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HANDBOOK OF IMPROVED IRRIGATION PROJECT MAINTENANCE PRACTICES FOR THE KINGDOM OF THAILAND

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USAID

WATER MANAGEMENT SYNTHESIS II PROJECT

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HANDBOOK OF IMPROVED IRRIGATION PROJECT MAINTENANCE PRACTICES FOR THE KINGDOM OF THAILAND

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WMS Report 83

PREFACE

This study was conducted as part of the Water Management Synthesis II Project, a program funded and assisted by the United States Agency for International Development through the Consortium for International Development. Utah State University, Colorado State University, and Cornell University serve as co-lead universities for the Project.

The key objective is to provide services in irrigated regions of the world for improving water management practices in the design and operation of existing and future irrigation projects and give guidance for USAID for selecting and implementing development options and investment strategies.

For more information about the Project and any of its services, contact the Water Management Synthesis II Project.

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KINGDOM OF THAILAND

ROYAL IRRIGATION DEPARTMENT

65

HANDBOOK OF IMPROVED IRRIGATION PROJECT MAINTENANCE PRACTICES

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3

HANDBOOK OF IMPROVED
IRRIGATION PROJECT MAINTENANCE PRACTICES

Table of Contents

	Page
I. Introduction	M-01-01
II. Maintenance Phase of the Operations and Maintenance Learning Process	M-02-01
III. Job Functions in the Maintenance Phase	M-03-01
A. Maintenance Survey of Flow Control Structures	M-03-02
B. Essential Structural Improvements Plan	M-03-02
C. Diagnostic "Walk-Thru" Maintenance Survey	M-03-03
D. Preparation of Maintenance Plan	M-03-03
E. Annual Maintenance Work Plan	M-03-03
F. Annual Maintenance Completion Report	M-03-04
G. Preventive Maintenance Plan	M-03-04
IV. Physical Phenomena Causing Maintenance Problems	M-04-01
A. Earthen Channels	M-04-02
B. Concrete-Lined Channels	M-04-06
C. Roads and Berms	M-04-13
Roads	M-04-13
Berms	M-04-15
D. Sedimentation	M-04-17
E. Aquatic and Vegetative Growth	M-04-20
F. Fishing	M-04-21
G. Role of Drainage	M-04-24
Surface Drainage	M-04-24
Subsurface Drainage	M-04-24
H. Impact of Structures	M-04-25
Constant Head Orifice Outlet Structures	M-04-25
Drop Structures	M-04-27
Bridges	M-04-29
Other Structures	M-04-29
Culvert Drains	M-04-32

4

Table of Contents (cont.)

	Page
V. Maintenance of Channels	M-05-01
A. Aquatic and Vegetative Growth	M-05-01
B. Erosion and Sedimentation	M-05-02
Roadway and Berm Erosion	M-05-03
Erosion from Cut-Banks	M-05-03
Overflow from Adjoining Channels and Ponds	M-05-03
Animal Crossings	M-05-06
Fishing Activities	M-05-06
C. Sodding	M-05-08
D. Road and Berm Embankments	M-05-08
Compaction	M-05-09
Surface Drainage	M-05-12
Subsurface Drainage	M-05-14
E. Concrete-Lined Channels	M-05-19
F. Earthen Channels	M-05-22
G. Drains	M-05-22
VI. Maintenance of Structures	M-06-01
A. Drain Culverts	M-06-01
B. Bridges	M-06-02
C. Drop Structures	M-06-02
D. Culverts and Inverted Siphons	M-06-05
E. Constant Head Orifice Outlet Structures	M-06-07
F. Gate Structures	M-06-10
G. Other Structures	M-06-11
VII. Maintenance Survey of Flow Control Structures	M-07-01
VIII. Essential Structural Improvements Plan	M-08-01
A. Physical Description of Irrigation System	M-08-01
B. Proposed Flow Measurement Program	M-08-01
C. Proposed Program for Evaluating Channel Losses	M-08-02
D. Essential Structural Improvements	M-08-03
E. Costs of Essential Structural Improvements	M-08-03
F. ESI Implementation Plan	M-08-03
G. Field Notes and Sketches	M-08-04

Table of Contents (concl.)

	Page
IX. Diagnostic "Walk-Thru" Maintenance Survey	M-09-01
X. Preparation of a Maintenance Plan	M-10-01
A. Physical Description of Irrigation Project	M-10-01
B. Essential Structural Improvements	M-10-02
C. Status and Costs of ESI Plan	M-10-02
D. Inventory of Required Maintenance	M-10-02
E. Maintenance Costs	M-10-03
F. Priority Maintenance Needs and Costs	M-10-03
G. Maintenance Equipment Requirements	M-10-03
H. Maintenance Manpower Requirements	M-10-04
I. Maintenance Plan	M-10-05
Maintenance Issues	M-10-05
Method of Implementation	M-10-06
Implementation Schedule	M-10-06
J. Field Notes and Sketches	M-10-07
XI. Administrative Accountability in Implementing a Maintenance Plan	M-11-01
A. Review and Approval of Maintenance Plan	M-11-01
B. Submitting a Budget Request (BR)	M-11-03
C. Submitting Annual Maintenance Work Plan	M-11-06
D. Review and Approval of Annual Maintenance Work plan	M-11-06
E. Budget Control and Accountability	M-11-06
F. Submittal of Annual Maintenance Completion Report	M-11-07
G. Computerized Maintenance Planning and Reporting (Compare)	M-11-08
XII. Preventive Maintenance Plan	M-12-01
A. Physical Causes of Maintenance Problems	M-12-02
B. Extent of Maintenance Problems	M-12-02
C. Maintenance Equipment Requirements	M-12-02
D. Maintenance Manpower Requirements	M-12-03
E. Maintenance Requirement for Water Users Groups	M-12-03
F. Annual Maintenance Costs	M-12-04
G. Preventive Maintenance Plan	M-12-04
Maintenance Issues	M-12-04
Preventive Maintenance Activities	M-12-04
Preventive Maintenance Requirements	M-12-05

HANDBOOK OF IMPROVED

IRRIGATION PROJECT MAINTENANCE PRACTICES

List of Figures

Number	Title	Page
M-02-1	Maintenance Phase of the Operations and Maintenance Learning Process.....	M-02-02
M-04-1	Earthen Irrigation Channel in a Cut Area with Bank Sloughing and Erosion.....	M-04-03
M-04-2	Leakage Along the Berm Embankment of an Earthen Irrigation Channel.....	M-04-05
M-04-3	Medium-Sized Cavity Behind Concrete Lining.....	M-04-07
M-04-4	Huge Cavity Behind Concrete Lining.....	M-04-07
M-04-5	Damaged Concrete Lining with Berm Surface Erosion.....	M-04-10
M-04-6	Damaged Concrete Lining in Cut Area.....	M-04-10
M-04-7	Damaged Concrete-Lined Canal in a Deep Cut Area...	M-04-11
M-04-8	Concrete-Lined Channel in Excellent Condition because Adjacent Land is Below the Invert Elevation.....	M-04-11
M-04-9	Sediment Lying on Berm Embankment that will Erode and Wash Sediment into the Irrigation Channel During the Next Monsoon Season.....	M-04-12
M-04-10	Bank Erosion Along Roadway Embankments.....	M-04-14
M-04-11	Road Constructed High Above Irrigation Channel....	M-04-14
M-04-12	Horizontal Cracks in Concrete Lining Panrld as a Result of Soil Settlement in the Berm Embankment..	M-04-16
M-04-13	Concrete-Lined Irrigation Channel with Much Sediment.....	M-04-18
M-04-14	Cut Bank which is A Source of Sediment into the Irrigation Channel.....	M-04-18

List of Figures (Cont.)

Number	Title	Page
M-04-15	Many People Enjoy Fishing the Irrigation Channels.	M-04-23
M-04-16	A Fish Pond with Water Provided by Irrigation Project is a Productive Business for a Farmer.....	M-04-23
M-04-17	Failed Constant Head Orifice (CHO) Outlet Structure Because of Too Much Drop.....	M-04-26
M-04-18	Failed CHO Outlet Structure and Pipe Outlet Structure is Undermined and will Soon Fail.....	M-04-26
M-04-19	CHO Outlet Structure with Downstream Channel Concrete-Lined to Prevent Structure Failure.....	M-04-28
M-04-20	CHO Outlet Structure with Concrete-Lined Chute to Prevent Failure of the Outlet Structure.....	M-04-28
M-04-21	Small Hole in Concrete Lining Joint Commonly Found at End of USBR Stilling Basin VI Outlet Transition Structure.....	M-04-30
M-04-22	Large Cavity at Bridge Abutment.....	M-04-30
M-04-23	Broken Concrete Lining Panels Underneath Bridge...	M-04-31
M-05-1	Wading Laborer Pulling Weeds by Hand from an Irrigation Channel.....	M-05-02
M-05-2	Some Recommended Practices for Controlling Erosion and Sedimentation from Roadway and Berm Embankments	M-05-04
M-05-3	Typical Cross-Section of a Cut-Bank.....	M-05-05
M-05-4	Removal of Buffalo Wallow and Reshaping of Embankment.....	M-05-07
M-05-5	Reconstruction of Berm Embankment between Adjoining Irrigation Channels.....	M-05-07
M-05-6	Reconstruction of an Inadequately Compacted Embankment.....	M-05-10
M-05-7	Exploration for Leakage Holes and Reconstruction of Embankment.....	M-05-11

List of Figures (cont.)

Number	Title	Page
M-05-8	Collection of Surface Drainage From a Roadway and Conveyance into the Irrigation Channel.....	M-05-13
M-05-9	Reconstruction of Eroded Bank.....	M-05-13
M-05-10	Collection of Surface Runoff on Top of Enbankment and Conveyance Doen the Bank Slope and Erosion Protection at the Toe of the Bank.....	M-05-15
M-05-11	Typical Cross-Sections for Open Drains for a High Roadway Embankment in a Cut Area.....	M-05-17
M-05-12	Typical Cross-Sections for Open Drains and Use of a Surface Runoff Interceptor Drain and Perforated Pipeline Drain for Providing both Surface and Subsurface Drainage.....	M-05-17
M-05-13	Use of Weep Holes to Relieve Hydraulic Pressure Behind Concrete Lining.....	M-05-18
M-05-14	Use of Porous Robble Masonry with Filter to Relieve Hydraulic Pressure Behind Concrete Lining	M-05-18
M-05-15	Procedures for Filling of Cavities and Repair of Concrete Panels.....	M-05-21
M-06-1	Construction of Rubble Masonry Above Concrete Lining to Bridge Abutments.....	M-06-03
M-06-2	Maintenance of Leaking Pipeline Drop Structures..	M-06-04
M-06-3	Maintenance Remedies to Relieve Hydraulic Pressure at the Outlet Transition for a Drop Structure.....	M-06-06
M-06-4	Discharge Measurement Technique for Determining When Maintenance is Required at a Inverted Siphon or Culvert.....	M-06-08
M-06-5	Construction of Rubble Masonry Transition Between CHO Outlet and Tertiary Channel for Drops Loss Than 30 cm.....	M-06-09

List of Figures (concl.)

Number	Title	Page
M-06-6	Construction of Concrete Chute Transition Between CHO Outlet and Tertiary Channel for Drops Greater Than 30 cm.....	M-06-09
M-11-1	RID Review and Approval Process for a Budget Request Regarding Operations and Maintenance.....	M-11-02

HANDBOOK OF IMPROVED

IRRIGATION PROJECT MAINTENANCE PRACTICES

List of Tables

Number	Title	Page
M-09-01	Examples of field Notes and Sketches Extracted from the "Maintenance Plan for the Lam Phra Plerng Irrigation Project".....	M-09-03
M-09-02	Examples of Field Noted and Sketches Extracted from the "Maintenance Plan for the Lam Nam Oon Irrigation Project".....	M-09-09

Section I.

INTRODUCTION

Most countries in the world, including Thailand, have already constructed the most economical irrigation projects. Consequently, the major focus in the future will be on improving management practices to increase crop production on existing lands. However, deteriorating irrigation channels and inadequate operating procedures often preclude any significant improvement. To overcome these problems, an "Operations and Maintenance Learning Process" has been introduced. This process was developed in Thailand to provide a technological and institutional framework for operating an irrigation system.

An irrigation system can be divided into four major subsystems:

1. Water Source;
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 Source, Water Delivery and Water Removal subsystems support the Farm subsystem. An adequate technological and institutional framework for operating the irrigation system in accordance with design criteria must be established. If these frameworks are not in place, system failure or low agricultural production levels are likely to result even if the four irrigation subsystems have been properly designed.

A common problem in irrigation systems is the continual cycle of irrigation system construction, followed by deterioration because of inadequate maintenance, followed by rehabilitation (which ends up being major re-construction), followed again by deterioration. This significantly inhibits the development of irrigated agriculture. As irrigation channel networks deteriorate, the capability of delivering water equitably throughout the system is decreased. 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. In some cases, a portion of the lands have to be abandoned for lack of water. The consequences are very slow progress in agricultural development.

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, technological changes and institutional modifications will usually 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 farmer. First of all, in order to operate and maintain an irrigation system on a long-term basis, high-ranking government officials need to provide the necessary manpower, equipment and budget. Secondly, the personnel responsible for

maintenance and operations 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 emphasis on technology alone. Such a process must be capable of being adapted to each "site specific" situation in order to be transferable.

The Operations and Maintenance "Learning Process" provides one technological approach for effectively sustaining an irrigation network over a long period of time. This process emphasizes:

1. maintaining rather than rehabilitating;
2. documenting maintenance needs to improve financial management and accountability;
3. using existing flow control structures in irrigation channels for water management;
4. developing more detailed physical knowledge about what is occurring within the system;
5. increasing sensitivity about operating the system to meet the needs of farmers; and
6. documenting the need and costs for irrigation system improvements.

In discussing operations and maintenance (O&M) issues, it is useful to subdivide the water delivery subsystem into the main subsystem, usually called the main system, and the tertiary subsystem. The tertiary system is the land served by the last flow control structure along the main system. An irrigation project consists of a main system channel network that serves numerous tertiary systems. Most irrigation projects have a division of O&M responsibilities between the main system and the tertiary systems. Usually, RID is

responsible for O&M activities in the main system, while the farmers are responsible for O&M activities in the tertiary channel network.

This O&M process focuses upon the water delivery subsystem, but the same principles would apply to the water removal subsystem, which is the surface and subsurface drainage channel network. Most likely, the farmers would be responsible for maintaining the drainage channels in the tertiary subsystems.

For new irrigation projects, and recently rehabilitated systems, the initial emphasis of the O&M Learning Process would be the operations phase followed shortly afterwards with initiating activities under the maintenance phase. 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.

Section II.

MAINTENANCE PHASE OF THE OPERATIONS AND MAINTENANCE LEARNING PROCESS

The Main System of an irrigation project consists of irrigation channels. The channels start from the dam or river, and end at the outlets along each lateral and sub-lateral. Each outlet provides irrigation to a Water Users Group. The network of irrigation channels downstream from each outlet is defined as the tertiary system.

The Royal Irrigation Department is responsible for the maintenance of the main system, but not the operation and maintenance of the tertiary system.

The first step in the Maintenance Phase of the O&M Learning Process is to Conduct a 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.

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 laterals and sub-laterals, and CHO or outlet structure serving the tertiary system at each Water Users Group. In addition, check structures are valuable for flow control.

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

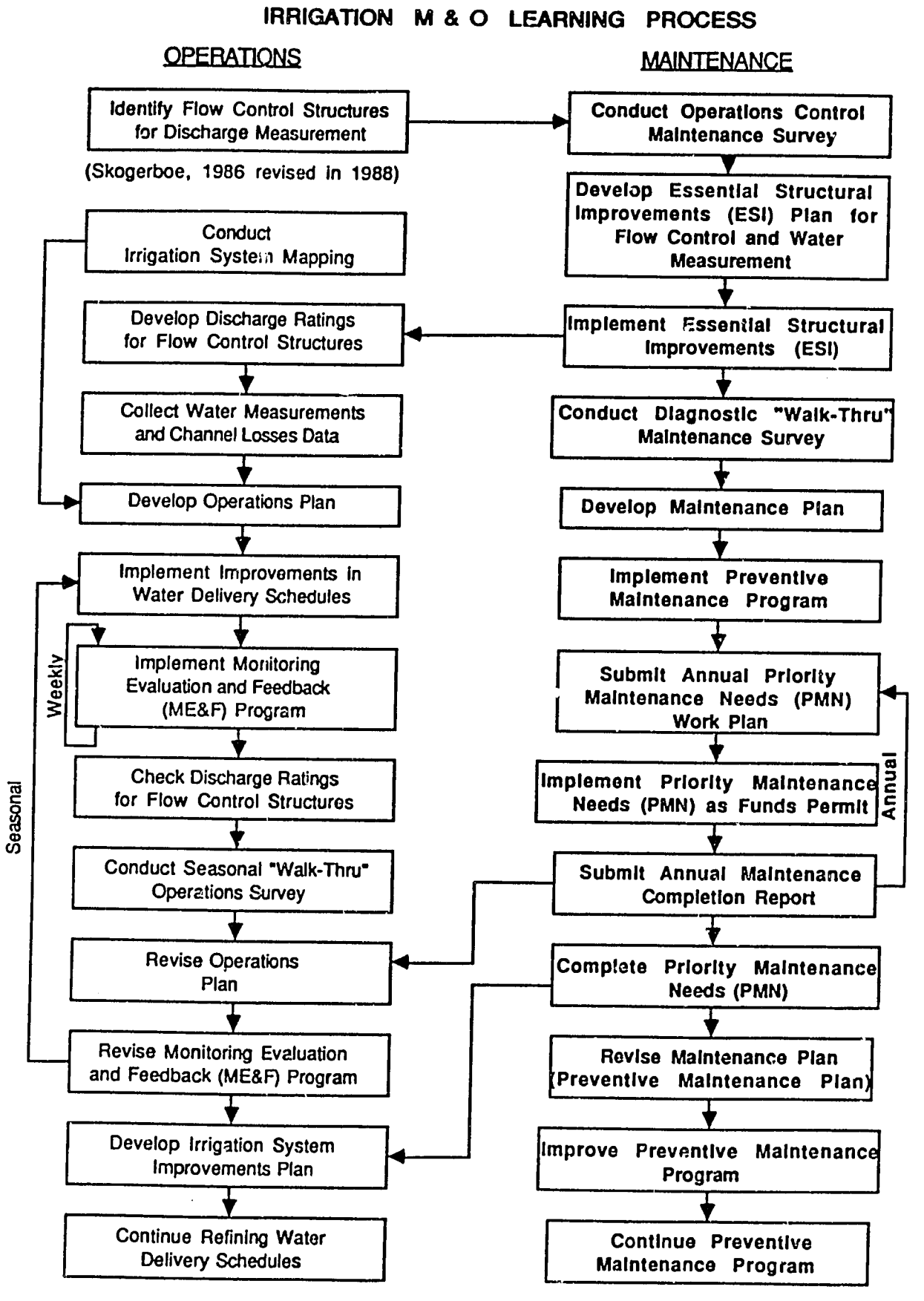


Figure M-02-01. Maintenance Phase of the Operations and Maintenance Learning Process.

noted. In some cases, structures may need to be replaced or additional structures constructed.

The term "Essential Structural Improvements" refers to those structures in the irrigation channels that are important for:

1. controlling the flow of water; and
2. measuring the discharge rate.

Fortunately, the same structure can often be used for both purposes. A detailed "Essential Structural Improvements Plan" should be prepared that includes:

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 Improvements (ESI);
5. Costs of Essential Structural Improvements; and
6. ESI Implementation Plan.

Once the Essential Structural Improvements 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 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 next step in the maintenance phase of the "Operations and Maintenance 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, lateral and sub-lateral, including the outlet structures to each tertiary system. This survey requires two to three individuals, such as a Water Master and Zonemen, walking along each irrigation channel, taking notes on each maintenance need.

"Walk-thru" rather than "riding-thru" is very important to be sure that all of the maintenance needs, such as small cavities, are actually seen. When "riding-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; (2) cavities along the concrete lining that need to be filled, along with an estimate of the cavity volume; (3) cavities at structures such as bridge abutments and gate structures; (4) repair of holes in concrete lining panels; (5) replacement of failed concrete lining panels; (6) grading of roadway; (7) repair or replacement of gates; and (8) sodding.

A report should be prepared by the staff of each irrigation project that describes a "Maintenance Plan" that will correct all

maintenance needs within five years, or less. This report should include: (1) Essential Structural Improvements for water control and flow measurement; (2) costs of Essential Structural Improvements; (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 eliminating sediment sources, reducing deterioration of channel lining, and minimizing seepage losses; (b) method of implementation, such as force account maintenance, private contractor maintenance, or contract main system maintenance with Water Users Groups; (c) implementation schedule including the first-year priority maintenance needs work plan and proposed work plans for the second, third, fourth and fifth years.

For each fiscal year, a Priority Maintenance Needs Work Plan would be forwarded to appropriate RID authorities in the provincial, regional and central offices for approval and funding. Although most maintenance work is done between irrigation seasons, this work plan should also describe what maintenance activities can be completed during each irrigation season. 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.

At the end of each fiscal year, the Irrigation Engineer for each project would prepare a Annual Maintenance Completion Report that lists each maintenance need 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, provincial, regional and 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.

When the operations phase of the O&M Learning Process has proceeded to the point where channel losses are being measured in the main system, then the maintenance plan should be refined. The periodic measurement of channel losses is an excellent indicator of the quality of the maintenance program; good maintenance reduces channel losses. Revisions in the previous maintenance plan can be made based on new information and experience gained during implementation.

If a program on "Irrigation Water Management In Tertiary Systems" has been undertaken, then the results can be incorporated into the revised maintenance plan. As a minimum, the Water Master, the Water Users Group Leader for the particular tertiary system being inspected, and the Zoneman responsible for delivering water at the main system outlet to the tertiary system should walk along the tertiary channel network and collectively prepare detailed notes on 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 Groups; (6) estimated annual maintenance costs; and (7) preventive maintenance plan.

This document should be forwarded to the provincial, regional and central headquarters offices for appropriate review and approval. If the maintenance phase of the Operations and Maintenance Learning Process is pursued and followed properly, it will greatly assist in the correction of problems and improved operation of the irrigation system.

Section III

JOB FUNCTIONS IN THE MAINTENANCE PHASE

The field maintenance activities are done by the Operations and Maintenance Section. The Head of this section is also called a Water Master, who is usually a graduate from the RID School of Irrigation, which requires that he attend the full 12 years of High School and graduate with an emphasis in science; he then attends the RID School of Irrigation for 3 academic years, plus 6 months of practical training. The Water Master supervises Zonemen, who are usually graduates from a technical institute that is attended for 2-4 years following completion of 9 years in the public school system. The Zoneman has a crew of Gate Tenders and Laborers that he supervises.

A Project Engineer is in-charge of a large-scale irrigation project, while the Provincial Irrigation Engineer serves in the capacity of Project Engineer for a medium-scale irrigation project.

At a large-scale irrigation project, the Head of the Engineering Section handles maintenance activities on behalf of the Project Engineer. This is also the case at the Provincial Irrigation Office, where the Head of the Engineering Section handles maintenance activities at any medium-scale irrigation project in the Province on behalf of the Project Engineer (Provincial Irrigation Engineer). In this handbook, this position will be referred to as Head of Engineering.

At a large-scale irrigation project, the Head of the Water Management Section looks after operations activities on behalf of the Project Engineer. At the Office of the Provincial Irrigation Engineer,

the Head of the Operation and Maintenance Section looks after operations activities at medium-scale irrigation projects on behalf of the Project Engineer (Provincial Irrigation Engineer). In this handbook, this position is referred to as the Head of Operations.

A. MAINTENANCE SURVEY OF FLOW CONTROL STRUCTURES

- The Head of Operations provides to the Head of Engineering the Flow Control Structures to be calibrated for discharge measurement in the Operations Phase of the O&M Learning Process.
- The Head of Engineering provides the listing of flow control structures required by each Water Master for the area under his jurisdiction.
- The Water Master conducts the maintenance survey, accompanied by the Zoneman when in that portion of the area serviced by the Zoneman.

B. ESSENTIAL STRUCTURAL IMPROVEMENTS PLAN

- The Head of Operations prepares the first three sections of the ESI Plan and submits this material to the Head of Engineering.
- The Water Master(s) rewrite their notes and sketches in a format for inclusion in the final section of the ESI Plan and submits this material to the Head of Engineering.
- The Head of Engineering completes the ESI Plan and submits it to the Project Engineer for comments.
- The completed ESI Plan is submitted by the Project Engineer to the Irrigation Regional Office.

C. DIAGNOSTIC "WALK-THRU" MAINTENANCE SURVEY

- The "walk-thru" survey is conducted by the Water Master, who prepares all of the field notes and sketches.
- The Water Master should provide field training experience to each Zoneman; in particular, when conducting the "walk-thru" in the area serviced by a Zoneman, then he should accompany the Water Master so experience is gained of the maintenance problems in the Zoneman's area and the causes of these problems.

D. PREPARATION OF MAINTENANCE PLAN

- The Water Master(s) rewrite their field notes and sketches in a format suitable for inclusion in the final section of the Maintenance Plan and submit this material to the Head of Engineering.
- The Water Master(s) compile the Inventory of Required Maintenance for their area, plus prepare cost estimates, and submit this material to the Head of Engineering.
- The Head of Engineering compiles the Maintenance Plan in consultation with the Water Master(s) and the Project Engineer, then submits the complete Maintenance Plan to the Project Engineer for comment.
- The Project Engineer submits the Maintenance Plan to the Irrigation Regional Office.

E. ANNUAL MAINTENANCE WORK PLAN

- The Head of Engineering prepares the Annual Maintenance Work Plan in consultation with the Water Master(s) and the Project Engineer, then submits a completed copy to the Project Engineer for comment.

♦ The Project Engineer submits the Annual Maintenance Work Plan to the Irrigation Regional Office.

F. ANNUAL MAINTENANCE COMPLETION REPORT

♦ The Water Master provides a monthly report to the Head of Engineering on completed maintenance activities, including manpower, equipment, time and materials used for each maintenance task.

♦ The Head of Engineering determines the costs of completing each maintenance activity based on the monthly reports submitted by the Water Master(s).

♦ The Head of Engineering compiles the Annual Maintenance Completion Report in consultation with the Water Master(s) and the Project Engineer, then submits a completed copy to the Project Engineer for comment.

♦ The Project Engineer submits the Annual Maintenance Completion Report to the Irrigation Regional Office.

G. PREVENTIVE MAINTENANCE PLAN

♦ The Head of Engineering prepares the "Preventive Maintenance Plan" in consultation with the Water Master(s) and the Project Engineer, then submits a copy to the Project Engineer for comment.

♦ The Project Engineer submits the Preventive Maintenance Plan to the Irrigation Regional Office.

Section IV.

PHYSICAL 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. There are five distinct areas of concern. The most serious problem is the formation of cavities behind the concrete lining panels which eventually leads to the actual failure of the panels themselves. Second, seepage losses from earthen channels can be quite significant in canals, laterals, sub-laterals and tertiary channels, particularly when operating at high water levels. Third, sedimentation is a serious problem in some channels, but not others; the theoretical approach to this problem is to prevent the sediment from ever entering the irrigation channels. Fourth, aquatic growth is a difficult problem, especially as the present level of technology generally allows for such growth to be removed only by hand or mechanically. The fifth area of major concern is a problem unique to Thailand -- the extensive use of the irrigation system for fishing; fishing practices have resulted in considerable maintenance being required, and in some cases extensive damages have occurred.

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

A. EARTHEN CHANNELS

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 (Figure M-04-1).

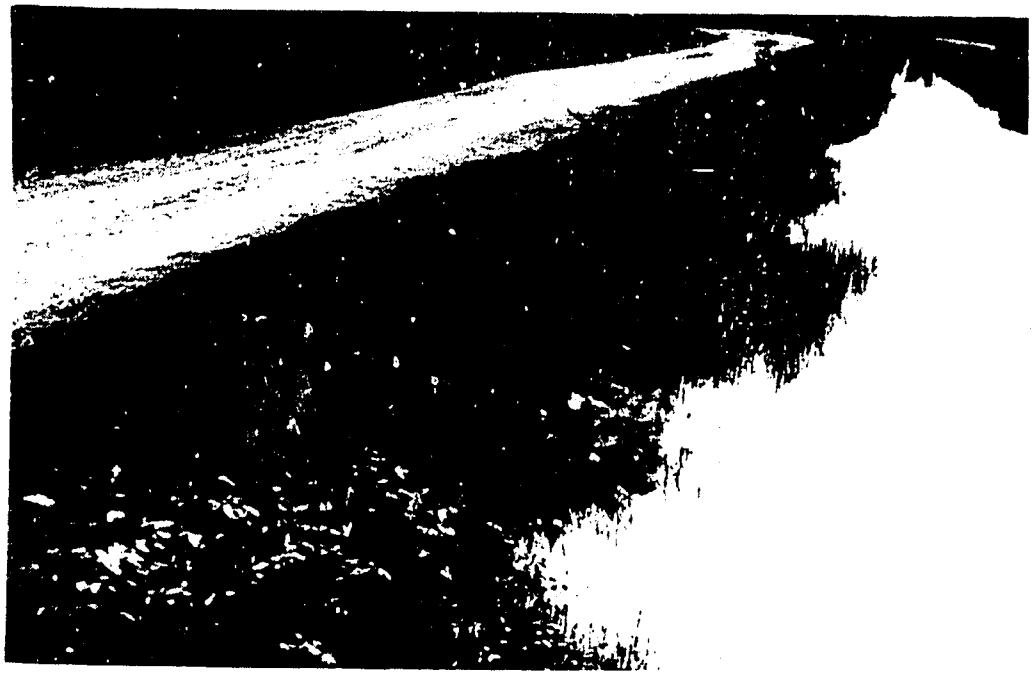


Figure M-04-1. Earthen Irrigation Channel in a Cut Area with Bank Sloughing and Erosion.

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 (Figure M-04-2). 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 allows 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.

Figure M-04-2. Leakage Along the Berm Embankment of an Earthen Irrigation Channel.

B. CONCRETE-LINED CHANNELS

The most serious long-term damage to the concrete-lined irrigation channels is the formation of cavities behind the wall panels such as shown in Figures M-04-3 and M-04-4. The systematic physical process of cavity formation followed by eventual failure of the concrete panel(s) results from the combination of lining panel joints and monsoon rains, with many other contributing factors. This problem is further aggravated in the Northeast because of sandy soils.

Generally, the concrete lining panels are three meters in length. Alternate panels are formed with wood strips and then poured in-place. Later, the wood strips are removed and the open space three meters in length is completely filled with concrete. A triangular-shaped piece of wood is used shortly after pouring to etch a joint about 1-2 cm deep. However, upon drying, there is frequently an open joint between the concrete panels that is 2-5 mm wide. These open joint openings are the result of concrete shrinkage. The wider joint openings are most likely caused by the more rapid drying of the poured concrete due to inadequate curing, with the thickness of the lining as a possible contributing factor.

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

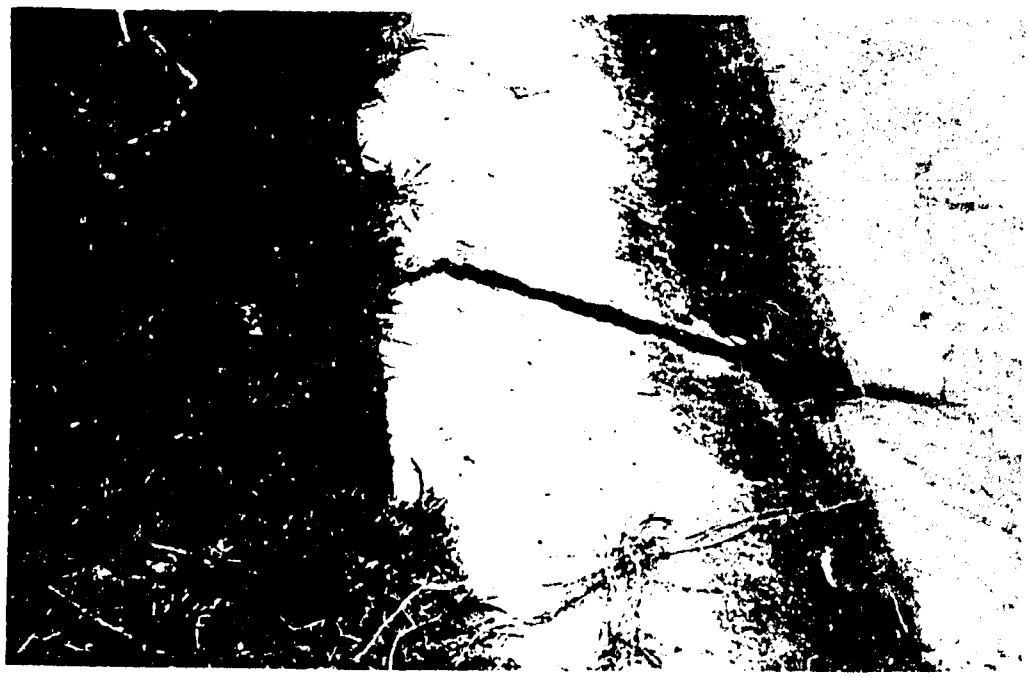


Figure M-04-3. Medium-Sized Cavity Behind Concrete Lining.

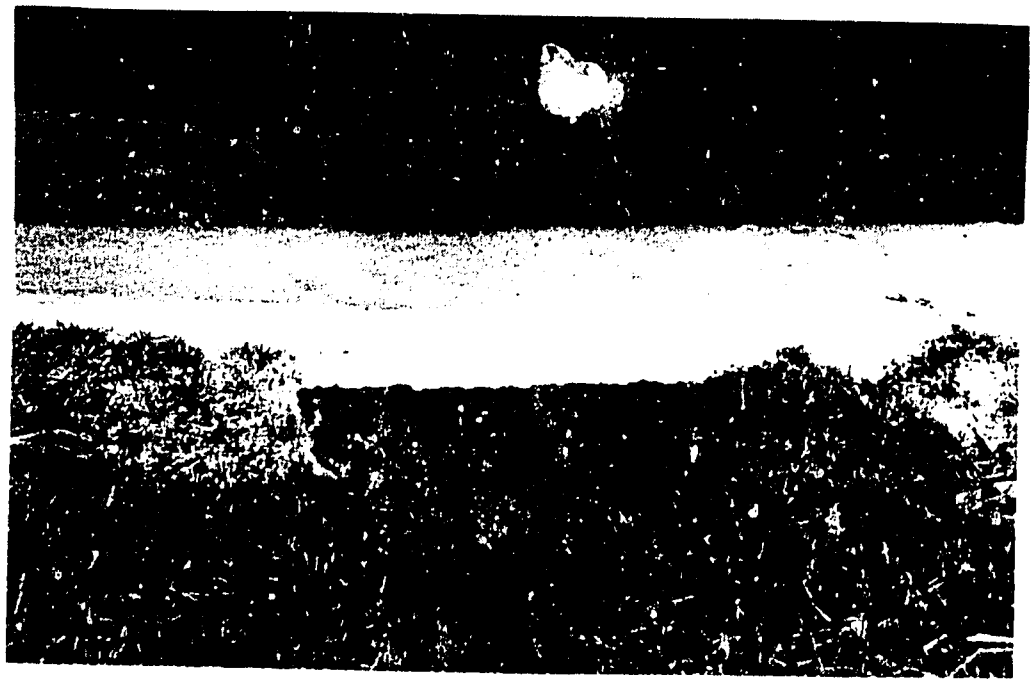


Figure M-04-4. Huge Cavity Behind Concrete Lining.

lining wall panel. Then, as surface runoff during the monsoon rains starts running down 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 concrete on the sides of the joint opening begin to break off, most commonly just above the floor level, but sometimes much higher. Next, hairline cracks will likely occur, first near the joint but perhaps later across the full width or height of the panel. Soon, a small chunk of concrete adjacent to the joint will break off, thereby leaving a small hole in the lining (Figure M-04-5). This small hole further aggravates the problem by allowing the cavity underneath to further enlarge, so that larger chunks of concrete eventually break off (Figure M-04-6). 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 phenomena is the failure of the concrete 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.

Concrete-lined irrigation channels located in cut areas are highly susceptible to cavity formation and eventual failure of the lining panels (Figure M-04-7). (In contrast, concrete lining in fill areas, such as shown in Figure M-04-8, 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 M-04-9). 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.

Figure M-05-5. Damaged Concrete Lining with Berm Surface Erosion.

Figure M-04-6. Damaged Concrete Lining in a Cut Area.

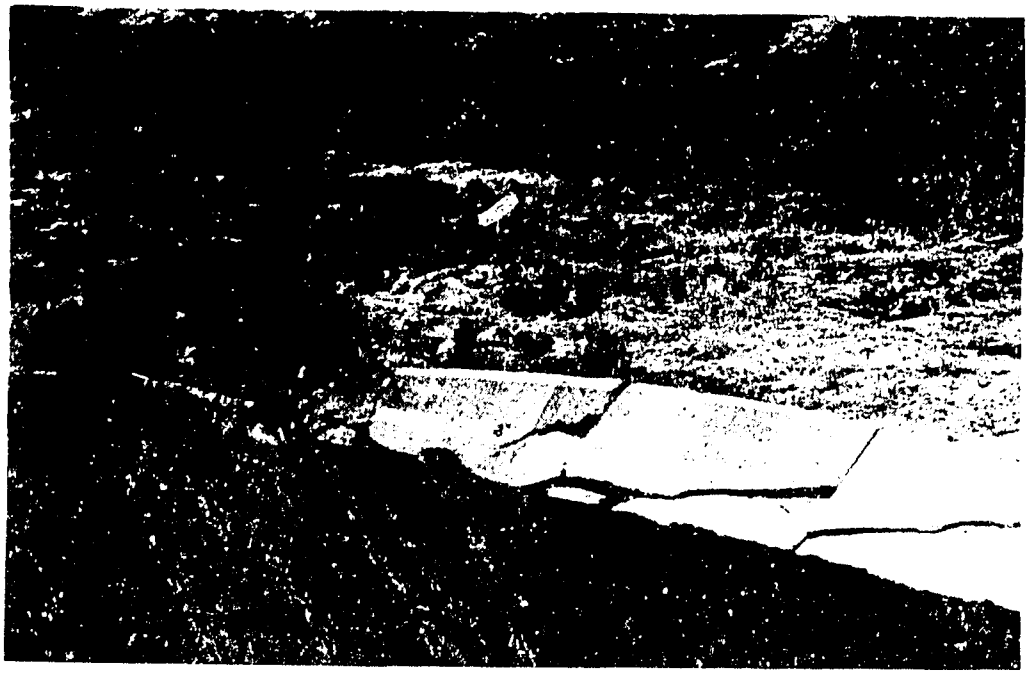


Figure M-04-7. Damaged Concrete-Lined Canal in a Deep Cut Area.

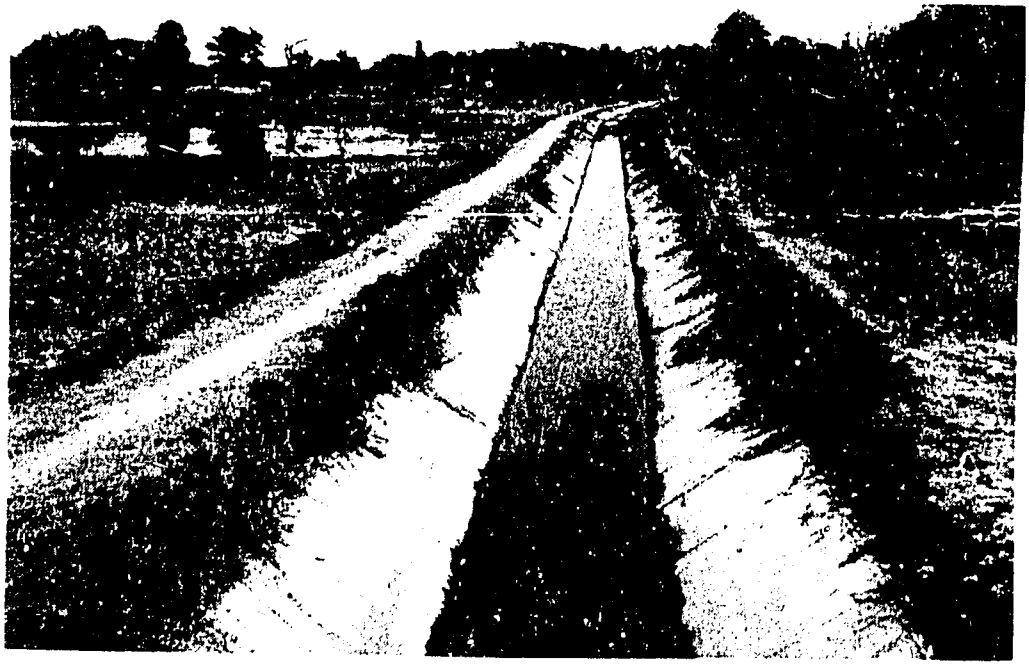


Figure M-04-8. Concrete-Lined Channel in Excellent Condition Because Adjacent Land is Below the Invert Elevation.

35

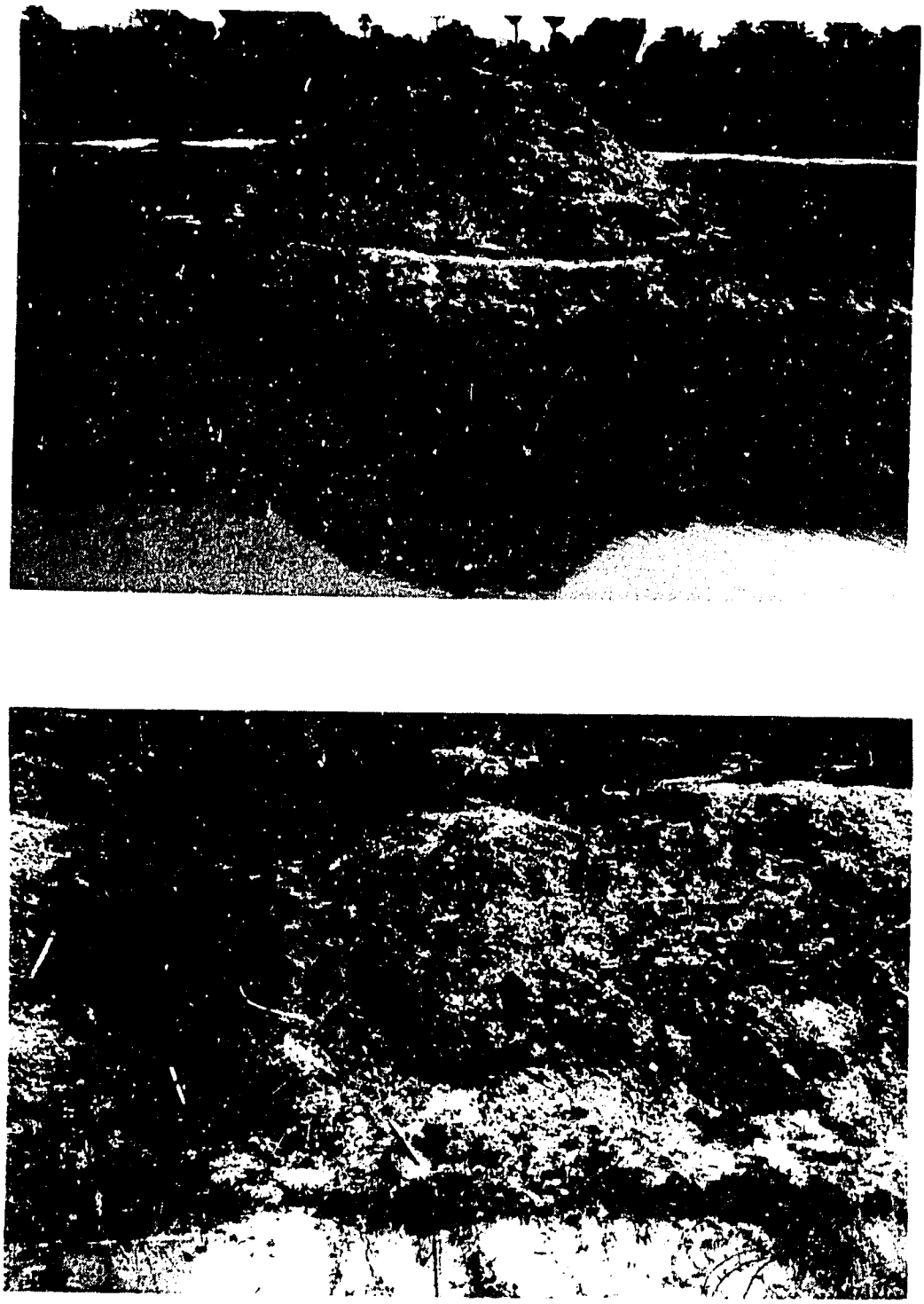


Figure M-04-9. Sediment Lying on Berm Embankment that will Erode and Wash Sediment into the Irrigation Channel During the Next Monsoon Season.

C. ROADS AND BERMS

Roads

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.

The second major problem with roads is bank erosion on the bank opposite to the irrigation channel (Figure M-04-10). 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.

Another important problem with roads is that they are often constructed too high above the top of the irrigation channels (Figure M-04-11). 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 concrete-lined channel, which will cause more cracked, broken, and failed panels. The best remedy is to lower the road elevation to a level about 15 cm above the top of the concrete lining panels. Although the ideal solution would be to place the roadway at the same elevation as the top of the lining panels, there are two advantages in placing it 15 cm higher. First, vehicles will be prevented from riding on the edge of the panels and inflicting damage. Secondly, the grader

Figure M-04-10. Bank Erosion Along Roadway Embankments.

Figure M-04-11. Road Constructed High Above an Irrigation Channel.

40

will avoid catching the machine's blade on the top of the panels, a problem which has occurred, thereby causing their displacement and subsequently, possible failure.

Berms

The biggest problem with berms is that the soil is not as well compacted as under roadways. Secondly, berms are not as wide as roads.

For earthen channels, the berm embankments are likely to contain more biological life than the road embankments. Thus, the seepage loss rates 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 concrete-lined channels, soil settlement in the berm embankment can be detected by horizontal cracks in the concrete lining panels (Figure M-04-12). In some reaches, all of the concrete lining panels along the berm embankment will have horizontal cracks, while the concrete 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 concrete-lined channel because of wide joint openings or deteriorated lining, the outlying bank of the berm embankment should be inspected for small leakage holes.

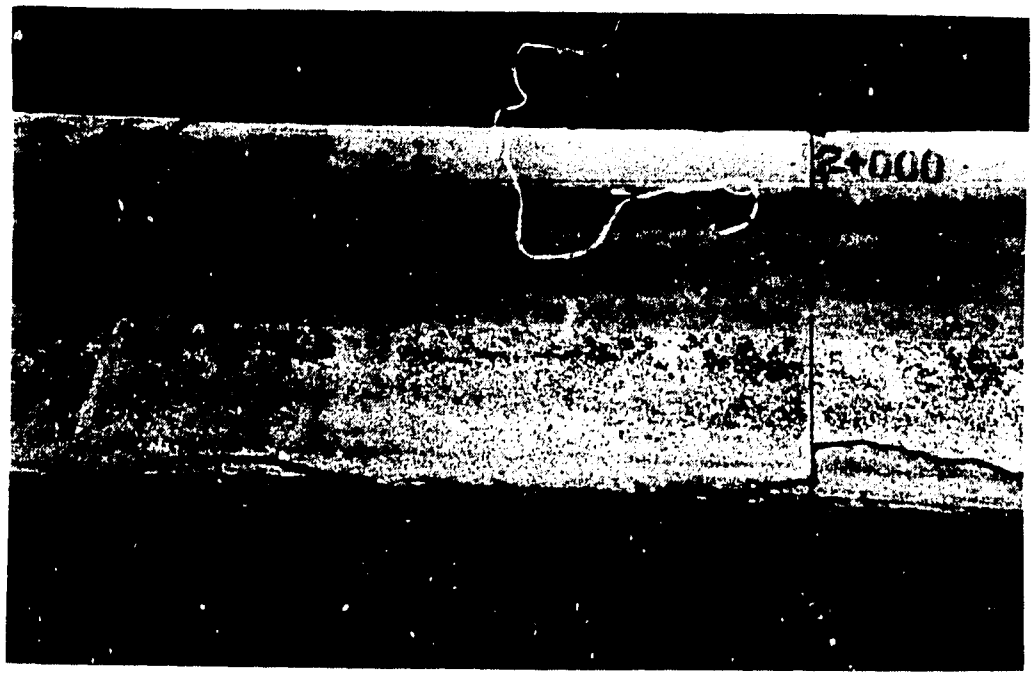


Figure M-04-12. Horizontal Cracks in Concrete Lining Panels as a Result of Soil Settlement in the Berm Embankment.

42

D. SEDIMENTATION

There is a tremendous variation in the amount of sedimentation that occurs in the canals and laterals. This sediment comes from surface drainage inflows into the irrigation channel (Figures M-04-13 and M-04-14) -- some of which are planned, such as at concrete surface drainage inlet structures, while most is the result of:

1. Roadway and berm erosion;
2. Erosion from cut banks;
3. Erosion resulting from farmers and persons fishing (includes men, women, boys and girls) tampering with the control gates, thereby resulting in overtopping of the concrete lining panels and serious erosion and even failure of the panels;
4. Overflow from adjoining earthen irrigation channels or ponds into the concrete-lined channel; and,
5. Animals crossing the earthen or concrete-lined laterals, 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 of it, that is, some 90 percent. (Certainly, the situation illustrated in Figure M-04-9 could easily be eliminated.)

Roadway and berm erosion can be greatly reduced by lowering the roadway to only 15 cm above the top of the concrete lining panels, then sodding the bank adjoining the panels, and grading the roadway so that surface runoff flows away from the irrigation channel. The berm should be cut down to the level of the top of the panels, and then graded so that surface runoff flows away from the irrigation channel.

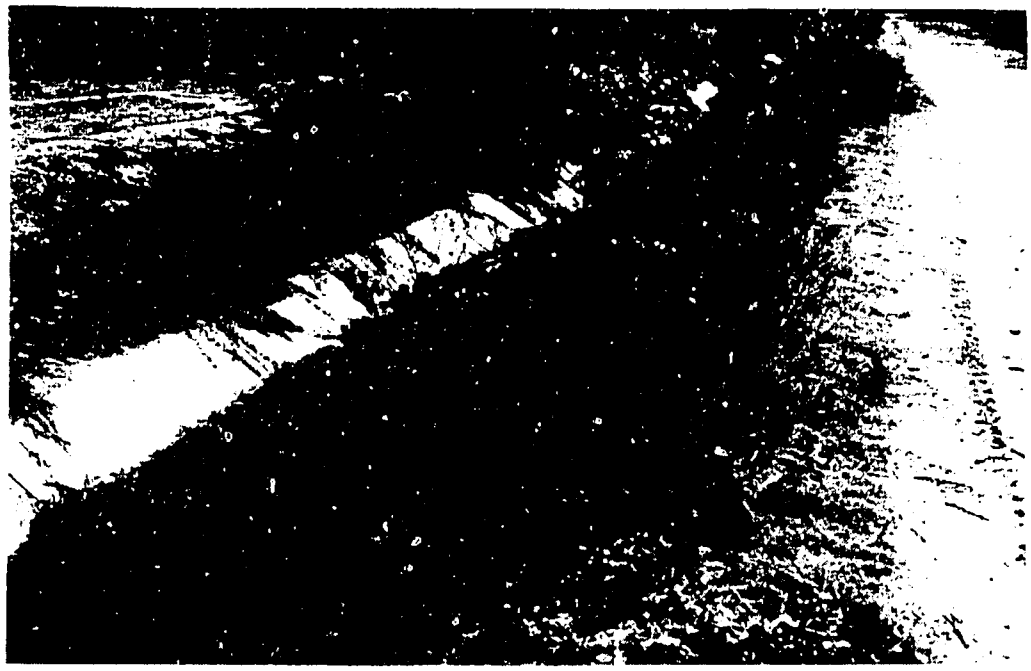


Figure M-04-13. Concrete-Lined Irrigation Channel with Much Sediment.

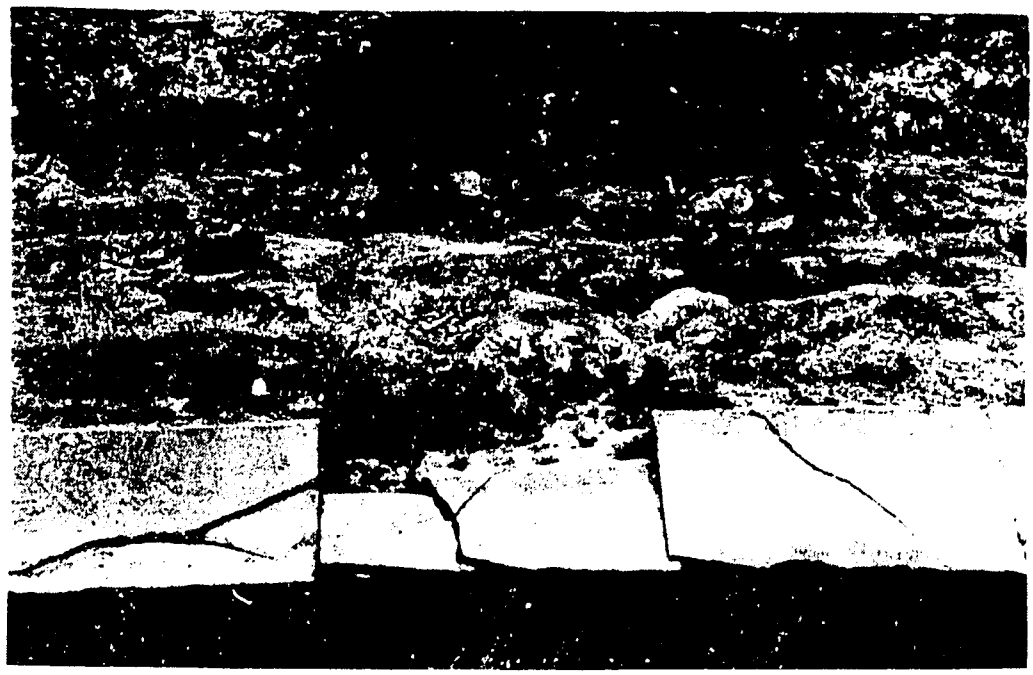


Figure M-04-14. Cut Bank which is a Source of Sediment into the Irrigation Channel.

Erosion from cut banks can be prevented from entering the irrigation channel by constructing a large open drain at the base of the cut bank. This open drain will require frequent maintenance; otherwise, it will soon fill with sediment. Consequently, the cut bank should be sodded to minimize erosion. Also, at the top of the cut bank, surface runoff should be diverted so that the flow over the cut bank is minimized.

The most difficult erosion problems to correct have occurred as the result of gate tampering by farmers and people fishing creating subsequent disastrous events. Unfortunately, the precedent has already been set that allows farmers to operate the Constant Head Orifice turnout structures to regulate their irrigation water deliveries. Attempts have been made to improve the locks on the Constant Head Orifice gates, but they have not been particularly successful. A combination of better locks, public education, and sanctions appears to be in order to overcome this problem.

Overflow erosion from adjoining earthen irrigation channels and ponds can be avoided by investigating each location and constructing the necessary control structures. In some cases, a higher berm between the two channels is needed. This could result in more surface drainage and erosion from the berm, a situation which can be alleviated by proper grading, shaping, and sodding of the berm. In some cases, the problem results from adjoining buffalo wallows, which can be prevented by providing other nearby sites for buffalo wallows and informing farmers about the damage their animals can cause.

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 concrete-lined channels, animal crossings can also lead to cavity formation because of the surface runoff not flowing into the channel, but rather behind the concrete lining panels.

E. AQUATIC AND VEGETATIVE GROWTH

One of the most persistent maintenance problems, besides sedimentation, is aquatic growth. The most difficult of the aquatic growths are underwater (submerged) weeds, most of which require some sediment for establishing roots, while a few species can attach to concrete. This is a frustrating problem because once the aquatic growth has been removed from a channel, it will return to the same degree of growth 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.

For concrete-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.

F. FISHING

Another significant maintenance problem is the result of fishing, an activity that is seemingly undertaken by everyone living within the boundaries of each irrigation system (Figures M-04-15 and M-04-16). Considerable damage has resulted from fishing activities, but at the same time, fishing is major benefit of each irrigation system. The reservoir, canals, laterals, and adjoining earthen channels and ponds are extensively fished. The argument can be made that in order to be a good designer of irrigation systems in Thailand, an extensive knowledge of fishing practices is definitely needed.

47

The most serious problem resulting from fishing activities is the opening and closing of gates. This practice not only interferes with the operation of the system, but also has caused considerable damage on a few occasions. Many of the prefabricated concrete walkway panels installed on the Constant Head Orifice turnout structures have been removed by people wanting to catch fish by damming of the irrigation channel to trap fish. Nowadays, the Royal Irrigation Department neither installs these walkway panels on Constant Head Orifice structures, nor replaces them on the existing structures. Riprap placed at the end of Constant Head Orifice outlet structures for erosion control is commonly removed to build temporary dams in the downstream earthen channel in order to trap fish in the outlet structure and in downstream channels. In addition, riprap is removed from the compacted backfills surrounding USBR Stilling Basin VI structures in order to pond the stilling basin. As a consequence, rubble masonry is being recommended rather than riprap alone. In other cases, soil is removed from the irrigation channel bank to from an earthen dam, allowing rainfall runoff to quickly erode more soil from the disturbed area into the channel.

Figure M-04-15. Many People Enjoy Fishing the Irrigation Channels.

Figure M-04-16. A fish pond with Water Provided by an Irrigation Project is a Productive Business for a Farmer.

G. ROLE OF DRAINAGE

Surface Drainage

The primary purpose in providing surface drainage is to prevent surface runoff from entering the irrigation channel because of: (a) the sediment load being conveyed by the surface runoff; and (b) the potential for cavity enlargement or formation in concrete-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 concrete-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.

Subsurface Drainage

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

Cut areas, in particular, require that the design of the irrigation channel include effective subsurface drainage. This can be usually 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.

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. Preferably, the adjacent land will be at, or below, the invert elevation of the irrigation channel.

H. IMPACT OF STRUCTURES

Constant Head Orifice Outlet Structures

Constant Head Orifice outlet structures are usually in good structural condition if the adjacent land is above the invert elevation of the irrigation channel. If the drop in water surface elevation between the Constant Head Orifice outlet structure and the downstream earthen channel is 10 cm or more, then the outlet structure will likely fail because of soil erosion immediately downstream from the outlet structure as shown in Figures M-04-17 and M-04-18. This erosion soon undermines the end panels, which crack, then break, and eventually fall into the scour hole. If the drop in water surface elevation is sufficiently great, then the entire outlet structure will fail soon. In some cases, even the concrete pipe sections between the Constant Head Orifice and the outlet structure have failed.

For small drops in water surface elevation, say 10-30 cm, rubble masonry can be placed at the end of the outlet structure along the walls, and even more importantly, in the downstream channel floor in such a manner as to dissipate the excess hydraulic energy. This serves as a good temporary measure until the on-farm facilities are

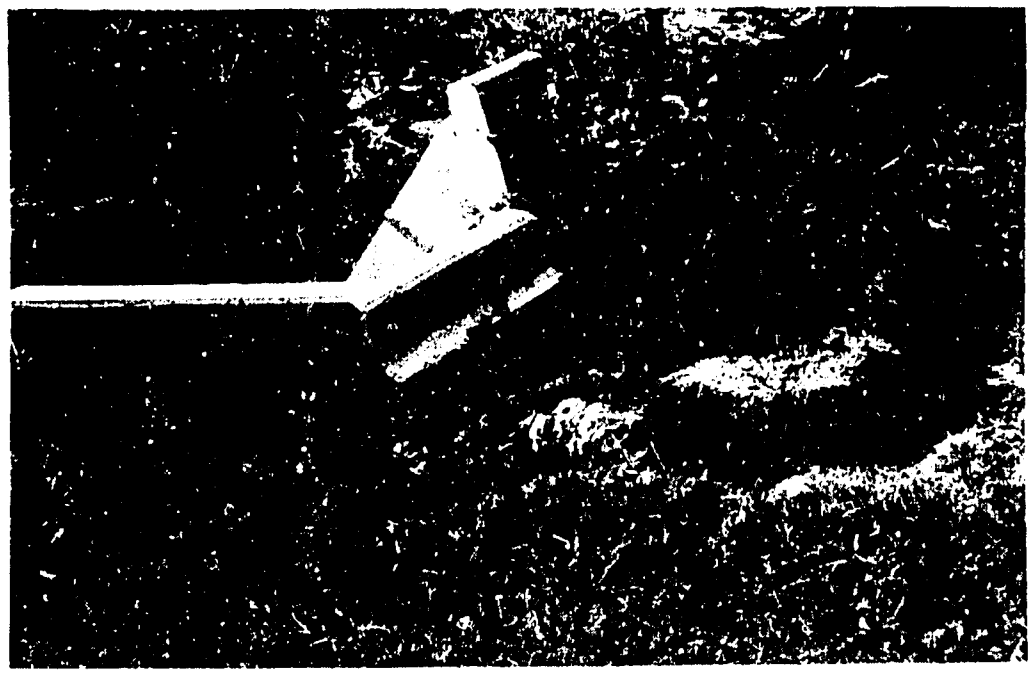


Figure M-04-17. Failed Constant Head Orifice (CHO) Outlet Structure Because of Too Much Drop.

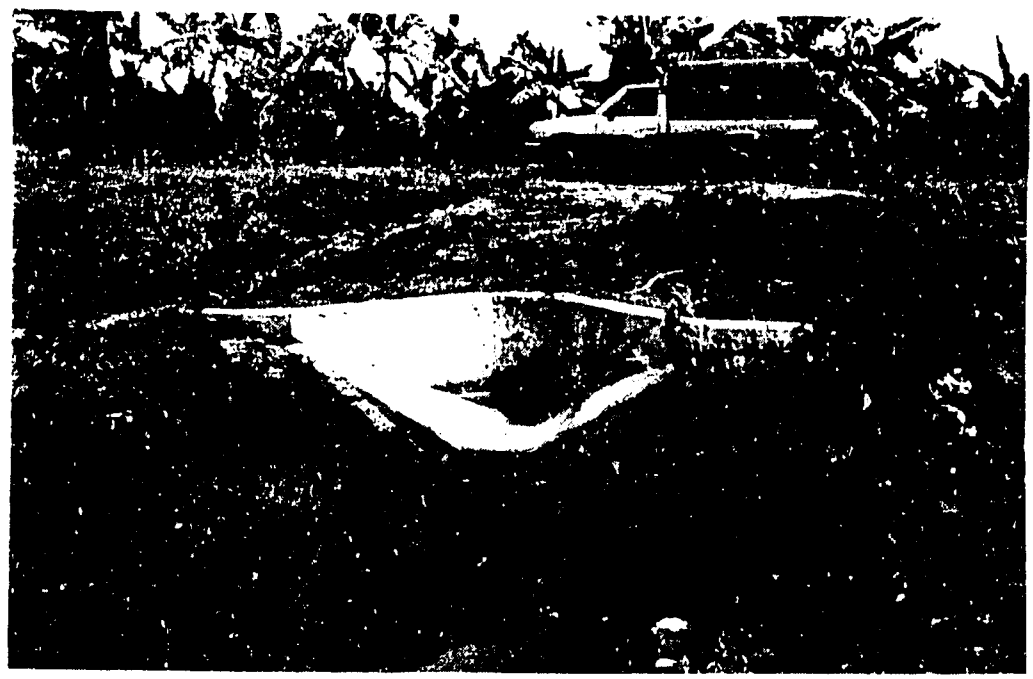


Figure M-04-18. Failed CHO Outlet Structure, and Pipe Outlet Structure Which is Undermined and Will Soon Fail.

52

constructed which will solve the problem on a more permanent basis. When the drop in water surface elevation is more than 30 cm, then a rubble masonry or concrete chute should be constructed, along with a lined stilling basin for dissipating the hydraulic energy such as shown in Figures M-04-19 and M-04-20.

Drop Structures

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 pipeline between the inlet and outlet structures; and (c) a USBR Stilling Basin VI and an outlet transition structure.

Sometimes, cavities form near the headwall 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 the joint between the end of the outlet transition structure and the beginning of the downstream irrigation channel section as shown in Figure M-04-21. This primarily occurs because the outlet is structurally stronger than the irrigation channel concrete lining panels; the large hydraulic pressures, resulting from the high nearby roadway and berm, are most easily relieved at this particular joint. This problem can be partially relieved by: (a) lowering the roadway ahead of the inlet structure so that the roadway will not be so high above the outlet structure; (b) placing an open drain alongside the roadway and berm that is sufficiently deep to provide subsurface drainage, as well as surface drainage; and (c) installing more small-diameter weep holes in the outlet transition structure.

Figure M-04-19. CHO Outlet Structure with Downstream Channel Concrete Lined to Prevent Structure Failure.

Figure M-04-20. CHO Outlet Structure with Concrete-Lined Chute to Prevent Failure of the Outlet Structure.

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.

Oftentimes, cavities have formed behind the concrete lining panels underneath the bridge because of surface runoff near the abutments as shown in Figures M-04-22 and M-04-23. To prevent such cavities from forming underneath bridges, rubble masonry should be placed between the top of the concrete lining panels and the bridge abutments. If the bridge settles, then the rubble masonry will crack, and the cracks can be filled with asphalt or mortar.

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 and behind adjoining concrete lining panels. Only in a few instances have these cavities endangered the structure (an exception would be the Constant Head Orifice outlet structures) but frequently they have resulted in cracked, broken, or failed concrete lining panels. The remedy for this situation is to fill the cavities with mortar and then properly shape the surrounding soil surface.

Figure M-04-21. Small Hole in Concrete Lining Joint Commonly Found at the End of USBR Stilling Basin VI Outlet Transition Structures.

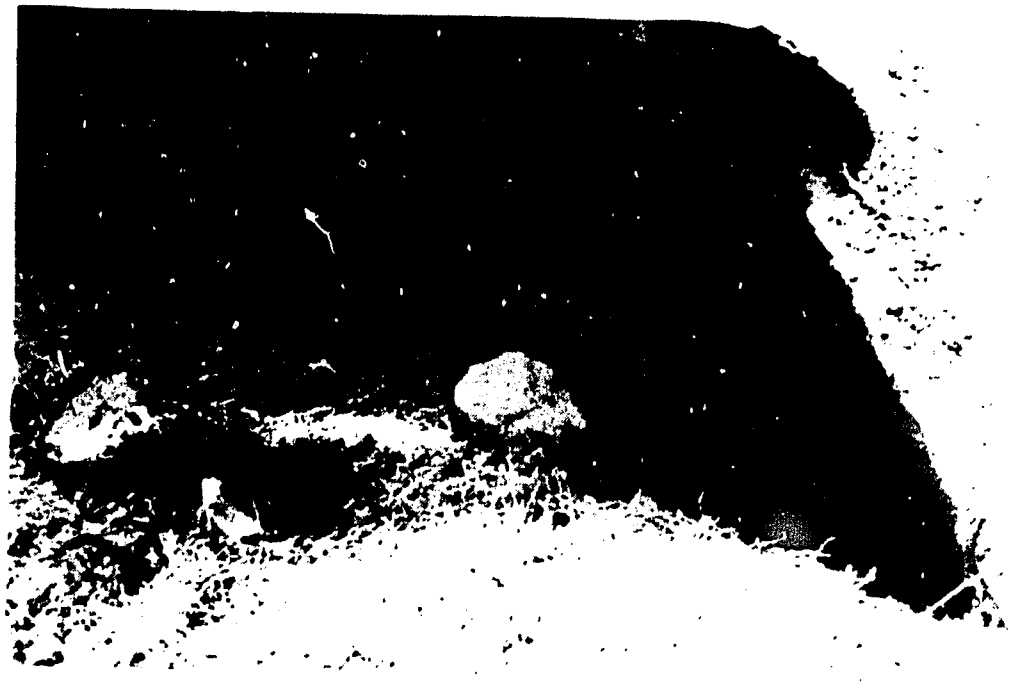


Figure M-04-22. Large Cavity at a Bridge Abutment.

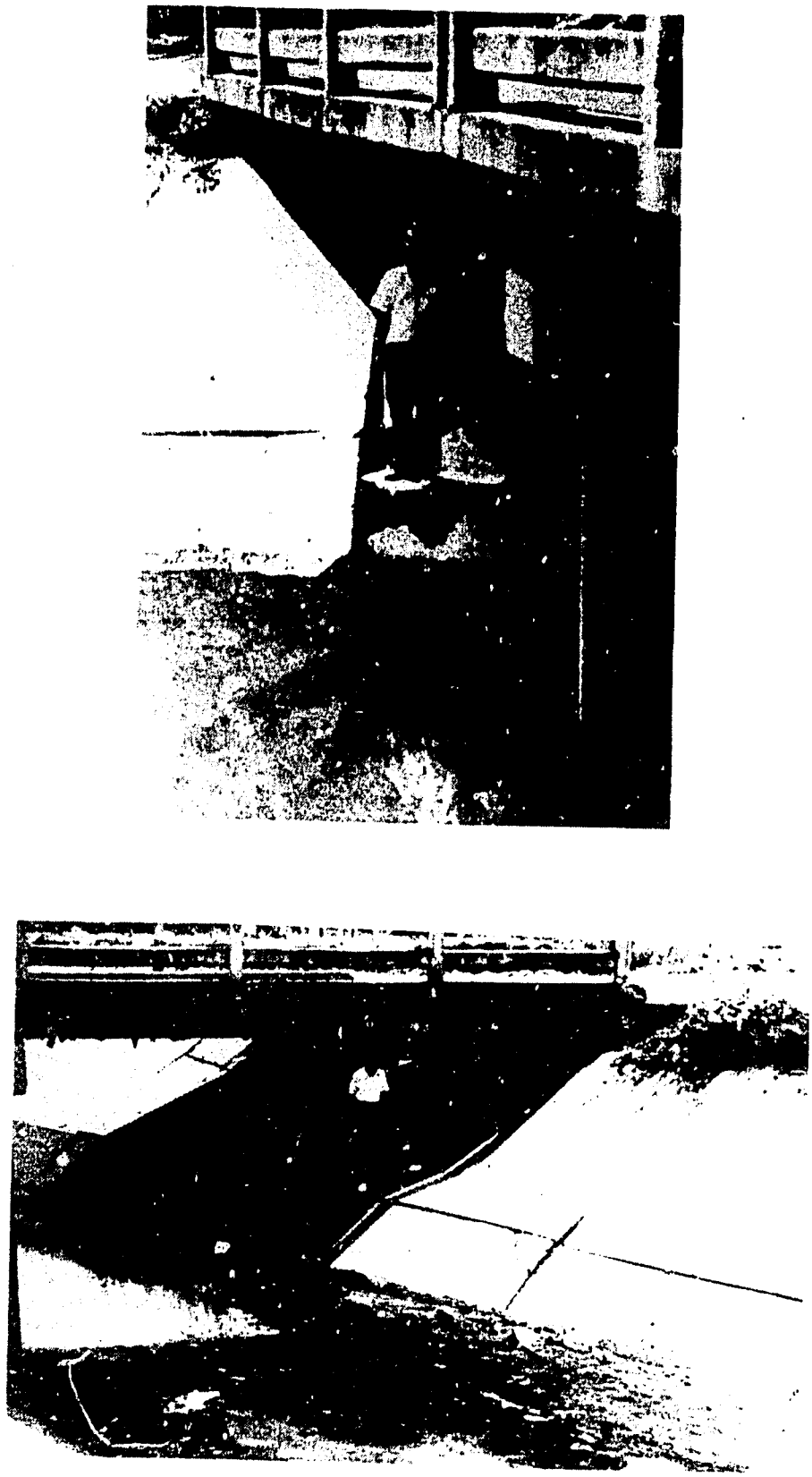


Figure M-04-23. Broken Concrete Lining Panels Underneath a Bridge.

Culvert Drains

In general, the culvert drains 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. The maintenance problem associated with drain culverts is the removal of sediment and shrubbery in the outlet and inlet structures. These drain culverts are very important as potential outlets for open drains or pipe drains alongside the roadway or berm embankments, if required, even though they were primarily installed to convey the flow in natural channels underneath the irrigation channel.

Section V.

MAINTENANCE OF CHANNELS

The order of 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 concrete-lined channels are presented first. In this way, these same topics do not have to be repeated at the end of this section when discussing the maintenance of lined and unlined channels.

A. AQUATIC AND VEGETATIVE GROWTH

For clearing aquatic and vegetative weeds growing in irrigation channels, the common practice is to use hired temporary laborers. Pulling weeds from the bed sediments by wading laborers (Figure M-05-1) has proved more effective than cutting by hand blade because the regrowth rate is reduced. Thus, no tools are required.

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 laterals.

B. EROSION AND SEDIMENTATION

For each irrigation project, maintenance planning should include a program for eliminating as many sources of sediment that enter the irrigation channels that 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.

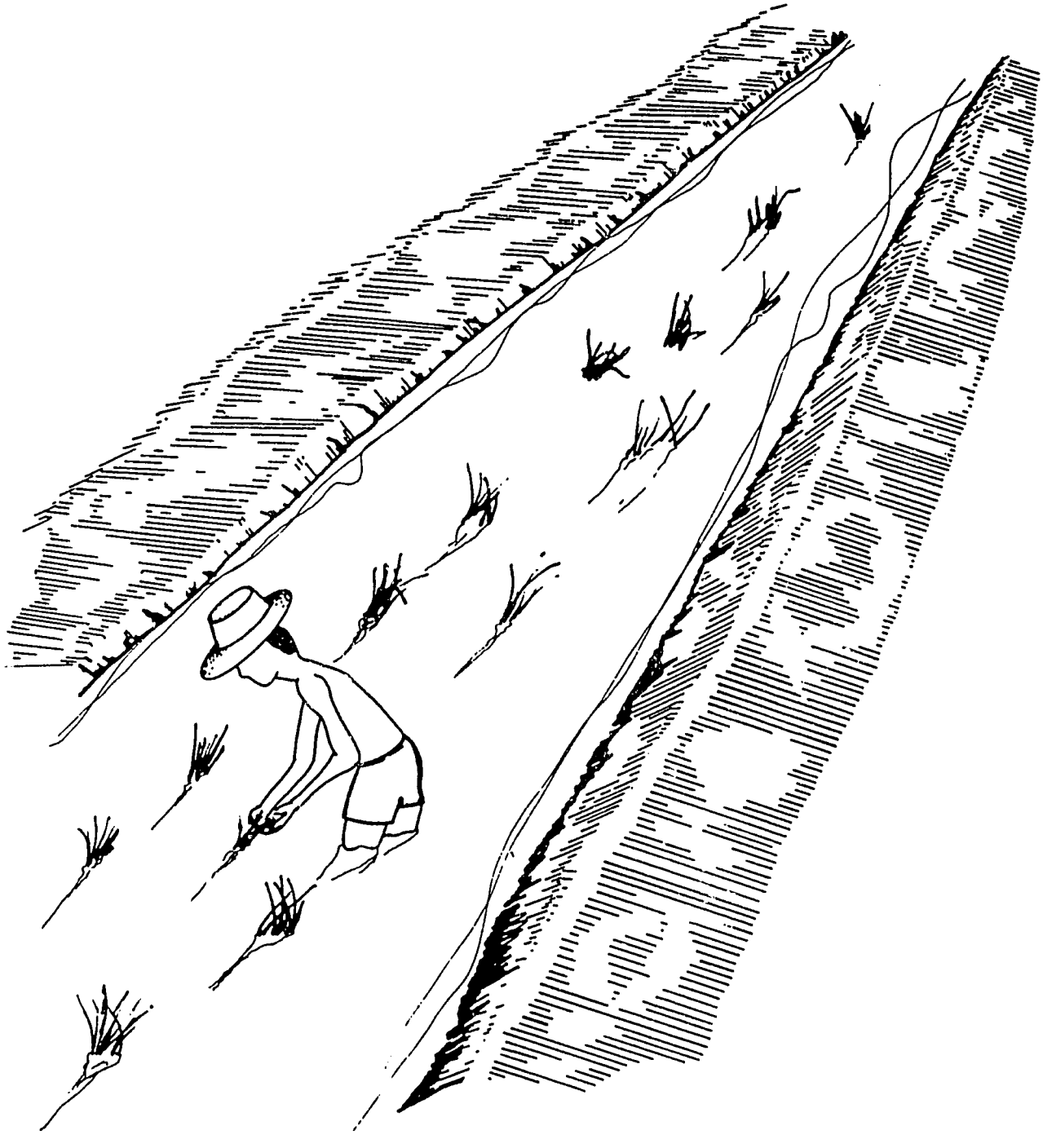


Figure M-05-1. Wading Laborer Pulling Weeds by Hand from an Irrigation Channel.

Roadway and Berm Erosion

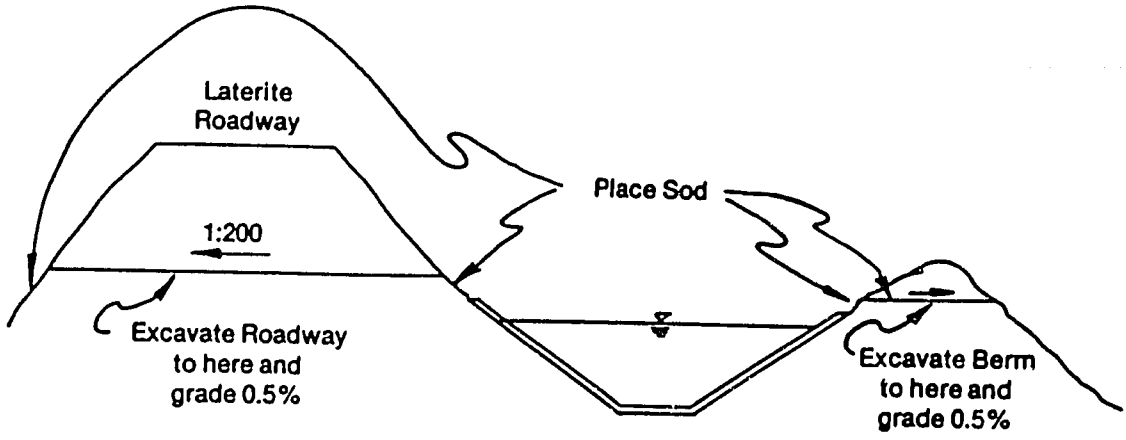
Lowering roadway and berm embankments to only the required heights would reduce the degree of erosion and result in less maintenance costs. For example, these embankments do not have to be higher than 30 centimeters above "Full Supply Level" (FSL) for earthen channels and 15 centimeters above the top of the lining panels for concrete-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 M-05-2).

Erosion from Cut-Banks

The most significant maintenance problems usually occur where irrigation channels have had to be constructed in cut areas. A typical cut-bank cross-section is shown in Figure M-05-3. 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 event will then 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.

Overflow from Adjoining Channels and Ponds

There are situations where tertiary system channels flow nearby main system channels, usually sub-laterals. Also, there are cases where small ponds or buffalo wallows exist nearby an irrigation



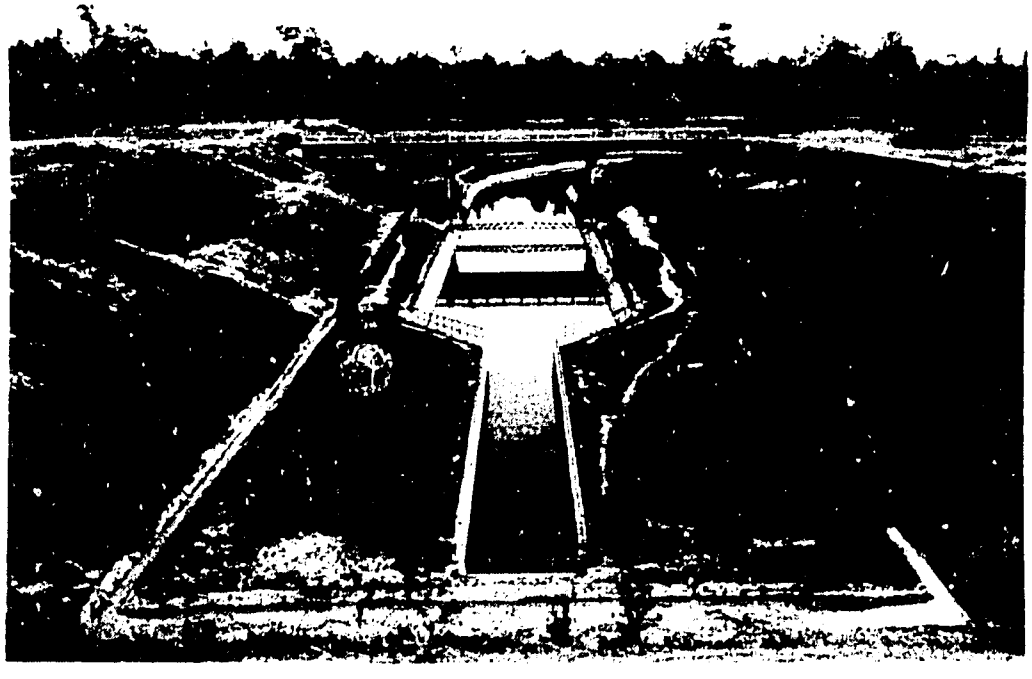


Figure M-05-2. Some Recommended Practices for Controlling Erosion and Sedimentation from Roadway and Berm Embankments.

62

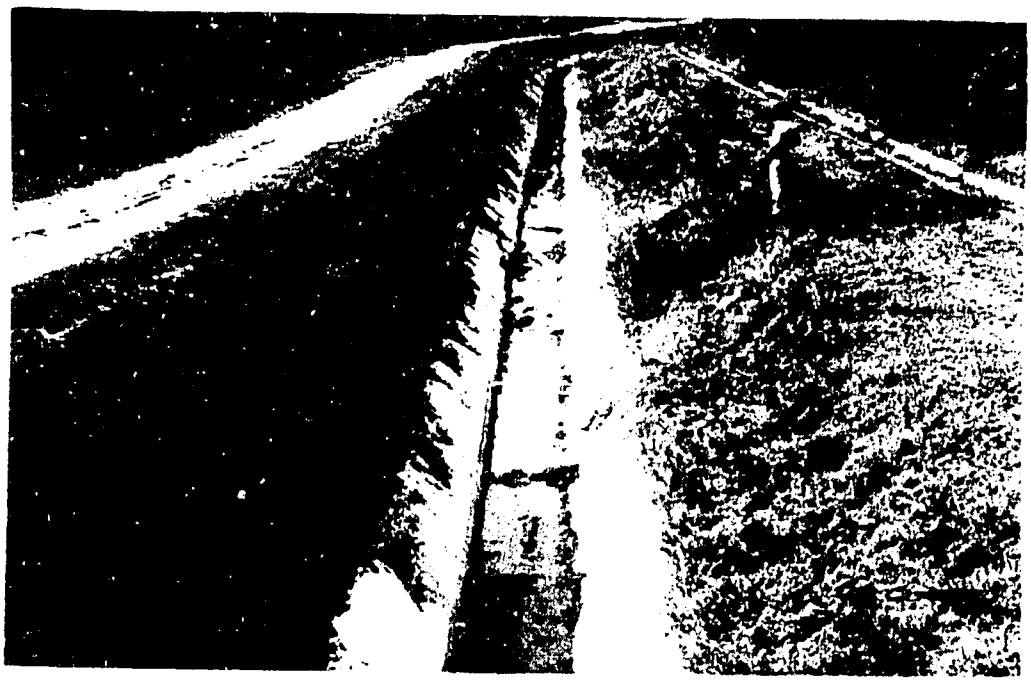


Figure M-05-3. Typical Cross-Section of a Cut-Bank.

67

channel. The first remedy is to request that the farmer move to other buffalo wallows, then excavate the buffalo wallow, replace with compacted soil, and then shape the embankment so that it will not collect or pond water in the future (Figure M-05-4).

For the situation with adjoining irrigation channels (Figure M-05-5), it is necessary to have a berm of adequate height so that one of the channels cannot overtop and flow into the other channel. Also, this berm should be well-compacted, particularly if one (or both) of the channels is concrete-lined. If the compaction of the existing berm is doubtful, then the berm material should be excavated and the berm reconstructed, with the berm height being plenty adequate to prevent flow from one channel into the other, even under unusual operating conditions, such as having higher than design water levels.

Animal Crossings

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 an animal crossing.

Fishing Activities

One of the lessons learned is not to place riprap downstream from any type of outlet structure, because the rocks will be removed to trap fish during canal closure. Instead, rubble masonry is required.

For the situations where gates have been tampered with, or banks cut to obtain soil for trapping fish, the best remedy is to inform the

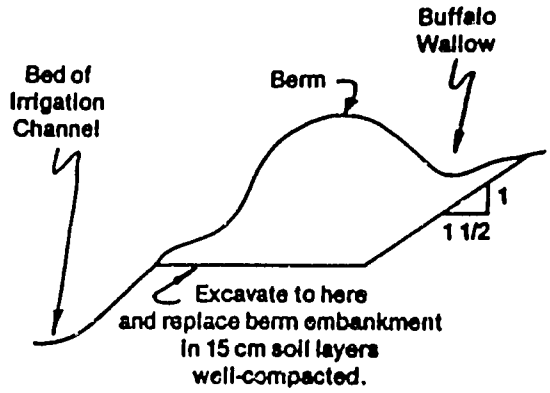


Figure M-05-4. Removal of Buffalo Wallow and Reshaping of Embankment.

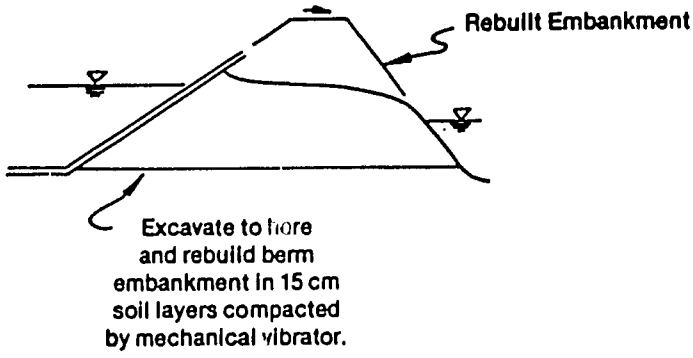


Figure M-05-5. Reconstruction of Berm Embankment Between Adjoining Irrigation Channels.

farmers and villagers of the damage they cause. This needs to be done many times, including showing the situation where damage has occurred.

C. 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.

D. ROAD AND BERM EMBANKMENTS

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

Compaction

For concrete-lined channels, horizontal cracks are evidence of inadequate compaction, usually of the berm embankment. If the concrete 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 M-05-6). If there are also cavities, then the appropriate maintenance procedures would be to first fill the cavities after excavating the embankment, then reconstruct the embankment.

Other 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 laborers 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 concrete-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 M-05-7).

The necessity for reconstruction of embankments may not be realized until implementing the Operations Phase of the O&M Learning Process. The measurement of seepage loss rates with various water levels will disclose the magnitude of the seepage losses and how rapidly the seepage loss rate is changing near the usual operating water levels; rapidly increasing values of seepage loss rate indicates

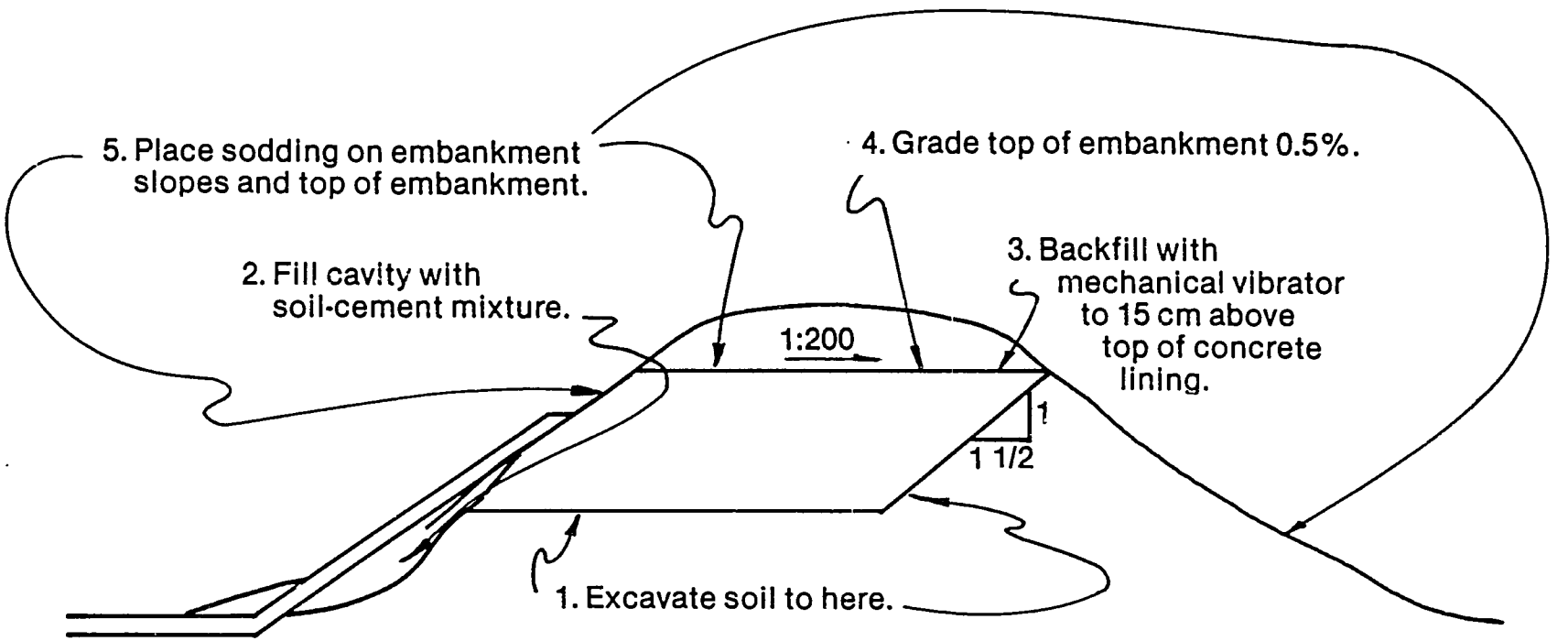


Figure M-05-6. Reconstruction of an Inadequately Compacted Embankment.

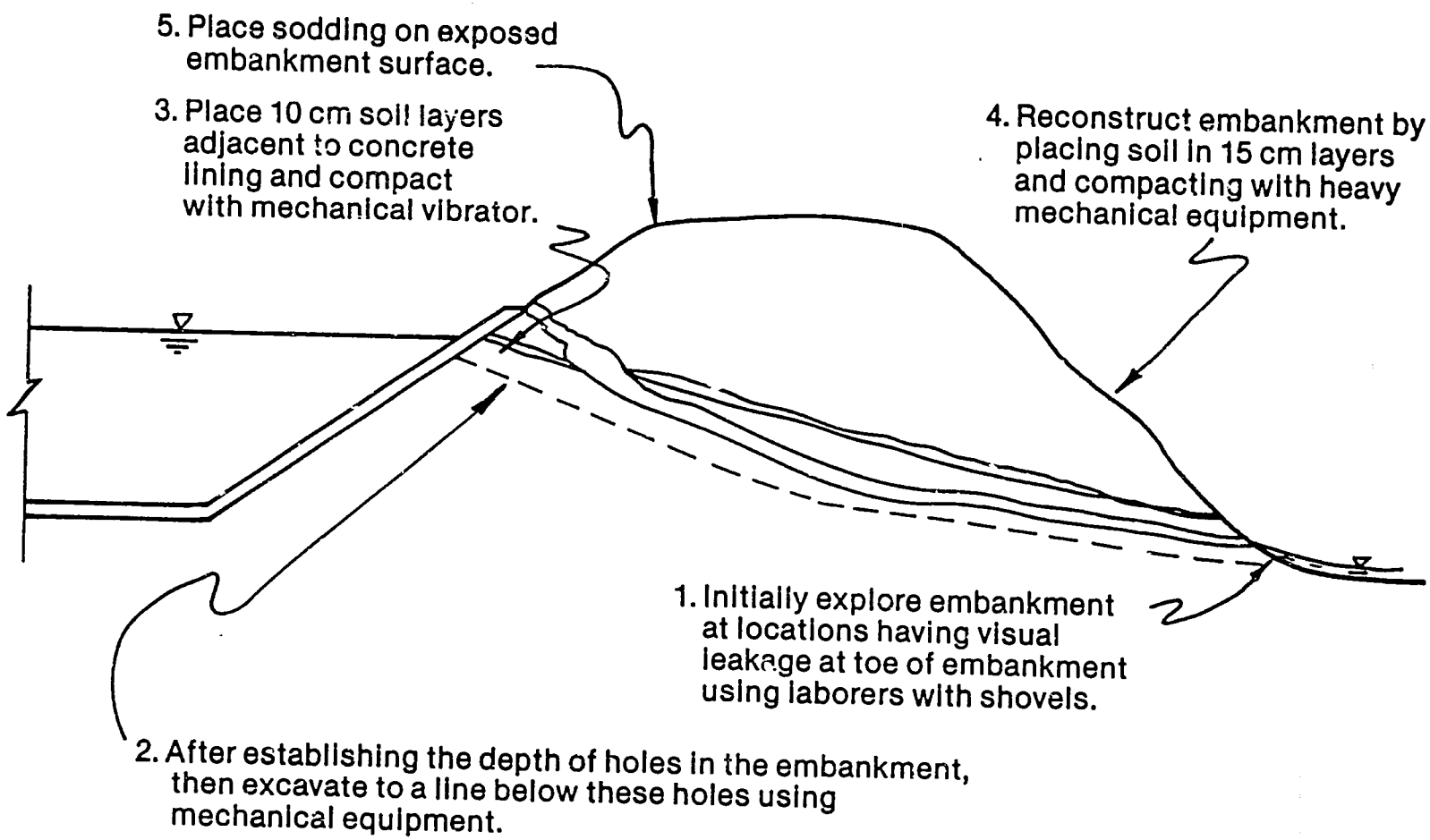


Figure M-05-7. Exploration for Leakage Holes and Embankment Reconstruction.

that the embankments should be explored, using laborers, for determining if small holes and caverns exist. This situation is more likely to occur for earthen channels than concrete-lined channels, but certainly does occur for either lined or unlined channels. Reconstruction of the embankment may be done as shown in Figure M-05-7.

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 right turning bends (in the downstream direction) which result in surface runoff into the irrigation channel:

1. Place a curb of 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 M-05-8); 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 too steep so 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 flatter), then cover with laterite.

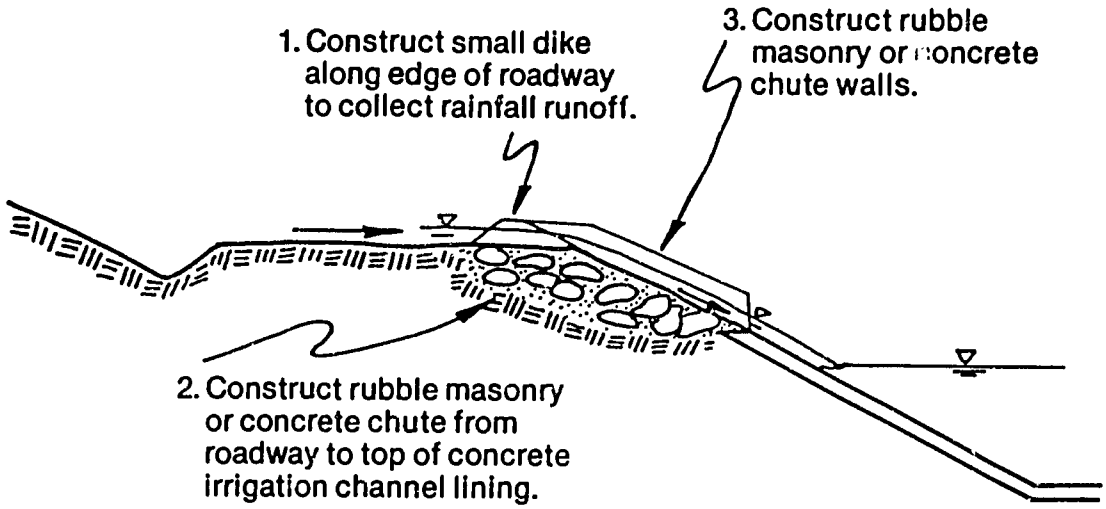


Figure M-05-8. Collection of Surface Drainage from a Roadway and Conveyance into the Irrigation Channel.

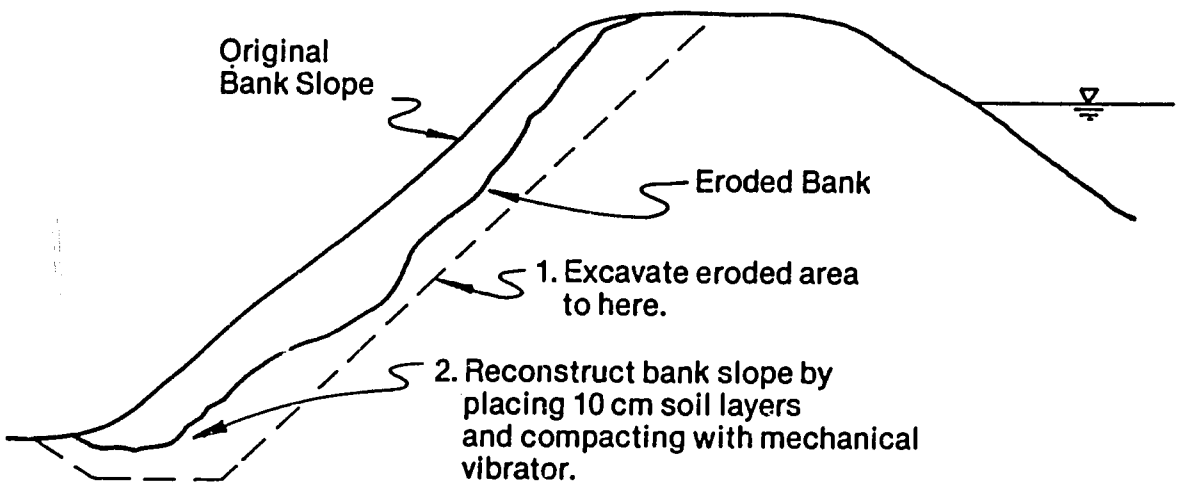


Figure M-05-9. Reconstruction of an Eroded Bank.

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 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 will established (Figure M-05-9). 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 curb will have to be constructed along the outside edge of the top of the embankment (Figure M-05-10). The curb would serve to collect the surface runoff and then it would be conveyed down the bank slope in a concrete-lined 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 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 is to provide relief from the hydraulic pressures using either weep holes or filters.

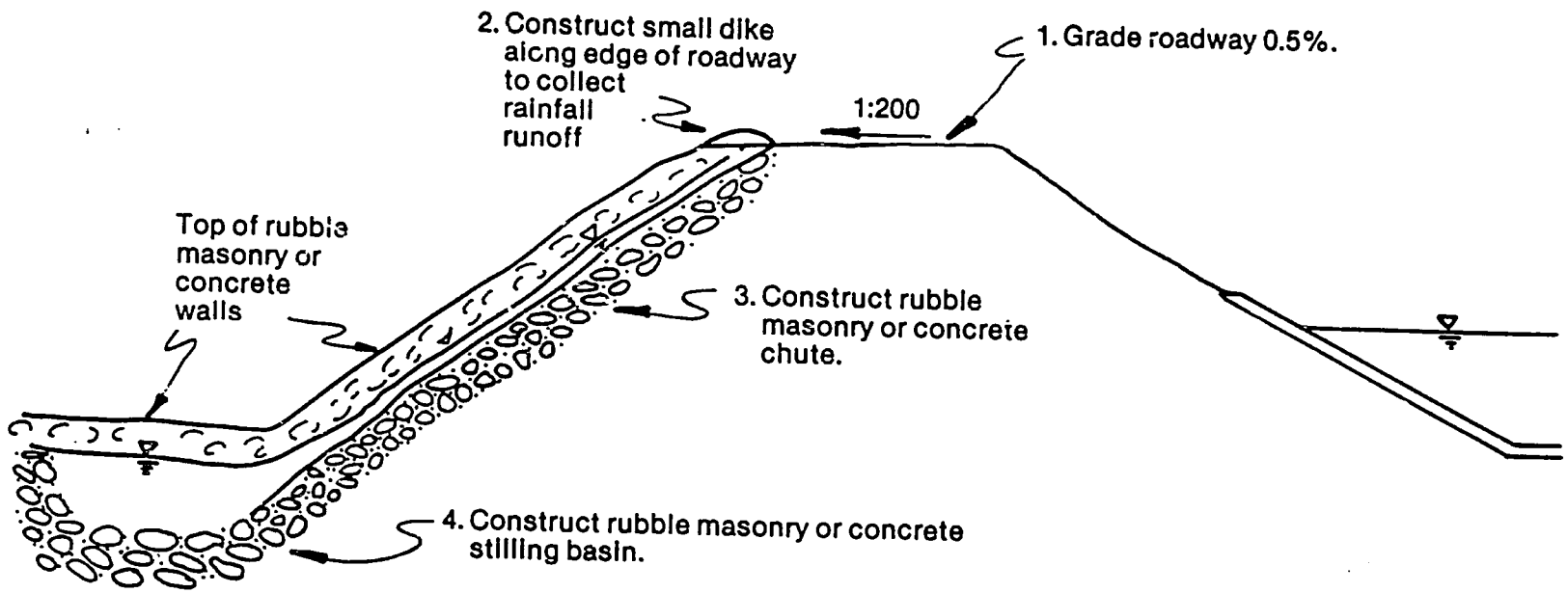


Figure M-05-10. Collection of Surface Runoff on Top of an Embankment, Conveyance Down the Bank Slope, and Erosion Protection at the Toe of the Bank.

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 M-05-11 where open drains are used to provide both surface and subsurface drainage, or Figure M-05-12 which illustrates the use of a surface Runoff Interceptor Drain for surface drainage and a Perforated Pipeline Drain for subsurface drainage. Figure M-05-12 also illustrates the use of a Perforated Pipeline Drain to provide subsurface drainage for a cut-bank.

Weep holes can be used to relieve hydraulic pressures behind concrete lining panels as shown in Figure M-05-13. Also, rubble masonry that is porous, or any other porous material can also be used as shown in Figure M-05-14. 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 concrete lining panels to be washed into the irrigation channel.

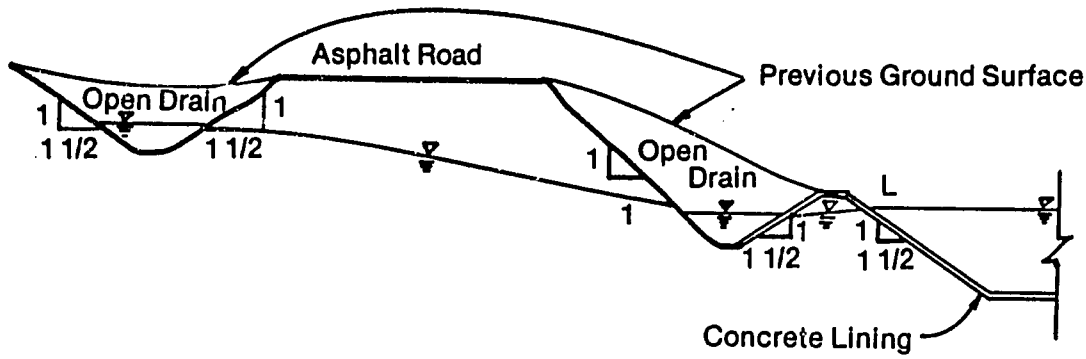


Figure M-05-11. Typical Cross-Sections for Open Drains for a High Roadway Embankment in a Cut Area.

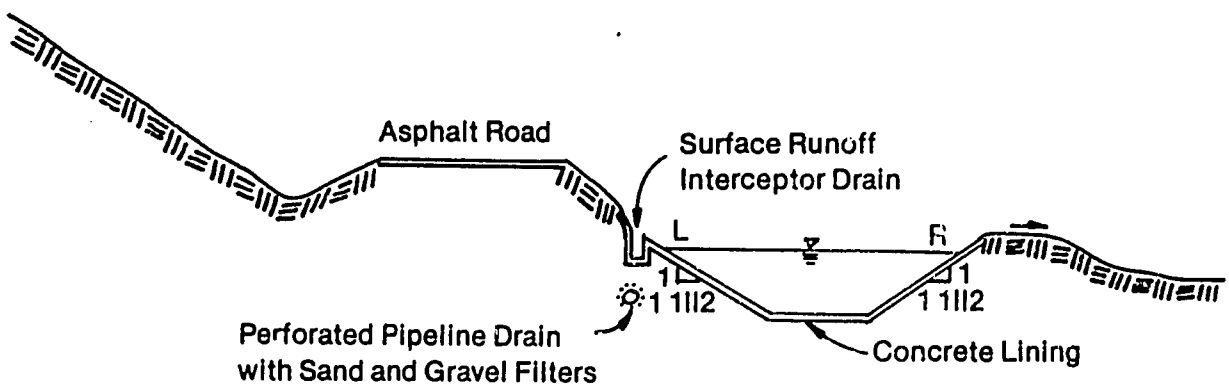


Figure M-05-12. Typical Cross-Sections for Open Drains and Use of a Surface Runoff Interceptor Drain and a Perforated Pipeline Drain for Providing both Surface and Subsurface Drainage.

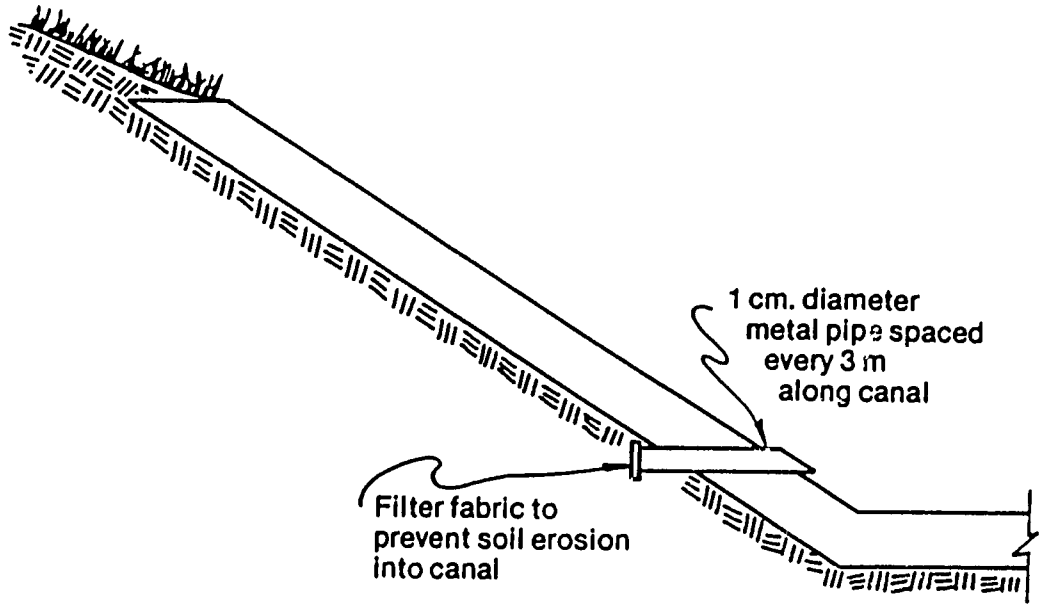


Figure M-05-13. Use of Weep Holes to Relieve Hydraulic Pressure Behind Concrete Lining.

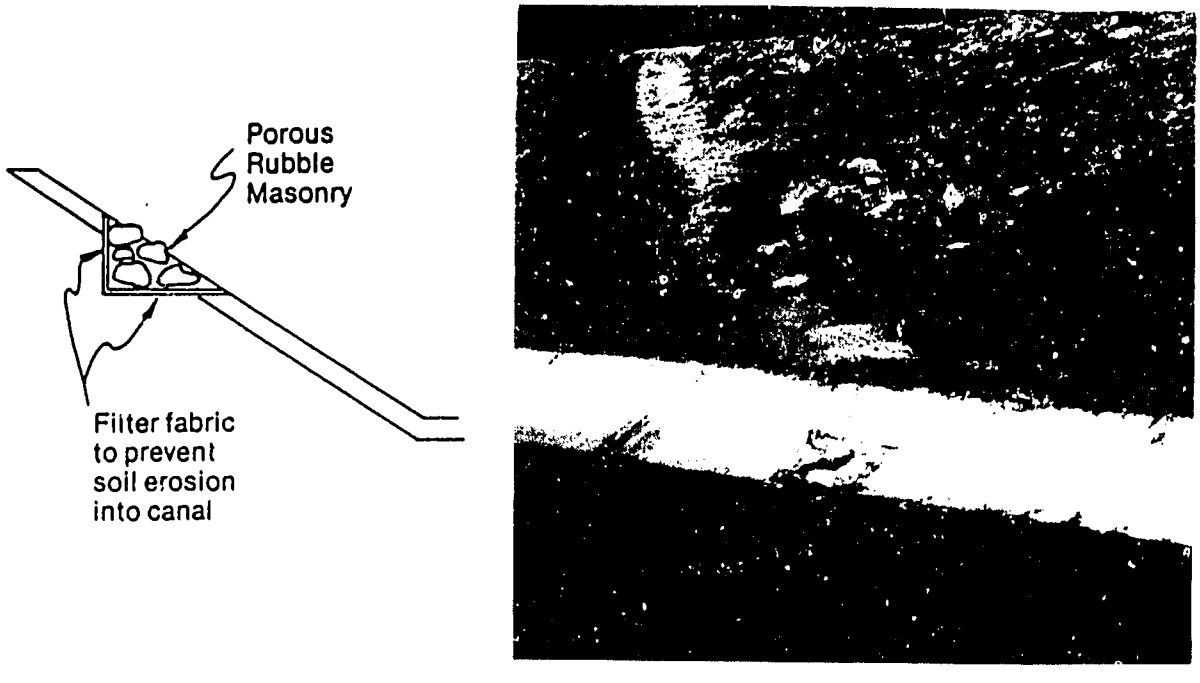


Figure M-05-14. Use of Porous Rubble Masonry with Filter to Relieve Hydraulic Pressure Behind Concrete Lining.

E. CONCRETE-LINED CHANNELS

The formation of cavities behind the inclined concrete lining panels causes the most deterioration of concrete-lined channels. This is the most important of all maintenance activities, because of the great loss in capital or investment costs each year and the tremendous cost of rehabilitation in a relatively short time period of 5-15 years, rather than 50 years, which would be the case if proper maintenance practices were being employed.

The filling of cavities is an expensive maintenance cost. Usually, by the time a cavity is being 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 concrete lining unsupported. Also, there may be a sizeable hole in the lining. If so, one procedure is to remove the broken pieces of concrete 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 labor 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 concrete lining.

If the cavity cannot be detected at the top of the concrete lining panels, but only by a small opening in the joint, then the best procedure is to break the concrete 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 M-05-15.

If there is extensive damage in a channel reach resulting from the lack of subsurface drainage, then the facilities shown in Figures M-05-11, M-05-12 and M-05-14 should be considered and appropriate measures implemented.

Finally, the roadway bank or berm bank adjacent to the lining panels 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.

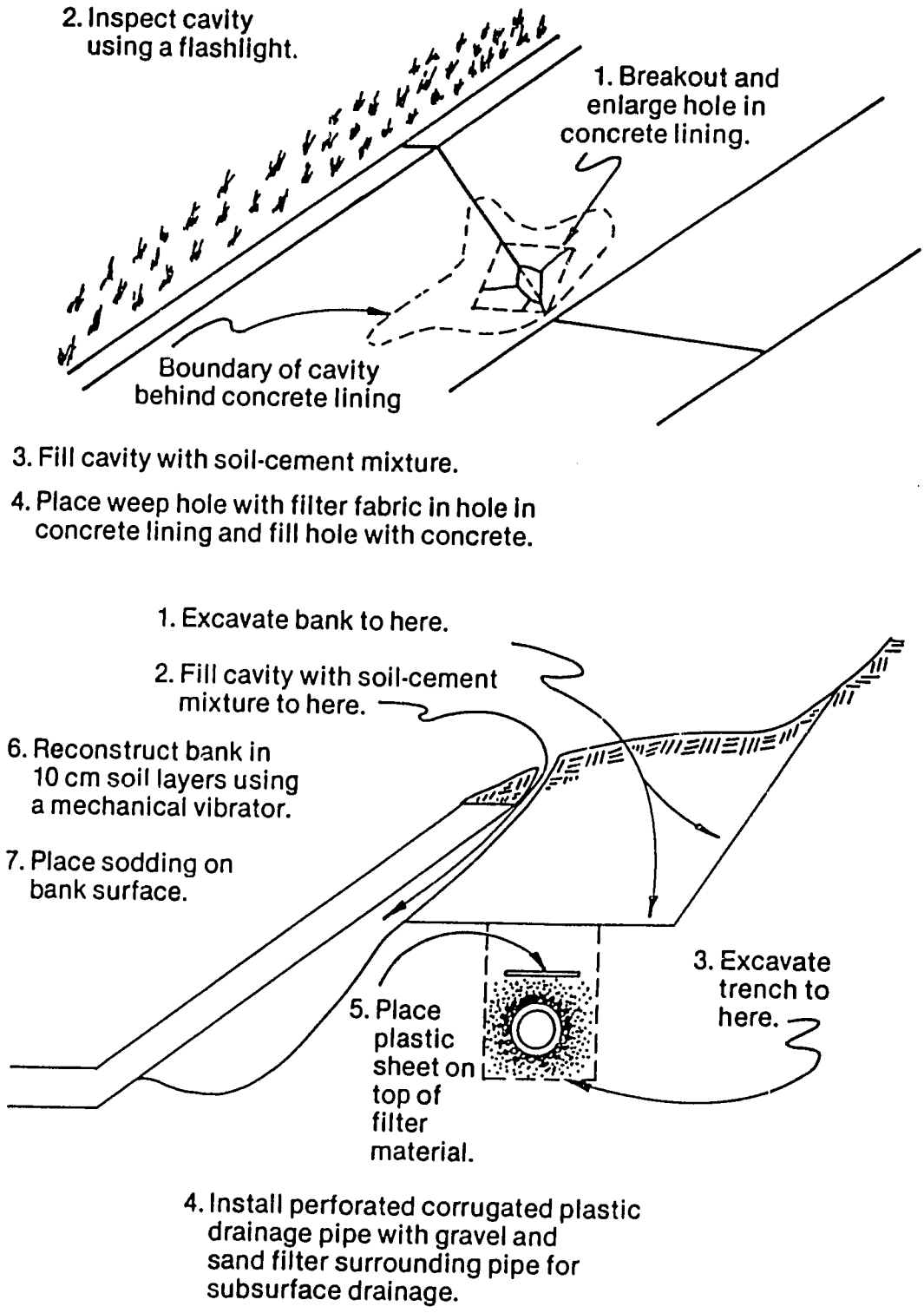


Figure M-05-15. Procedures for Filling of Cavities and Repair of Concrete Panels.

F. EARTHEN CHANNELS

For earthen channels, the most obvious maintenance problems are sedimentation and aquatic and vegetative growth. Removal of these materials from the channels and sodding of the channel banks will be important maintenance activities.

The most important maintenance problems will perhaps only be discovered while implementing the Operations Phase of the O&M Learning Process. The seepage loss rate measurements, particularly at high operating water levels, will disclose whether or not the embankments may require reconstruction, or if concrete lining should be considered. This type of field data should also be collected in the tertiary channels; then, the Water Users Group Leader and the farmers should be informed of the results. RID field personnel could provide technical advice to the farmers on reconstruction of their channels if the seepage losses are significant.

G. DRAINS

The open drain network often suffers from a lack of maintenance. Also, the hydraulic effectiveness of the drainage channels are rarely evaluated. The biggest problem is clogging from extensive vegetative growth, followed by an accumulation of sediment. In some low-lying areas, it is difficult to move machinery into the area, such as draglines or backhoes, which is the preferred methods for cleaning large drains. In the tertiary systems, where the drains are much smaller, the farmers will clean their drains by their own labor.

Section VI

MAINTENANCE OF STRUCTURES

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

A. DRAIN CULVERTS

The most common maintenance requirement for drain culverts 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.

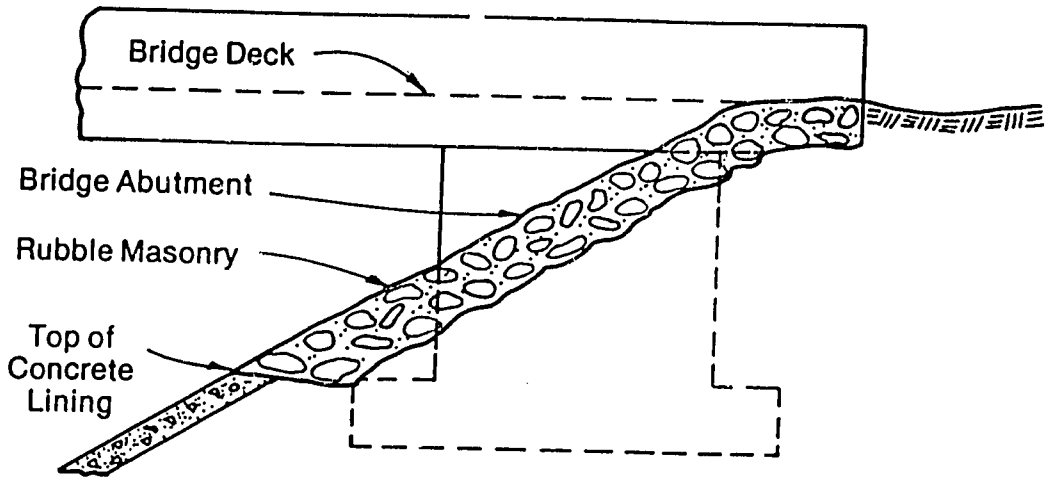
B. BRIDGES

Bridges are usually a problem for concrete-lined canals. Commonly, surface runoff from rainfall causes erosion at the bridge abutments and the formation of cavities behind the concrete lining panels. The required maintenance is to place rubble masonry between the top of the concrete lining and the bridge abutments as shown in Figure M-06-1. This remedy should be incorporated into the design criteria for such structures in the future.

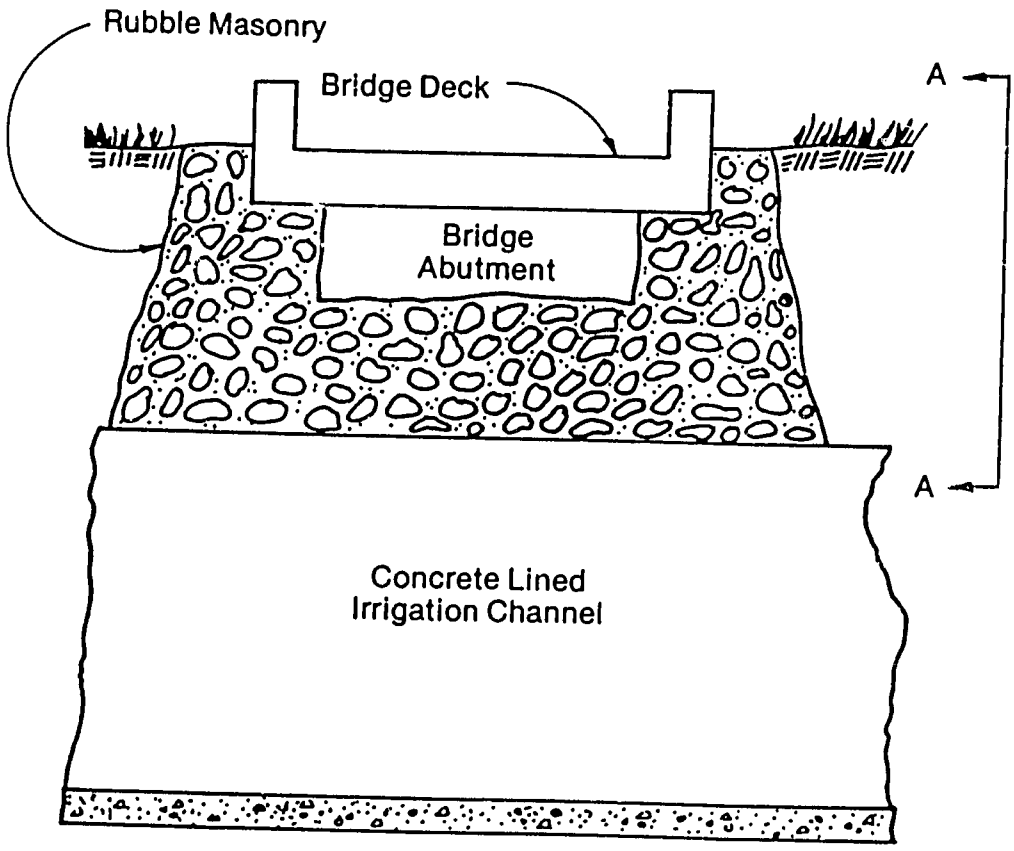
C. DROP STRUCTURES

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.

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 M-06-2). 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.



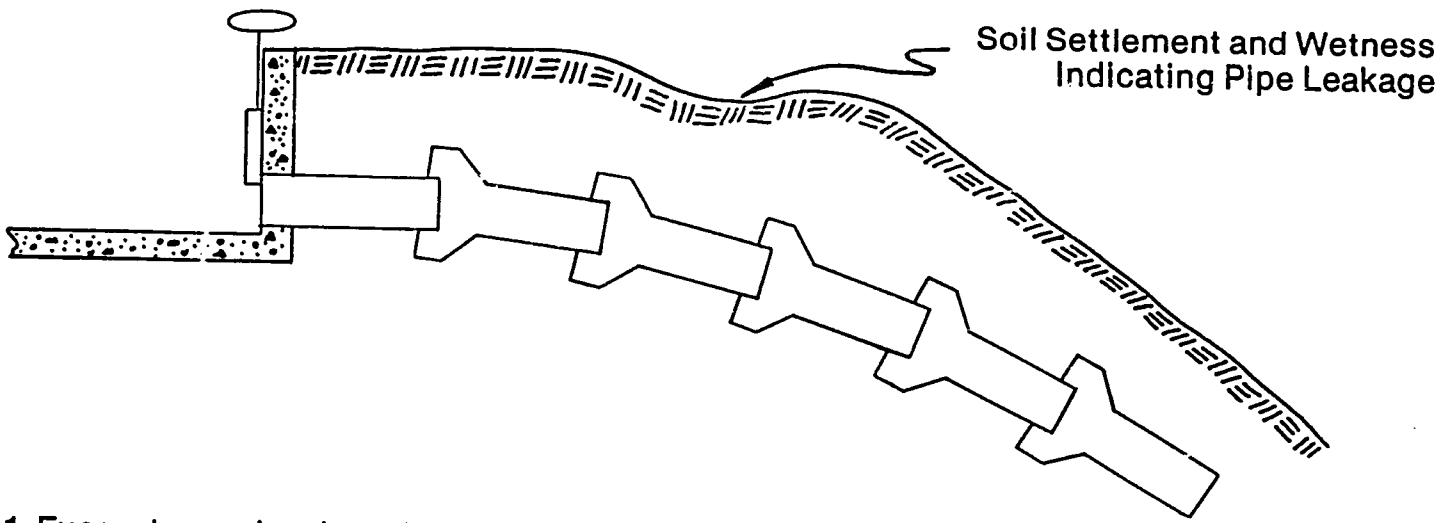
Section A-A



Elevation

Figure M-06-1. Construction of Rubble Masonry Above Concrete Lining to Bridge Abutments.

83



1. Excavate overburden with backhoe or using laborers with shovels.
2. Remove soil surrounding pipeline using laborers 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 M-06-2. Maintenance of Leaking Pipeline Drop Structures.

Often, a hole will have been created by deterioration of the concrete at the joint opening of the end of the outlet transition structure. This is the result of hydraulic pressures behind the structure. The remedies, as shown in Figure M-06-3, 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 M-05-13) or small sections of porous rubble masonry with a filter in the concrete walls (Figure M-05-14).

D. 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 accumulating 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 laborer enter the inverted siphon to remove the accumulated material.

In order to determine whether or not 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

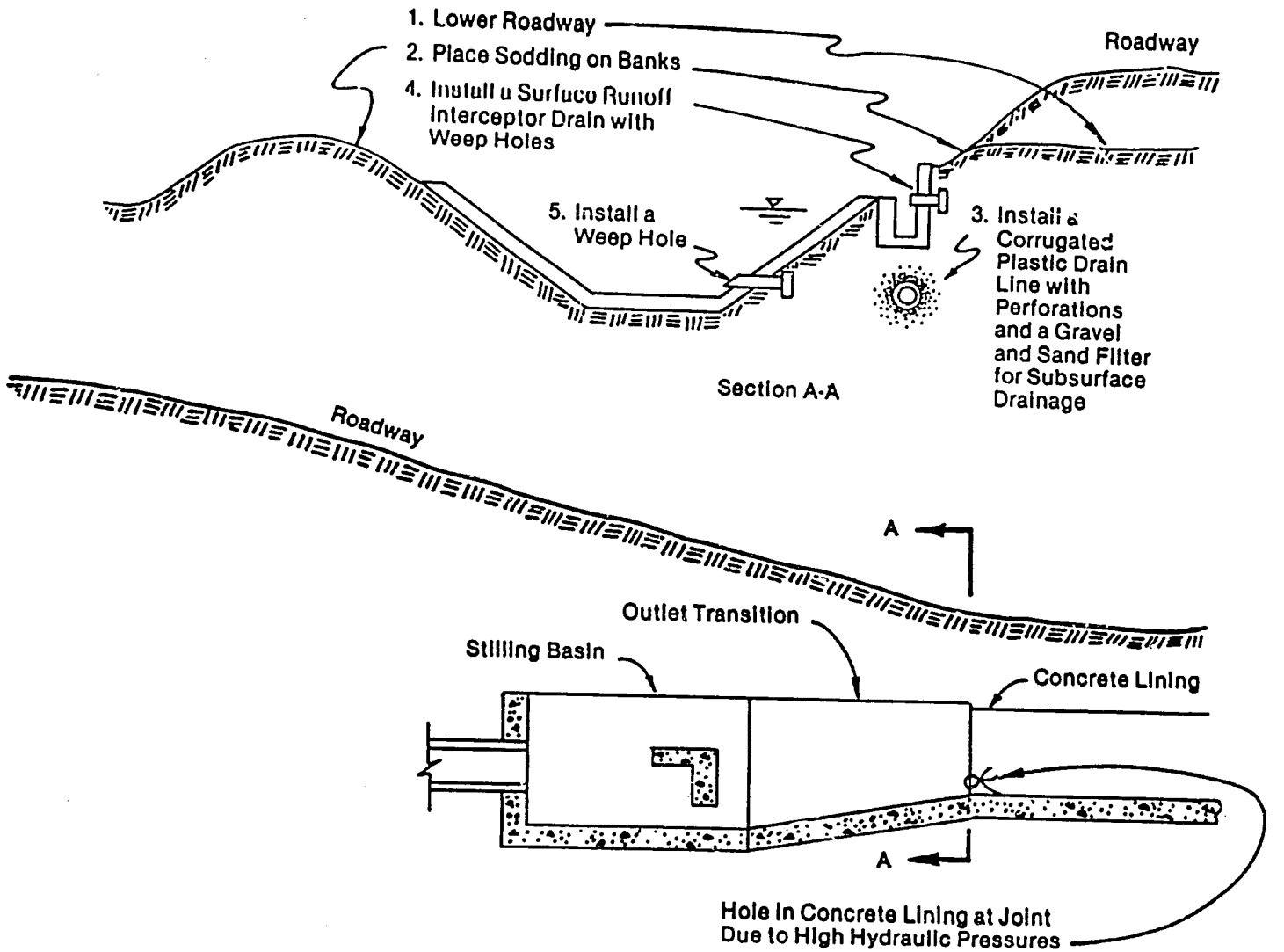


Figure M-06-3. Maintenance Remedies to Relieve Hydraulic Pressure at the Outlet Transition for a Drop Structure.

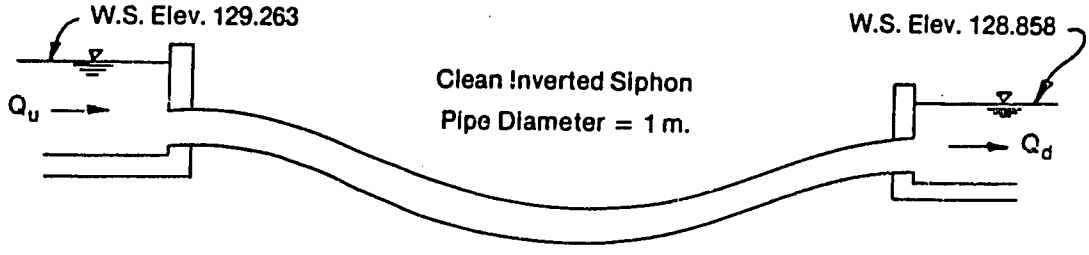
surface elevations (See the Operations Phase of the O&M Learning Process for the activity, "Check Discharge Ratings for Flow Control Structures"). If material is accumulating, either in a culvert or inverted siphon, where submerged outlet control exists, the coefficient of discharge will decrease (Figure M-06-4). 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.

E. CONSTANT HEAD ORIFICE OUTLET STRUCTURES

The principal maintenance problem with Constant Head Orifice (CHO) structures is when they are used as the outlet from the main system to serve a tertiary system. The maintenance problem is the transition from the outlet structure to the tertiary channel, where small drops in elevation of only 10 centimeters may result in failure of the CHO outlet structure.

For small drops in water surface elevation, say 10-30 cm, rubble masonry can be placed at the end of the outlet structure along the walls, and even more importantly, in the downstream channel floor. This will allow the excess hydraulic energy to be dissipated (Figure M-06-5).

When the drop in water surface elevation, between the CHO outlet structure and the beginning of the tertiary channel, is more than 30 cm, then a rubble masonry or concrete chute should be constructed. A lined stilling basin for dissipating the hydraulic energy should also be built (Figure M-06-6).



Example:

By current meter measurements,

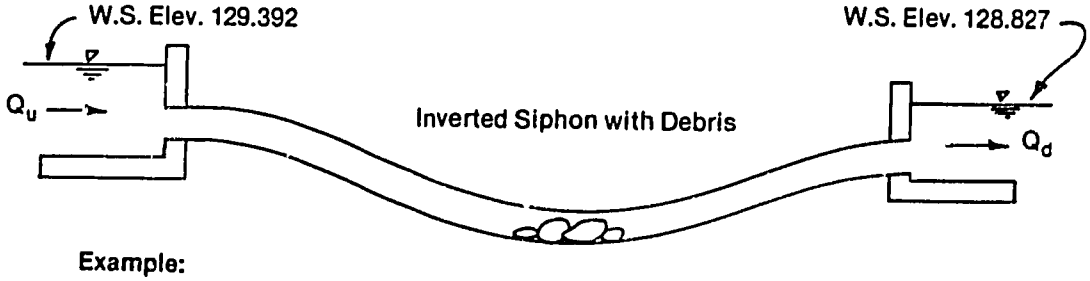
$Q_u = 1.536\ m^3/s$ $\qquad$ $Q_d = 1.561\ m^3/s$

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 $Q = 1.330\ m^3/s$

$$C_d = \frac{1.330\ m^3/s}{0.7854\ m^2\sqrt{2(9.81\ m/s^2)}\ (129.392m - 128.827m)^{0.5}}$$

$$= 0.509$$

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

Figure M-06-4. Discharge Measurement Technique for Determining When Maintenance is Required at an Inverted Siphon or Culvert.

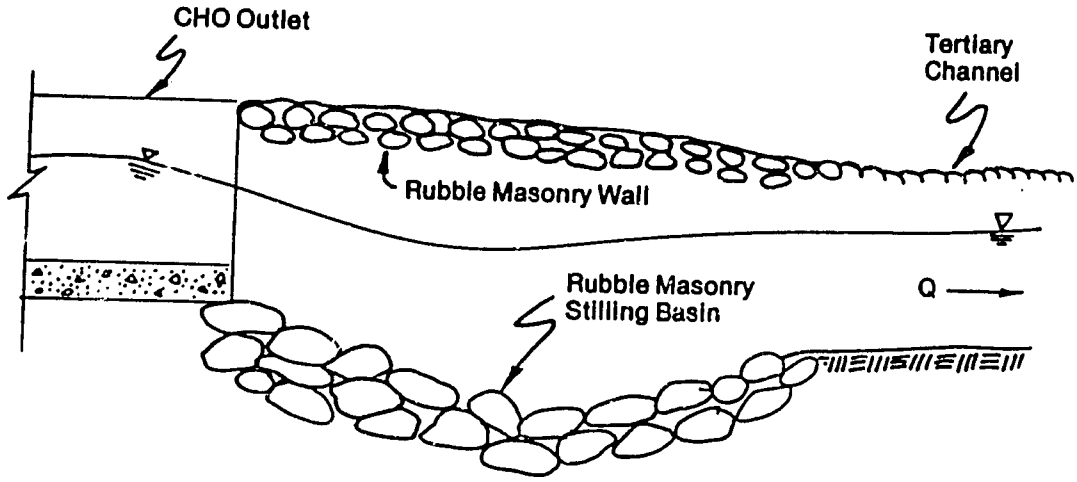


Figure M-06-5. Construction of Rubble Masonry Transition Between CHO Outlet and Tertiary Channel for Drops Less Than 30 cm.

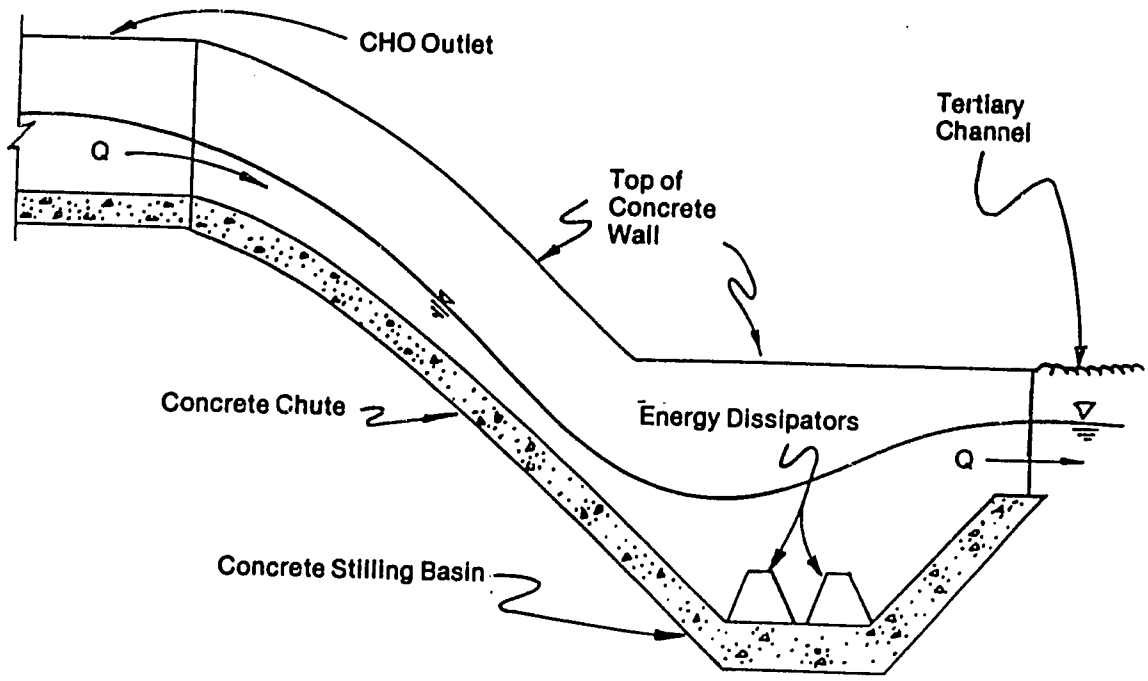


Figure M-06-6. Construction of Concrete Chute Transition Between CHO Outlet and Tertiary Channel for Drops Greater Than 30 cm.

09

F. 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 O&M Learning Process.

The usual visual indicators of gates and gate frames requiring maintenance are gate leakage, bent gate rods, 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 much 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 become weak inside without being visible, until the gate buckles. This is usually the result of infrequent cleaning and painting.

G. OTHER STRUCTURES

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

The necessary maintenance practices are the filling of 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.

Section VII

MAINTENANCE SURVEY OF FLOW CONTROL STRUCTURES

The section on "Identifying Flow Control Structures" in the Handbook of Improved Irrigation Project Operations Practices should be consulted. In this portion of the Maintenance Survey, the intent is to fix 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 O&M 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 these 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 will be gate structures.

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 the location of staff gauges, benchmarks, or piezometers for measuring water levels 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 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,) which 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 of 15 measurements (3 measurements at 5 locations). This last information is extremely important in interpreting the field measurements when developing discharge ratings later.

Section VIII

ESSENTIAL STRUCTURAL IMPROVEMENTS PLAN

A detailed "Essential Structural Improvements Plan" should be prepared that includes:

1. Physical description of irrigation system;
2. Proposed flow measurement program for equitably distributing water supplies;
3. Proposed program for evaluating channel losses using the inflow-outflow method;
4. Essential Structural Improvements (ESI);
5. Costs of Essential Structural Improvements;
6. ESI 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 canals, laterals and sub-laterals, each properly labeled. The lengths of each sub-lateral, lateral and main canal can be provided, along with their design discharge capacity and irrigable area served.

B. PROPOSED FLOW MEASUREMENT PROGRAM

This section of the ESI Plan needs to 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.

C. PROPOSED PROGRAM FOR EVALUATING CHANNEL LOSSES

Assuming the completion of Essential Structural Improvements and the Development of Discharge Ratings for the flow control structures, state an operational program for evaluating seepage loss rates in various reaches of the main canals, laterals and sub-laterals using the Inflow-Outflow Method. 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. 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 lateral for one discharge on a single day, which would require three days, 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 IMPROVEMENTS

The results from the "Maintenance Survey of Flow Control Structures" described in the previous section provides all of the field data required to prepare this particular section of the ESI 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, Gate Rods and Gate Frames. Then, under each of these three major categories, the specific maintenance activities can be listed and the quantities of maintenance required.

E. COSTS OF ESSENTIAL STRUCTURAL IMPROVEMENTS

This is a relatively short section that utilizes the lists of required maintenance activities, and the quantities from the previous section of the ESI 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 Improvements. If there are any particular problems with some of the unit costs being used, this should be presented in the writing.

F. ESI IMPLEMENTATION PLAN

A proposed time schedule for completing the Essential Structural Improvements should be presented. The discussion should state any particular problems that might disrupt the proposed time schedule.

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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 Budget Request for additional funds.

G. FIELD NOTES AND SKETCHES

Preferably, a copy of the field written notes and sketches should be appended to the ESI 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.

Section IX

DIAGNOSTIC "WALK-THRU" MAINTENANCE SURVEY

There is only one activity in the Maintenance Phase of the O&M Learning Process that is more important than conducting the diagnostic "walk-thru" maintenance survey -- that is completing priority maintenance needs in the field. The "causes" of maintenance problems was discussed in Section IV, while the "remedies" were presented in Sections V and VI. Conducting the diagnostic "walk-thru" maintenance survey provides the field personnel a greater understanding and sensitivity regarding the causes of maintenance problems. Participating in the actual maintenance by completing the priority maintenance needs provides field personnel with extremely valuable experience in the application of remedies to maintenance problems.

The Water Masters should have already received field training prior to undertaking this activity, or they should be receiving supervised training while conducting this "walk-thru" survey. If the Water Master(s) have received training previously, then they can conduct this survey in conjunction with the Zonemen under their supervision, thereby extending the training to these Zonemen. However, it must be strongly emphasized that the Water Master is expected to do this "walk-thru" survey over every meter of canal, laterals and sub-laterals under his jurisdiction. The Zonemen can participate by also walking along with the Water Master.

Prior to conducting this field survey, the Water Master should have compiled a complete listing of structures and their location for his area of jurisdiction, which may be a medium-scale irrigation

project or a portion of a large-scale irrigation project. 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 Zonemen can help. Either one or two Zoneman can assist the Water Master. Certainly, when conducting the "walk-thru" in the area of operation for a Zoneman, he should participate with the Water Master in this survey since it is his area of responsibility. Initially, when training the Zonemen, the Water Master will have to walk along both channel embankments to be sure that all of the maintenance problems are being detected. Then, when the Water Master has a high degree of confidence in the capability of a Zoneman, he can allow the Zoneman to walk along one of the embankments, while the Water Master walks along the opposite bank.

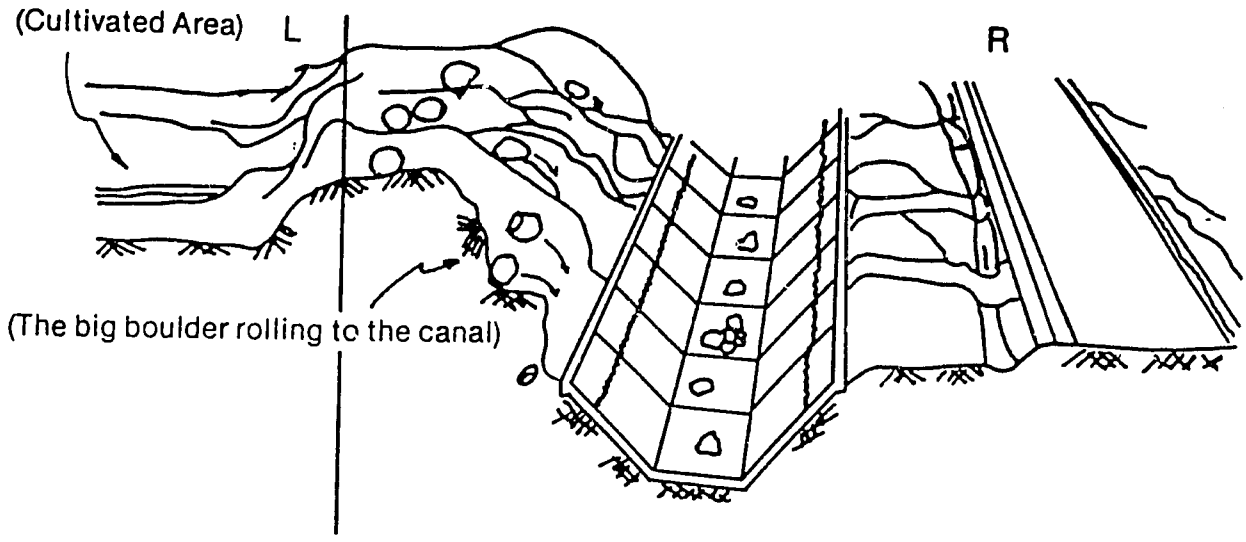
All of the field notes should be written by the Water Master. A very important part of the field notes should be numerous sketches illustrating the maintenance problem being described, along with any proposed remedies. Another important point is to provide sufficient detail in the field notes so that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

Examples of field notes are shown below. Some have been extracted from the Maintenance Plan for the Lam Nam Oon Irrigation Project. Other examples have been taken from the Maintenance Plan which was the output from a 15 calendar day training course wherein the participants

prepare the main report. Many of the sketches prepared by the participants were excellent in portraying the maintenance problems.

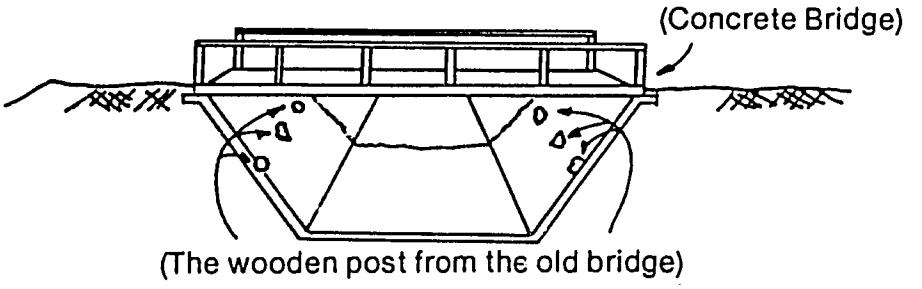
Table M-09-01. Examples of Field Notes and Sketches Extracted from the "Maintenance Plan for the Lam Phra Plerng Irrigation Project".

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 much lower than the top of the concrete lining.



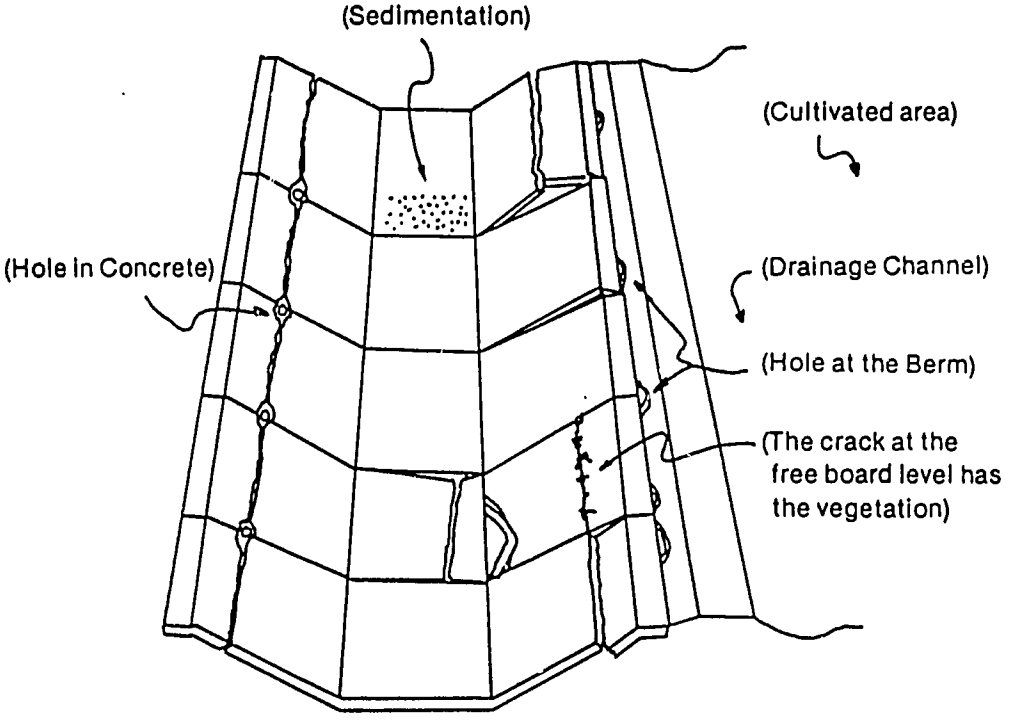
100

13+500 The bridge is in good condition, but there are six holes in the concrete panel underneath the bridge due to the original wooden bridge columns.

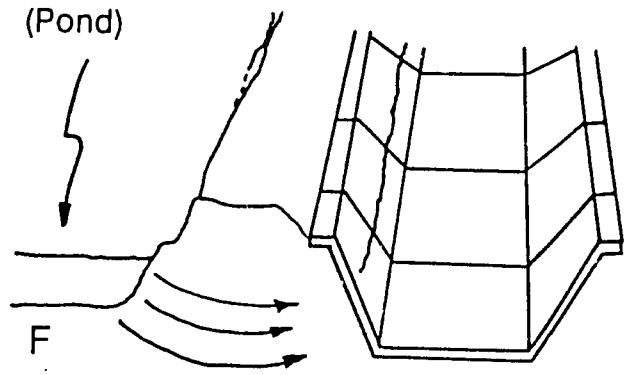


KM 20 + 000 - 20 + 475

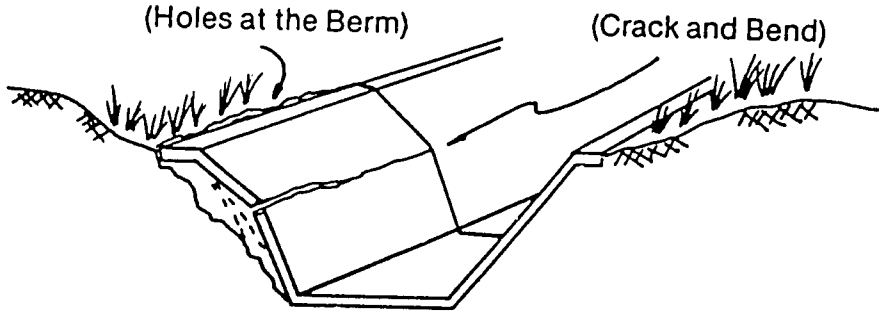
The concrete panels should be replaced due to 20 holes at the berm diameter size 0.30 m., which maka the extended concrete panel at the free broad collapsed. The water table pressure has cracked the concrete panels and isplaced and formed cavities under neath and at the connection of the old and the new concrete. There are 23 concrete panels that were damaged, 3 concrete beds were cracked. There are 60 holes at the concrete panels along the extended concrete joint which 60 holes at the concrete panels along the extended concrete joint which also has vegetation in the holes. The depth of weeds and silt is 0.05 m.



33+000 - 35-200 At the left side of the canal is a pond which caused damage to the concrete panels along the left side of the canal because of the hydraulic gradient when the canal was empty.

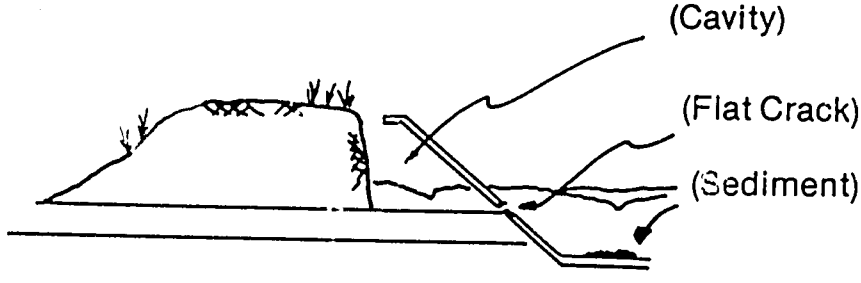


36+146 A concrete panel is cracked at the left side of the canal. Soil volume = 0.15 x 3.00 x 2.70 = 1.215 m^3. Concrete volume = 0.05 x 3.00 x 2.85 = 0.428 m^3.

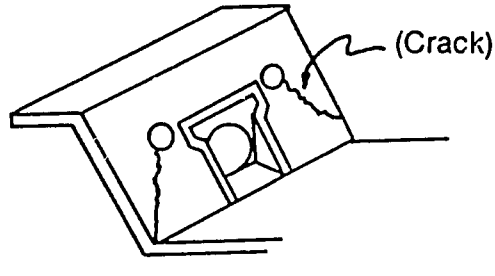


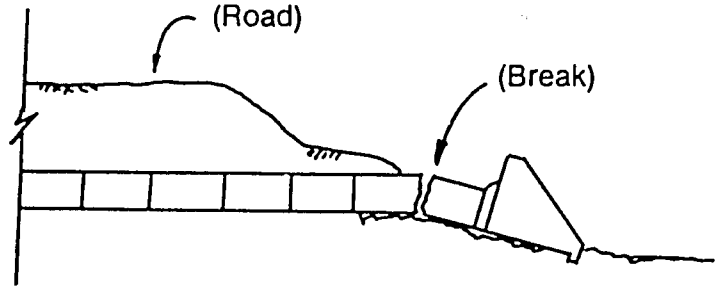
10V

37+476 A large cavity has formed behind the concrete lining on the left side of the canal. This was caused by the cracking of the concrete in the old turnout. Water seeps into the canal from above, carrying soil and undermining the lining. This should be repaired as soon as possible. Soil volume = 0.50 x 3.00 x 1.50 = 2.25 m^3.

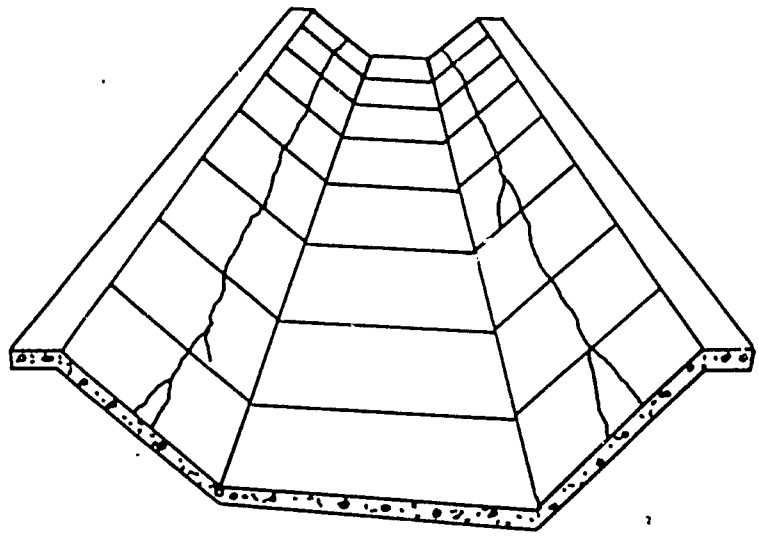


39+663 The inlet transition to the farm turnout is cracked and needs repair. The outlet transition is covered with weeds, and the soil around the structure has been eroded. One of the pipe joints is broken and needs repair.

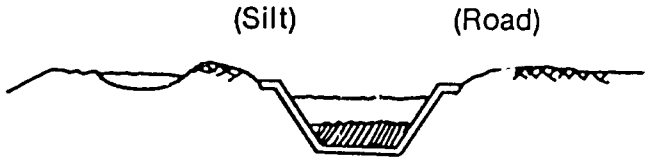


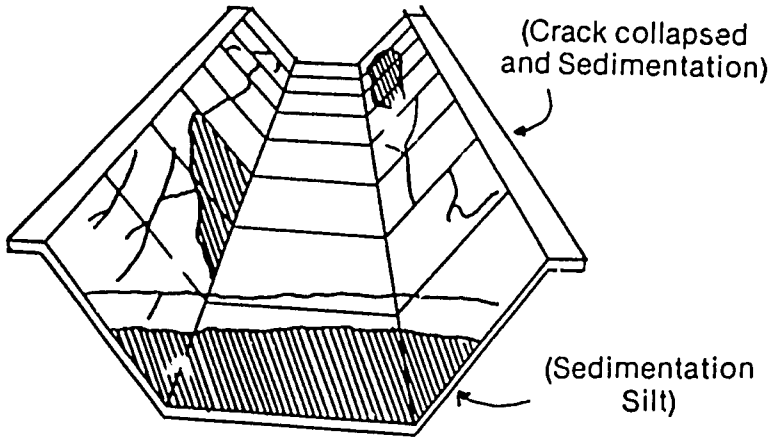


0+018 - 0+102 Lateral 3R-L. There are cracks along both sides of the concrete panels, requiring alphalt sealing. Soil compaction of the embankments was inadequate. Weep holes should be installed to relieve pressure on the lining when the canal is empty.



3+200 - 4+630 Lateral 3R-L. This part of the canal 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.





69+857 The inlet pipe (0.20 m diameter) at the left side extends into the canal, beyond the concrete lining. The embankment has eroded partially, depositing soil in the canal.

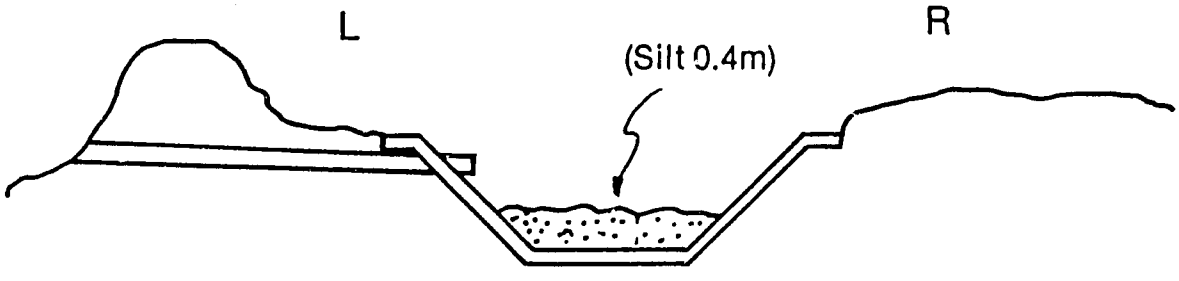
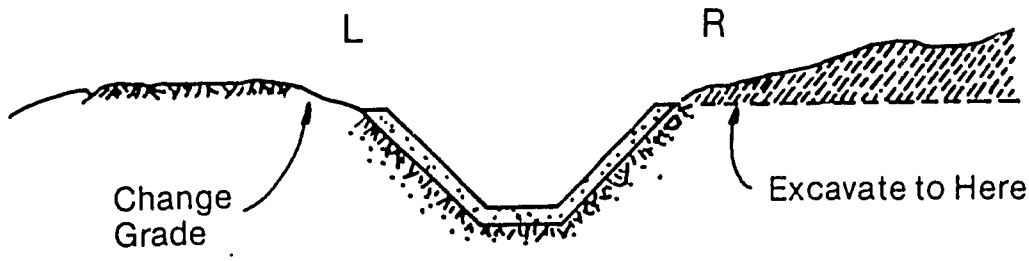


Table M-09-02. Examples of Field Notes and Sketches Extracted from the "Maintenance Plan for the Lam Nam Oon Irrigation Project".

≈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.



≈6+940 Nine m of left panels have failed.

≈6+950 Hole in righ panel.

To solve the problems, from ≈6+800 to 7+000 will require subsurface drainage on <u>both</u> sides.

6+994 Bridge. There are cavities at left downstream and right upstream abutments that have resulted from bridge deck drain holes running water onto soil above lining and creating these cavities. Plug drain holes (2) and fill cavities.

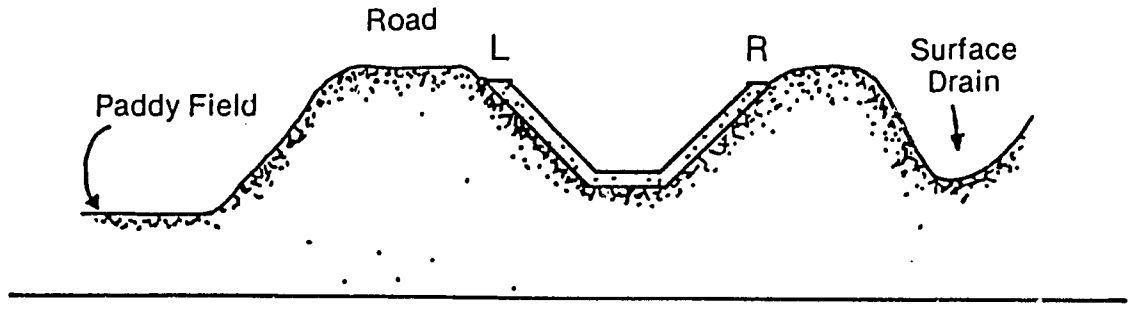
<u>Sub-Lateral R-6L-2L-IL-IR (5.400 km)</u>

0+000 Double CHO Regulator. The two gates on the downstream CHO are not operable, so that when the water level is raised in Lateral R-6L-2L-IL, then water will flow through these gates. The gates on the upstream CHO canfunction, but they still need repair. Outlet structure, good.
Aquatic growth.

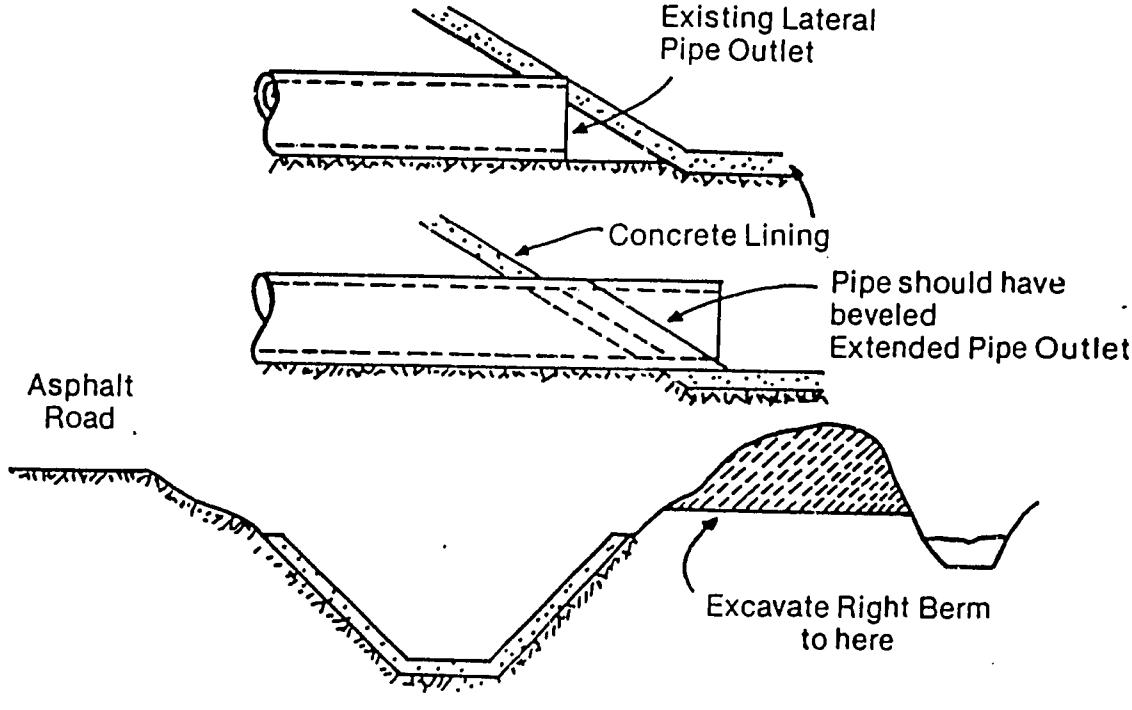
≈0+150 Roadway erosion on right bank. (Road on right of lateral.)

106

0+300 to 1+200 Lining looks very good in this area because land on both sides is lower than lateral.



1+125 Last month, a concrete pipe outlet was installed that has a circular concrete lid for a gate. Unfortunately, the concrete lid does not fit the concrete pipe.



2+000 Many cracked left and right panels, but only a few small holes in panels. Cracked floor panels. Therefore, subsurface drainage is needed, which can be accomplished by having invert of surface drains as low as possible, but at least below F.S.L. of IMC.

2+590	Concrete Bridge is structurally good, but one railing pipe has been broken off. No cavities or cracks in undelying panels.
2+600	Two CHO's Right CHO has first gate missing. Rith oulet structure is good, but downstream lining has been busted in many places. Left CHO is good, but has one concrete walkway panel lyning in lateral and another inside CHO structure. Left outlet structure is good. One-tenth sediment.
3+000	Tail Regulator. Inlet structure is good. Outlet structure is good.
3+010	Final CHO Outlet Structure. CHO is very good. Pipe outlet structure is good.

This was an excellent design. The lateral invert is above the adjacent lands along nearly the full length. As a consequence, this lining, which was constructed nine years ago, is in excellent condition.

Section X

PREPARATION OF A MAINTENANCE PLAN

As described above in this handbook, a Maintenance Plan should document a proposed program for catching-up on deferred maintenance, so that afterwards the irrigation project can function properly on a routine or preventive maintenance program. The proposed outline for preparing a Maintenance Plan is:

1. Physical Description of Irrigation Project
2. Essential Structural Improvements (ESI)
3. Status and Costs of ESI 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 Improvements (ESI) Plan should be included here. In addition, more background about channel sizes might be provided in a list included in a table. Also, the number of outlets along different

sub-laterals and laterals should be listed, as well as along various reaches of the main canals.

B. ESSENTIAL STRUCTURAL IMPROVEMENTS

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

C. STATUS AND COSTS OF ESI PLAN

First of all, the present status of the ESI plan should be presented. Has it been approved ? If so, what fraction of the work has been completed ? Then, the costs of the ESI 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 Budget Request for maintenance. Also, the topic listing for the sub-sections in Sections V and VI on Maintenance of Channels and Maintenance of Structures can be used as a guide.

E. MAINTENANCE COSTS

Each irrigation project has unit costs for various types of maintenance activities that they commonly use in preparing a Budget Request. In preparing the estimated costs for this section of the Maintenance Plan, there may be some difficulty if, for example, the project field staff are not experienced in the filling of cavities. If this is the case, then the Project Engineer at an 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 all cases, the degree of deferred maintenance will exceed the capacity of the irrigation project to complete 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 Maintenance Plan, followed by the second highest PMN for the second year, and so on until all of the deferred maintenance would be alleviated. The same tabular format used in presenting the "Inventory of Required Maintenance" and "Maintenance Costs" would 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 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 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. Then, if certain staff vacancies exist that would seriously hamper the implementation of the Maintenance Plan, then this deficiency should be clearly stated and good justification provided for filling such vacancies. Finally, the amount of temporary labor usually employed by the irrigation project, and the annual capacity of this temporary labor to undertake the proposed maintenance activities should be presented. If additional temporary labor 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. MAINTENANCE PLAN

Maintenance Issues

The Maintenance Plan should address, as a minimum, the following three issues:

1. Eliminating sediment sources;
2. Reducing deterioration of channel lining; and,
3. Minimizing seepage losses.

The first issue, eliminating sediment sources, should clearly come from the field notes while conducting the "walk-thru" maintenance survey. However, it is very important that the Maintenance Plan clearly address this issue, so that when the deferred maintenance is completed, the quantities of sediment entering the irrigation channels afterwards will only be a very small fraction of what is presently entering the channels.

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

Finally, the problem of minimizing seepage losses will be an issue of increasing importance with each passing year. This question is difficult to address unless the Operations Phase of the O&M Learning Process has also been implemented. Thus, for irrigation projects that have earthen channels, this issue should be addressed in a very quantitative manner, because the Operations Phase would likely be

implemented prior to this Maintenance Phase. However, for irrigation projects that have predominantly concrete-lined channels, then the Maintenance Phase would likely be implemented prior to the Operations Phase, so this issue can only be addressed qualitatively.

Method of Implementation

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

1. Force account maintenance;
2. Private contractor maintenance; and
3. Contract main system maintenance with the Water Users Groups.

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.

Implementation Schedule

The number of years proposed for completing the 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 Budget Request document that could be forwarded following review and approval of the Maintenance Plan. The summarized Work Plan for the succeeding years would not be based on so much detail, but would be best estimates based on subdividing the total maintenance requirements and costs into annual workloads that can be accommodated by the irrigation project staff.

J. FIELD NOTES AND SKETCHES

Based upon the original field notes and sketches, this work would be recopied and appended to the Maintenance Plan. This material can be recopied by hand and appended 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 or the Annual Maintenance Completion Report. Although appending all of the field notes and sketches to the Maintenance Plan adds a lot of bulk, it is extremely important documentation for use during implementation of the Maintenance Plan.

Section XI

ADMINISTRATIVE ACCOUNTABILITY IN IMPLEMENTING A MAINTENANCE PLAN

A. REVIEW AND APPROVAL OF MAINTENANCE PLAN

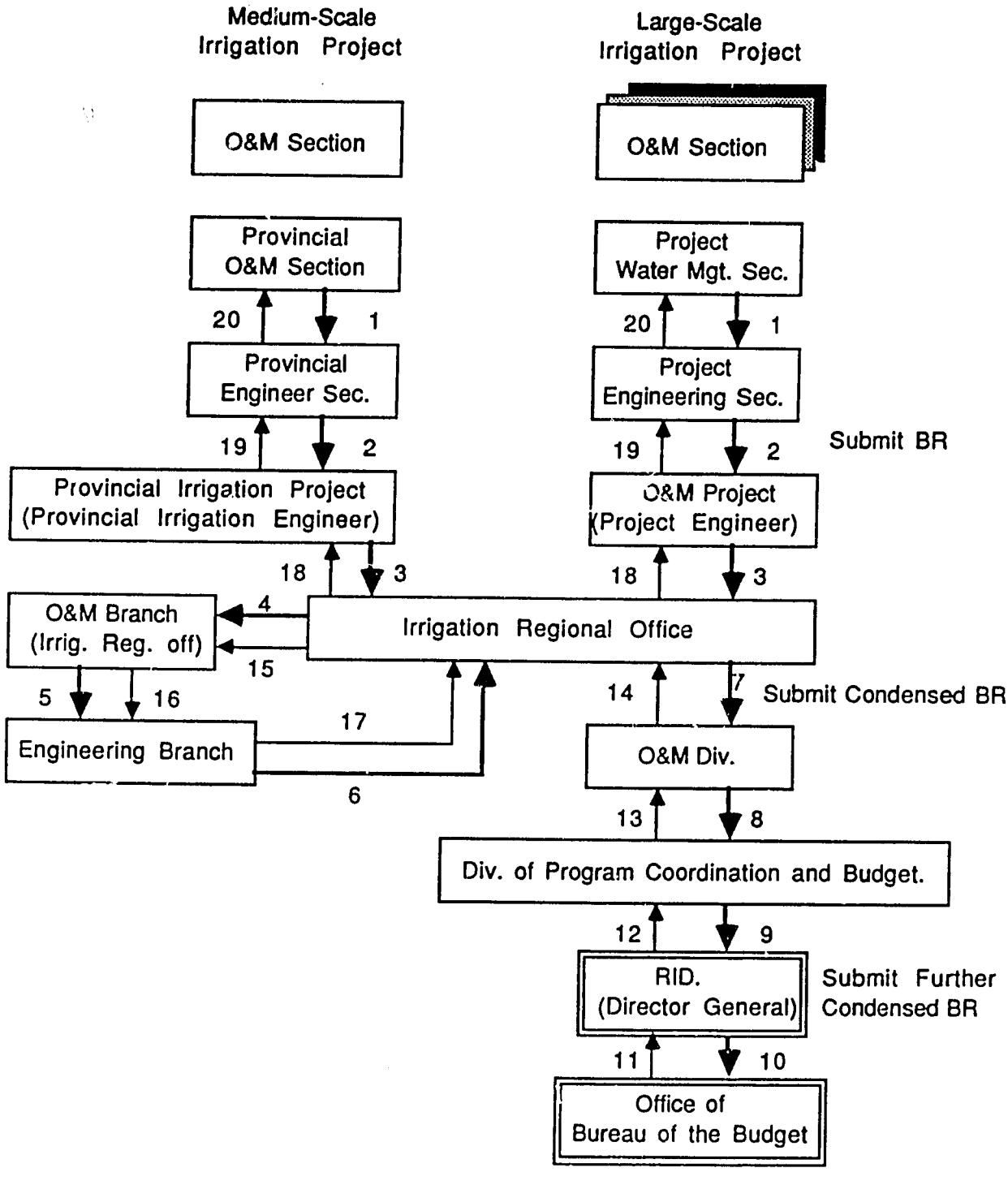
The review and approval process for any Budget Request (BR) pertaining to proposed operation and maintenance activities at either a large-scale or medium-scale irrigation project is shown in Figure M-11-1. For a medium-scale irrigation project, the individual serving in the capacity as Project Engineer is the Provincial Irrigation Engineer.

An O&M Section does the actual field work for one or more medium-scale irrigation projects, while for a large-scale irrigation project, there would be a number of O&M Sections. The Head of an O&M Section is a Water Master, who supervises a number of Zonemen and each Zoneman has a crew of Gate Tenders and Laborers.

The Head of the Provincial O&M Section looks after the project operations on behalf of the Provincial Irrigation (Project) Engineer. The Head of the Provincial Engineering Section, or the Head of the Project Engineering Section, is usually called the Office Engineer, in both cases.

The Operation and Maintenance Division is located at RID headquarters in Bangkok; the Director answers to the Deputy Director General (O&M). The Director of the Division of Program Coordination and Budget answers directly to the Director General of RID.

The Bureau of the Budget is a separate agency that receives Budget Requests from many government agencies.



M-11-1 RID Review and Approval Process for a Budget Request Regarding Operations and Maintenance.

117

To begin the review and approval process, the Project Engineer should submit copies of the Maintenance Plan to the RID Irrigation Regional Office. In this case, approval is needed up to the Director General of RID (see Figure M-11-1).

B. SUBMITTING A BUDGET REQUEST (BR)

In order to provide an understanding of the procedures involved in obtaining funds for improved maintenance practices, the standard procedures presently used by RID will be briefly described. Figure M-11-1 illustrates the steps in obtaining approval (Steps 1-10), as well as the reverse process for disbursing funds (Steps 11-20).

First of all, the O&M Section(s) collect the basic field data which is recorded on standard RID forms, such as:

A1. Manual excavation of sediment from irrigation channels;

A2. Repair of concrete-lined irrigation channels;

A3. Maintenance of irrigation channels;

A4. Repair and maintenance of pumps;

A5. Repair of buildings, houses and other facilities;

A6. Sodding of earthen embankments (dam and channels);

A7. Manual compaction of replaced embankments;

A8. Weed control and removal;

A9. Maintenance of service roads along irrigation channels; and

A10. Improvement of irrigation structures.

These forms are compiled by the Head of Operations (Head of Provincial O&M Section for a medium-scale irrigation project, or Head of Water Management Section for a large-scale irrigation project) and

submitted to the Engineering Section. The Office Engineer, who is the Head of the Engineering Section, is responsible for preparing the Budget Request (BR) under the direction of the Project Engineer (Provincial Irrigation Engineer for medium-scale irrigation projects). Again, there are a series of forms, in which the first form is the summary and the last forms in this list provides the detailed information:

B1. Summary of BR by items, quantities, unit costs and total costs;

B2. Presentation of BR and the approved budget for each item;

B3. Breakdown of Central (Bangkok) costs and local Provincial costs for Repair and Improvement for each 4-month period during the fiscal year;

B4. Breakdown of Central (Bangkok) costs and local Provincial costs for Administration for each 4-month period during the fiscal year;

B5. Action Plan for monthly expenditures for each activity item;

B6. Action Plan for monthly expenditures for Construction;

B7. Plan of Improvements by item, cost, drawing number, and reasons; and

B8. Detailed compilation of work activities to be undertaken.

The BR is submitted by the Project Engineer (or Provincial Irrigation Engineer) to the appropriate Irrigation Regional Office, where a review process occurs as indicated in Figure M-11-1. After approval, the Regional Director submits a condensed version of the BR to the O&M Division at central headquarters in Bangkok.

After approval by the O&M Division, the condensed BR is forwarded to the Division of Program Coordination and Budget, which answers directly to the Director General of RID. After approval by the

Director General, the BR is further condensed by the Division of Program Coordination and Budget. Then, the Director General submits the very condensed BR to the Office of Bureau of the Budget for final approval and funding.

The Provincial Irrigation Engineer or the Project Engineer are notified by the Irrigation Regional Office of the approval and the amount of funding that they will actually be provided. After being informed of the funding levels, they have four forms to prepare regarding the expenditure of these funds:

C1. List of construction materials to be purchased;

C2. List of office and O&M materials to be purchased;

C3. Plan for using materials by month; and

C4. Plan for purchasing and employment.

There are a series of reporting forms that have to be completed by the Project Engineer or Provincial Irrigation Engineer during, and at the end, of the fiscal year:

D1. Monthly report of outputs and expenditures;

D2. Road laterite maintenance output report for 4-month period;

D3. Road asphalt maintenance output report for 4-month period;

D4. A set of 3 forms showing goals and actual accomplishments for maintenance activities for each 4-month period;

D5. Output report for each activity for 4-month period;

D6. Report of plan and output for each 4-month period during the fiscal year; and

D7. Listing of activities, units of work, and expenditures of Central funds and Provincial funds for the fiscal year.

This reporting using standard forms are submitted to the Irrigation Regional Office for review, then the O&M Division, Division of Program Coordination and Budget, and finally the Director General.

C. SUBMITTING ANNUAL MAINTENANCE WORK PLAN

Once the Maintenance Plan is approved, it should take a very short time for the Project Engineer to submit the Annual Maintenance Work Plan. The reason is that this document should have been prepared while completing the preparation of the Maintenance Plan.

The format for submitting the Annual Maintenance Work Plan would be identical with Submitting a Budget Request. There are numerous standard forms that allow the various types of proposed maintenance activities to be listed, such as sediment removal, repair of concrete-lined channels, maintenance of irrigation channels, repair and maintenance of pumps, sodding, earth backfill and compaction, irrigation structures, weed protection, and maintenance of roads.

D. REVIEW AND APPROVAL OF ANNUAL MAINTENANCE WORK PLAN

The review and approval process for the Annual Maintenance Work Plan would be identical to the RID review and approval process for a Budget Request pertaining to an operation and maintenance activity.

E. BUDGET CONTROL AND ACCOUNTABILITY

In order to document the costs of various maintenance activities, it is very important for RID 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 Head of Engineering to assure quality control in the maintenance procedures and for the Project Engineer to quickly review the progress being made.

The maintenance documentation also facilitates periodic evaluation by RID personnel in the Irrigation Regional Office or the Operation and Maintenance Division.

F. SUBMITTAL OF ANNUAL MAINTENANCE COMPLETION REPORT

The "Annual Maintenance Completion Report" should list each maintenance need contained in the Field Notes appended to the 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 Budget Request for the Annual Maintenance Work Plan.

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

The next section should be on "Lessons Learned" during implementation of this Maintenance Phase of the O&M Learning Process. 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 the Maintenance Plan." When completed, copies of the Annual Maintenance Completion Report should be forwarded to the RID Irrigation Regional Office by the Project Engineer.

G. COMPUTERIZED MAINTENANCE PLANNING AND REPORTING (COMPARE)

Obviously, the documentation required while implementing the Maintenance Phase is quite substantial. Yet, if the Maintenance Plan was prepared on the microcomputer, then all of the later reporting--the Annual Maintenance Work Plan and the Annual Maintenance Completion Report--could be readily done. In the near future, microcomputer software will be available that will greatly reduce the administrative workload during the implementation of this Maintenance Phase.

Section XII

PREVENTIVE MAINTENANCE PLAN

By the time that the Priority Maintenance Needs have been nearly completed, 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 corrected. Therefore, the irrigation project is ready to enter a new phase of maintenance activity that will require much fewer resources. Another term commonly used is Routine Maintenance. If there is a distinction between Preventive Maintenance and Routine Maintenance, it would be that Preventive Maintenance represents a minimized form of Routine Maintenance because the deferred maintenance has already been corrected, and many of the causes of maintenance problems have been eliminated.

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, and the level of required resources is expected to be minimized, but certainly kept adequate to maintain the irrigation project in good condition.

A. PHYSICAL CAUSES OF MAINTENANCE PROBLEMS

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

B. 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 canals, and for each lateral and sub-lateral.

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, perhaps some equipment needs special repair or replacement. Also, there may be some pieces of equipment that can be identified which would make the Preventive Maintenance Program 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 Program will require less manpower. Certainly, all of the permanent RID 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 laborers much less. The manpower requirements and annual costs for the Preventive Maintenance Program should be presented, and then compared with the manpower requirements while completing the Priority Maintenance Needs.

E. MAINTENANCE REQUIREMENTS FOR WATER USERS GROUPS

Hopefully, at the time of preparing this Preventive Maintenance Plan, the irrigation project field staff will have spent sometime collecting field data in the tertiary systems as part of the Operations Phase of the O&M Learning Process. 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 and requirements for alleviating these problems by the Water Users Groups. The Preventive Maintenance Plan should discuss how the irrigation project field staff might provide technical assistance to the Water Users Groups 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 the Operations Phase will be very helpful in assessing seepage and leakage

losses, which would be indicative of the need for improved maintenance practices.

F. ANNUAL MAINTENANCE COSTS

An estimate of the annual maintenance costs under a Preventive Maintenance Program should be presented. The format required in preparing a Budget Request should be used.

G. PREVENTIVE MAINTENANCE PLAN

Maintenance Issues

The maintenance issues addressed in preparing the Maintenance Plan should also be addressed in the Preventive Maintenance Plan, which are:

1. Eliminating sediment sources;
2. Reducing deterioration of channel lining; and
3. Minimizing seepage losses.

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 Program in addressing these issues should be presented.

Preventive Maintenance Activities

A summary of 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 program for project staff to provide technical assistance to Water Users Groups to improve their maintenance practices on the tertiary channels.

Preventive Maintenance Requirements

A summary of 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 Program.

WATER MANAGEMENT SYNTHESIS PROJECT REPORTS

WMS 1 Irrigation Projects Document Review

Executive Summary
Appendix A: The Indian Subcontinent
Appendix B: East Asia
Appendix C: Near East and Africa
Appendix D: Central and South America

WMS 2 Nepal/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 3 Bangladesh/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 4 Pakistan/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 5 Thailand/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 6 India/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 7 General Asian Overview

WMS 8 Command Area Development Authorities for Improved Water Management

WMS 9 Senegal/USAID: Project Review for Bakel Small Irrigated Perimeters Project No. 685-0208

WMS 10 Sri Lanka/USAID: Evaluation Review of the Water Management Project No. 383-0057

WMS 11 Sri Lanka/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 12 Ecuador/USAID: Irrigation Sector Review

WMS 13 Maintenance Plan for the Lam Nam Oon Irrigation System in Northeast Thailand

WMS 14 Peru/USAID: Irrigation Development Options and Investment Strategies for the 1980's

WMS 15 Diagnostic Analysis of Five Deep Tubewell Irrigation Systems in Joydebpur, Bangladesh

WMS 16 System H of the Mahaweli Development Project, Sri Lanka: 1980 Diagnostic Analysis

WMS 17 Diagnostic Analysis of Farm Irrigation Systems on the Gambhiri Irrigation Project, Rajasthan, India: Volumes I-V

WMS 18 Diagnostic Analysis of Farm Irrigation in the Mahi-Kadana Irrigation Project, Gujarat, India

WMS 19 The Rajangana Irrigation Scheme, Sri Lanka: 1982 Diagnostic Analysis

WMS 20 System H of the Mahaweli Development Project, Sri Lanka: 1983 Diagnostic Analysis

WMS 21 Haiti/USAID: Evaluation of the Irrigation Component of the Integrated Agricultural Development Project No. 521-0078

WMS 22 Synthesis of Lessons Learned for Rapid Appraisal of Irrigation Strategies

WMS 23 Tanzania/USAID: Rapid Mini Appraisal of Irrigation Development Options and Investment Strategies

WMS 24 Tanzania/USAID: Assessment of Rift Valley Pilot Rice Project and Recommendations for Follow-On Activities

WMS 25 Interdisciplinary Diagnostic Analysis of a Work Plan for the Dahod Tank Irrigation Project, Madhya Pradesh, India

WMS 26 Prospects for Small-Scale Irrigation Development in the Sahel

WMS 27 Improving Policies and Programs for the Development of Small-Scale Irrigation Systems

WMS 28 Selected Alternatives for Irrigated Agricultural Development in Azua Valley, Dominican Republic

WMS 29 Evaluation of Project No. 519-0184, USAID/El Salvador, Office of Small-Scale Irrigation - Small Farm Irrigation Systems Project

WMS 30 Review of Irrigation Facilities, Operation and Maintenance for Jordan Valley Authority

WMS 31 Training Consultancy Report: Irrigation Management and Training Program

WMS 32 Small-Scale Development: Indonesia/USAID

WMS 33 Irrigation Systems Management Project Design Report: Sri Lanka

WMS 34 Community Participation and Local Organization for Small-Scale Irrigation

WMS 35 Irrigation Sector Strategy Review: USAID/India; with Appendices, Volumes I and II (3 volumes)

WMS 36 Irrigation Sector Assessment: USAID/Haiti

WMS 37 African Irrigation Overview: Summary; Main Report; An Annotated Bibliography (3 volumes)

WMS 38 Diagnostic Analysis of Sirsia Irrigation System, Nepal

WMS 39 Small-Scale Irrigation: Design Issues and Government Assisted Systems

WMS 40 Watering the Shamba: Current Public and Private Sector Activities for Small-Scale Irrigation Development

WMS 41 Strategies for Irrigation Development: Chad/USAID

WMS 42 Strategies for Irrigation Development: Egypt/USAID

WMS 43 Rapid Appraisal of Nepal Irrigation Systems

WMS 44 Direction, Inducement, and Schemes: Investment Strategies for Small-Scale Irrigation Systems

WMS 45 Post 1987 Strategy for Irrigation: Pakistan/USAID

WMS 46 Irrigation Rehab: User's Manual

WMS 47 Relay Adapter Card: User's Manual

WMS 48 Small-Scale and Smallholder Irrigation in Zimbabwe: Analysis of Opportunities for Improvement

WMS 49 Design Guidance for Shebelli Water Management Project (USAID Project No. 649-0129) Somalia/USAID

WMS 50 Farmer Irrigation Participation Project in Lam Chamuak, Thailand: Initiation Report

WMS 51 Pre-Feasibility Study of Irrigation Development in Mauritania: Mauritania/USAID

WMS 52 Command Water Management - Punjab Pre-Rehabilitation Diagnostic Analysis of the Niazbeg Subproject

WMS 53 Pre-Rehabilitation Diagnostic Study of Sehra Irrigation System, Sind, Pakistan

WMS 54 Framework for the Management Plan: Niazbeg Subproject Area

WMS 55 Framework for the Management Plan: Sehra Subproject Area

WMS 56 Review of Jordan Valley Authority Irrigation Facilities

WMS 57 Diagnostic Analysis of Parakrama Samudra Scheme, Sri Lanka: 1985 Yala Discipline Report

WMS 58 Diagnostic Analysis of Giritale Scheme, Sri Lanka: 1985 Yala Discipline Report

WMS 59 Diagnostic Analysis of Minneriya Scheme, Sri Lanka: 1986 Yala Discipline Report

WMS 60 Diagnostic Analysis of Kaudulla Scheme, Sri Lanka: 1986 Yala Discipline Report

WMS 61 Diagnostic Analysis of Four Irrigation Schemes in Polonnaruwa District, Sri Lanka: Interdisciplinary Analysis

WMS 62 Workshops for Developing Policy and Strategy for Nationwide Irrigation and Management Training. USAID/India

WMS 63 Research on Irrigation in Africa

WMS 64 Irrigation Rehab: Africa Version

WMS 65 Revised Management Plan for the Warsak Lift Canal, Command Water Management Project, Northwest Frontier Province, Pakistan

WMS 66 Small-Scale Irrigation--A Foundation for Rural Growth in Zimbabwe

WMS 67 Variations in Irrigation Management Intensity: Farmer-Managed Hill Irrigation Systems in Nepal

WMS 68 Experience with Small-Scale Sprinkler System Development in Guatemala: An Evaluation of Program Benefits

WMS 69 Linking Main and Farm Irrigation Systems in Order to Control Water (5 volumes)

WMS 70 Integrating Strategies for Improving Irrigation System Design and Management

WMS 71 The USU Unit Command Area Model

WMS 72 Development of a Branching Canal Network Hydraulic Model

WMS 73 User's Manual for the FORTRAN Version of the USU Main System Hydraulic Model

WMS 74 Hydraulic Modeling Applications in Main System Management

WMS 75 User's Manual for the Pascal Version of the USU Main System Hydraulic Model

WMS 76 Formulation and Evaluation of the USU Main System Allocation Model

WMS 77 Irrigated Land Use and Irrigation Distribution Systems for Four Schemes in the Polonnaruwa District of Sri Lanka

WMS 78 Classification of Gravity Irrigation Systems and their Operation

WMS 79 Development and Management of Small Marais

WMS 80 Baskets of Stones: Government Assistance and Development of Local Irrigation in a District of Northern Sumatra

WMS 81 Implementing the Irrigation Maintenance and Operations (M & O) Learning Process Regionally or Nationally

WMS 82 Handbook of Improved Irrigation Project Operations Practices for the Kingdom of Thailand

WMS 83 Handbook of Improved Irrigation Project Maintenance Practices for the Kingdom of Thailand

WMS 84 USU Irrigation Main System Hydraulic Model: Replication of Modeling Capability in Other Countries

WMS 85 Development of the Centre International de l'Irrigation

WMS 86 Forum on the Performance of Irrigated Agriculture in Africa: Papers and Proceedings

WMS 87 Niger Irrigation Scheme Case Studies (English & French)

WMS 88 Irrigation Management for Development

WMS 89 Bureaucratic and Farmer Participation in Irrigation Development

WMS 90 Irrigation System Management: An Interdisciplinary Synthesis of Water Management Studies

WMS 91 Assessment Report: Maharashtra Irrigation Program. USAID/India

WMS 92 Irrigation System Operation Intensity and Relative Water Supply: The Asian Case

WMS 93 Methodologies for Interdisciplinary Diagnosis of Irrigation Systems

WMS 94 Management-Focused Improvement of Irrigated Agriculture

WMS 95 Diagnostic Analysis for Improving the Management of Irrigation Systems