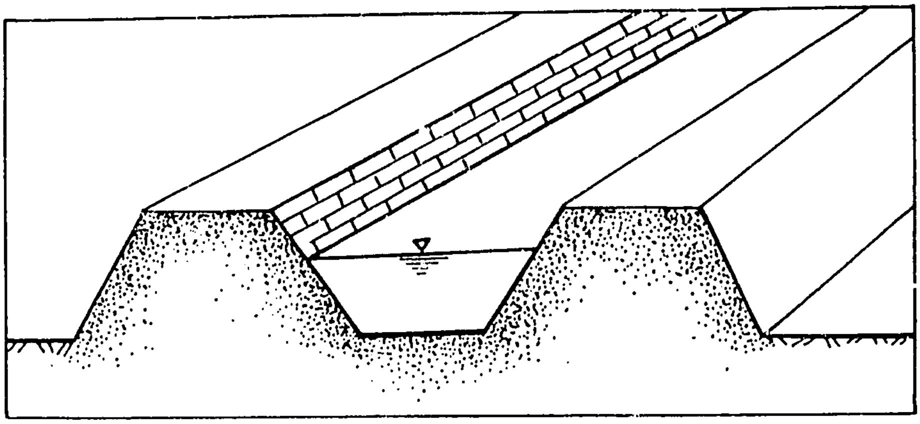


Figure 5.1-8. Lined Channel in Excellent Condition because Adjacent Land Is Below the Invert Elevation.

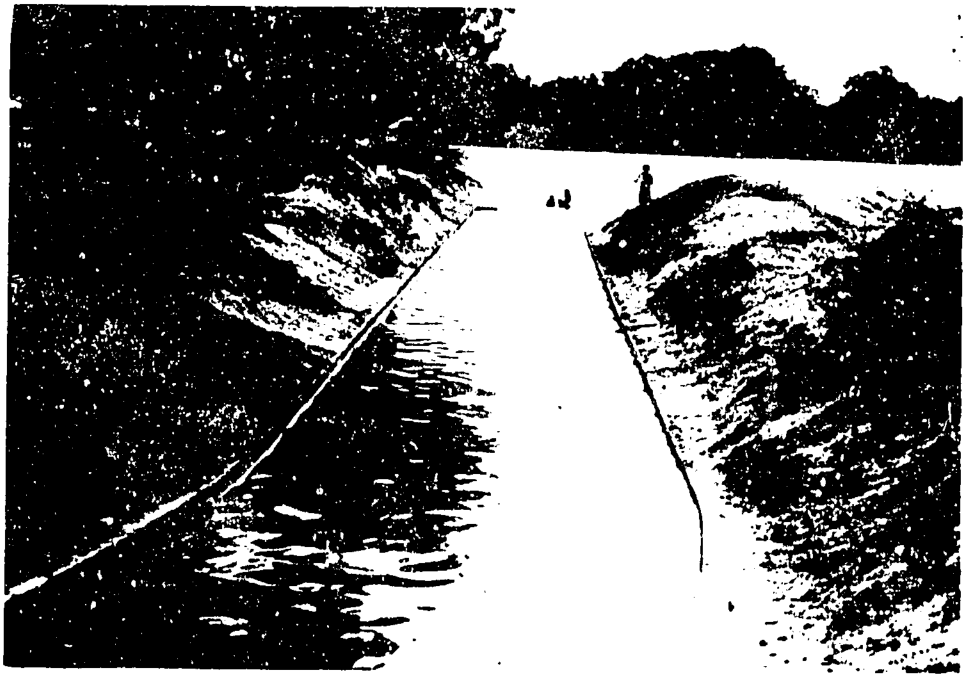


Figure 5.1-9. Sediment Lying on Berm Embankment That Will Erode and Wash Sediment into the Irrigation Channel during the Next Monsoon Season.

## E. Irrigation Channel Embankments

The physical environment of an irrigation channel embankment plays a tremendous role in expected maintenance problems. Examples of a fill embankment, a cut embankment, and a balanced cut-fill embankment are shown in Figure 5.1-10. The most ideal situation is the balanced cut-fill embankment. For earthen channels, the fill embankment will likely present the most serious maintenance problems. For lined channels, a cut embankment presents a serious threat to the lining, where frequently failure of the lining occurs, because of hydraulic pressures behind the lining walls and seepage flow into the channel through the lining joints; whereas, a fill embankment is an ideal physical situation for a lined channel (Figure 5.1-8). For earthen channels, cut embankments also present maintenance problems due to erosion from rainfall (and sloughing of cut natural ground due to hydraulic pressures resulting from saturation).

### 1. Enroachment

A major problem with earthen fill embankments is leakage as a result of biological life living just above the phreatic line. In particular, rodents burrowing holes in the embankment pose the greatest threat of leakage threatening the safety of the embankment. Usually, rodent holes can be seen above the water surface level in the irrigation channel; opening and filling these holes with soil that is rammed is a good preventive maintenance practice. More importantly, the toe of each outside bank should be carefully inspected for visible leakage from the embankments. This can easily be accomplished if vegetation is periodically uprooted or cut at the toe of each outside bank; otherwise, leakage may go undetected and eventually the embankment will fail. If the leakage water is muddy, then emergency maintenance must be undertaken immediately to close the holes.

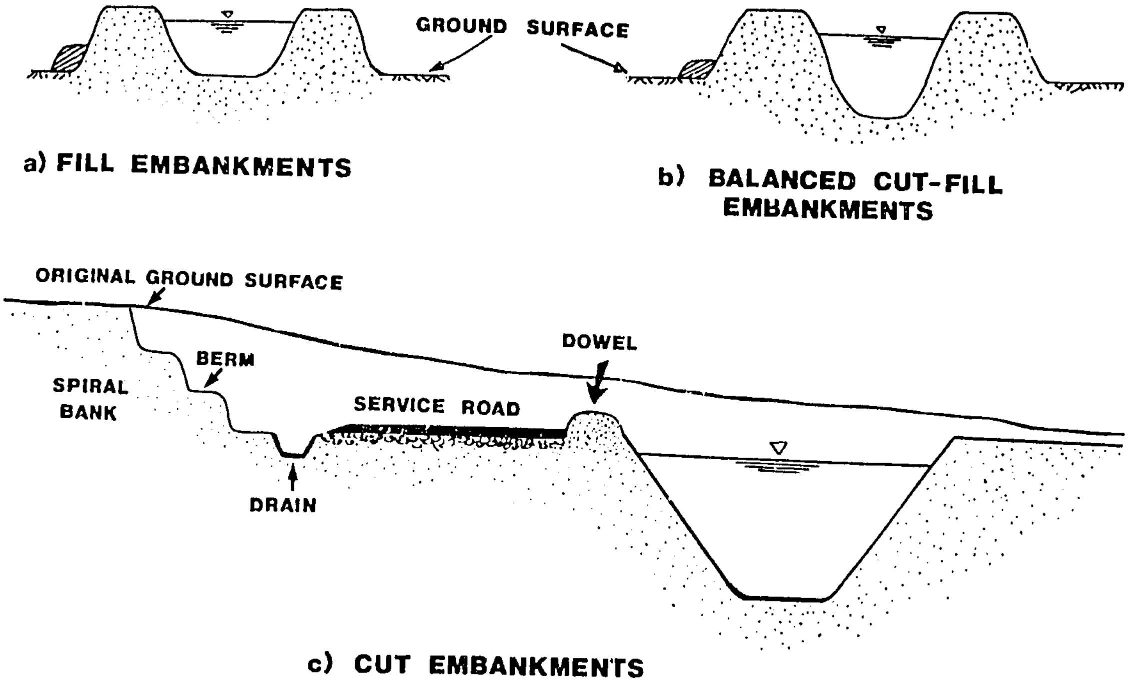



Figure 5.1-10. Examples of Cut, Fill, and Balanced Cut-Fill Irrigation Channel Embankment.

## 2. Service Road Embankments

In general, the roads are in good condition; however, there are a few locations that definitely need attention. The major problem with roads is that they are not always graded so that surface runoff flows away from the irrigation channel. Also, inadequate maintenance results in roadway depressions and pot holes, wherein vehicular traffic further deteriorates the roadway surface. The safety of an embankment is also endangered when soil is excavated at the toe of the outside bank (Figure 5.1-11). This will sometimes be done in order to repair erosion on the bank. However, this should never be allowed because it creates a tremendous hazard to the embankment as it will expose the Hydraulic Gradient Line which in turn can cause a breach. Instead, soil should be borrowed from an area adjacent to the canal boundary.

The second major problem with roads is bank erosion on the bank opposite to the irrigation channel (outside bank). This erosion can be the result of:

1. The cross-slope grading of the roadway being too steep so that surface runoff has a relatively high velocity;
2. The bank slope being too steep; or,
3. The bank height being too high.

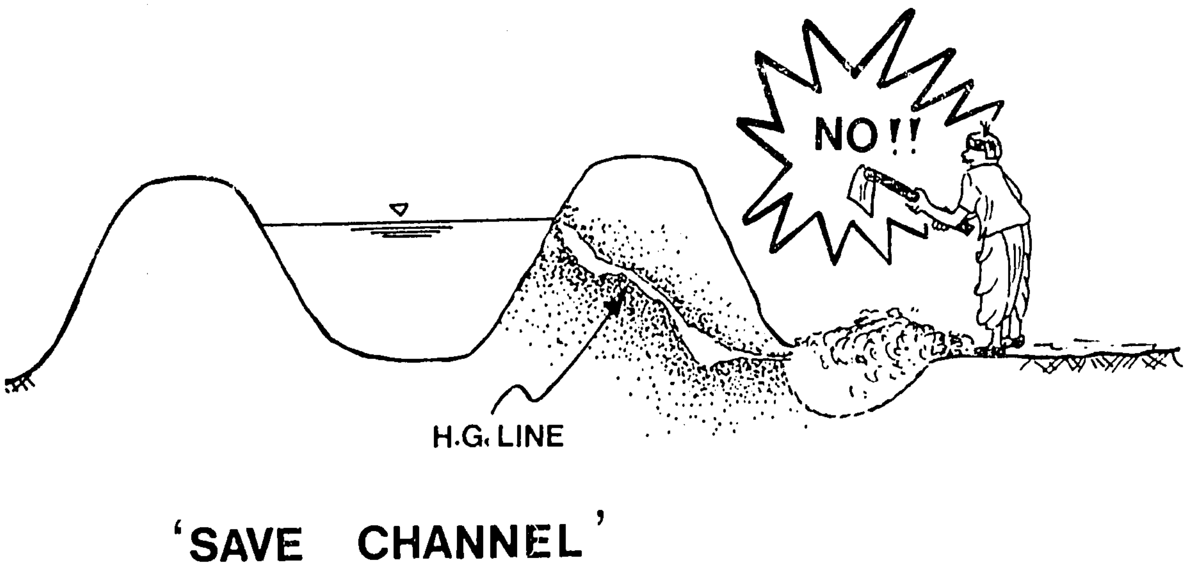



Figure 5.1-11. Excavation at the Outer Toe of the Outside Bank.

Another important problem with roads is that they are often constructed too high above the top of the irrigation channels (Figure 5.1-12). This situation results in more surface runoff moving at a higher velocity into the irrigation channel, thereby resulting in more sediment entering the irrigation channel. Also, this condition will result in higher soil-water pressures behind the lining panels in a lined channel, which will cause more cracked, broken, and failed bricks or panels.

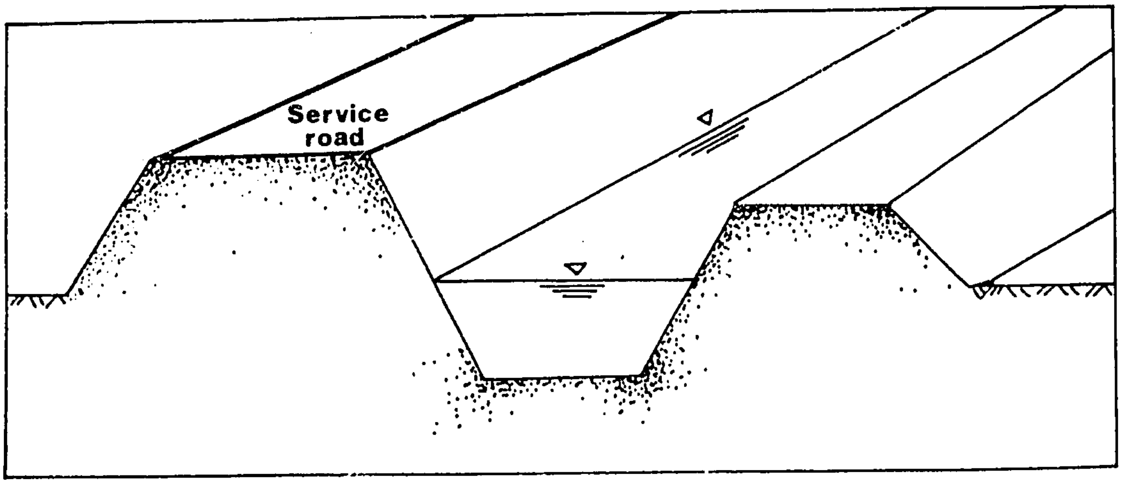



Figure 5.1-12. Road Constructed High Above an Irrigation Channel.

3. Berm Embankments (Non-Service Road Embankments)

The biggest problem with the berm embankment is that the soil is not as well compacted as under a Service Road embankment. Secondly, berms are not usually as wide as roads.

For earthen channels, the berm embankments are likely to contain more biological life than the road embankments. Thus, the seepage and leakage losses will be much greater through the berm embankment as compared with the roadway embankment because of: (1) more biological life; (2) less width; and (3) less compaction.

For lined channels, soil settlement in the berm embankment can be detected by horizontal cracks in the brick mortar or panels. In some reaches, all of the lining panels along the berm embankment will have horizontal cracks, while the lining panels on the opposite side of the channel along the road embankment will not have any horizontal cracks. Also, if the seepage losses are high in a lined channel because of wide joint openings or deteriorated lining,the outlying bank of the berm embankment should be inspected for small leakage holes.

## F. Sedimentation

There is a tremendous variation in the amount of sedimentation that occurs in the irrigation channels. This sediment comes from surface drainage inflows into the irrigation channel -- some of which are planned, such as at concrete surface drainage inlet structures, while most is the result of:

1. Sediment transported by the flows into the canal headworks;
2. Roadway and berm erosion;
3. Erosion from cut banks;
4. Overflow from adjoining earthen irrigation channels or ponds into the channel; and,
5. Animals crossing the earthen or lined channels, with subsequent erosion resulting in the animal pathways.

The basic philosophical approach towards sedimentation should be the elimination of all sources of sediment, so that no sediment enters the irrigation channels. However, the complete elimination of all sediment sources is nearly impossible, although it is quite possible to eliminate the majority flowing into the channel reaches. (Certainly, reducing the sediment transported through the canal head works is desirable, but often extremely difficult to accomplish.)

In order to manage the sediment load entering the head works, it becomes important to maintain sufficiently high velocities in the channels so that sediment deposition does not occur. This would indicate that operating the system at Full Supply Level (FSL) would be important in order to maintain "regime" throughout the system. Often, at the tail end of minors and distributaries, there will be heavy sediment deposition; this is indicative of low flow velocities, usually as a result of discharge rates being lower than the design discharge rates. The lower discharges can be the result of upstream outlets receiving more than their sanctioned discharge, or the seepage loss rates being greater than the design loss rate (8 cusecs per 1,000,000 square feet of wetted perimeter), or a combination of both factors. Thus, it would be helpful to operate an irrigation system, if possible, in such a manner that the tail ends of minors are receiving their sanctioned discharges. Then, if sediment deposition is still occurring, it would indicate that the design did not accurately predict the physical requirements for "regime" conditions to occur.

Animal crossings are not generally a major problem, but they are a definite source of erosion and sedimentation. At animal crossings, there is no vegetative growth, so that the soils in the pathway are easily eroded during rainfall, with the runoff and sediment being conveyed into the irrigation channel. Animal crossings are particularly destructive of earthen banks, even resulting in higher seepage losses for the smaller channels. For lined channels, animal crossings can also lead to cavity formation because of the surface runoff not flowing into the channel, but rather behind the lining panels.

## G. Aquatic and Vegetative Growth

One of the most persistent maintenance problems, besides sedimentation, is aquatic growth. The most difficult to control are underwater (submerged) weeds, most of which require some sediment for establishing roots, while a few species can attach to brick or concrete. This is a frustrating problem because once the aquatic growth has been removed from a channel, it will grow again within one or two months. The amount of aquatic growth that commonly occurs results in considerable reduction of the discharge capacity of the irrigation channel, often by 20-50 percent. This is also the case for vegetative growth that has its roots in the sediment lying in the channel bottom.

## H. Drainage

### 1. Surface Drainage

The primary purpose in providing surface drainage is to prevent surface runoff from entering the irrigation channel in order to avoid: (a) the sediment load being conveyed by the surface runoff; and (b) the potential for cavity enlargement or formation in lined channels. A second purpose in providing surface drainage is to prevent the ponding of water alongside the irrigation channel. Most of this ponded water will eventually percolate into the soil, thereby raising the underlying groundwater table, which in turn increases the seepage rate that weakens earthen channel banks and sediment transport through the joints in lined channels. Consequently, the emphasis of a surface drainage system should be the rapid conveyance of surface runoff to a drain culvert or natural drainage channel.

2. Subsurface Drainage

When lined irrigation channels are constructed in cut areas, the soil-water pressures behind the lining panels can increase significantly, particularly during the monsoon season. This condition results in higher seepage rates into the channel, and consequently, greater sediment transport through the lining joints. Also, these increased hydraulic pressures can cause wall panels to fail by sliding, or floor panels to fail by increased hydraulic uplift pressures.

Subsurface drainage is provided naturally when the irrigation channel is located in a fill area so that the adjacent land alongside the roadway and berm is below the water surface level in the irrigation channel so that seepage flows from the irrigation channel towards the toes of the outside banks. Preferably, the adjacent land will be at, or below, the invert elevation of the irrigation channel.

## I. Structures

1. Gate Structures

Because of high flow velocities passing through a gate opening, there will naturally be some scour immediately downstream. Every effort should be made to operate the gates in a manner that minimizes scour.

2. Fall Structures

Fall structures, by the very nature of their hydraulic design, will result in considerable scour immediately downstream. The first question is whether the degree of scour has stabilized, or is it aggravated every time water is turned into the canal.

3. Drop Structures (Syphons)

Drop structures usually consist of: (a) an inlet structure that may, or may not, have a gate for controlling the upstream water level; (b) a concrete chute or pipeline between the inlet and outlet structures; and (c) a stilling basin and an outlet transition structure.

Sometimes, cavities form near the head wall of the inlet structure and in the embankment overlying the concrete pipeline. These cavities can result from: (a) surface drainage into depressions; or (b) leaking concrete pipe joints.

Quite frequently, a hole has formed in a joint near the end of the outlet transition structure. This primarily occurs because of the large hydraulic pressures resulting from the high nearby roadway and berm which are most easily relieved at this particular joint.

If the downstream channel is earthen, then the channel should be inspected for visible evidence of scour. If much scour is occurring, then structural means for improving the hydraulic energy dissipation in the stilling basin should be sought.

4. Bridges

Generally, concrete bridges are in very good structural condition. The only structural problem usually found is the breaking of railings as a result of large trucks having to make sharp turns.

For earthen channels, there may be serious rain cuts along the bridge abutments. Measures should be taken to divert any rainfall away from the irrigation channel.

For lined channels, oftentimes, cavities have formed behind the lining panels underneath the bridge because of surface runoff near the abutments. If the bridge settles, then additional pressures will be placed on the lining and thereby there may be cracks.

5. Tail Clusters

A tail cluster is a structure constructed in brick/masonry at the tail of a distributary or minor which may be feeding the fields at their tail. The crest of the tail cluster is at the designed full supply level of the channel at the tail. It helps in heading up of water to the required full supply level and then diverting the water on to the tail outlets. Due to the required head available, these outlets are able to draw their due share of water. Because animals or people cross at these tail structures, they get damaged and their sill gets lowered at places. This results in non-building up of the required head at the tail and non-drawal of shares of supply by the outlets. The only way to check this is to block the animal's or people's pathway from over the crest of the tail cluster, or repairing it regularly before each irrigation season.

6. Under-Canal Tunnels (Culvert Drains)

In general, the culvert drains, which are used to convey natural surface drainage waters underneath the irrigation channels, are another example of excellent concrete construction. In some cases, more compacted backfill should have been placed behind the headwalls of the inlet and outlet structure to the culvert drain. The maintenance problem associated with drain culverts is the removal of sediment and shrubbery in the outlet and inlet structure. These drain culverts are very important as potential outlets for open drains or pipe drains alongside the Service Road or berm embankments, if required, even though they were primarily installed to convey the flow in natural channels underneath the irrigation channel.

## 7. Other Structures

In general, the concrete structures are usually in good structural condition. The quality of the construction work is usually very good. The primary difficulties have been the grading and shaping of the soil surface surrounding the structure. In some cases, rain cuts alongside the structure will result in sediment reaching the channel. Only in a few cases has this scour endangered the structure. However, for lined channels, these rain cuts have frequently resulted in cracked, broken or failed lining wall panels nearby.

## 5.2 Solutions to Phenomena Causing Maintenance Problems

### A. Maintenance Issues in Catchment and Head Works

1. Catchment and Reservoir

Simultaneous programmes for maintenance of the forest cover by preventing soil erosion and planting new trees in the catchment has to be taken up along with the formation of the reservoir.

On all Government land, extensive afforestation should be done, while on the private land, farmers should be advised to grow plants and trees in vulnerable areas.

Areas in the catchment should be identified which are vulnerable to soil erosion, and provision of contour bunds and check dams in the various nallahs and drains should be constructed.

Soil erosion could also be checked by adopting soil conservation measures like contour, dry stone walls, contour trenching, and bench terracing. Animal grazing in the catchment should be prohibited as far as possible. Land should be used according to its land use capability only. If it is used for other purposes, it should be properly protected from soil erosion.

Maintenance of the watershed should not be a charge to the normal maintenance budget of the Irrigation Department, but it should be done through the Forest and Soil Conservation departments under their normal watershed management plans.

Various soil conservation measures within the catchment are the only and best solution to check or minimize the silt accumulation in a reservoir. Large debris needs to be removed from the reservoir. Regular watch and control is required to check encroachment in the foreshore areas. Aquatic weeds need control at the source (i.e. in the reservoir itself) by their uprooting and destruction manually.

2. Head Works

The Central Water Commission has established a Dam Safety Organization in May, 1979 to assist the State Governments in various activities of dam safety. This organization has brought out a proforma for periodical inspection of large dams and also a check list for inspection of dams. The proforma deals in detail with the various observations to be made of all the components of the dam to ensure proper maintenance and to take timely action to set right the defects, if any are found. An extract of the check list as issued by the Chief Engineer (Irrigation) Tamil Nadu is enclosed for guidance. (Annexure I)

For proper upkeep and maintenance of dams, it is essential that a data book for each dam be maintained. This book contains details of the location, accessibility, and salient features of the dam and, also, the problems met during construction and how they were solved. This also contains details of foundations, geological aspects, hydrology, flow searching criteria, detailed drawings, instrumentation, etc. Knowledge of the details go a long way to assist in proper upkeep and maintenance of the dams.

The maintenance engineer should be alert and take precautionary steps to avert any unforeseen damages. The person in charge has necessarily to keep in stock jute bags, empty cement bags, rubble stones, sand and gravel material, petromaxes, lanterns, torches, coil ropes, stitching materials, iron pans, pick axes, etc. He should be able to mobilize labour at a short notice in case of emergency.

Regular inspection of the gate parts and their seals is required. They may be repaired or replaced as soon as possible whenever found defective in order to check leakage from the gates. The lifting arrangement and rollers, etc. should be oiled, greased and tested before the reservoir starts filling. The shutters and other steel works should be timely painted. The areas below the spillway bucket/apron should be checked after each monsoon season. If required, dewatering may also have to be done to see the condition of foundations below. If any scour/erosion of the foundation is observed, remedial measures to fill the pits with concrete or masonry should be done. Even anchoring and concreting of the rock stratas, if geological features so require, may have to be undertaken. So also the guide walls, wing walls, etc. should be checked to see whether there are any cracks, settlement or tilting and then remedial measures taken. So also the functioning of weep holes should be checked. If any leakage through the body of the dam is observed, the point/area of leakage has to be carefully located and marked. It may be due to masonry joints with damaged pointing, or due to pervious hollow masonry or concrete. Pointing may be used to close the joints, but guniting on the upstream face, or grouting of the masonry concrete may have to be resorted to in the case of pervious or hollow masonry/concrete.

Performance of drain pipes should be tested and if found choked, they should be cleaned by compressed air or air-water jets. The exhaust fans and ventilation ducts should be checked and proper ventilation of the inspection gallery ensured. The data observed from various instruments installed in the dam should be carefully examined and corrective measures taken whenever necessary.

The junction between the masonry and earthen dam are the weak zones since they cannot be bonded properly by machinery and because of the non-cohesive nature of the two materials. Such places need greater attention in watching for any seepage or settlement.

3. Earthen Dam

Jungle Clearance

Because of rainfall, lots of jungle, weeds, bushes, etc., grow on the upstream and downstream slopes and outer toes of earthen dams. These attract burrowing animals, rodents and stray cattle for grazing and burrowing holes in the body of the dam causing leakages and piping, thereby endangering the safety of the dam. The embankment and its toes should be kept free of such jungle and also to facilitate easy inspection of leakages and damages in the bunds.

## Top of Bund and Downstream Slope

The top of the bund should be meticulously kept free of pot holes. Its longitudinal and transverse slopes should be maintained properly, so that rainfall water spreads and is disposed of evenly. Water should not be allowed to collect in the pot holes, thereby entring the body of the dam. If slopes are not maintained properly, rainfall water will start flowing along steeper slopes. Concentrated flows of falling water will cause deep raincuts and runners causing heavy erosion of slopes. Any large scale widening and deepening of raincuts or gullies under torrential rains may pose danger to the safety of a dam. The flowing silt from the downstream slopes will choke the toe filters, rendering them ineffective. The raincuts should be back filled and compacted systematically and in timely fashion. The top of the bund and roadway should be gravelled once or twice in a year for smooth running of inspection vehicles. Frequent inspection should be carried out on the downstream slopes for indication of slides, raincuts, cracks, seepage and leakages, etc. and immediate corrective maintenance and repairs undertaken.

## Upstream Slope and Pitching

Generally, upstream slopes are protected with pitching and rip-rap against wave action during high wind velocities and sudden draw-down conditions. Pitching acts as an inverted filter and prevents eroding of soil particles. Any eroded of soil should be properly filled and rammed. Displacement of pitching and rip-rap should be repaired immediately. Upstream slopes should be carefully inspected for evidence of slides, cracks, erosion, displacement of pitching, etc. Pitching should be kept free of vegetation and any other materials such as silt and slipped earth.

## Toe Filter

A filter is provided at the outer toe of an earthen dam to arrest the displacement of soil particles due to seepage water through the lower portion of the body of the dam. If clear water is coming out of the filter, it means that soil particles are not being dislodged or disturbed. If muddy water is coming out of the filter, it indicates displacement of soil particles through the body of dam and acts as a signal towards possible breach of the dam. It requires the immediate attention of irrigation engineers and corrective measures should be taken without delay. The downstream filter should be kept free of vegetation and silt function effectively and also to facilitate proper inspection. Frequent inspections of the filter toe are required during filling time and at the time when the dam is full.

4. Distance Stones and Signboards

All distance stones/posts, signboards, data boards, etc. should be maintained properly. Painting and rewriting should be done after the monsoon season.

**B. Maintenance of Channels**

The topics discussed in this section are not necessarily presented in their order of priority. Instead, those topics that pertain to both earthen channels and lined channels are presented first. In this way, the same topics do not have to be repeated at the end of this section when discussing the maintenance of lined and unlined channels.

1. Aquatic and Vegetative Growth

For clearing aquatic and vegetative weeds growing in irrigation channels, the common practice is to use labourers. Pulling weeds from the bed sediments by wading labourers (Figure 5.2-1) has proved more effective than cutting by hand blade because the regrowth rate is reduced. Thus, no tools are required.

There is a significant advantage in periodically closing a channel, if possible, in order to reduce aquatic growth. Also, at this time, vegetative growth can be uprooted and then gathered and burned. This allows inspection of the channel bed and will reduce the total water losses from the channel over a cropping season.

Figure 5.2-1. Wading Labourer Pulling Weeds by Hand from an Irrigation Channel

For lined channels, vegetative growth can be largely eliminated by removing the sediment in the irrigation channels and by employing corrective measures to prevent sediment from entering the channel in the future. Any remaining vegetative growth would be found in broken joints and in holes in the lining panels; therefore, asphalt sealing of the joints and repair of the holes should eliminate this possibility.

Unfortunately, eliminating aquatic growth is an extremely difficult task. One alternative is to use chemicals; a procedure which should be attempted on an experimental basis. Presently, the only sure technique for removing aquatic growth is by hand or improvised mechanical tools. There is no known commercial machine for removing aquatic growth, but some irrigated areas in the world have developed a machine for their own use, usually a boat with cutters. A floating platform with power-driven cutters would appear to be a possible approach. Another approach is to drag a very heavy chain along a channel using two large tractors or bulldozers, one on each side of the channel. In order to get rid of the vegetative material, a large wasteway structure located downstream that can carry the full discharge of the irrigation channel can then be used to discharge all of the vegetative material, perhaps during one day. However, in the near future, the most feasible approach is to periodically close an irrigation channel in order to minimize aquatic growth, uproot vegetation by hand, and then gather and burn it.

At some time in the future, the use of mechanical methods will likely be used on the large-scale irrigation projects, at least for the main canals and large channels.

## 2. Erosion and Sedimentation

For each irrigation project, maintenance planning should include a programme for eliminating as many sources of sediment that enter the irrigation channels as can feasibly be accomplished. Some "Irrigation System Improvements" may be required to control sediment inflows; however, a large proportion of the sources of sediment can be eliminated with improved maintenance practices. Also, sediment removal should begin at the lower end of a channel and proceed upstream; if begun upstream and not completed, then the excavated material serves as a sediment trap.

Roadway and Berm Erosion

Lowering roadway and berm embankments to only the required heights would reduce the degree of erosion and result in less maintenance cost. For example, these embankments do not have to be higher than 30 centimeters above "Full Supply Level" (FSL) for earthen channels and 15 centimeters above the top of the lining for lined channels. The roadways and berms need to be periodically graded so that runoff from rainfall flows away from the irrigation channel; this may be particularly cumbersome on the berms because of narrow widths and sediment that has been removed from the channel piled on top of the berm (Figure 5.2-2), which should never be allowed.

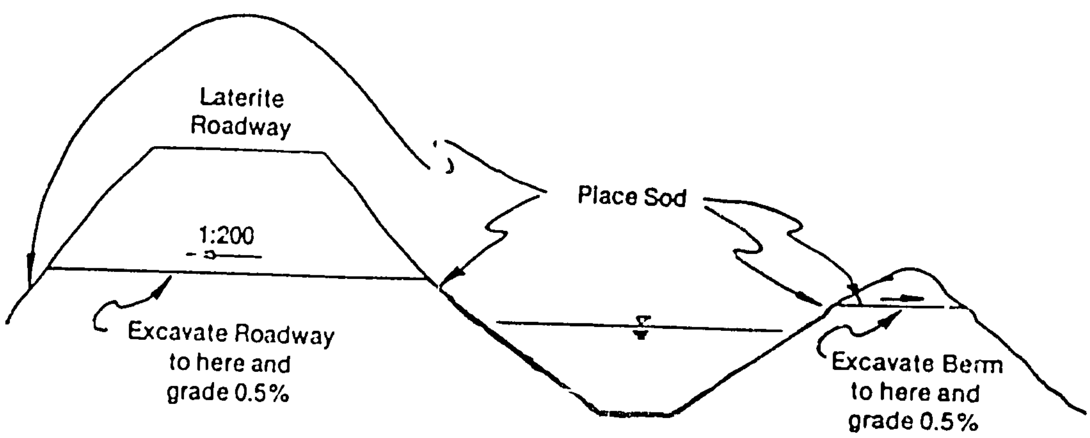



Figure 5.2-2. Some Recommended Practices for Controlling Erosion and Sedimentation from Roadway and Berm Embankments.

Although the ideal solution for lined channels would be to place the roadway at the same elevation as the top of the lining panels, there are two advantages in placing it about 15 cm higher. First, vehicles will be prevented from riding on the edge of the panels and inflicting damage. Secondly, there is less likelihood of ponding and subsequent cavity formation behind the lining.

### Erosion from Cut-Banks

The most significant maintenance problems usually occur where irrigation channels have been constructed in cut areas. A typical cut-bank cross-section is shown in Figure 5.2-3. Usually, the earthen toe drain fills with sediment each monsoon season. Removing the sediment from the toe drain is crucial, otherwise the surface runoff during and immediately following a rainfall will transport considerable sediment into the irrigation channel. Also, the berm should be sloped away from the irrigation channel towards the toe drain. Then, the placement and maintenance of vegetative cover on the berm, and even more importantly on the cut-bank, will minimize erosion.

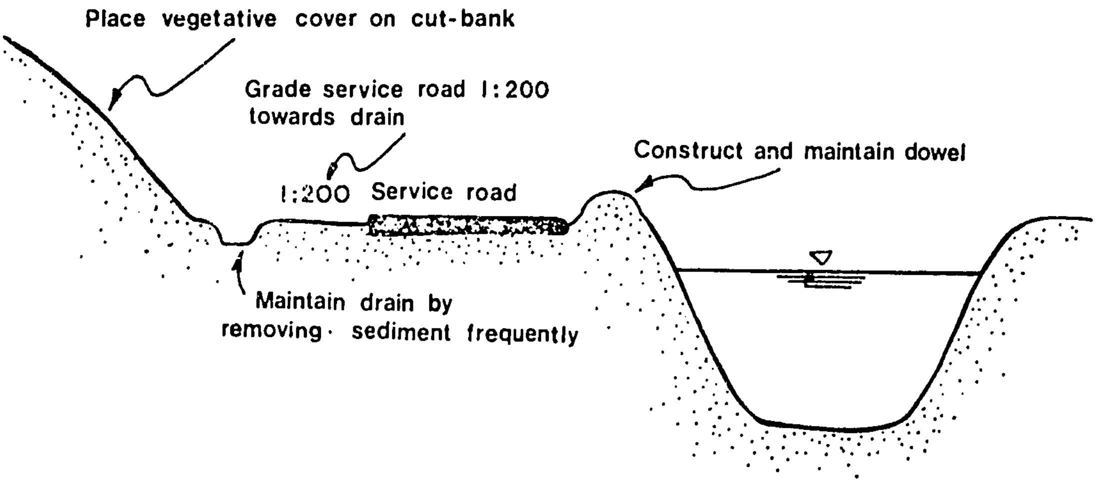



Figure 5.2-3. Typical Cross-Section of a Cut-Bank

Overflow from Adjoining Channels and Ponds

There are situations where tertiary system channels flow near main system channels. Also, there are cases where small ponds or buffalo wallows exist nearby an irrigation channel. The first remedy is to request that the farmer move to other buffalo wallows, then excavate the buffalo wallow, replace it with compacted soil, and then shape the embankment so that it will not collect or pond water in the future (Figure 5.2-4)

For the situation with adjoining irrigation channels (Figure (5.2-5), it is necessary to have a bank of adequate height so that one of the channels cannot overtop and flow into the other channel. Also, this bank should be well-compacted, particularly if one (or both) of the channels is lined. If the compaction of the existing bank is doubtful, then the bank material should be excavated and then reconstructed, with its height adequate enough to prevent flow from one channel into the other, even under unusual operating conditions, such as having higher than design water levels.

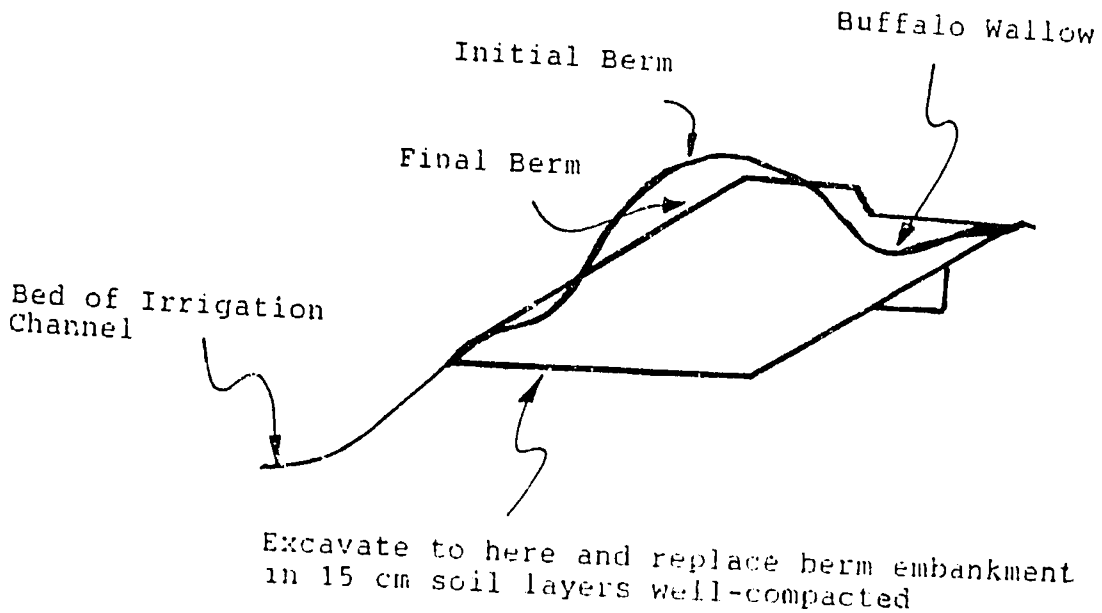



Figure 5.2-4. Removal of Buffalo Wallow and Reshaping of Embankment

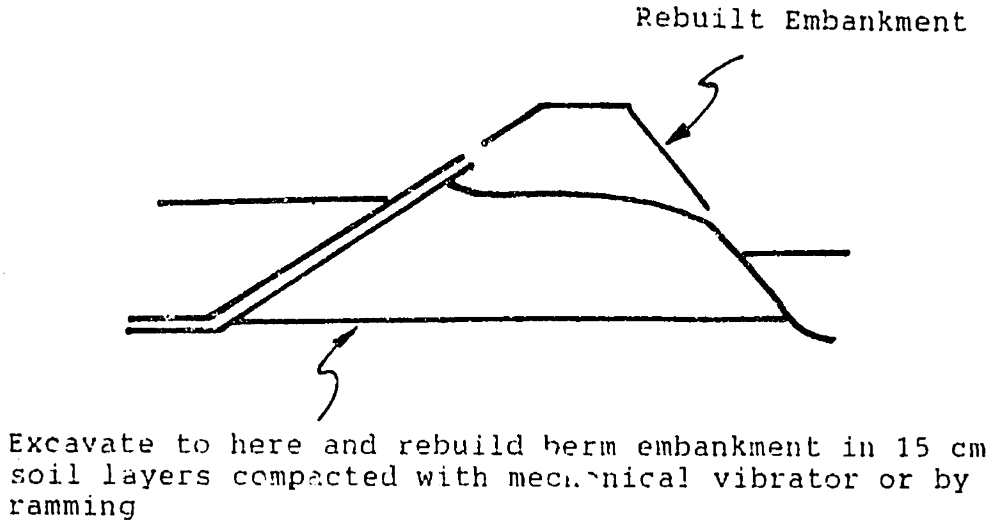



Figure 5.2-5. Reconstruction of Berm Embankment Between Adjoining Irrigation Channels.

## Animal Crossings

For earthen channels, in order to prevent erosion from animal crossings, a ramp on a slope of 3:1 is constructed. Bricks are used, which are laid on-edge. Periodically, about every meter, a protruding brick is placed that can be used by the animals as a foot-hold.

For lined channels, erosion resulting from animal crossings could be eliminated for the most part by installing a concrete bridge, but care should be taken to provide adequate measures to prevent surface erosion near the abutments. In some cases, farmers may need to be encouraged to use a nearby bridge for animal crossing.

Human Bathing and Washing

Bathing ghats (steps) are required, particularly for earthen channels, so that people living nearby can have ready access to the water in the irrigation channels for both bathing and the washing of clothes. These steps are usually made of brick, but concrete could also be used. Without these bathing ghats, erosion will occur in the pathways frequented by people.

3. Sodding

One of the most effective techniques for preventing erosion is good vegetative cover. Thus, as part of a long-term effort to eliminate sources of sediment flowing into irrigation channels, the provision of vegetative cover, oftentimes by sodding, is a primary activity. Once this job is completed for an irrigation project, then an important preventive maintenance activity is maintaining the vegetative cover.

Proper sodding requires meticulous care. First of all, appropriate plant species should be selected that are drought resistant. The plants must be grown in relatively fertile soil, periodic fertilizer applications may be required particularly during the first year of growth, and the plants may have to be irrigated to establish good root development. Then, cattle should not be allowed to graze on newly planted areas for at least one year

Preventive maintenance requires monitoring of areas where the sodding has failed and then determining the causes of failure, periodic irrigation during the dry season, and periodic fertilizer applications.

4. Service Road and Berm (Non-Service Road) Embankments

Road and berm embankments have already been discussed above in terms of "Erosion and Semimentation". More details will be provided below on the Service Road and surface drainage from embankments. Also, embankment compaction and subsurface drainage will be discussed below.

Visual evidence of the necessity for reconstructing the embankment is numerous leakage holes discharging along the outside bank, usually near the toe of the embankment. In such cases, a determination must be made as to the origin of the leakage holes. Usually, they begin on the inside bank just above the usual operating water level. A reach where this problem is most serious should first be slowly excavated by labourers and visually inspected for holes and small caverns. Perhaps, the embankment only needs to be excavated slightly below the usual water levels in the channel. This is particularly important for lined channels since it may allow long reaches to be excavated by mechanical equipment, and only a short upper portion of the lining panels would be exposed (Figure 5.2-6)

The necessity for reconstruction of embankments may not be realized until channel losses have been measured. The measurement of seepage loss rates with various water levels will disclose the magnitude of the seepage and leakage losses and how rapidly the seepage loss rate is changing near the usual operating water levels; rapidly increasing values of seepage loss rate indicates that the embankments should be explored, using labourers, for determining if small holes and caverns exist. This situation is more likely to occur for earthen channels than lined channels, but certainly does occur for either lined or unlined channels. Reconstruction of the embankment may be done as shown in Figure 5.2-6.

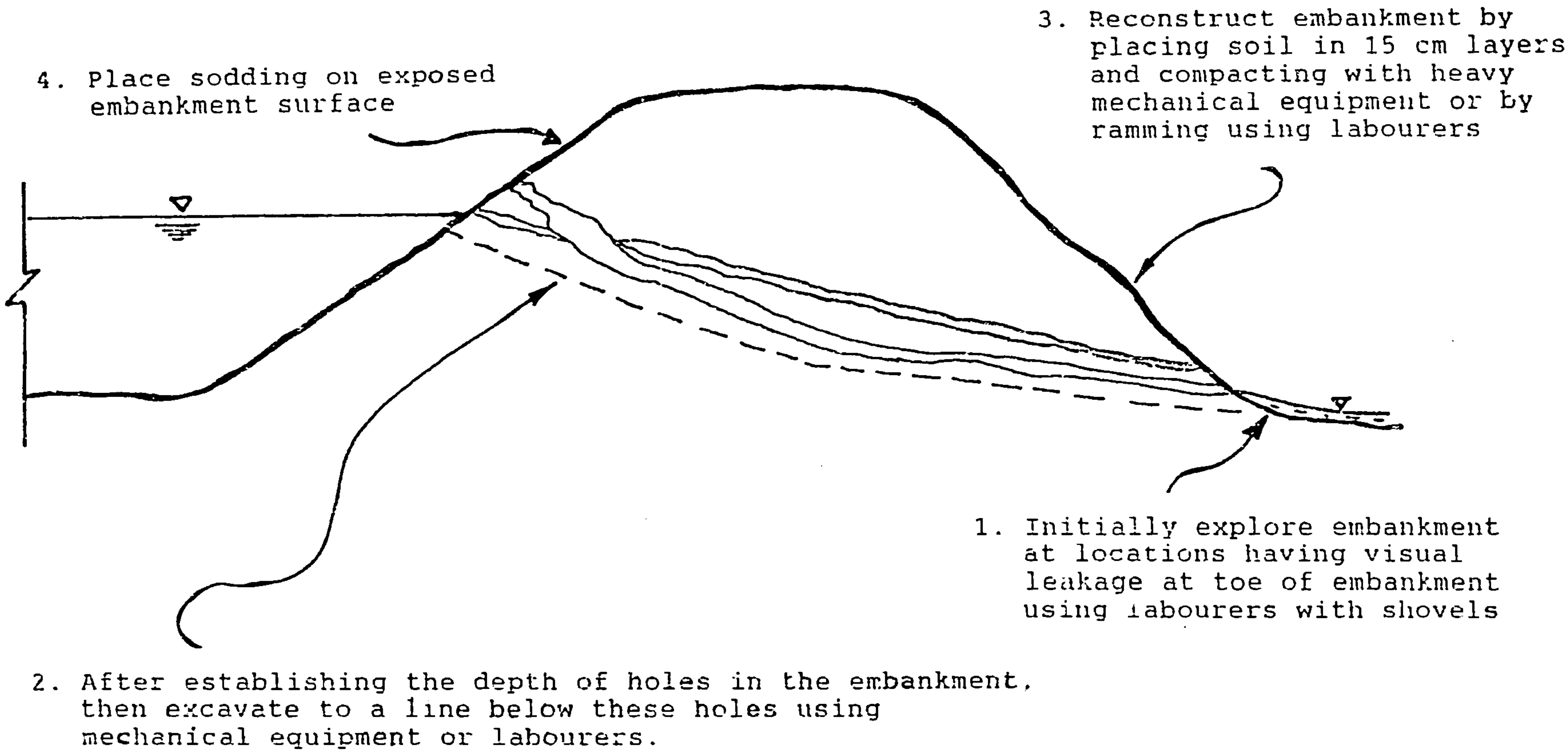



**Figure 5.2-6. Exploration for Leakage Holes and Embankment Reconstruction.**

## Compaction

For lined channels, horizontal cracks are evidence of inadequate compaction, usually of the berm embankment. If the lining panels are being endangered, then the embankment should be excavated, perhaps to half of the height, then heavily compacted, and good soil material placed in layers of 10-15 cm and heavily compacted (Figure 5.2-7). If there are also cavities, then the appropriate maintenance procedure would be to first fill the cavities after excavating the embankment, then reconstruct the embankment.

## Service Road

The Service Road should be inspected from the canal head works to the tail of each distributary and minor to insure that there is ready and rapid access to all reaches of the irrigation network. Pot holes, surface irregularities, and ruts should be noted and corrected. The gallows, which consist of two vertical metal poles embedded in the Service Road and a metal cross-bar on top, should be inserted to be sure that the size of vehicles having access to the Service Road is being properly controlled.

If there is a Boundary Road adjacent to the canal right-of-way, it should be inspected to be sure that tractors and vehicles can move easily along this road, thereby eliminating their interest in traveling on the Service Road. Also, the canal boundary (right-of-way) should be inspected to be sure there is no encroachment. If so, this should be noted and reported.

## Dowels

A dowel (curb) is constructed along the inside edge of the Service Road. The primary purpose of this dowel is to prevent surface runoff from the Service Road onto the inside bank and into the irrigation channel. Thus, any heavy rainfall will result in surface runoff over the outside bank. The dowel is usually consttructed of earth, but can be built using bricks.

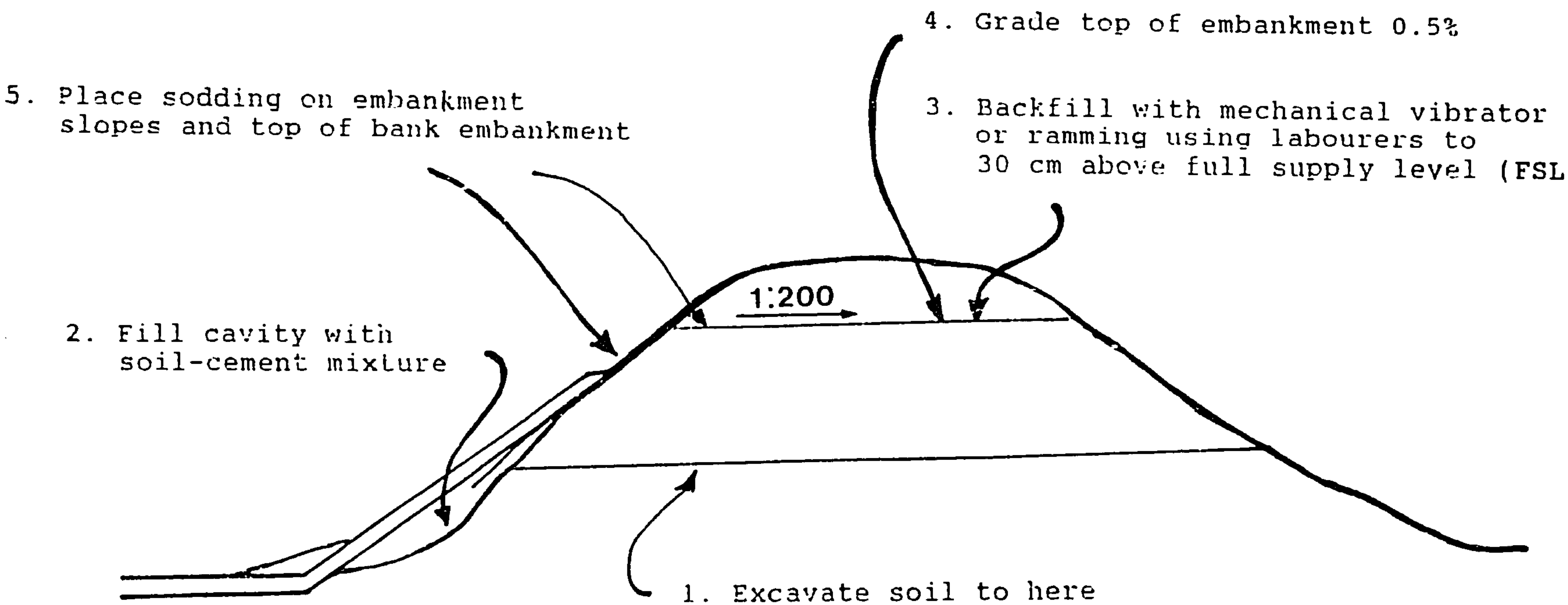



Figure 5.2-7 Reconstruction of an Inadequately Compacted Embankment

The dowel should be inspected to be sure there are no leaks, or cuts, that would allow surface runoff through the dowel. If such conditions exist at some locations, they should be noted and the dowel reconstructed at those locations.

## Surface Drainage

In order to eliminate the sources of sediment entering irrigation channels, the roadway and berm need to be graded so that surface runoff flows away from the irrigation channel. On road bends where super-elevation has been purposely constructed to facilitate vehicle traffic, there are two possible solutions for left turning bends ( in the downstream direction) which result in surface runoff flowing into the irrigation channel:

1. Place curb of earth, brick, concrete or asphalt on the inside of the bend near the irrigation channel and convey the water from the curb to the irrigation channel in a concrete-lined chute (Figure 5.2-8); or

2. Remove the super-elevation and grade the roadway so surface runoff will be conveyed away from the irrigation channel, then place a sign warning motorists to reduce the speed of their vehicle.

Sometimes, the cross-slope of the roadway is so steep that the surface runoff has a relatively high velocity, which increases even erosion of the roadway. This problem can be easily corrected by using compacted backfill in the eroded area if required, then grade the cross-slope to be much flatter (1/2 of 1 percent, or less).

Sometimes the bank slope is too steep, or too high or both. This results in bank erosion. The eroded bank needs to be reconstructed, usually by excavating a small amount of the exposed eroded soil, then replacing it with good soil that is compacted in small layers of 5-10 cm, and finally, sodding the exposed soil surface and meticulously looking after the vegetative growth until it is well established (Figure 5.2-9).

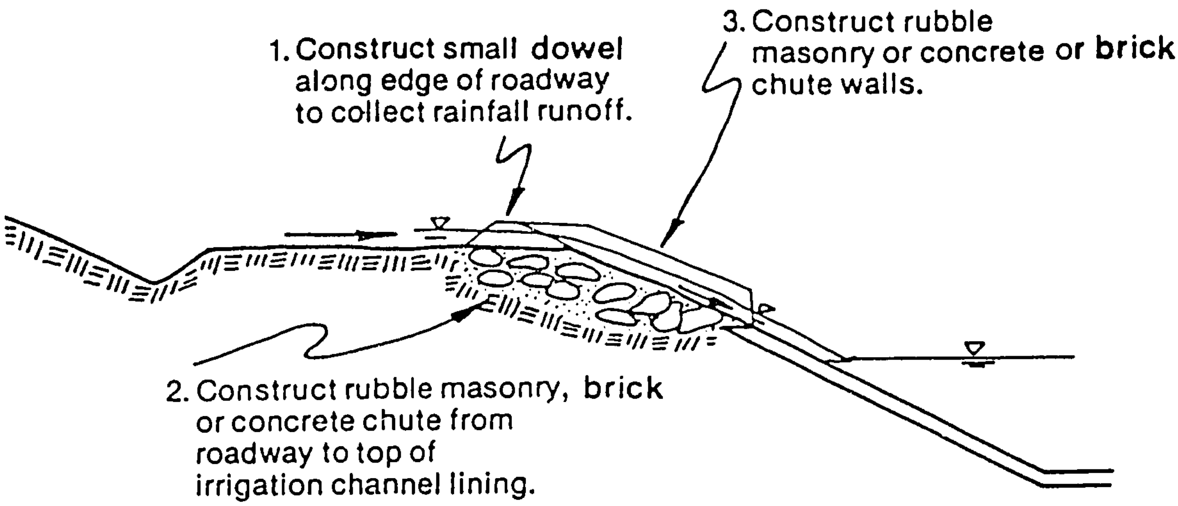



Figure 5.2-8. Collection of Surface Drainage from a Roadway and Conveyance into the Irrigation Channel.

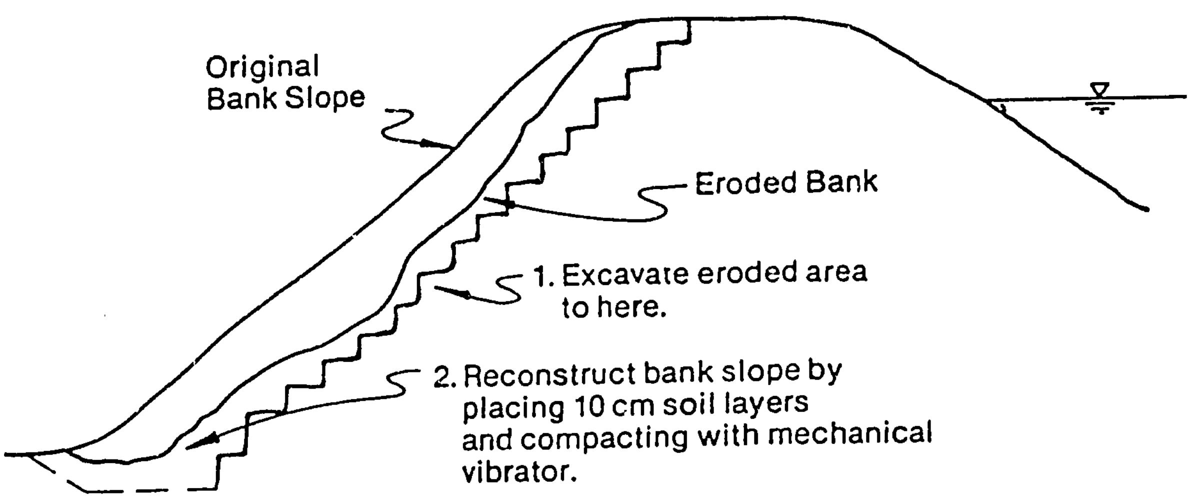



Figure 5.2-9. Reconstruction of an Eroded Bank

To prevent bank erosion in the future, it will be required that the surface runoff from the embankment surface be collected and then conveyed down the bank surface. In order to collect the surface runoff from the roadway or berm, a dowel (curb) will have to be constructed along the outside edge of the top of the embankment (Figure 5.2-10). The dowel would serve to collect the surface runoff and then it would be conveyed down the bank slope in a concrete-lined, brick or rubble masonry chute. At the toe of the outside bank, special measures will be required to avoid erosion, which will require a stilling pond lined with concrete, brick or rubble masonry.

Subsurface Drainage

Where irrigation channels have been constructed in cut areas, there are oftentimes enormous maintenance problems and costs because subsurface drainage was not used as a design criteria. Thus, it may be required to construct facilities that provide subsurface drainage.

The possible alternatives for providing subsurface drainage are: (1) open drains; and (2) interceptor pipe drains. Another alternative for lined channels is to provide relief from the hydraulic pressures by using either weep holes or filters.

Cut areas, in particular, require that the design of the irrigation channel include effective subsurface drainage. This is especially true for lined channels, but is often the case for earthen channels as well. This can usually be accomplished by excavating open drains alongside the roadway and berm provided they are sufficiently deep. Preferably, the invert elevation of the open drain should correspond with the invert elevation of the irrigation channel, or be even lower.

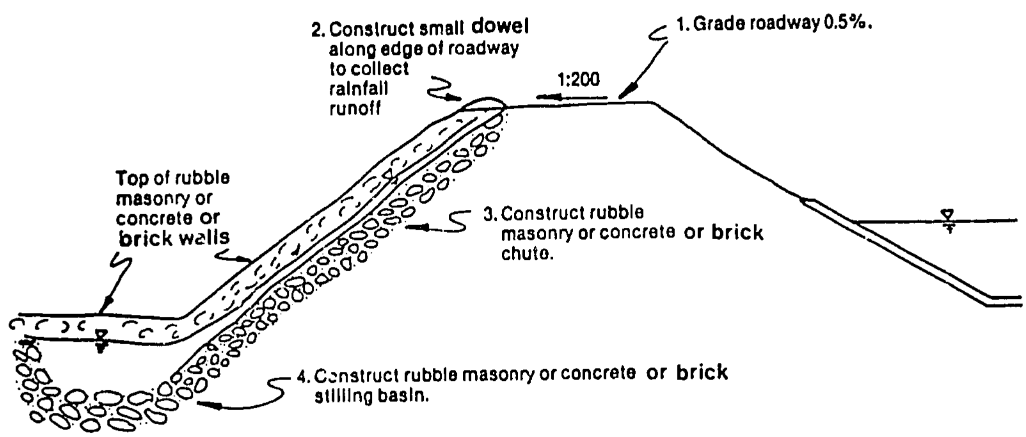



Figure 5.2-10. Collection of Surface Runoff on Top of an Embankment, Conveyance Down the Bank Slope, and Erosion Protection at the Toe of the Bank.

If the roadway embankment already has asphalt pavement, but the roadway is too high, then it may become too expensive to lower the roadway in order to provide better surface and subsurface drainage. Some alternatives are shown in Figure 5.2-11 where open drains are used to provide both surface and subsurface drainage, or Figure 5.2-12 which illustrates the use of a Surface Runoff Interceptor Drain for surface drainage and a Perforated Pipeline Drain for subsurface drainage. Figure 5.2-12 also illustrates the use of a Perforated Pipeline Drain to provide subsurface drainage for a cut-bank.

For lined channels, weep holes can be used to relieve hydraulic pressure behind lining panels as shown in Figure 5.2-13. Also, rubble masonry that is porous, or any other porous material, can also be used as shown in Figure 5.2-14. These are lower cost measures that treat the symptoms rather than the cause of the maintenance problems. However, this is very satisfactory if these measures continue to function well with time and do not become clogged, or they do not allow soil behind the lining panels to be washed into the irrigation channel.

Encroachment

Continual vigilance is required along the rights-of-way of the channel embankments in order to avoid encroachment. In extreme cases, encroachment takes place to the toe of the embankments. Not only must offenders be reported, but administrative mechanisms must be available for applying sanctions; otherwise, encroachment will continue to occur and the borrow and spoil areas along the rights-of-way will be lost in terms of maintaining the channels.

## 5. Operation of Irrigation Channel Network

The irrigation channels need to be operated at Full Supply Level (FSL) in order to minimize the deposition of sediment. Also, during canal closure, the water level in the channels needs to be lowered slowly in order to minimize the risk of bank sloughing for earthen channels or failure of channel lining due to significant uplift pressures.

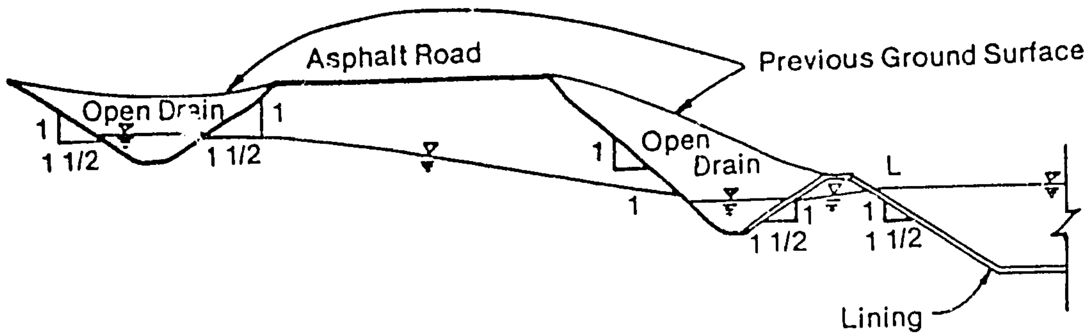



Figure 5.2-11. Typical Cross-Sections for Open Drains for a High Roadway Embankment in a Cut Area.

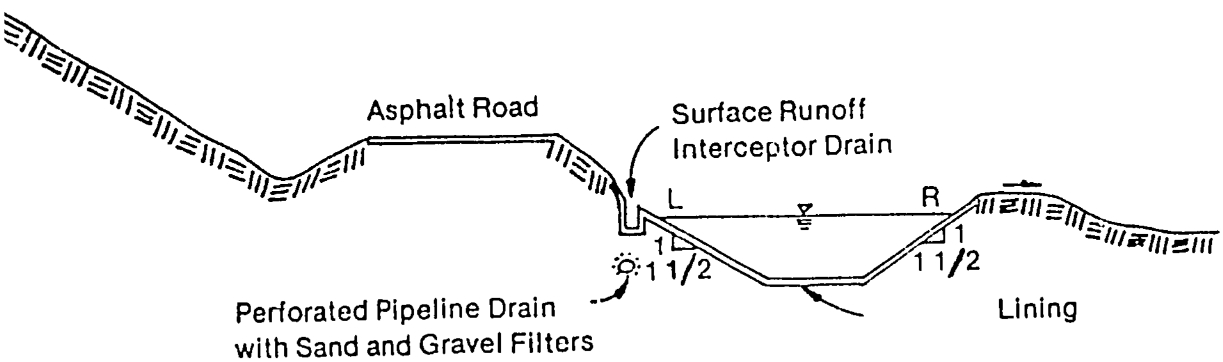



Figure 5.2-12. Typical Cross-Sections for Open Drains and Use of a Surface Runoff Interceptor Drain and a Perforated Pipeline Drain for Providing both Surface and Subsurface Drainage.

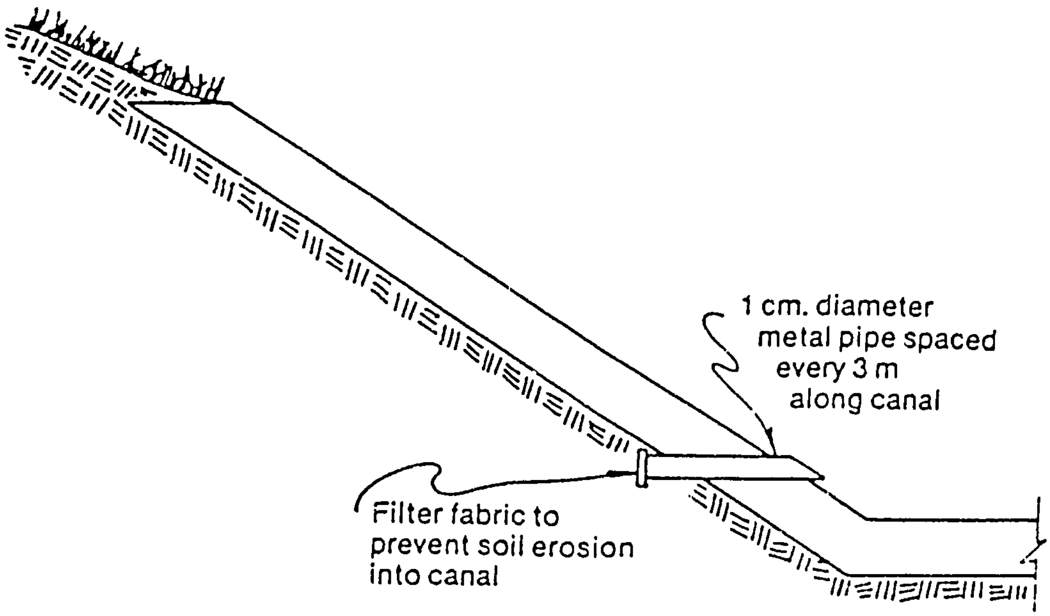



Figure 5.2-13. Use of Weep Holes to Relieve Hydraulic Pressure Behind Channel Lining.

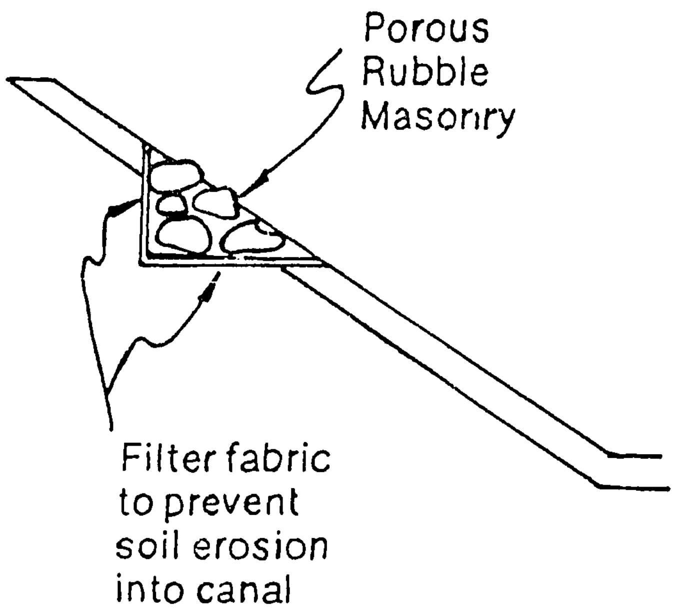



Figure 5.2-14. Use of Porous Rubble Masonry with Filter to Relieve Hydraulic Pressure Behind Channel Lining.

6. Lined Channels

Filling cavities is an expensive maintenance cost. Usually, by the time a cavity is filled it has become a huge cavernous opening that may extend 1-3 meters in width on each side of the joint opening, thereby leaving an extensive area of lining unsupported. Also, there may be a sizeable hole in the lining. If so, one procedure is to remove the broken pieces of lining material so that the size of the cavity can be seen. If the cavern size is quite large, then remove soil from the top of the cavity downward until a large opening has been made. Then, place a small amount of heavy soil (clay or silty clay) in the opening and compact this soil by hand labour using a wooden compactor. If only sandy soil is available, then consider using a mixture of sand and cement. Then, place a small amount of additional soil in the cavity and compact this soil. Continue this process until the cavity has been filled. Then repair the lining.

If the cavity cannot be detected at the top of the lining wall panels, but only by a small opening in the joint, then the best procedure is to break the lining that is already showing deterioration. Inspect the cavity, using a flashlight if necessary. If the cavern is small, then fill it with grout or a soil-cement mixture. If the cavity proves to be quite large, then excavate from the top of the lining down to the cavity and follow the procedure described in the paragraph above.

Preferably, the joint opening should be sealed with asphalt or some other sealant. If the cavity formation has resulted from the lack of subsurface drainage, and subsurface drainage is not going to be provided, then a weep hole should be placed when the concrete is repaired as shown in Figure 5.2-15.

If there is extensive damage in a channel reach resulting from the lack of subsurface drainage, then the facilities shown in Figure 5.2-11, 5.2-12 and 5.2-14 should be considered and appropriate measures implemented.

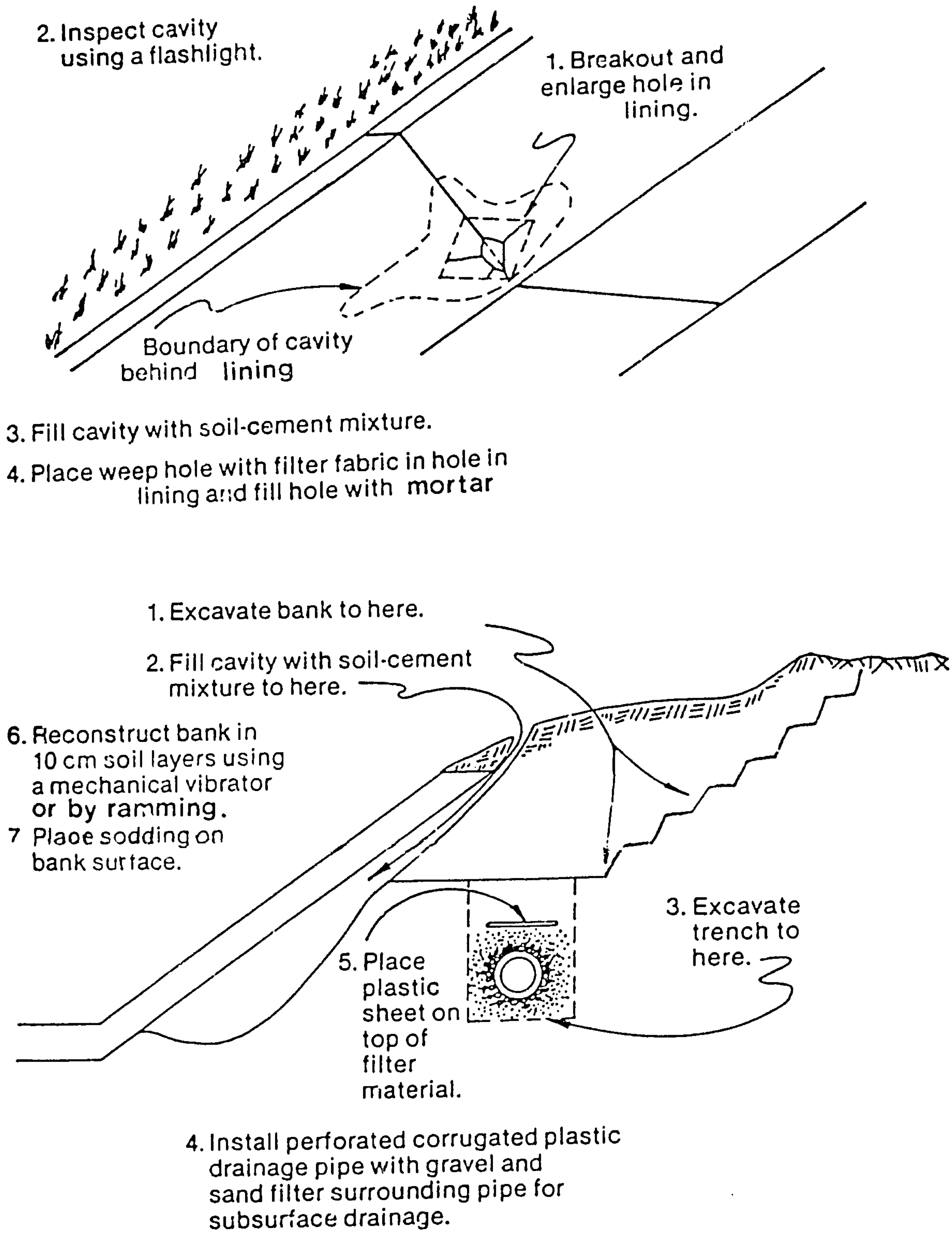



Figure 5.2-15. Procedures for Filling Cavities

Finally, the roadway bank or berm bank adjacent to the lining walls having the cavities must be graded and shaped. Then sod (vegetation) should be placed on the bank to prevent erosion. This sodding should be inspected weekly for a few months afterwards to be sure that proper vegetative cover is being provided, then inspected later as appropriate. If proper vegetative growth does not occur, then the soil should be removed and replaced with a more fertile soil, then sodded again, and taken better care of than before.

## 7. Earthen Channels

Before undertaking the sediment removal operation, proper longitudinal and cross-sectional levels should be observed and plotted. The designed cross-sections should be superimposed on the drawing. The depth of sediment deposition along the bed and banks should be ascertained. Proper layout for excavation should be given technically and then the sediment removal operation can begin. The earth/silt so excavated should be deposited far away from the canal, or in depressions, to avoid its re-entry into the canal. The desilting operation should be completed before the start of the cropping season.

Erosion can be repaired manually by refilling and compacting. Care should be taken to have proper bondage between the old and new earth surfaces; otherwise, the channel will again deteriorate at the same location. Heavy erosion of the bank sides below fall structures should be repaired by refilling earth with proper bondage and compaction, then placing boulders (riprap) on the slopes. Killa bushing on the sides is another very effective method of checking erosion.

### Leakage from Banks

The inside and outside banks of irrigation channels should be kept free of weeds to prevent attracting rodents and animals that burrow holes in the embankment, causing leaks near the outer toe. These leakages can cause a breach in the canal. The hole path of the leak should be dug manually and then backfilled and compacted.

### Jungle Clearance

Weeds (jungle, bushes, sarkanda, etc.) take root in the soil and grow on the slopes and banks of canals.

Similarly, aquatic weeds either root in water or in the earth, but their habitat is in water. Due to favourable soil moisture conditions, both types of weeds proliferate rapidly, obstructing the flow of water in the canals. They also choke the cross-section of the canal and reduce the carrying capacity of channels.

This menace can be effectively controlled if the weeds at a tender age are uprooted regularly without allowing them to flourish.

Manual methods such as cutting, uprooting and burning the uprooted weeds can control their growth.

Measuring Channel Losses

The most important maintenance problems will perhaps only be discovered while measuring channel losses. The seepage loss rate measurements, particularly at high operating water levels, will disclose whether or not the embankments may require reconstruction, or if lining should be considered. This type of field data should also be collected in the tertiary channels; then, the farmers should be informed of the results. Irrigation Department field personnel could provide technical advice to the farmers on reconstruction of their channels if the seepage losses are significant.

## C. Maintenance of Structures

Usually, the concrete structures will be in excellent structural condition, unless they are very old. The quality of the construction work has been very good. For lined channels, the primary difficulty with structures has been their impact on deterioration of the nearby lining panels. For both earthen and lined channels, there are problems with the flow control structures, primarily with the maintenance of gates.

### 1. Under-Canal Structures (Drain Culverts)

The most common maintenance requirement for drain culverts underneath irrigation channels is the removal of sediment and shrubbery at the inlet and outlet. The fact that shrubs exist, and often the growth is quite dense, is a good indicator that maintenance has been neglected.

In some cases, there has been erosion of the banks near the headwalls. This situation should be remedied by refilling and compacting soil in the eroded area, careful grading, and sodding, with special attention given for some time afterwards to assure that good vegetative growth is occurring in the sodded area and that the erosion problem has been corrected.

The drain culverts are valuable structures for serving as outlets for either open drains or pipe interceptor drains constructed along an irrigation channel to provide subsurface drainage. In some cases, it may be desirable to construct additional drain culverts to provide outlets for subsurface drainage facilities.

### 2. Bridges

Bridges are usually a problem for lined canals. Commonly, surface runoff from rainfall causes erosion at the bridge abutments and the formation of cavities behind the lining panels. The required maintenance is to place rubble masonry, brick or concrete between the top of the lining and the bridge abutments as shown in Figure 5.2-16. This remedy should be incorporated into the design criteria for such structures in the future. If the bridge settles, then the brick, concrete or rubble masonry will crack, and the cracks can be filled with asphalt or mortar.

### 3. Drop Structures (Syphons)

The inlet to a drop structure needs to be inspected for cavities along the outside walls and immediately upstream in the transition inlet structure. If cavities exist, or erosion is occurring, then the appropriate maintenance remedies should be applied.

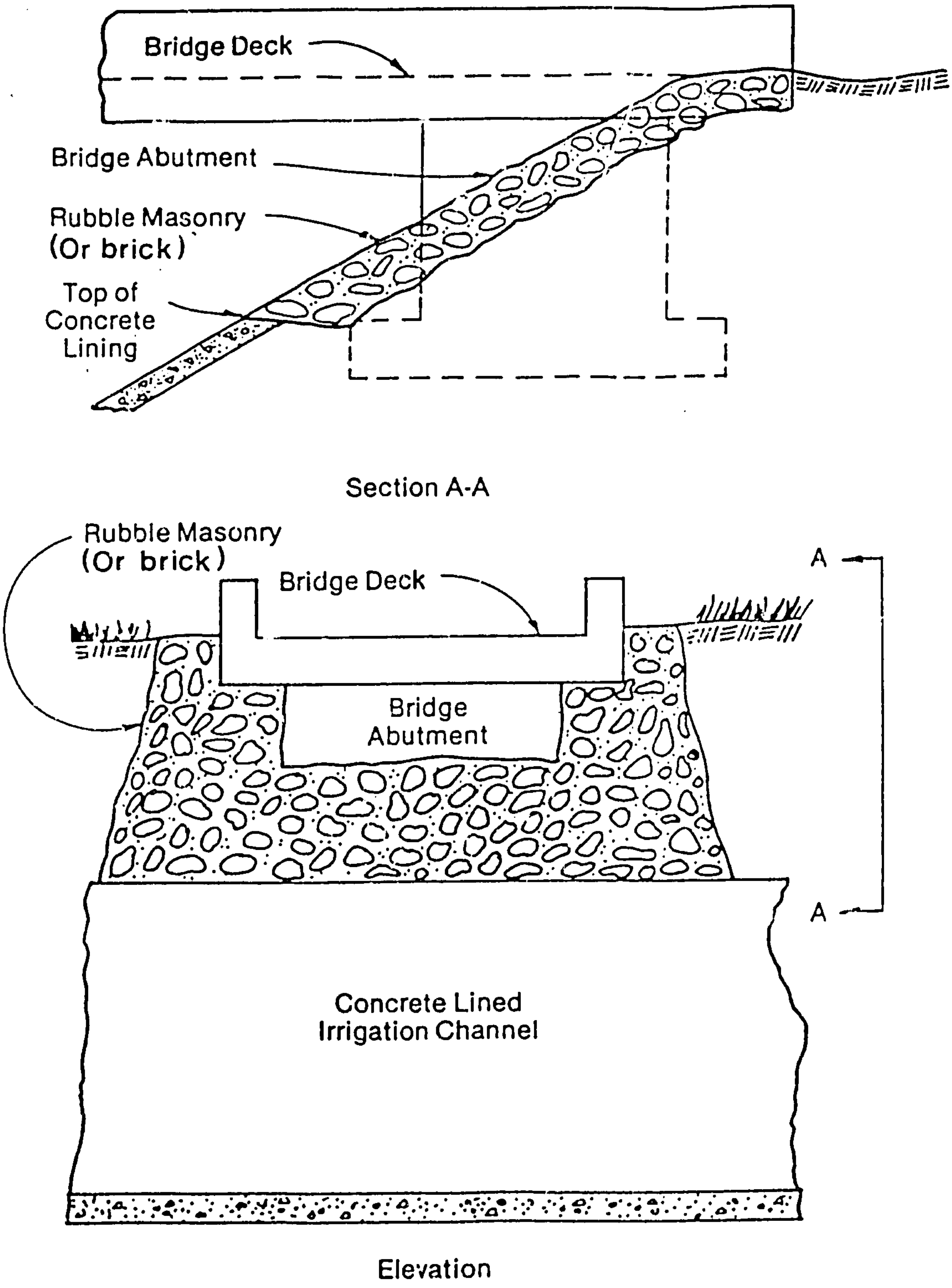



Figure 5.2-16. Construction of Rubble Masonry Above Channel Lining to Bridge Abutments.

If an open channel chute is used between the inlet and outlets for the drop structure, then the walls can be inspected for cavity formation and soil erosion, with the appropriate maintenance remedies applied. If a pipeline is used between the inlet and outlet, then the major concern is water leaking at one or two joints, usually because of soil settlement in the embankment. The visual evidence that significant leaking of the joints is occurring would be a cavity in the soil above the pipeline (Figure 5.2-17). If so, the overlying soils needs to excavated, the pipeline inspected and repaired as appropriate, the backfill properly compacted, the top of the embankment properly shaped to minimize the potential for erosion, and then sodded, with the sodding being given special attention during the following year.

Often, a hole will have been created by deterioration of the concrete at the joint opening at the end of the outlet transition structure. This is the result of hydraulic pressure behind the structure. The remedies, as shown in Figure 5.2-18, are:

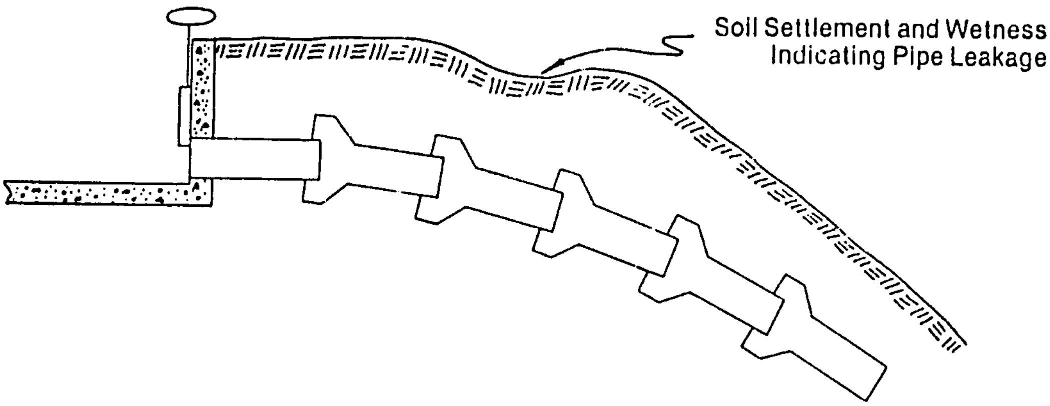
1. Lower the roadway, beginning at the inlet transition structure, so that the roadway will not be so high above the outlet transition structure;

2. Place an open drain, surface runoff interceptor drain, or perforated pipeline drain alongside the roadway and berm embankments that is sufficiently deep to provide subsurface drainage, as well as surface drainage; and,

3. Install either more small-diameter weep holes in the outlet transition structure (Figure 5.2-13) or small sections of porous rubble masonry with filters in the concrete walls (Figure 5.2-14).

4. <u>Fall Structures</u>

If scour is continuing to occur below a fall structure, then a concrete, rubble masonry, or riprap lined stilling basin should be constructed to dissipate much of the excessive hydraulic energy.




1. Excavate overburden with backhoe or using labourers with shovels.
2. Remove soil surrounding pipeline using labourers with shovels.
3. Inspect a minimum of 3 pipe joints for leakage.
4. Replace any broken pipe and caulk the pipe joints.
5. Replace the excavated soil in 10 cm layers using a mechanical vibrator.
6. Grade the ground surface for good surface drainage.
7. Place sodding on ground surface and adequately maintain for at least one irrigation season, or more if required to establish good plant cover.

Figure 5.2-17. Maintenance of Leaking Pipeline Drop Structures.

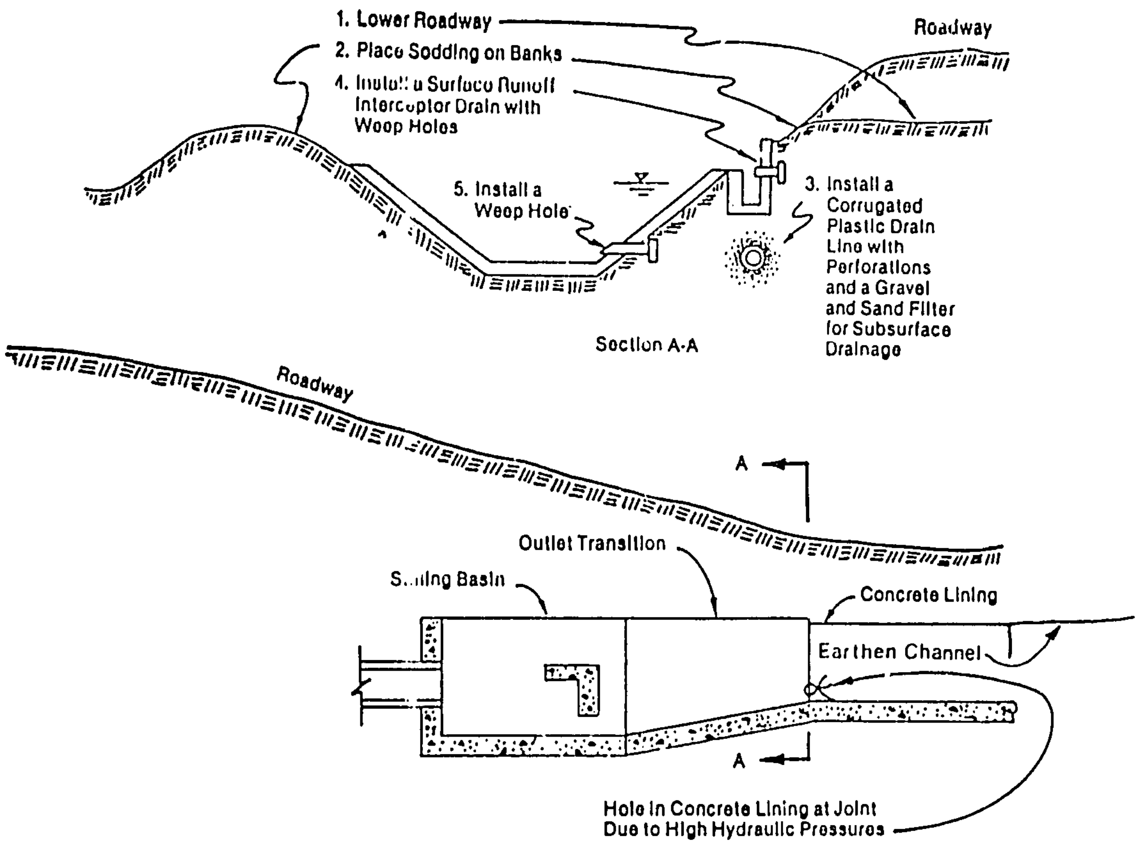



Figure 5.2-18. Maintenance Remedies to Relieve Hydraulic Pressure at the Outlet Transition for a Drop Structure.

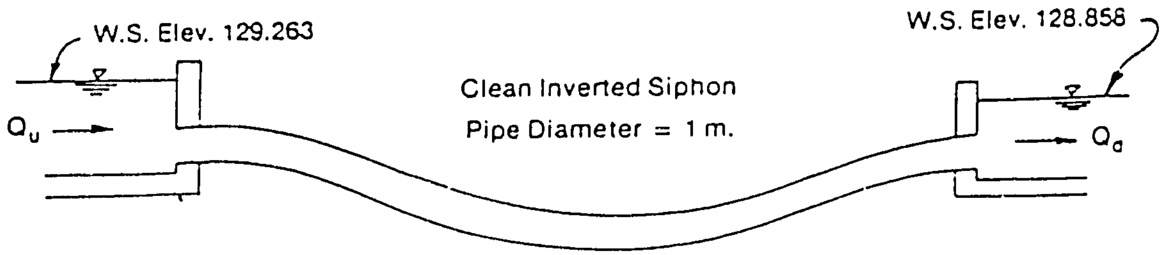
5. Culverts and Inverted Siphons

Usually, there are only minor maintenance problems with culverts, with the usual maintenance activity being the removal of debris at the culvert inlet. This would also be the case for inverted siphons.

The primary maintenance problem for inverted siphons is the accumulation of sediment, gravel and rock, twigs and branches, or pieces of lumber. The maintenance is expensive because after canal closure, the water in the inverted siphon has to be pumped out, and then a labourer enter the inverted siphon to remove the accumulated material.

In order to determine whether maintenance is required for an inverted siphon (or a culvert), a useful technique is to periodically check the coefficient of discharge for the structure. This can be done with a single discharge measurement using a current meter, along with the difference between upstream and downstream water surface elevations

If material is accumulating, either in a culvert or inverted siphon, where submerged outlet control exists, the coefficient of discharge will decrease (Figure 5.2-19). When the flow capacity of the structure has been reduced to the point where downstream operations are affected, then the accumulated material should be removed.




Example:

By current meter measurements,

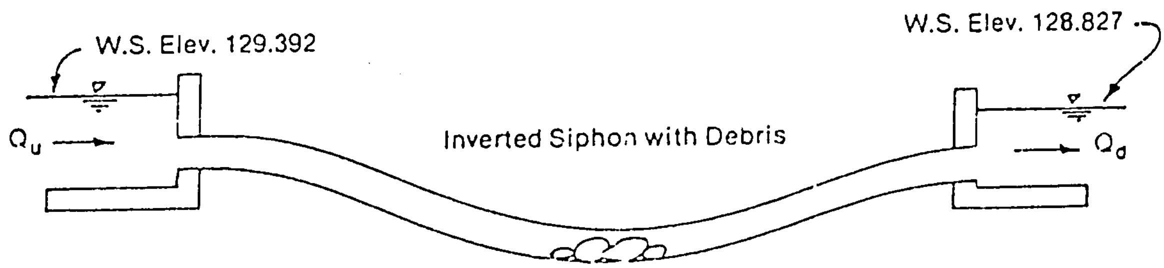
$Q_u = 1.536\ m^3/s$ $\qquad$ $Q_d = 1.561\ m^3/s$

Average $Q = 1.548\ m^3/s$

$$C_d = \frac{Q}{A\sqrt{2g}\,(h_u - h_d)^{0.5}} = \frac{1.548\ m^3/s}{0.7854\ m^2\sqrt{2.9.81\ m/s^2}}$$

$$= \frac{1.548\ m^3/s}{0.7854\ m^2\sqrt{2(9.81\ m/s^2)}\ \ (129.263m - 128.858m)^{0.5}}$$

$$= 0.699$$




Example:

By current meter measurements,

$Q_u = 1.341\ m^3/s$ $\qquad$ $Q_d = 1.318\ m^3/s$

Average $Q = 1.330\ m^3/s$

$$C_d = \frac{1.330\ m^3/s}{.7854\ m^2\sqrt{2(9.81\ m/s^2)}\ \ (129.392m - 128.827m)^{0.5}}$$

$$= 0.509$$

If this flow reduction is not satisfactory, then schedule the required maintenance.

Figure 5.2-19. Discharge Measurement Technique for Determining When Maintenance Is Required at an Inverted Siphon or Culvert.

## 6. Gate Structures

One of the important activities to support improved operations of an irrigation project is continued good maintenance of gate structures, most of which are used as flow control structures. Fortunately, the design of gate structures is quite standardized, which provides many advantages when improving the hydraulic operation of the irrigation channel network. Usually, the construction, fabrication and installation of gate structures has been very good, except in some cases where standardization was affected by gate frame installation.

The maintenance of gate structures should include maintaining standardization to support the Operations Phase of the M&O Learning Process.

The usual visual indicators of gates and gate frames requiring maintenance are gate leakage, bent gate rods, gears needing lubrication, and poorly installed gate frames. Special attention should be given to correcting these deficiencies and then continually maintaining these gate structures.

If a gate frame was improperly installed, then the frame should be removed and installed properly. In some cases, the gate frame will have to be replaced.

If the gate rod is bent, then it should be removed, taken to a workshop, and straightened or replaced.

If there is gate leakage, attempt first of all to correct the problem in the field. If this becomes too difficult, then remove the gate and gate frame, haul to an appropriate workshop, and correct the deficiencies.

Gates and gate frames should be cleaned and painted frequently, preferably every year. Commonly, metal gates will corrode and the metal becomes weak inside without being visible, until the gate buckles. This is usually the result of infrequent cleaning and painting.

If scour below the structure is substantial, then serious consideration should be given to constructing a concrete, rubble masonry, or riprap lined stilling basin to dissipate the excessive hydraulic energy that will result in lower velocities entering the downstream earthen channel section.

## 7. Other Structures

When inspecting other irrigation structures, the primary maintenance problems will be cavities along a wall and erosion because of improper grading near the structure. Correcting these maintenance problems is usually a relatively simple task and is particularly important for lined channels because of the damage that often results to nearby lining wall panels. These simple maintenance problems for the structure may result in significant maintenance costs to salvage the nearby lining wall panels.

The necessary maintenance practices are filling cavities, proper grading around the structure, and sodding. These maintenance problems should be detected early before they result in significant damage, then corrected soon in order to minimize maintenance costs.

Two of the more serious problems that can occur with structures are: (1) undermining due to scour and erosion; and (2) piping. Piping can usually be avoided by frequent visual inspection to look for evidence of cavities, particularly along the walls. Scour and erosion are also very visible, but the solutions may be more difficult. In simple cases, the use of brush and cut trees properly placed may solve the problem; whereas, in more difficult cases, a concrete energy dissipating structure may be required.

## 8. Outlet Structures

The types of outlet structures are discussed and illustrated in chapter 2.1, whereas the maintenance problems associated with these structures are discussed in Section 5.1.

If a few outlets have been tampered with, then the situation can be technically corrected. For those outlets which are too low, then they should be reset at the appropriate elevation. For those outlets wherein the constriction has been made larger, then the outlet opening must be reconstructed. In some cases, for an Adjustable Proportional Module (APM), a cast iron APM block embedded in concrete has been used, which is extremely effective in avoiding tampering. After correcting any deficiencies in the outlet structures, they should be checked during every season to be sure there has been no further tampering.

If numerous outlets have been tampered with, say 25 percent or more, then the situation is not likely to be corrected by technical measures alone. This becomes an extremely difficult social problem that must be dealt with by all parties concerned, including both Irrigation Department staff and farmers. The solutions are not really known, except for perhaps strict enforcement. But serious consideration should be given to documenting the discrepancies between actual structural measurements, elevations and discharge rates, as compared with authorized or sanctioned measurements, elevations and discharge rates. Then, this information should be extensively communicated with the farmers in the irrigation system, so that possibly they can resolve the problem of tampering among themselves, with perhaps the Irrigation Department staff playing an intermediary technical assistance role.

## D. Maintenance of Communication and Ancillary Works

Apart from routine inspection, high standards of maintenance are possible by establishing an efficient monitoring system. Performance can be checked by a dependable communication system such as inspection roads, telephones, telegraph network or wireless, etc. These provide the higher supervisory personnel with important feedback.

### 1. Service and Inspection Roads

Inspection roads along the main canal, branch canals, distributaries and minor canals should be maintained in a pothole free condition. Jungle clearance, patching of potholes, refilling of raincuts, maintenance of cattle water drains, and maintenance of dowels should be adequately done. The maintenance of the service and inspection roads in good condition is very necessary to ensure efficient water regulation. These roads facilitate carrying materials for maintenance works. Care should be taken to see that sufficient width for passing of vehicles has been provided at frequent intervals.

A dry road surface disintegrates rapidly and it is therefore necessary that the road should be watered regularly. On the main canal and branches, after watering, the surface should be worked with rollers to give a good even surface. On distributaries, the watering of the road surface should be done as frequently as possible. Inspection roads which are not maintained should be closed to traffic immediately after a rainfall; otherwise, the surface will get badly damaged and also it may create a traffic hazard by being soft and slippery.

2. Telephone and Telegraph Services

Telegraph or telephone lines and instruments should be repaired/maintained regularly from the concerned departments to ensure their dependability.

3. Ancillary Works

Buildings such as offices, labourers' quarters, officers' residential buildings and rest houses should be whitewashed regularly and damages, if any, repaired. This is generally done once in a year depending upon constraints of budget. Tree plantation along the canals and in the colonies also needs proper care and maintenance. A systematic new tree plantation programme during every monsoon season should be practised.

## E. Maintenance of Tertiary Systems (Micro-Networks)

### 1. Maintenance Procedures by Farmers

The system below the outlet consists of a water course network, turnout, drops, etc. Its construction and maintenance is the collective responsibility of the community, i.e. the group of farmers who have a common right to use it. Regular and routine maintenance is required from the farmers. With the flow of water, the outlet draws its share of silt from the parent channel. This silt gets deposited in the bed and the sides of the water course resulting in a reduction of its carrying capacity. Generally, silt formation is confined to the head reaches of the water course, where water flows most of the time. In order to run the authorised full supply discharge, it becomes essential to remove extra silt deposited in the bed of the water course and also to remove berm formation on the sides. Similarly in the filling reaches, the bed and banks get eroded due to high velocity and the embankment is weakened. These embankments need strengthening to avoid any breaches or seepage through the banks. Apart from this, weeds and bushes also grow in the water course and hamper the flow of water.

Sometimes, structures are damaged by the water flow. Displacement of stones, disintegration of joints, or cracks need timely repairs. Careful watch must be maintained for undermining of structures. Wooden planks fixed in the turn outs for regulating the direction of flow of water generally leak and water is wasted. These leakages can be controlled by placing earth behind the wood planks.

Farmers generally elect one leader to manage the maintenance and repairs of the system to be done collectively by the farmers. This leader is someone who has the respect and confidence of the other farmers. He distributes the maintenance quantum of work to each farmer in proportion to their land holdings within the outlet command and directs and supervises the maintenance activities.

Some farmers who are unable to participate in the maintenance activities due to unavoidable circumstances provide labourers on their behalf for this work. In a few cases, if some farmers neither turn up themselves nor provide labourers the team leader has their share of work done by others, who are paid in money, and the money recovered from the absentee farmers. This activity is generally done once in a crop period before the water is first released in the water course. Thereafter, the shareholders maintain the water course between the nakka points related to their holdings.

2. Emphasis on Technical Assistance

The tertiary portion of the irrigation system is quite complex because it contains three irrigation subsystems: (1) water delivery; (2) the farm; and (3) water removal.

The tertiary subsystem is generally the most neglected portion of irrigation projects in India. Increased emphasis on improving the performance of the tertiary channel network will enhance the Irrigation Department's communication and credibility with farmers, and even more importantly, strengthen the organizational effectiveness of Water Users Groups.

The initial emphasis will be on assisting each Water Users Group in providing more equitable water distribution to individual farmers. This will be accomplished by evaluating channel losses throughout the tertiary network, with participation by leadership in the Water Users Group, followed by communicating the results in open meetings with all Water Users Group members (farmers). First of all, these results will disclose whether improved maintenance needs to be performed by the Water Users Group. Also, this data will give an indication as to whether any improvements in the tertiary system are needed for providing an adequate water supply, or for equitably distributing water among farmers. This will be a highly participatory process of farmer involvement, with the department providing technical assistance.

3. Evaluating the Outlet Structure

An important consideration for the farmers being served by an outlet structure is whether modular flow conditions exist, and whether the discharge rate corresponds with the authorized or sanctioned discharge. If non-modular flow conditions exist, then it may be possible for the farmers to achieve modular flow conditions by improving the hydraulic characteristics of the watercourse by:

- o lowering the bed elevation of the watercourse;
- o increasing the width of the watercourse; and
- o decreasing the hydraulic roughness by removing vegetation and smoothing the watercourse perimeter.

Usually, the discharge rate of the outlet structure is checked by measuring the hydraulic head and calculating the discharge rate from the standard modular flow equation. Instead, it would be better (but more time consuming since it would take 1-2 hours of time) to install a portable flow measuring device, such as a cutthroat flume, and measure the discharge rate. Any device needs to be installed a sufficient distance downstream from the outlet (say 50 meters) so that the backwater effects do not extend upstream to the constriction in the outlet structure. At the same time, the hydraulic head on the outlet constriction should be measured and the discharge calculated, so that the two discharge rates can be compared. If there is a discrepancy, then first of all, re-check the flume installation and flow depth readings; if these are correct, then calculate the coefficient of discharge (see Section 2.2) for the outlet structure using the flume discharge.

4. Measuring Channel Losses

An important element of field evaluations is to determine the channel losses in various reaches of the tertiary network. The methods described in Section 2.4 on "Measuring Irrigation Channel Losses" would apply. Wherever possible, the Inflow-Outflow Method should be used. At the head of the watercourse, the outlet structure calibration can be used in conjunction with placing a portable flow measuring device downstream for a few hours in order to determine the channel losses.

Further downstream in the tertiary network, however, two cutthroat flow measuring flumes will have to be temporarily installed for 2-8 hours, which will result in a slightly higher water level in the reach and a higher measured value of the seepage loss rate. Also, it is very feasible to construct dikes at the upstream and downstream ends of a reach for conducting a ponding test, which could be repeated at a number of locations in the tertiary system (Figure 5.2-20).

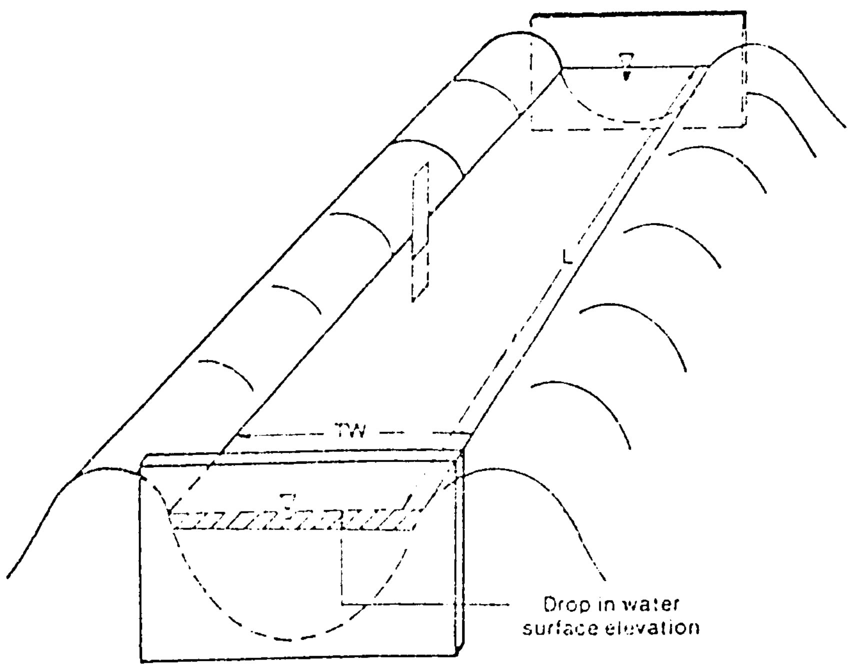



Figure 5.2-20. Ponding Test for a Tertiary Channel Using Metal End-Plates.

If the water losses are considerable, then the causes of these losses must be established. For example, perhaps the earthen channel banks have become narrow and weak because of encroachment by adjoining farmers, or heavy vegetation or sedimentation have caused the water levels to rise so that the seepage loss rate is much greater, or some of the farm nakkas are leaking water, or animals crossing the channels or wallowing in the channel have weakened the banks, or rodent holes are causing leakage at many locations. Determining the causes of the water losses is crucial to developing appropriate maintenance solutions.

The results of the channel loss measurements should be conveyed to the farmers, preferably in an open meeting. If the channel losses are significant, it is very likely that the farmers will have a keen interest in undertaking the appropriate maintenance measures in order to reduce their water losses.

5. Watercourse Maintenance

The most immediate indicator of the need for watercourse maintenance is a dense growth of vegetation or significant accumulations of sediment. After that, having measured channel losses in the watercourse provides the most valuable information regarding the necessity for maintenance. The greater the channel losses, then the greater is the need to do maintenance. If the losses are highly significant (say greater than 25-30 percent), then it will be desirable to have the farmers reconstruct their watercourse channels in order to reduce seepage and leakage losses.

6. Watercourse Structures

Technical assistance can be provided by Irrigation Department field personnel regarding minor maintenance needs, repairs, or replacement of structures. If necessary, the farmers can employ local masons to make necessary repairs and replacements. Also, in some cases, the elevation of a structure will need to be reset; here again, the Irrigation Department can provide technical assistance.

7. Farm Drains

The visual indicators of the necessity for maintenance of farm drains is heavy vegetative growth and significant deposits of sediment in the bed of the field drains. In either case, the necessity for maintenance should be obvious to farmers. With their own labour, they can remove and burn vegetative growth, as well as remove accumulations of sediment and place this material away from the drain banks so it cannot be washed back into the farm drains.

## F. Maintenance of Drains

1. Purpose of Drainage Network

Certainly, one of the most important roles of a open drain network is to provide surface drainage during the monsoon season. When too much rainfall occurs, it is important that farmers can drain the water from their fields fairly rapidly.

In some irrigation systems, the use of an open drain network for subsurface drainage is also extremely important. Although open drains are sometimes constructed to provide subsurface drainage, rarely are these networks field evaluated to determine their effectiveness in draining the fields.

2. Monitoring of Groundwater Levels

There is extreme importance in monitoring the depth of groundwater below the ground surface in any irrigation system. If the groundwater levels are deep, then perhaps only a single observation well in the lower reaches of the irrigation system is adequate. But, the history of irrigation projects is that groundwater levels usually continue to rise with time, unless there is substantial groundwater pumping. Certainly, wells can be used for observing depths to the groundwater.

Where groundwater levels are shallow, say less than 5 meters, then groundwater monitoring becomes extremely important, not only for indicating impending waterlogging and salinity problems, but also to indicate the effectiveness of the open drain network for subsurface drainage. Also, the fluctuations in the groundwater levels in response to cleaning of the drains can be observed, which is another indicator of the effectiveness of the network for subsurface drainage and the relative importance of properly maintaining the open drains.

### 3. Erosion and Sedimentation

A major emphasis should be placed on minimizing the flow of sediments into the drainage network. This can begin with the practices used by farmers in releasing ponded water from their fields. Then, the flow of water in the tertiary systems should be observed for cases of scour and erosion, wherein the farmers should be advised and requested to take appropriate measures.
A "Walk-thru" along the drainage network will undoubtedly disclose many sites where water is allowed to run into the open drains in a manner that causes erosion. Then, because drains are located in the low lands, their gradient is usually very flat, so sediments are readily deposited in the bed of the drains.

### 4. Aquatic and Vegetative Growth

The greatest difficulty in the maintenance of drains is the clearing of vegetative growth. Often, there is massive growth that becomes a tremendous job to clear. The problem is aggravated by stagnant ponds of water that support both aquatic and vegetative growth.

Unfortunately, drains usually receive insufficient attention. Usually, there are no service roads along the drainage network, so "out of sight, out of mind". Also, if there are insufficient funds for maintaining the irrigation delivery subsystem, then it becomes quite natural to ignore the water removal subsystem -- unless heavy monsoon rains occur! By that time, it is too late.

The best means for removing vegetative growth is uprooting the plants by hand labour. This can usually be done easily in the bed of a drain, but will become difficult high on the drain bank, where the vegetative growth will have to be cut by hand labour. The vegetative material should be stockpiled and removed, or burned.

## 5. Hydraulic Performance

Rarely is the hydraulic performance of a drain network evaluated. Everyone assumes that the drains are performing as designed. Actual field measurements will likely prove to be shocking. Almost assuredly, a field evaluation would result in much greater emphasis on more frequent maintenance of the drains.

Although many drainage networks have very few structures, invariably there will usually be some culverts or bridge crossings. Consideration should be given to either calibrating these structures for discharge measurement, or constructing a few control structures that can be calibrated, or modifying existing structures to better serve as flow measurement structures.

Monitoring of discharge rates at just a few locations in the drainage network combined with monitoring of groundwater levels at some locations, as well as rainfall, will provide valuable insights into the hydraulic performance of the drains. This, in turn, will provide guidance regarding the scheduling of maintenance activities.

## ANNEXURE-I

WHAT TO CHECK BEFORE AND DURING MONSOON FOR DAM SAFETY.

### EARTH DAMS

1. Check the emergency stock piles at vulnerable locations downstream for suitable and sufficient quantities of filter materials, sand gravel, empty cement bags.

2. Patrolling round the clock should be implemented once the reservoir is near FRL and the anticipated inflow is sizeable.

3. Check for any holes of burrowing animals, cracks, depressions, wet patches, sloughing, erosion of materials from the foundations and abutments, seepage at interface between the earth dam and masonry/retaining walls, sluices, outlet conduits and regulators, integrity of surface drains, etc., and seepage through interfaces between foundations and structures.

4. Examine the data observed from various instruments if any have been installed and analyze the data for corrective measures where necessary.

5. Look for boils that may occur on the downstream in the entire reach.

6. See if any material is being washed out with the seepage water, taking careful measurements of the silt content of seepage water.

7. Check the spillway channel against all obstructions to the safe carriage of designed flood discharge.

8. Look for cracks, both longitudinal and transverse, near the outlet location.

## MASONRY DAMS

1. Check for excessive settlement, deflection, seepage uplift pressures, deterioration of concrete/mortar.

2. Inspect the drainage system in the foundation and dam leaks, cracks, spallings on the surface of the dam and openings, and scour downstream of spillway.

3. Ensure normal conditions by timely, effective remedial measures where necessary.

4. Ensure fool proof availability of access to vital parts and adequate lighting and auxiliary facilities.

5. Where there is provision for pumping drainage water, ensure an alternative source of power for uninterrupted pumping in order to avoid build-up of pressure.

## GATES, HOISTS AND OTHER OPERATING MECHANICS

To avoid a catastrophe the following checks are prerequisites for the safe operation of gates:

1. See that the paint on the gates is in good condition.

2. Clean and lubricate the gate wheels and ensure that the wheels are rotating on the bearings, check by actually raising and lowering the gates through their full range of travel.

3. Check the seals for wear and tear and replace the damaged seals.

4. Check for any foreign materials, boulders, logs, etc., in the gate grooves and inspect all embedded parts to see that they are in proper shape.

5. Examine all wire ropes and chains for rusting, broken stands reduction in cross section, etc., and see that they are in good working order with proper lubrication, etc.

6. Ensure that all bearing points, hinges, spur gears, pinions, etc., are properly lubricated.

7. Check gear teeth for any cracks, undue wear, etc., and replace/repair if necessary.

8. Check for gear oil in worm gear reducer and limit switches. Drain oil from boxes, rinse with cleaning oil and fill them up to the marked level with suitable oil.

9. Ensure that the brake shoe will not drag but will bear tightly when applied.

10. Check the electrical wiring system and ensure that there are no loose contacts/defects.

11. Keep hand cranks under lock and key and do not attach to the hoist mechanism when operated by electrical energy.

12. Check all keys and bolts of the hoist mechanism and tighten, if loose.

13. See that the operating crane is in good working condition. See that hoist loads are in a vertical direction only and ensure that the allowable capacity of the crane is not exceeded.

14. Ensure that fully trained operators familiar with operating instructions are on site for the operation of the gates.

15. See if any unusual phenomena like excessive vibrations, noises, etc., are noticed, especially when the gate is operated.

16. Keep adequate stock of the spare parts that are generally required on site.

17. Ensure power supply from two independent sources. See that diesel generating sets of adequate capacity to serve as stand by are kept in good working order.

OTHER ASPECTS

1. See that the data book in complete shape is kept ready for reference, which comprises a complete set of design calculations, assumptions made, construction drawings, etc., at the site in respect to the dam and appurtenant structures.

2. Ensure that operating manuals/instructions issued by the manufacturers of the gates, instruments, etc., are available at the site.

3. See that copies of geological reports, details of special foundation treatment carried out, details of instruments embedded, details of construction stages, etc., are incorporated in the data book as available.

4. Ensure that the reservoir area is free from any potential slips and slides, and floating logs and wood should be closely watched and removed quickly to prevent a triggering action.

5. Ensure that there is a gauge observation site well upstream of the reservoir so that the travel time of water from the gauge site to the dam site is at least 10 to 12 hours to serve as a forewarning. Also ensure the existence of a fool proof communication system so that the reservoir can be depleted to a low level to absorb the incoming flow and to ensure the spillway is saved from heavy anticipated discharges.

6. Ensure that competent personnel are in position at the site who can take command of the situation and act boldly by making correct decisions and implementing them during the period of emergency.

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