REPUBLIC OF YEMEN

MINISTRY OF AGRICULTURE AND IRRIGATION

IRRIGATION IMPROVEMENT PROJECT

(IDA Credit No. 3412 – YEM)

Main Technical Assistance Package for IIP

WORKING PAPER 26

Options for Improving Zabid Main Canals

December 2003

ARCADIS EUROCONSULT

IN ASSOCIATION WITH

Halcrow

PAN YEMEN CONSULT

YEMENI ENGINEERING GROUP

CONTENTS

LIST OF APPENDICES

ABBREVIATIONS, ACRONYMS

IIP	Irrigation Improvement Project
iSIS	Hydro-dynamic modelling software
MCM	Million Cubic Metres
PIU	Project Implementation Unit
PMU	Project Management Unit
TDA	Tihama Development Authority of MAI
ToR	Terms of Reference

GLOSSARY

Term	Explanation
Bed load	Sediment transported along a channel by movement along the bed. Bed load tends to settle immediately there is a reduction in the sediment transport capacity of the water
Command	The difference in water level between a canal and the field necessary for proper irrigation at the required flow
Offtake	A structure where a branch canal joins a larger canal (also called turnout)
Reach	A length of canal between two main structures
Regime	The naturally overall stable condition of a channel
Suspended load	Sediment transported along a channel in suspension in the water. Suspended load takes time to settle out

WORKING PAPERS

WP 1	Water Management in Wadi Tuban & Wadi Zabid	–	Alan Clark
WP 2	Concept Paper Management Information Systems	–	Thomas R. E. Chidley
WP 3	Training Report No.1 – Orientation Workshops	–	Olaf Verheijen
WP 4	Procedure Manual on Participatory Irrigation Management	–	Olaf Verheijen
WP 5	Concept Paper for Flood Warning System	–	John Windebank
WP 6	Hydrological Analysis	–	David T. Plinston
WP 7	Community Awareness Campaigns	–	Darryl Kuhnle
WP 8	Gates Assessment – Interim Report	–	David A. R. Wood
WP 9	Initial Roads Study	–	Abbas A. Abu Taleb
WP 10	Training Report 2	–	Olaf Verheijen
WP 11	Training Report 3	–	Olaf Verheijen
WP 12	Issue Paper on PIM	– –	Wicher Boissevain Olaf Verheijen
WP 13	Irrigation Management (First Mission Report)	–	Wicher Boissevain
WP 14	Hydrological Analysis-Interim Report 2	– –	David Plinston Abdul-Aziz Al-Ariki
WP 15	Progress Report MIS-GIS	– – –	Reint-Jan de Blois Md. Hodish Abdulrahman Mujahed
WP 16	Training Report 4	–	Olaf Verheijen
WP 17	Mission Report Information Analyst	–	Tom Chidley
WP 18	Output Communication Specialists	– –	Christina van Schoot Abdu Ghalib Alyousufi
WP 19	Construction Supervision	–	René van Douveren
WP 20	GIS Manual	– – –	Inga Rasing Abdulrahman Mujahed Md. Hodish
WP 21	WUA Contracts - Manual of Procedures	–	Wicher Boissevain
WP 22	Concept Paper for Spate Management Model	–	Khaled El-Askari
WP 23	Second Output Communication Specialists	– –	Christina van Schoot Abdu Ghalib Alyousufi
WP 24	Training Report 5 - WUA Training Programme and Selection of Training Providers	–	Olaf Verheijen
WP 25	Hydrological Analysis - Final Report	–	David Plinston

1 EXECUTIVE SUMMARY

1.1 EXISTING PROBLEMS

The problems in the Wadi Zabid main canals are classified into two types, relative and absolute.

Relative problems are those that cannot be solved in isolation with others, as solution of one may increase the severity of other. The relative problems are interlinked sedimentation and command problems. These problems lead to several adverse effects that prevent the proper operation. The canals slopes are flatter than the wadi slope. As the sediment-laden water enters the canal; the sediments start depositing after the head regulator. This reduces the intake capacity of the headworks. Also the deposited sediment has reduced the relative heights of banks so the risk of overtopping has increased

The farmlands are rising at up to 2cm/year, depending on receipt of sediment-laden flood water. This progressively worsens the command problem and irrigation of many fields is not possible without raising the water level in the main canals. Farmers make either temporary embankments across the canal bed or block the drop structures with stones and trash to raise the water level.

The absolute problems are those that can be solved individually. These are related to vegetation growths in the canals, damages to drop structures and bank erosion due to rainwater and overflows from the adjacent field. This paper concentrates on the options for reducing the relative problems. Similar problems have been observed on most of the modernised canals so the solutions will tend to be similar, but subject to adjustment for the local situation.

1.2 CAUSES

The root causes of the relative problems are inappropriate design assumptions. The canal bed slopes are very flat, of the order of 0.03% to 0.04%, resulting in velocities too low to transport the incoming sediment. It appears that the design assumption is based on non-erosive velocities, suitable for relatively clean water. Similarly, in the design of offtakes, it has been assumed that the canals operate at their design full supply levels and all the offtakes draw their share. Cross regulation arrangements have not been provided to enable the farmers to control main canal water levels and divert water during part flow conditions. They have consequently found it necessary to build bunds and other obstructions within the main canals. The progressive rise in field levels due to sedimentation does not appear to have been provided for during the design of the canal system.

The sediment deposition in the canals is made worse by the diversion structure design. Although sluices are provided at the headworks for sediment exclusion; however, both the experience and the model tests show that the design of these sluices is unsatisfactory. The present way of operation of these sluices when canals are taking in water increases the entry of sediments into the canals. However, the value that farmers place on irrigation Water means that the sluices are rarely operated and this has worsened the accretion of sediment upstream of the headworks. Options for improving the diversion structures have been studied separately using physical model testing. They are not discussed in detail here.

1.3 REMODELLING OPTIONS

The objective of this paper is to identify possible options for improving main canal operation although full correction of the identified problems may not be physically or financially feasible. The problems for head reaches and other reaches should be treated separately since any attempt to raise water levels in the head reach may have a negative effect on the inflow at the headworks. In other canal reaches raising water levels does not adversely affect the flow because of the drop structures.

The Project Preparation Report suggested restoration the original design profiles. This option does not address the weaknesses of the original design and the current sediment problems will re-emerge. The command problem may be made temporarily worse in some locations since lower bed levels result in lower water levels.

The options to reduce the sediment problem for the head reach of each canal are:

1. Reinstate and maintain the gravel trap provided in the original designs.
2. Steepen the slope in the reach in order to spread the gravel deposit along the reach. This may involve:
   (a) raising the diversion weir;
   (b) reducing the drop at the end of the reach (which will worsen any command problems); or
   (c) preventing any irrigation from reach.
3. Ensure that suitable equipment is available for the removal of deposited coarse material during the irrigation period.

The options to reduce the command problems in the head reach are:

4. Raise he diversion weir;
5. Use / construct an alternative intake further upstream for the command area of the head reach;
6. Provide control structures to effectively regulate the canal level (this will encourage sediment deposition); and
7. Excavate material to lower the highest land.

Options for other reaches are more simple and comprise (2a), (2b), (6) and (7) combined with reducing the water level drop at the structure at the upstream end of each reach to raise water levels within the reach.

1.4 COSTS

Approximate costs have been estimated for selected combinations of options. These indicate that expenditure of between US$ 50,000 and US$ 150,000 per kilometre of canal may be needed, depending on the extent of existing problems and the solutions that are appropriate. Most options involve raising of canal banks and/or construction of new canals which will require land, which forms a significant part of the cost. Donation of this land may be an acceptable form of beneficiary contribution.

2 INTRODUCTION

2.1 OVERVIEW

Conveyance of irrigation water to farmers' fields is usually carried out through a network of canals and associated flow control system. The irrigation canal networks should be designed and operated in such a way that:

- Needed flows are passed at the required water level
- No overall erosion of canal banks or bottom occurs
- The sediment that enters the canal is not settled but is transported to the farmland through the off takes.

Further the canals and associated structures should be robust enough that they function satisfactorily over a considerable period of time with minimum of maintenance. This is important in new concept of participatory irrigation, which aims at the operation and maintenance transfer of large irrigation schemes to farmers' organisations. Farmers, being the ultimate operators of their systems, should also be consulted at all stages of the design process.

Experience shows that in many irrigation projects, irrigation networks fail to conform to the characteristics mentioned above and result in numerous difficulties being faced by the operating authorities (government agencies or farmers' organisations). Even more severe problems are faced at the Spate Irrigation Schemes due to highly fluctuating discharges over a short period of time sometimes a few hours and heavy sediment loads carried by floodwaters.

Irrigation Improvement Project - Phase 1, aims at the improvement and rehabilitation of spate irrigation networks in Wadi Tuban and Wadi Zabid. In addition to the improvement of civil infrastructure, farmers are to be organised and handed over the operation and maintenance responsibility of the infrastructure serving their respective command areas.

2.2 OBJECTIVES AND METHODOLOGY

The core objective of this study is to analyse the possible options for the canal remodelling in Wadi Zabid and to choose those that ensure the proper operation with minimum maintenance requirements. The core objective is to be attained through a methodology that includes:

- Study of the existing situation through field visits to headwork, canals and ancillary structures.
- Identifying the main problems and the causes of these problems.
- Preparing a list of all possible solutions and carrying out a qualitative analysis of these considering their conformation to operational rules, ease of construction and economic feasibility and selecting the appropriate solutions for quantitative analysis.
- The analysis of the selected options through a preliminary outline design adequate for relative cost estimates.
- To make recommendations for the appropriate solutions for canal remodelling for the range of conditions found in the field.

For background on sediment data, this paper uses the information presented in the report "Wadi Zabid Diversion Structures - Field Performance Measurements". HR Wallingford report No. OD 73 dated April 1986.

3 PROBLEM IDENTIFICATION

3.1 OVERVIEW

The irrigation infrastructure in Wadi Zabid was modernised in 1970s. The modernised system was designed to comprises of 5 diversion weirs, diverting wadi flows to 9 main canals that through further subdivisions make 16 modern canals serving some 15,000 ha of land.

The main canals are facing numerous problems that hamper the smooth operation of the networks. Many of these are consequences of assumptions in the design such as limitations on permissible velocities and assumption of turnout operations at the design full supply levels. These problems need remedial measures to ensure that better operational conditions are restored.

3.2 FIELD WORK

The evaluation of the existing situation has been made on the basis of the site visits to the diversion weirs 1, 2 and 3 and the originating canals. Drive and walkthrough surveys have been made along the canals serving the command areas along the right and the left bank of the main wadi. The strategic structures including the drops, main bifurcation structures and turnout have been observed in detail. Owing to the fact that networks associated with each diversion in the wadi system have general similarities, it is considered that the major problems faced should be of similar nature and so should be the solutions.

Further appreciation of field conditions was gained through discussions with the PIU staff accompanying during the site visits and at Zabid Project Office.

3.3 SEDIMENTATION IN CANALS

Slopes of modernised canals in the project area are much flatter than the wadi slopes. As the sediment-laden water enters the canal head reach, it starts shedding the sediments due to reduction in the transport capacity. The result is longitudinal slope of the canal is redefined as it tries to enhance its transport capacity to match the sediment input. The rise in the bed level of the canals visited is observed at the start of every reach as there is a drop structure at the end of each reach, which controls the water levels and the bed levels at the downstream end of each reach. The comparison between the designed existing profiles of Ebri-Gerhazi canal in its first reach is given on Drawing 1 in Appendix B. The head reach of each canal is particularly affected. This sedimentation has resulted in the following main problems.

3.3.1 REDUCTION IN INTAKE CAPACITY AT HEAD REGULATOR

Coarse sediment deposition in the head reach results in significant reduction of the water diverted to the canal, as due to rise in water level in canal the working head is reduced at the head regulator. The head regulators are meant to divert the entire wadi flow up to a certain limit before it starts spilling of the main weir. But as the working head is reduced, water level rises upstream of the head regulator so much so that it rises above the main weir level. This hampers the flow diversion according to the water allocation rules established. In the worst case the sediment deposition in the canal blocks the head regulator.

3.3.2 CHOKING OF TURNOUTS

Most of the turnouts are pipe outlets provided with vertical sliding gates to facilitate flow regulation. In the start of every reach in general and in the first reach in particular, heavy deposits of sediment has completely blocked the turnouts, leaving it impossible for the farmers to have any diversion through these structures. Photograph 1 in Appendix A illustrates the chocking problem.

3.3.3 REDUCTION IN CARRYING CAPACITY

The sediment deposition raises the canal bed above the design levels thus reducing the cross sectional area and loss in the provided free board. Due to the raised beds the canals appear to be at the risk of overtopping in the initial reaches at an inflow much less than the design discharge.

3.3.4 RISING OF FIELDS

The fine sediment entering the supply canals is deposited on the fields. Due to the perception that the transported sediments add to the fertility of the soils, farmers make efforts to get as much of it as possible into their fields. However, the sediment will arrive, whether wanted or not, because it is suspended in the flood water. The consequence is the field levels keep on rising, estimated at a rate of up to 2cm per year, making worse the command problems that are discussed in more detail in the subsequent section. The rise in levels is largest in the areas that receive most flood water, which tend to be adjacent to the upstream parts of the canal systems. Future sediment deposition and the rise in field level must be accounted for while determining the required water levels at the offtakes.

3.4 COMMAND PROBLEMS

It has been observed during the field studies that in many locations the levels of the fields are higher than the bed levels of the adjacent supply canals and command is not possible without backing up of water. The adverse affects of this problem are described below.

3.4.1 DAMAGE TO DROP STRUCTURES

Farmers have found it necessary to raise the water level at the drop structures to generate command required for irrigating their fields. They do so by putting sand bags, weeds, banana stems and also the stones they remove from the protections downstream. When the dam is removed or washed out, the stones hit the chute and the baffle blocks provided in the energy dissipation structures and have destroyed some of those.

3.4.2 SEDIMENTATION

Since the backwater effect caused by the checks created by the farmers retards the velocity, it increase the rate of sedimentation in the canals already facing this problem due to low design velocities. This causes loss in flow capacity. The other problems associated with sedimentation of canals have already been elaborated in section 3.3.

3.4.3 BANK EROSION AND WEAKENING

It has been noticed during the walkthrough survey along the Mawi and Mawi-Yusufi canals that severe erosion and weakening of canal banks has taken place, more prominently along the left bank. Moreover deep rain cuts are visible at several places along both the banks. The erosion is more severe immediately downstream of the drop structures. It appears some stone protection was provided at structures but has been removed by the farmers as they use the stones for checking the water level at the drop structures.

The checking of water at drops and the reduction in relative bank height at the start of reach increases the risk of overtopping and thus may cause further damage to embankments.

3.5 MAINTENANCE AND MANAGEMENT PROBLEMS

3.5.1 VEGETATION GROWTH

Tall standing plants are seen all over the banks and at places on the bed of the supply canals of diversion structure 3. Most of these plants are Sorghum and it appears the farmers have planted those as the canals beds have been ploughed and planting is in regular rows. According to PIU staff, these crops are not sown until after the irrigation period and harvested down to the root level before the next flood season. However, the practice may cause damage to the embankments due to softening because of cultivation.

Unlike the canals of diversion weir 3, heavy growth of wild vegetation has been observed along the banks of Mansuri –Rayan and Mansuri canals. This vegetation includes bushes and tall trees with significant girth. This tall vegetation further retards the flow, increases the flow depth and may result in overtopping of the banks.

3.5.2 IRRIGATION REJECTION FLOWS

The water management practices in the Wadi Zabid follow a first riparian served first rule. After diversion from the supply canals, there are no or very short length secondary canals. Water is directly applied to the fields in quantities of up to 40cm depth between the high bunds surrounding the fields. Fields are in the form of terraces that allow water to spill into the next field once the demand is satisfied. Eventually, if all fields have been irrigated then water is rejected into a canal, damaging its embankment. Several cuts are visible along the Mansuri canal deeply incised in the embankment and some of them more than 2m x 2m in area. Heavy rainfall can also collect on access tracks and then cause gulleying where it spills from low points.

3.6 CAUSES OF PROBLEMS

The main reason for most of the problems discussed above is the original design. The review and analysis of the design drawings has revealed that the design was based on assumptions that were inappropriate. The causes are further elaborated in the subsequent sections.

3.6.1 SEDIMENT EJECTION AT THE HEADWORKS

The sediment control measures at the headworks provided in the modernisation of the irrigation infrastructure include sluices to exclude the bed load. However, both experience with the diversion structures and model testing have shown the design to be unsatisfactory. If the sediment sluices are operated while the canals are drawing water then sediment entry into the canals is increased. Closure of headworks gates during flushing is time-consuming and subject to the farmers agreeing to the temporary loss of water.

In addition the design profile of Ebri-Gerhazi canal shows the existence of a sediment settling basin at the head. This cannot be located on the site anymore as it is now buried under sediment in the absence of sufficient cleaning. However, sediment removal using either sluicing at the head regulator or flushing of a sediment basin, if such arrangement were constructed requires water that farmers consider to be a loss.

3.6.2 ASSUMPTIONS FOR HYDRAULIC DESIGN

The velocity of water in open channels is function of the hydraulic slope and the resistance to flow, termed as Manning's n, which in turn dictates the sediment transport capacity of the canal. A review of the design profiles of Ebri-Gerhazi and Mawi-Yusufi canals shows relatively flat bed slopes of only 0.04% and 0.03% respectively and Manning's n of 0.02, which is unrealistically low for an earth channel. The result is design velocities too low to transport the incoming sediment load. It appears that the design assumption is based on non-erosive velocities appropriate for relatively clean water. The design bed slopes are flatter than the terrain slopes and the additional head is dissipated through drop structures located at the end of each reach with drop height varying between 2m to 5m.

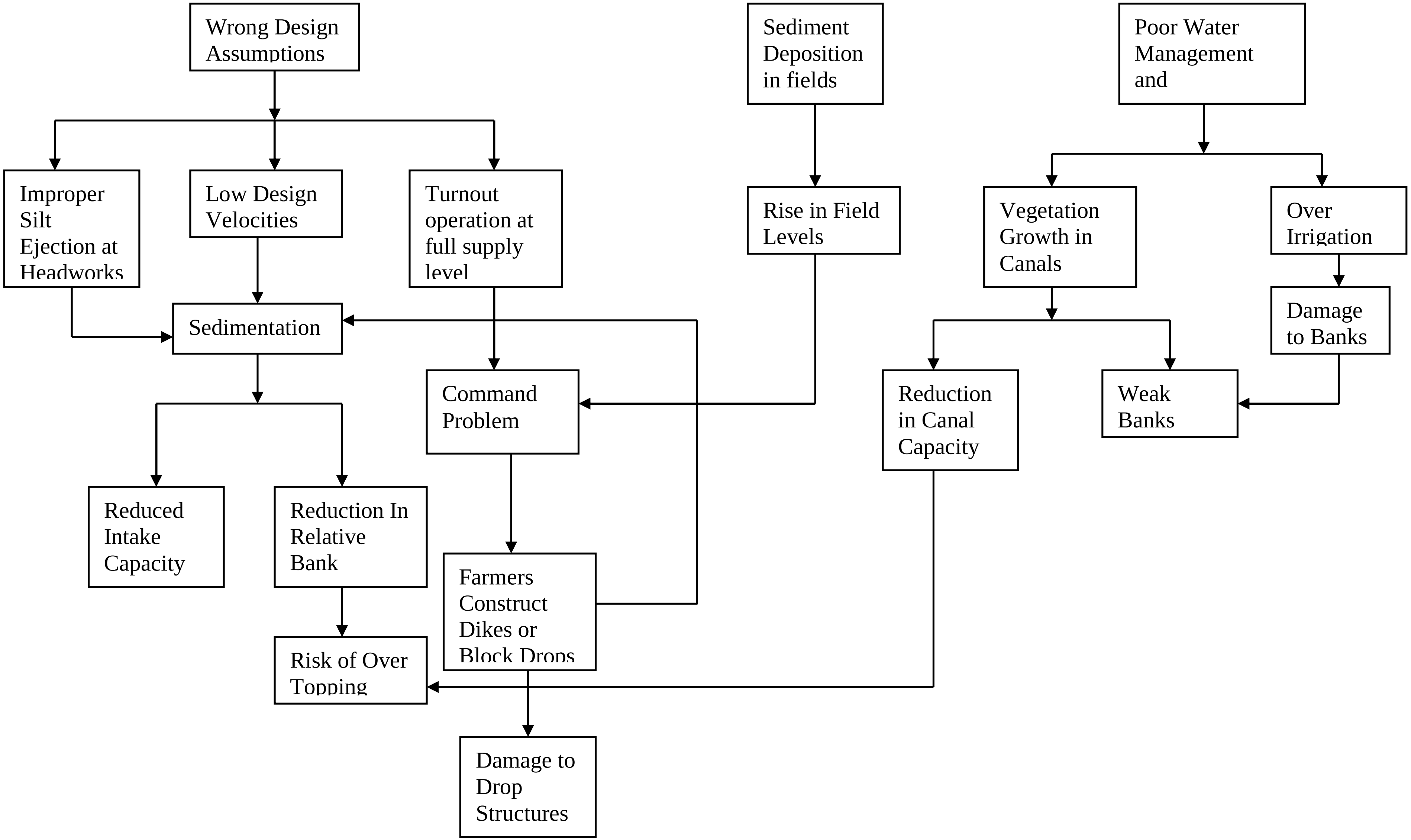
3.6.3 ASSUMPTIONS FOR THE DESIGN OF TURNOUTS

The design appears to assume that the main canal flows at design full supply level and each offtake takes its share of flow. In reality, spate irrigation canals seldom flow at the design discharge and therefore achievement of full supply level is infrequent. Cross regulation arrangements that would enable the farmers to divert sufficient water during part flow conditions were not provided in the original design.

Further, no allowance appears to have been made for the continuing rise in field levels due to sediment deposition. The water level in the canal even at full supply level is not sufficiently high to irrigate the land at most of the offtakes unless further raised by constructing small temporary embankments across the canal or by putting stones, trash and soil at the drop structures.

A flow diagram of the causes, problems and adverse affects is given in Figure 3-1.

FIGURE 3-1


Wrong Design Assumptions
Sediment Deposition in fields
Poor Water Management and
Improper Silt Ejection at Headworks
Low Design Velocities
Turnout operation at full supply level
Rise in Field Levels
Vegetation Growth in Canals
Over Irrigation
Damage to Banks
Sedimentation
Command Problem
Reduction in Canal Capacity
Weak Banks
Reduced Intake Capacity
Reduction In Relative Bank
Farmers Construct Dikes or Block Drops
Risk of Over Topping
Damage to Drop Structures

4 REMODELLING OPTIONS

4.1 CLASSIFICATION OF PROBLEMS

The identified problems can be classified into two general groups that are relative and absolute in terms of remedial options. Sedimentation and command problems fall in the former class, since they are interlinked and possible solutions for one problem would add to the severity of the other. Therefore they need solutions that are relative and have no overall adverse effects. This means that solutions may not eradicate problems completely, but tend to optimise the situation towards the core objective of better operation with reduced maintenance. The relative problems are:

1A Reduced intake capacity at headworks

1B Reduced capacity of canals

1C Choking / burial of turnouts by deposited sediment

1D Insufficient water level to irrigate fields

1E Lack of cross regulation provisions to provide adequate water levels in canals

The second group of problems include bank weakening, damage to drop structures, lack of cleaning and canal flooding from fields. These problems can be dealt within individual capacity and further some of these would automatically be eradicated while dealing with group one problems. These absolute problems are:

2A Weak and eroded canal banks

2B Heavy vegetation growth

2C Damaged drop structures

2D Rain and irrigation cuts in canal banks

A flow diagram of options for solutions of the main problems along with constraints is presented in Figure 4-1.

4.2 SOLUTIONS FOR THE RELATIVE PROBLEMS

4.2.1 PROJECT PREPARATION REPORT PROPOSALS

The project preparation report suggests rehabilitation by removing the deposited sediments to restore the conditions as per original design. A few cross regulators were proposed. Re-excavation would allow the flow of water as for a limited period of the time but this solution does not address the underlying problems.

- The sediment deposition is a result of high incoming sediment loads and low design velocities, therefore the canals will quickly fill with sediments again.
- The command problem is very severe and will not be addressed by this option at all. The restoration of the original bed profiles would further worsen this problem by lowering canal water levels.

Among this group, problem 1A is specific to the head reach of the canals and remainder of the problems are common for most the reaches. Therefore, a distinction needs to be made between the head reach and rest of the reaches while considering the remodelling options.

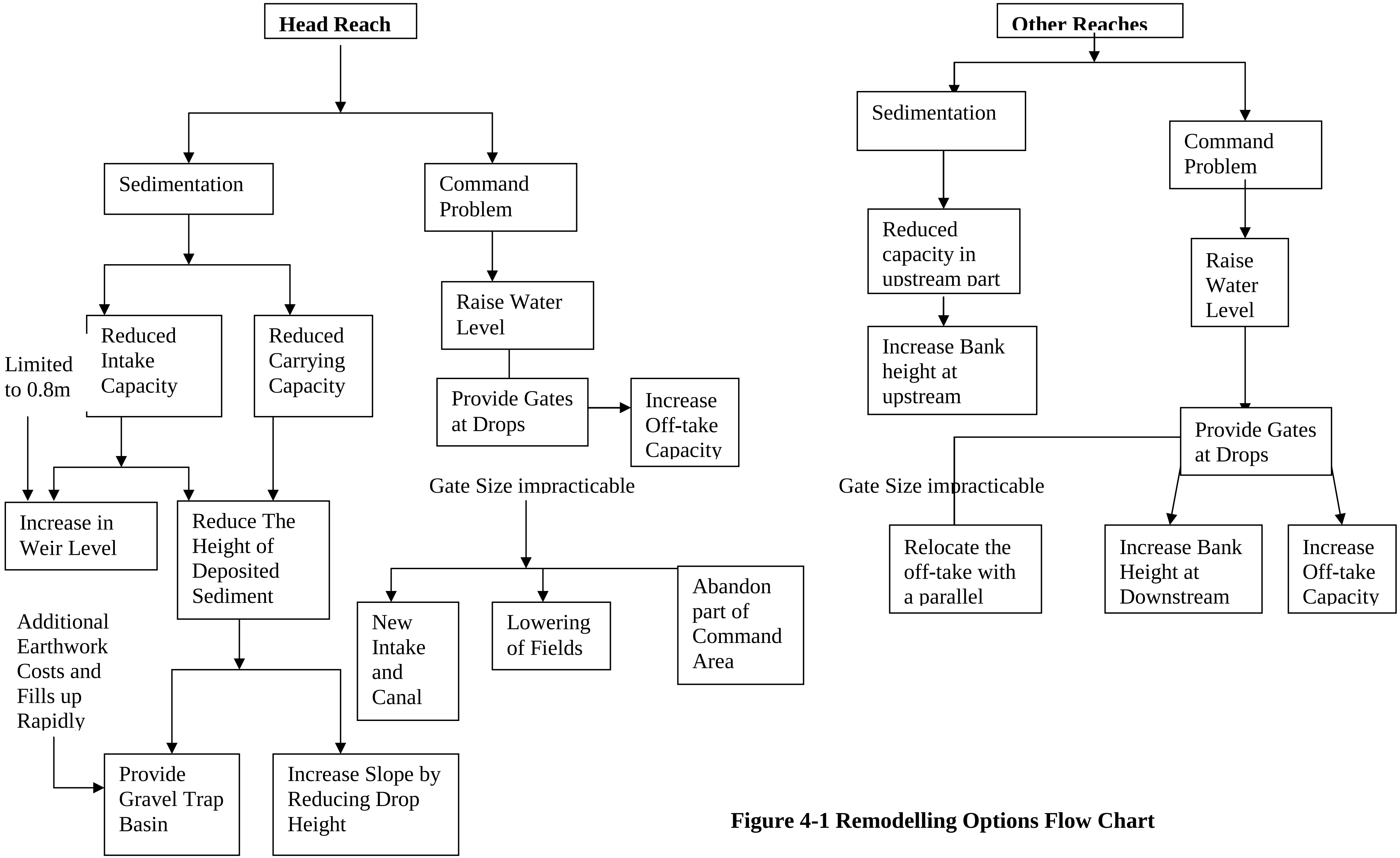


Figure 4-1 Remodelling Options Flow Chart

4.3 HEAD REACH

4.3.1 SEDIMENT DEPOSITION

In addition to the general problem of command, the head reaches are subject to more intense sedimentation as the gravel bed load entering through the head regulator start depositing downstream of it. A large shoal of gravel is visible at the start of all the canals visited. In November 2003 the problem was most severe on the Mawi-Yusufi canal where the head regulator gates were almost completely blocked. The coarse sediment load, particularly the gravel bed load, tends to be deposited in the head reach as the transport capacity of the canals can not match the input, being flatter than the wadi slopes. Finer sediment will also be deposited in the head reach if velocities are reduced by any checking of the flow to raise water levels for irrigation (see section 4.2.3). Ideally, velocities should be maintained in any reach to avoid deposition of material that would otherwise be transported through the canal system. Therefore some steepening of the head reach slope may need to be provided to ensure sediment transport capacity similar to any improvements in reaches further downstream.

Options for improved sediment exclusion at the headworks have been studied by model tests undertaken in UK. The main features of the proposed solution are a sediment barrier in front of the head regulator and raising of the weir crest by 80cm to ensure that the flow depth over the barrier is at least as much as over the sill of the head regulator under the current condition. The modification is expected to reduce, but not eliminate, bed load entry into the canals. The long-term effectiveness of the proposed intervention will depend upon removal of material from upstream of the barrier, either by flushing through the sluiceways or equipment. It is planned to construct the changes at weir 3 and possibly one other weir, possibly weir 2.

Apart from improved exclusion of bed load, the only solution to the formation of the gravel shoal is periodic cleaning of the head reaches. The gravel may be allowed to settle in a basin, provided at the beginning of the canal or by allowing it to spread over the entire length of the reach through increasing the slope of the canal, or both. For both of the options, periodic cleaning to maintain full flow capacity may mean several times during one flood season.

It is understood that basins were provided as part of the original designs, but were not cleaned sufficiently frequently and are no longer visible. The provision of a basin, provided it is cleaned sufficiently frequently, would reduce the effect of a gravel shoal impeding the flow through the head regulators. Some material that would otherwise pass down the canal system would be trapped but this will be small. The basin should be self-draining to eliminate ponding and facilitate cleaning during low flows. However, given the relatively flat slopes already existing, there is limited potential to provide self draining basins. Therefore, it will be necessary to procure equipment such as long reach backhoe excavators or draglines capable of cleaning the basin under water instead of using bulldozers or loaders which need relatively dry conditions to operate effectively and safely. The use of trucks to carry excavated material away would avoid the build-up of material on the banks of the canal.

Spreading of the gravel along the length of the reach requires an increase in slope. The increase in weir level would help achieve this to a limited extent. However, the slope and velocity required to transport gravel are greater than can be provided, particularly where there are command problems. Overall, the same quality of material will need to be removed per year.

The overall requirements for eliminating the reduction in flow in the head reach are: (a) flushing of gravel deposits from in front of the head regulator whenever it is not the canal’s turn to receive water (if not, then the area will need to be cleared using equipment) and (b) timely removal of gravel deposited in the head reach, which is likely to be several times during a flood season. The frequency of gravel removal will depend on whether or not a basin is provided. The frequency of cleaning can be reduced by either providing a basin or steepening the head reach, but the overall quantity of material to be removed each year will not change significantly.

4.3.2 COMMAND PROBLEMS

Command problems for the offtakes in the head reach are distinct from similar problems in rest of the reaches because any rise in canal water level directly reduces the inflow from the wadi through the head regulator. In addition, the rise of water level would retard the velocity and increase the deposition of sediment in the head reach. There are six basic options for improving command in the head reach.

1. Raising of main canal water level by providing gates at drop structure to create cross regulators. This formalises the arrangement currently used by some farmers. The main drawback of this option is that the increase in canal slope would be neutralised by backing up of water at the drop and thereby prevent improvement of the sedimentation problem.
2. Raising of the diversion weir to increase the available water level. However, if this rise is used to improve command then benefits of increased canal flow and sediment transport will be reduced.
3. Lowering of high fields by excavation. The option is practicable if the excavated material is needed for earth filling in raising banks, in head and other reaches. The volume of excavated material for 1m lowering is 10,000m³/ha. So a balance has to be achieved between the materials required for filling and material to be excavated to determine the area that can be economically brought under command.
4. Provision of a new intake structure, upstream of existing weir and a new canal to irrigate the higher fields in the headreach. The major constraint for this option is land acquisition for right of way of the new canal. Alternatively, irrigate the high land from an existing canal or fields at a higher elevation. This would effectively make the farmers “tail-enders” on an upstream canal
5. Abandoning the higher part of the command area for spate irrigation (irrigation from groundwater remains an option). Since these fields are in the upstream reaches of the canals where the farmers have the first water right as per allocation rules, termination of irrigation of these areas would need to be agreed by the farmers.
6. In some cases, the command problem and time to irrigate land can be reduced by the provision of additional offtake capacity (from the main canal into a secondary canal) in order to minimise the headloss at the off-take. This is especially important if the offtake has exclusive rights to available water until irrigation has been completed.

In some cases raising of water levels will not solve the command problems. For example for Gouhar offtake, located in the head reach of the Ebri-Gerhazi canal, the adjacent field level is 184.75m while the crest level at the drop downstream is 180.9m and the crest level of diversion weir 3 is 183.67m (levels refer to local datum). After allowance for head losses, this area cannot be served with the existing supply canals even if the diversion weir is raised. For such cases, the possible options are numbers 3, 4 and 5 above.

It should be appreciated that while it is possible to irrigate some upstream land with a low flow resulting from a small available head, this effectively deprives downstream users of their opportunity to receive water. The situation will progressively worsen in the future due to sediment deposition on fields and any proposed investments should aim to work satisfactory for the next 25 years. Solutions should remain viable for their economic life.

4.4 OTHER REACHES

The major problems in the other reaches include the sedimentation in the start of the reach reducing the cross sectional area and thus increasing the risk of overtopping at or near the peak discharge and the command problems.

4.4.1 SEDIMENTATION

Deposition of sediment at the start of every reach redefines the bed slope within the reach. The deposition modifies the bed slope to be steeper than the design slope which increases the overall velocity to facilitate transport of the remaining sediment. The actual bed slopes provide an indication of the regime slope appropriate to the sediment load in the canal. The consequence of the sediment deposition is to reduce the available channel depth due to the raising of the canal bed, thus reducing channel capacity.

The preferred option is to maintain the steeper slopes and raise the banks at the upstream side to prevent the risk of over topping. The higher water levels also ease the command problems.

A possible solution would be the removal of the deposited sediments and restore the designed cross section and slope, but the problem will re-emerge during the subsequent floods. The preferred option is to leave the deposited sediments and increase the cross sectional area of flow through raising the banks. This will need land acquisition, as the base width of embankment would increase at the outside.

A further consequence of the sediment deposition is that offtakes, particularly those in the upstream and middle parts of each reach, can become buried by the sediment.

4.4.2 COMMAND PROBLEMS

The command required to irrigate the fields is to be attained by raising the water level, relocating the offtakes to the upstream reach or a combination of both. The design water level is to be established first. This should be sum of existing field level; allowance for future rise in field level due to sediment deposition; head loss at field inlet; head loss along the secondary canal; head loss across the main offtake in supply canal. A general estimate of these maybe (for a plot situated at 500 metres along the secondary canal):

1. An allowance for future sedimentation at an approximate rate of 2cm/year for 25 years = 50cm
2. Depth of water on field = 35cm
3. Headloss across field inlet =15cm
4. Headloss along a 500m secondary canal at slope of 0.001m/m = 50cm
5. Headloss across main offtake (depends on required discharge and type and size of the offtake), allow = 30cm

This gives the design water level at the offtake in main canal to be 1.8m above the existing field level. There are two options in the event that the current water level is not high enough. These are to (a) move the offtake further upstream and construct a new or longer secondary canal; and (b) provide gates on the drop structure to raise the water level in the main canal. The appropriate solution can be determined from the location of the existing offtake which will influence the relative costs of the two options. In some cases, the command problem and time to irrigate land can be reduced by the provision of additional offtake capacity to increase the flow and reduce the head loss.

4.4.3 PROVIDE CROSS REGULATORS

Gates can be added to the existing drop structures to create cross-regulator structures. The gate height would be that necessary to provide sufficient command under low flow conditions. Very high gates may be required to give sufficient command at some offtakes. However, an essential consideration for the cross regulators is to pass sufficient discharge when the gates are shut. A suggested safe value of this discharge would be the design discharge minus the sum of offtake capacity in the reach immediately upstream. This is because the flow can change more quickly than the gates can be operated and also floods mainly come in the night when no one may be present to operate the gates. It is probably necessary to raise both the top of the existing drop structures and the upstream canal banks at locations where gates are provided.

The structure is required to pass the entire flow, less any upstream abstractions, when gates are closed. The depth of water over the sharp crested weir will be:

$Q = 0.602 \times 2/3 \sqrt{(2g)} \times bh^{1.5}$

Where Q is flow, b is width of weir and h is depth on it. For a flow of $45m^3/s$ through an 8.5m wide structure the depth over the top of the gates would be 2m. The required height of wall relative to the weir crest is:

Wall Height = 1.5 (gate) + 2 (depth over gate) + 0.25 (free board) = 3.75m, or 2.25m above the top of the gate.

Several options are available for the cross-regulating gates at the drop structures such as radial gates and vertical slide gates and underflow or overshot gates. Radial gates require less operating effort but are usually more expensive than the vertical slide gates. Vertical undershot gates are the most economical option, provided with a spindle-operated lifting gear and placed in steel channels fabricated together. Vertical overshot gates would provide easier control of water levels but have greater potential for damage because the spindles would need to be longer and remain in the water during flood flows where they are likely to catch trash and create obstructions.

The operating effort of radial gates is less than for vertical gates. However, the existing radial gates at other structures have a maximum width of 5m which represents the upper limit without making the gates much stronger and heavier. Radial gates are also more expensive than vertical gates. It is not attractive to provide two radial gates because there would be substantial cost in providing a central support. Therefore vertical gates are the only practical solution for structures wider than 5m and, for manual operation, the individual gate size should not exceed 1.5m square. A set of vertical gates will require substantial support. The lower parts of the gate frames can be anchored to the drop structure. The upper parts of the gate frames can be supported by a footbridge / operating platform structure.

4.4.4 NEW SECONDARY CANALS

The alternative option to providing a high gate is to relocate the offtake to before the next drop structure upstream where a much lower gate would be sufficient. This is a hydraulically more satisfactory solution but would require land for right of way of the parallel canal and associated costs of construction so a decision should be made on the basis of cost comparison.

4.4.5 INCREASED OFFTAKE CAPACITY

The existing offtakes are pipe culverts regulated by means of vertical slide gates. It may be necessary to increase their capacity. Box culverts with similar regulation arrangement will have larger flow capacity than pipes of the same diameter. The size of the culvert would depend upon the area to be irrigated and the head available. The maximum width should not exceed 1.5m to avoid the gate sizes wider than the height, causing a risk of jamming. In case for wider area requirement more than one cell should be provided. The discharge of the offtake is likely to be in the range of 10 l/s/ha to 100l/s/ha but needs to be determined in conjunction with the farmers on the basis of area to be irrigated and the target period for irrigation.

Considering a standard cell 1.2m wide and 1.2m high for a headloss of 30cm the discharge is:

$Q = 0.7\ A\ (2g\Delta h)^{1/2}$

$Q = 2.5m^3/s$

For an irrigation duty range of 20 l/s/ha to 100 l/s/ha, the offtake can irrigate 25 to 125ha. If irrigating 25ha the time required to attain a depth of 350mm (net) or 550mm (gross) will be about 15 hours and for 125 ha with similar depth the time is about 3 days.

Not all land suffers command problems and not all offtakes suffer capacity problems. The appropriate solution may involve retention of existing oftakes and canals to ser those areas where command is not a problem, and providing new offtakes and canals for land which is currently difficult to command. Such options would have to be considered for individual situations.

4.5 SOLUTIONS FOR ABSOLUTE PROBLEMS

The identified absolute problems are:

- Weak and vulnerable banks.
- Heavy vegetation growth
- Damaged drop structures
- Rain and Flood cuts

The solutions to these problems include:

- The vegetation of both types, sown crops and wild trees, would be removed during annual maintenance and the reconstruction.
- The repair of the damaged chute and baffle blocks would be made part of the construction drawings for transformation of drops into cross regulators while the provision of gates would reduce the risk of similar problems arising in the future.
- Further the downstream ripraps shall be rehabilitated with proper design matching the stone properties with the hydraulic parameters.
- The provision of gates at the drops would eliminate the need to check water there through temporary blockade using stones removed from downstream aprons.
- The repair of the minor rain cuts would be addressed with new strong embankments. However properly designed inlet structures would be required where flooding from fields has damaged the canals.

5 COSTS OF REMODELLING OPTIONS

5.1 INTRODUCTION

This section presents the analysis of the remodelling options presented in the previous section. The analysis is based on the costs of each option for head and the other reaches to address the major problems of sedimentation and command. Supporting design is also given where necessary. The detailed calculations are given Appendix C and sketches for remodelling options in Appendix B. The cost estimates only include the basic items of work. There is no provision for minor items or contingencies. The primary objective at this stage is to provide comparative costs for different options.

5.2 REMODELLING OPTIONS FOR HEAD REACHES

5.2.1 SEDIMENTATION

The major problem caused by sedimentation is the head reach is the reduction in intake capacity caused by deposition of coarse sediment in the head reach of the main canal. The options (which may be used in combination) to attain an improved condition are:

1. Provide a sediment basin or gravel trap into which the coarse sediment will be deposited without interfering with the flow.
2. Increase the slope and sediment transport capacity of the head reach by reducing the drop height at the end of the reach
3. Raise the diversion weir to increase the hydraulic slope (this may be combined with option 2.) The embankment height at the upstream end will have to be increased to eliminate the risk of overtopping.

Provision of Sediment Basin / Gravel Trap

It is understood that basins were provided in the original design, but were not cleaned sufficiently frequently. However, this remains a preferred option provided the cleaning is undertaken to ensure that the canal flow is not constricted.

The simplest form of gravel trap would be to deepen the first 100m of the head reach by one metre. The cost of constructing this will depend on the canal width and would be in the range of US$ 2,000 to US$ 5,000. This cost can be reduced if the excavation is carried out by equipment used for subsequent maintenance and re-excavation. The gravel trap may need to be re-excavated several times per year depending on the nature of the floods and amount of sediment transported.

A flushing arrangement for the basin would reduce maintenance costs but would require a concrete lined basin, control gates and a substantial amount of water to remove the gravel. The overall cost would be substantial and it is unlikely that the farmers would agree to this “loss” of water. Therefore flushing has not been studied further.

Increasing Canal Slope by Reducing the Drop Height

The slope and sediment transport capacity can be improved by reducing the height of the first drop. Irrigation of any adjacent land within adequate command can be maintained by providing gates on the lowered drop structure to temporarily raise the water level, although temporary checking of the water would increase the amount of sediment deposited. The gates would be opened to increase the hydraulic slope and velocity when irrigation is not being carried out in the upper reach. The benefit of the steepening option will depend on the amount the drop height is reduced and the reach length.

The costs to increase the slope by cutting the drop height would include:

- Sediment removal from the reach.
- Demolition costs
- Possible gates on the drop structure to regulate water levels, if needed
- Excavation of canal bed to the new design bed slope

Cost estimates have been made following assumptions

- The lowered canal bed width would be narrower than the existing to stay within the existing banks with side slopes 1 vertical : 1.5 horizontal
- Sediment depth at start is 2.0m above the canal design bed level tapering to 0m at the end of the reach
- Reduction of the drop height by 0.6m will approximately double the slope of the reach (depending on the length).
- Width of drop structure sill is 0.35m.

The cost of this option is estimated US$ 77,000/km (excluding any gates). Detailed cost estimates are given in Table 1 at the end of this section.

Higher Upstream Level Resulting from Increase in Weir Height

An increase in height of Weir 3 and possibly Weir 2 by 0.8m is under consideration, so at these locations the increase in slope can be achieved through a bed raised by 0.8m at the start of the reach. This alternative will help address command problems and maintain the full flow in the canal. The costs of modifying the canal to accommodate the higher potential water level and inflow would include:

- Sediment removal costs.
- Increase in embankment height at the upstream.
- Land acquisition due to increased base width of higher embankments.

The estimated costs are given in Table 1 at the end of this section. The cost estimate for canal remodelling with this option is US$ 66,000/km of canal but is possible only at those weirs where crest level will be raised (which is estimated to cost about US$ 60,000).

5.2.2 HEAD REACH COMMAND PROBLEMS

The options for solving the command problems include:

1. Raising the main canal level by providing gates on the drop structure at the end of the head reach.
2. Raising of the diversion weir.
3. Lowering of high fields.
4. Provision of a new intake and supply canal from further up the wadi, or irrigation from an existing canal or fields at a higher level.
5. Provision of additional offtake capacity where this is a constraint.

In the above list, option 4 is the most appropriate provided that the costs are acceptable and the land acquisition problem can be solved by the WUA. In some situations the option to exclude high land from surface irrigation may be the best overall solution. A cost estimate for option 4 is presented in Table 2 at the end of this section, based on assumptions:

- The canal is 1.5 km long, with initial 500m length in average cut of 4m, 500m in average cut of 2m and remaining 500m in average fill of 0.75m.
- The bottom width is3m, canal depth 1.5m, side slopes are 1.5H: 1V.

Total cost for a 1500 m new canal is estimated to be US$ 150,000. This estimate includes the cost of a simple gated head regulator to prevent excess flow from passing down the canal.

Table 5.1 Summary of Typical Costs– Head Reach

Description	Unit	Cost (US$)
Sedimentation Problems		
1- Removal of sediment	A typical 1km length	54,000
2- Excavation of gravel trap	Sum	4,500
3- By reducing drop height	Sum	15,500
4- By raising weir crest	A typical 1km length	28,500
Command Problems		
New Canal from upstream of weir	1500 m long canal	150,000

The above costs can be applied in isolation or combination. Other costs, such as for a new offtake, are similar to those in Table 5.2.

5.3 OTHER REACHES

5.3.1 SEDIMENTATION

Sedimentation in the canals is best addressed by increasing the canal slope. This involves raising the bank at the upstream end. The costs for the option include the earth filling for embankment rising and land acquisition to accommodate the greater width of raised banks. The cost estimates for the option are given in Table 3, Appendix B made on the assumption that bank raising is 1.5m at the upstream end tapering to zero at the downstream end, bank width is average 4m, it is already 0.5m in fill and the side slopes are 1.5H: 1V. The estimated cost for the option is estimated to be US$ 46,500 for a nominal 1km reach.

5.3.2 COMMAND PROBLEMS

The options identified to solve the command problems in other reaches are:

1. Transform the drop structures into cross regulators by installing moveable gates. The maximum height of a gate for manual operation is considered to be 1.5m. The structure sidewalls and the canal banks upstream will need to be raised. Ponding the water will reduce the benefits of steepening the reach to improve sediment transport.
2. Relocate the offtake to the next reach upstream. This will require a parallel canal and land acquisition, but the cost of these can be reduced if the new canal can utilise the bank of the main canal as one bank.

Selection of the appropriate option will depend on costs, for which the primary factors are the extent of water level raising required and the distance from the offtake to the next drop upstream. In addition to the selected option for command improvement, if the existing offtakes are either buried or form a flow constriction then they should be replaced with box culverts with vertical slide gates.

Option 1 – Cross Regulation

The costs for the option shall include the new cross regulation gates with accessories, increase in height of drop structure walls and associated increase in the embankments, access platform for operator and land cost for widened higher banks. The cost estimate is based on the following assumptions:

1. The width of the drop structure is 8.5 m.
2. The height of walls and banks is 1.75 m
3. The discharge is 45 m^3/s
4. Banks are 1m in fill
5. The required bank top level is 3.75 m above the bottom of the gates.

Cost estimates for one cross regulator and associated modifications in canal embankment are given in Table 4 at the end of this section. The cost for transforming a drop structure into a cross regulator is about US$ 21,000 and associated canal bank raising for a 1 km reach is about US$ 69,000.

The cost of a 1.2 m square box culvert offtake with gate is about US$ 6,000. Whether a new offtake is required depends on whether the existing structures have insufficient capacity.

Option 2 – Relocation of Offtake

The cost estimate for this option is based on a canal cross-section having bottom width 1.5m, channel depth 1.5m, side slopes 1.5H: 1V, bank top width 1m and depth of fill 1.2m. This is appropriate for a bed slope of 0.002 and a flow of 2.5m^3/s. The costs are given in Table 5, Appendix B. The cost for a new parallel canal is US$ 40,000 /km for both banks new and US$ 22,000/km if one bank of the main canal can be used (which should normally be the case). About 40% of the cost is for land acquisition. A new offtake would also be necessary.

The costs for all the options are summarised in Table 5.2 for other reaches.

Table 5-2 Cost Summary Other Reaches

Description	Unit	Cost US$
Sedimentation Problems		
Steeper slopes with raised u/s banks.	A typical 1km length	42,500
Command Problems		
By cross regulation at drops		
(a) Modifications in drop structure with radial gate	Sum	31,000
(b) With vertical gates	Sum	21,000
(c) New modified offtake (if needed)	Sum	6,000
(d) Canal Bank raising	A typical 1km length	69,000
By relocating the offtake and new canal		
(a) Cost of all new canal	A typical 1km length	40,000
(b) Cost of part new canal (one bank shared with main canal)	A typical 1km length	22,000
(c) New modified offtake	Sum	6,000

It can be seen that the cost of providing a parallel secondary canal is cheaper than complete raising of a main canal reach to provide command. Local factors that will influence the actual costs in a particular situation are whether there are command problems on each side of the main canal and the actual length of the main canal reach. The latter will affect earthworks costs in proportion to length but structure costs will be constant. A smaller value of main canal raising will substantially reduce costs. There may be circumstances where a cross regulator structure can effectively serve land adjacent to two reaches, both directly and via new secondary canals.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 OVERALL APPROACH

High sediment loads during floods is a feature of Wadi Zabid and is unlikely to change. The strategy behind any improvements has to be to accommodate the entry of sediment and minimise the adverse effects of deposited sediment on water distribution. This means ensuring that canals do not become choked by sediment and also providing in the design for sufficiently high water levels to be able to irrigate fields that are progressively raised by the deposition of fine sediment. The historical solution was, as the fields became higher, to move the diversion site further upstream. With modern structures this ceases to be an easy option and raising of structures and canals, in their current locations is the alternative that extends their working life. Within this overall raising, steepening of canal slopes to be closer to their regime slopes will reduce sediment deposition within their channels. Entry of coarse sediment into the canal system is likely to continue and has to be removed as maintenance.

6.2 HEAD REACHES

6.2.1 SEDIMENTATION DEPOSITION

The sedimentation problem in the head reaches is caused by a combination of factors:

- Coarse bed material entering the head regulator
- Relatively flat canal bed slopes giving insufficient sediment transport capacity
- Raising of canal water levels to irrigate high land, which further reduces the flow velocity
- Non-availability of equipment suitable for cleaning the head reach while there is water

The main effect of the sediment problem is to constrict the flow in the canal and, in the extreme situation, cause blockage of the head regulator.

The measures for reducing the problem are

- Modifications to the intake to reduce the ingress of coarse material (proposals are being developed after hydraulic model testing)
- Provision of a gravel trap to accommodate the coarse material without it impeding the flow
- Steepening the bed slope to spread the deposition of sediment by raising the diversion weir and/or reduction in the height of the drop at the end of the reach
- Provision of suitable equipment (long-reach backhoe or dragline) capable of cleaning the gravel trap and head reach during the irrigation season

Initial excavation of a gravel trap would cost in the order of US$ 5,000. Steepening of the reach by lowering the drop structure and excavation of the canal bed would cost about US$ 74,000 for a 1 km reach. Raising of the weir would cost about US$ 60,000 (but may benefit more than one canal) and raising of the banks to accommodate a higher upstream water level would cost about US$ 66,000 for a 1km reach.

The infrastructure modifications all depend on appropriate operation and maintenance practices to be successful: Flushing or excavation of coarse bed material immediately upstream of the intake is necessary and routine excavation of material in the head reach is required. The proposed works only delay the time before the sediment restricts the flow of water. Suitable equipment for the excavation work is required.

6.2.2 COMMAND PROBLEMS

There are several options available for resolving the command area each having its own advantages and problems.

1. Cross regulation at drop structure is an option, but is not recommended since any backing up of water would reduce the velocity and will increase the sediment deposition.
2. Excavating the highest fields. This is possible only if the excavated material can be used as earth fill for raising the banks. This option has little practicality in case if the problem area is large and the depth of excavation required is excessive.
3. Construct a new canal from a location further up the wadi The cost of one such canal if 1.5 km long is estimated to be more than 150,000 US$. The other constraint is right of way for the new canal, which needs to be resolved by the water users association.
4. The last option is to stop irrigating these fields with spate water but switch over to well irrigation, a common practice in Wadi Zabid.

The cost of a new canal is high, but it is most practical option provided that WUA can resolve the right of way problem Apart from switching over the irrigation of the fields from spate to groundwater. As long as the upstream farmers have no other option but to divert water through obstructing the main canal, the sedimentation problem cannot be solved for the head reaches and this affects the performance of whole of the canal due to reduction in inflows at the head regulator. The progressive deposition of sediment will cause the field levels to rise and will worsen the command problem. Any solution should provide for the likely rise in field levels during the life of the works to be constructed.

6.3 OTHER REACHES

6.3.1 SEDIMENTATION PROBLEM

In other reaches the sediment deposits, which are deepest at the upstream ends, have redefined the bed slope, making it steeper than the design and thus able to transport the balance of the sediment. The water level is raised and creates the risk of overtopping. An option is to remove the sediment deposits and restore the design bed levels but is not recommended as new sediments would be deposited and the current situation will re-emerge. Higher water levels may also be desirable for command purposes. The recommended solution is to raise the canal banks in the upstream part of each reach. The cost for bank raising to accommodate a steeper bed slope is estimated at US$ 42,500 for a 1km reach.

6.3.2 COMMAND PROBLEMS

The difficulty of getting sufficient flow of water from canals onto fields has been caused by inappropriate assumptions in the original designs combined with the ongoing rise in field levels due to deposition of fine sediment. Effectively, canal water levels need to be raised to facilitate irrigation.

The options to provide the required head for irrigation include:

1. Conversion of drop structures into cross regulators that can raise water levels in a controlled manner
2. Relocating the offtakes to upstream of the drop at the end of the preceding reach and providing parallel secondary canals.

The cost of modifying one structure into a cross regulator with a gate height of 1.5m is estimated at as US$ 21,000 while the cost of raising banks to contain the higher water levels is estimated at US$ 69,000 for a 1km reach.

The costs of a new parallel canal are US$ 22,000/km if using one bank of the main canal. The only constraint is the right of way for the new canal. Therefore it is recommended to relocate the offtakes particularly if those on the upstream side of a reach if the WUAs are able to resolve the land allocation issues.

The existing turnouts have many deficiencies in meeting the requirements of their functions. New offtakes are needed for several situations including (i) the existing offtake is buried in sediment; (ii) the existing offtake has insufficient flow capacity; and (iii) to supply new parallel canals. New offtakes would be constructed as box culverts up to size of 1.2m square. The cost of one such culvert including the operating gate and accessories is estimated at US$ 6,000.

The optimal solution for individual problems could be a combination of the identified options. This may include limited raising of main canals sufficient to divert flow into offtakes, plus new parallel secondary canals. The preferred solutions for each reach may be different. For example one raised reach can serve both land directly supplied from it and, via new secondary canals, the land currently served by the reach downstream.

When any of the options are combined and applied to the lengths of canal that are affected, the total expenditure required will be several million US$. Land acquisition forms a significant proportion of the estimated costs where bank raising or new canals are proposed. Donation of the land can be valued as a contribution towards the cost of the works.

LIST OF APPENDICES

A. PHOTOGRAPHS

Choked Turnout

Temporary Dike to Raise Water Level

Blocking at Drops To Raise Water Level

Eroded Banks of Mari-Yousafi Canal

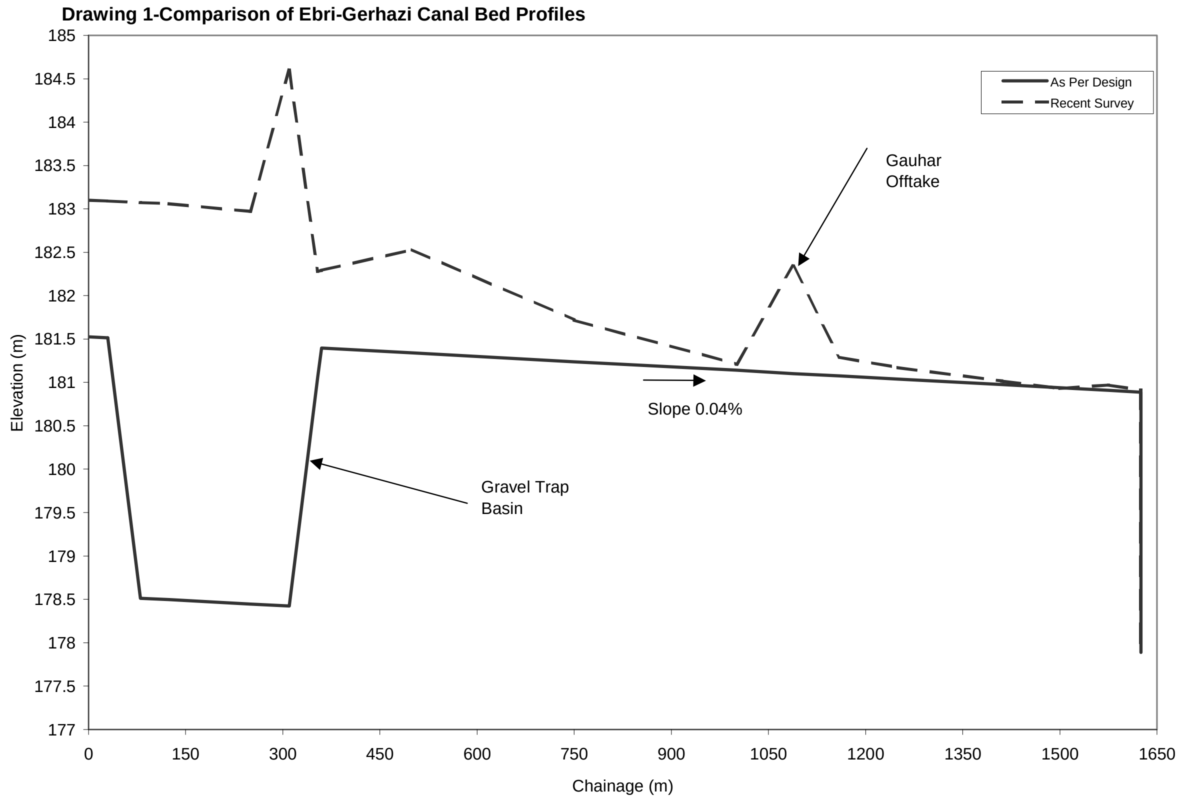
Damaged Drop Structure

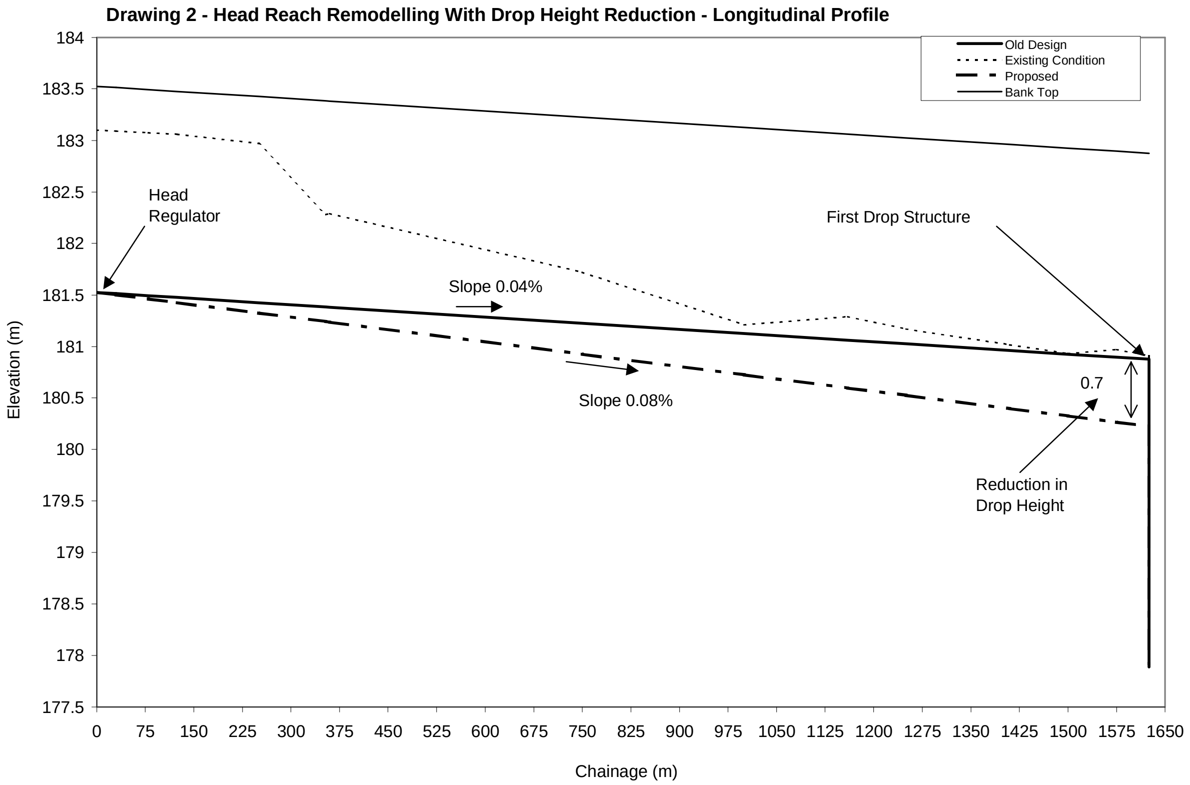
Wild Growth of Vegetation in Mansouri-Ryan Canal

Deep Incised Cut in Mansuri Canal Bank Due to Flooding

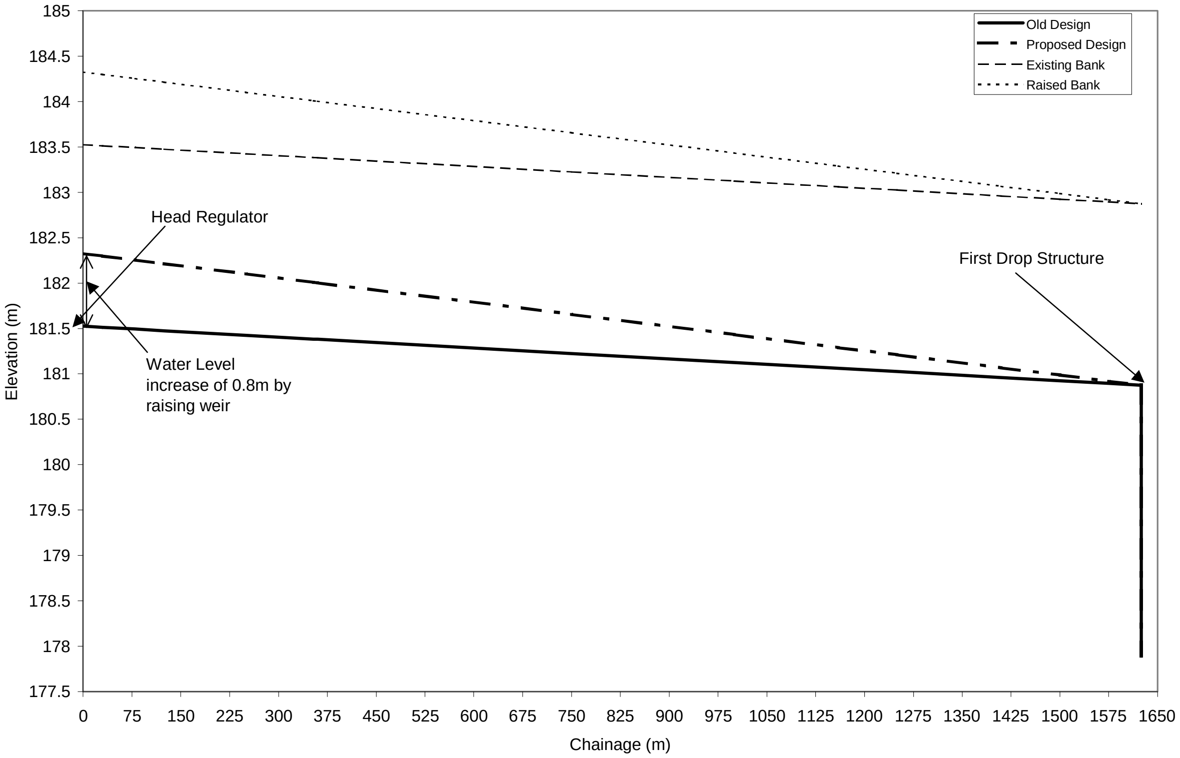
Deposited Sediment In Front of Head Regulator

B. DRAWINGS

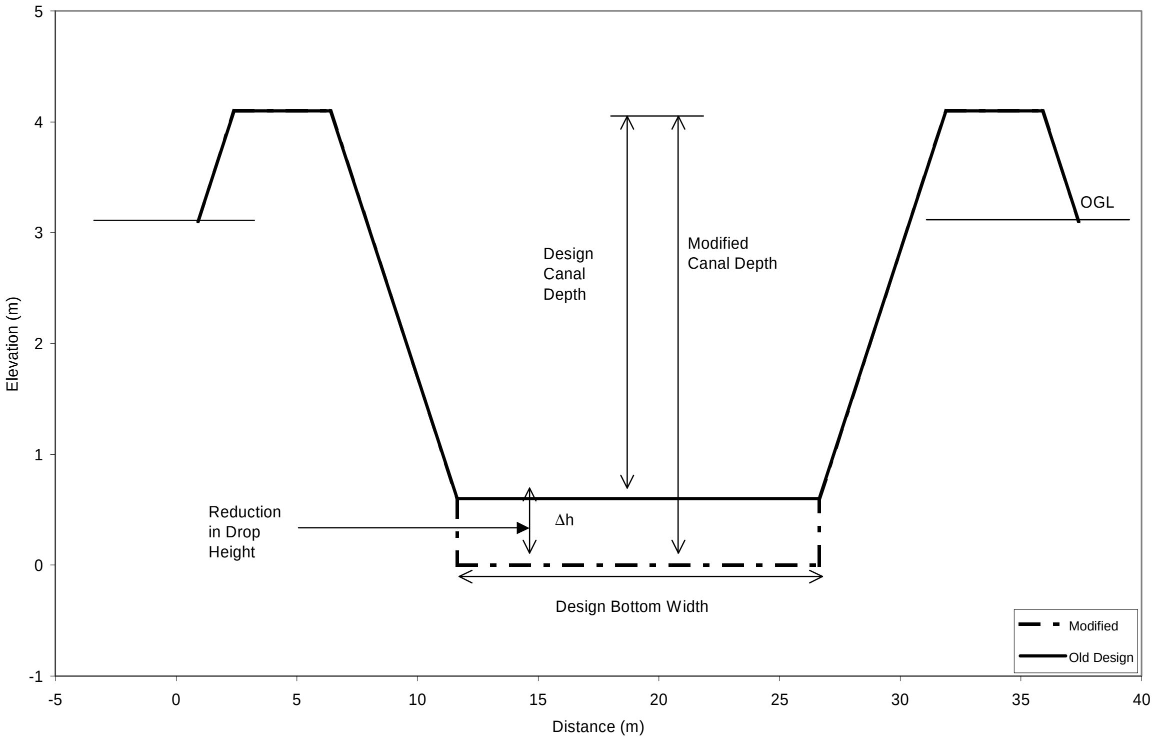

Drawing 1-Comparison of Ebri-Gerhazi Canal Bed Profiles
As Per Design
Recent Survey
Gauhar
Offtake
Slope 0.04%
Gravel Trap
Basin
Elevation (m)
Chainage (m)


Drawing 2 - Head Reach Remodelling With Drop Height Reduction - Longitudinal Profile
Old Design
Existing Condition
Proposed
Bank Top
Head
Regulator
First Drop Structure
Slope 0.04%
Slope 0.08%
0.7
Reduction in
Drop Height
Elevation (m)
Chainage (m)

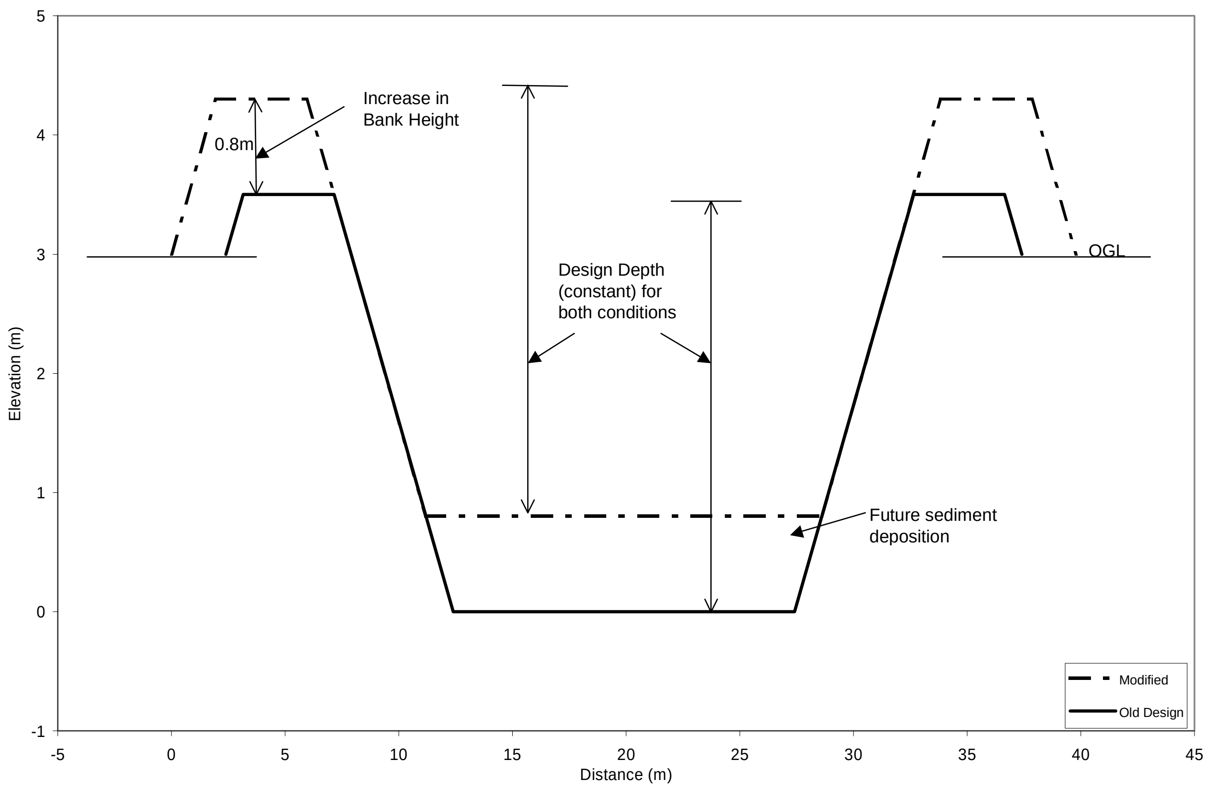
Drawing 3 - Head Reach Remodelling With Weir Raising (Longitudinal Profiles)



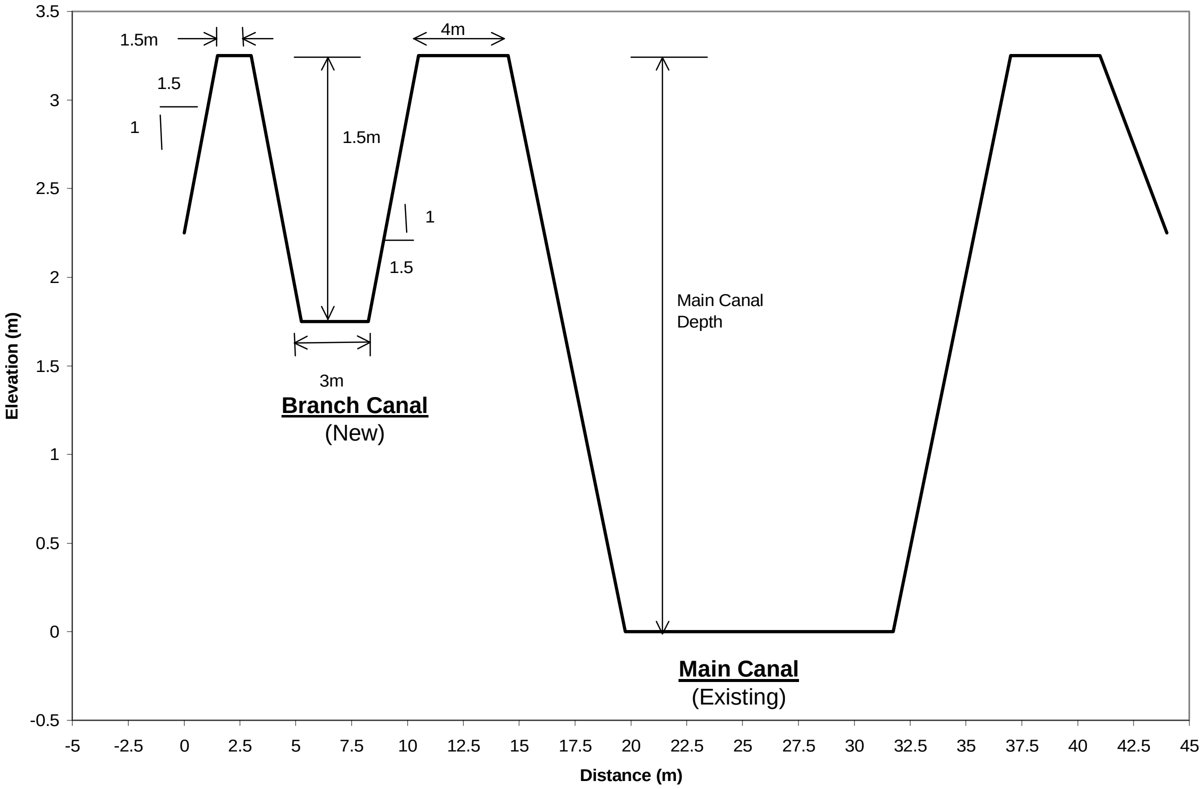
Drawing 4 - Modified Cross Section With Reduced Drop Height

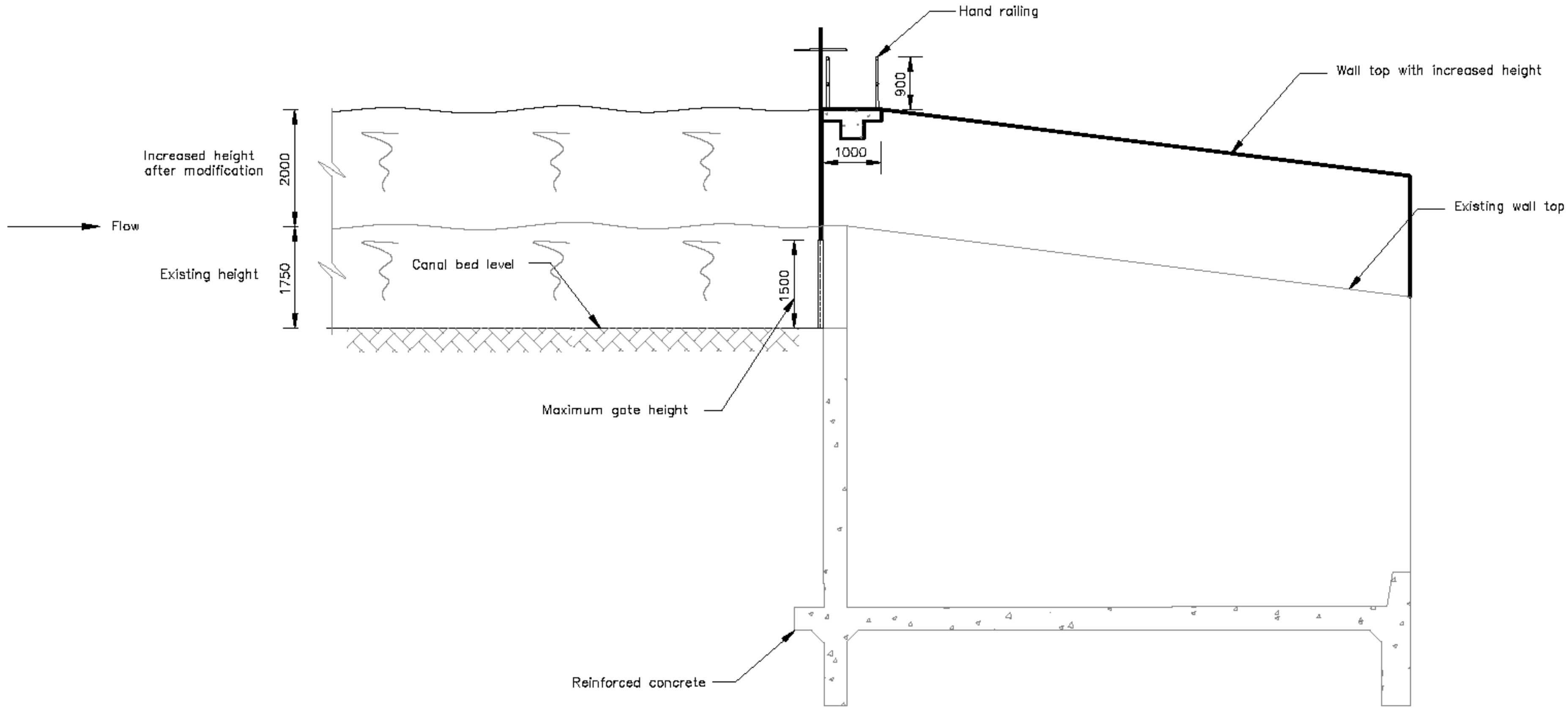


Drawing 5 Modified Cross Section With Raised Weir Crest Level



Drawing 6 - Parallel Branch and Main Canals with Relocated Offtake





Drawing 7: Section Through Modified Drop Structure

C. CALCULATIONS

Remodelling of Main Canals - Wadi Zabid
Cost Estimate Tables

Table 1 - Head Reach Sedimentation - Assumed 1km reach

Item No	Description	Unit	Rate US$	Quantity	Amount US$
	Sediment removal + construction of gravel trap				
1-1	Removal of existing sediment	m³	3	18000	54,000.0
1-2	Excavation of gravel trap	m³	3	1500	4,500.0
	Sub-total for gravel trap				**58,500.0**
	Additional for lowering of drop structure				
1-3	Demolition / rebuilding	sum	2000	1	2,000.0
1-4	Deepening of canal bed	m³	3	4500	13,500.0
	Sub-total for lowering drop structure				**15,500.0**
	Additional if weir crest raised to contain higher water level				
1-5	Earthfilling for bank raising in u/s section	m³	3	3500	10,500.0
1-6	Land acquisition	m²	1.5	12000	18,000.0
	Subtotal for bank raising if weir crest raised				**28,500.0**
	Total Cost (US$)				**102,500.0**

Note: If gates required on drop structure then the cost will be similar to item 4-4

Table 2 - Head Reach Command, New Canal 1,500m long from further upstream

Item No	Description	Unit	Rate US$	Quantity	Amount US$
2-1	Excavation	m³	2.75	20000	55,000.0
2-2	Earthfilling in Embankments	m³	3.75	6500	24,375.0
2-3	Land Acquisition	m²	1.5	27000	40,500.0
2-4	Canal head regulator	Sum	-	1	30,000.0
	Total Cost (US$)				**149,875.0**

Table 3 - Sedimentation Other Reaches - Typical 1km reach

Item No	Description	Unit	Rate US$	Quantity	Amount US$
3-1	Earthfilling in Embankments	m³	3.75	10625	39,843.8
3-2	Land Acquisition	m²	1.5	4500	6,750.0
	Total Cost (US$)				**46,593.8**

Table 4 - Command Problem for Other Reaches

Item No	Description	Unit	Rate US$	Quantity	Amount US$
	Canal Modifications				
4-1	Earthfilling in Embankments	m³	3.75	15375	57,656.3
4-2	Land Acquisition	m²	1.5	7500	11,250.0
	Total Cost (US$/m)				**68,906.3**
	Cross Regulator				
4-3	Reinforced Concrete	m³	180	50	9,000.0
4-4	Gates				
	(a) 8.5m wide radial gate with operating Mechanism and all other accessories	m²	12.8	1850	23,680.0
	(b) 1.4m x 1.5m vertical slide gates with frame, spindle and handle	no	2000	6	12,000.0
	Total Cost radial gate)US$				**101,586.3**
	Total Cost (vertical gates)US$				**89,906.3**
	New Offtake				
4-5	Excavation and backfilling	m³	4	120	480.0
4-6	1.2m x 1.2m Box Culvert	no	3800	1	3,800.0
04-Jul	Vertical Slide Gate to suit Box Culvert Complete in All Respects	no	1700	1	1,700.0
	Total Cost (US$)				**5,500.0**

Table 5 - Parallel Canal With Offtake Relocated - typical 1km

Item No	Description	Unit	Rate US$	Quantity	Amount US$
	(a) Two New Canal Banks				
5-1	Excavation	m³	2.75	200	550.0
5-2	Earthfilling in Embankments	m³	3.75	6600	24,750.0
5-3	Land Acquisition	m²	1.5	9700	14,550.0
	Total Cost US$/m				**39,850.0**
	(b) Using One Bank of Main Canal				
5-4	Excavation	m³	2.75	200	550.0
5-5	Earthfilling in Embankments	m³	3.75	3300	12,375.0
5-6	Land Acquisition	m²	1.5	6100	9,150.0
	Total Cost (US$/m)				**22,075.0**