EVALUATION OF EXISTING WATER CONVEYANCE, STORAGE AND CONTROL STRUCTURES: A CASE OF AMIBARA IRRIGATION SCHEME, ETHIOPIA

Wondafrash Wondmagegn Meshesha

A Thesis Submitted to

The Department of Water Resource Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resource Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies

Adama Science and Technology University

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APPROVAL SHEET

I/We, the advisors of the thesis entitled "**Evaluation of Existing Water Conveyance, Storage and Control Structures: A Case of Amibara Irrigation Scheme; Ethiopia**" and developed by **Mr. Wondafrash Wondmagegn**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Major Advisor	Signature	Date
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Co-Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Mr. Wondafrash Wondmagegn** have read and evaluated the thesis entitled "**Evaluation of Existing Water Conveyance, Storage and Control Structures: A Case of Amibara Irrigation Scheme; Ethiopia**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in **Water Resource Engineering (Specialization in Irrigation Engineering)**.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Department Head	Signature	Date
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School Dean	Signature	Date
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Office of Postgraduate Studies, Dean	Signature	Date

DECLARATION

I hereby declare that this Master Thesis entitled "**Evaluation of Existing Water Conveyance, Storage and Control Structures: A Case of Amibara Irrigation Scheme; Ethiopia**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

______________________	____________________	____________
Name of the student	Signature	Date

RECOMMONDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Evaluation of Existing Water Conveyance, Storage and Control Structures: A Case of Amibara Irrigation Scheme; Ethiopia**" prepared under my guidance by **Mr. Wondafrash Wondmagegn** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in **Water Resource Engineering (Specialization in Irrigation Engineering)**.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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Co-Advisor	Signature	Date

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ACRONYMS AND ABBREVIATIONS

AIP	Amibara Irrigation Project
ASI	Asset Sustainability Index
CD	Check Drop
CI	Condition Index
FAO	Food and Agriculture Organization
FDRE	Federal Democratic Republic of Ethiopia
ICA	Infrastructure Condition Assessment
IMT	Irrigation Management Transfer
IVI	Infrastructure Value Index
MAESCo	Melkasedi Agricultural Estate Share Company
SC	Secondary Canal
TC	Tertiary Canal
UTM	Universal Transverse Mercator

ABSTRACT

Agricultural development may be limited due to shortage of water unless efficient use of irrigation water is applied. Assessment based evaluations of the irrigation system's physical condition with the functionality of the infrastructure components are all needed to overcome water scarcity problem. This study was done primarily to identify the causes that lead the scheme to perform below expectation and recommend remedial measures for sustainability of Amibara Irrigation Scheme (AIS) in Afar Region, Ethiopia. The conditions of existing water conveyance, storage and control infrastructures were assessed and evaluated through field investigation, predefined house hold questionnaires and interview with operational staffs. Priority was also set using priority indexing method for rehabilitation of the scheme for future development and sustainability of the scheme. Issues that potentially affect the performance of the scheme were identified and ranked based on their level of influence on the scheme performance. The priority index was defined by combining the assessed condition of components of the system with a measure of its strategic importance and the area served by that specific component. The overall score and ranking was judged for sampled irrigation hydraulic structures for further actions of rehabilitation. The research included investigation and condition assessment of the headwork, 1 main canal, 7 out of 10 secondary canals, 10 out of 42 tertiary canals, all the 6 gated check drops (CD) on main canal, 7 out of 10 gated offtakes that are offtaking irrigation water from main canal to the secondary canals. The evaluation of the scheme infrastructures indicated that the major causes for the scheme to perform under expectation were change of institution in fast rate, significant load of sediment from high lands to the head work, flooding, poor drainage network and salinity problems. The analysis indicated that the headwork took the highest value (180) of priority index and it was failed to deliver irrigation water to the scheme. It was found that the headwork comprising the weir, the intake, the head regulator and the scour sluice was almost collapsed and not maintainable. The main, secondary and tertiary canals were observed with diminished shape, size due to sediment load, and weed growth on the section and banks of the canals. The main problems observed on the check drops & gated offtakes were the failure of gates for operation due to lack of annual maintenance. Most of the concrete structures are in a good condition with minor maintenance requirements. The research recommended changing the location of the headwork and reconstruction of new one where river section is stable with non-silting velocity.Rehabilitation of the canal networks and all structures along the canal network is mandatory. Deterioration and failure of drainage infrastructures needs special attention for sustainability of the scheme. Moreover, there should be responsible institution that took the responsibility of coordinating and organizing stakeholders for operation and maintenance of the scheme.

KEYWORDS*:* Condition assessment, priority Index, deterioration, strategic **i**mportance, performance constraints, scheme infrastructure, headwork

CHAPTER 1. INTRODUCTION

1.1. Background of the Study

To control the dynamic nature of climate, water infrastructure development is conceived as a means, allowing the development of productive activities that depend on a sustained and secure supply of water. With irrigation infrastructure (storage reservoirs, aqueducts etc.), it becomes possible to regulate a variable water supply and provide sustainable and equitable allocation of the resource through a better match between when and where it is available and when and where it is needed. (Vicuna *et al*., 2014).

However, operational skills and expertise are required for manually operated large-scale irrigation schemes that can cope with the complex hydrodynamics; on the other hand, many schemes in developing countries are lacking operational skills and expertise. The performance of large-scale irrigation schemes generally lower than expectations. The poor performance of these schemes, particularly in developing countries, has greatly affecting productivity because of the fact that the complex hydrodynamic behavior of the schemes is generally not clearly understood (Zeleke *et al*., 2015). Accurate evaluations based on the assessment of physical condition of irrigation infrastructures including the functionality of its components and irrigation efficiency are all needed to resolve the shortage of irrigation water. The assessments of physical condition and functionality of irrigation infrastructures are metrics used to establish the performance index value of the irrigation system. Moreover, the performance index value can be used to identify sections that need maintenance and to define the level of damage that has influenced the irrigation network infrastructure (Yuli & Mamok, 2018).

To quantify the performance of infrastructures in respect to the objectives established for the system, it is important to ensure that the selected indicators are relevant to describe the intended performance measurement. Meaningful indicator can be used in two distinct ways. It tells a manager what the current performance is of the system and, in conjunction with other indicators, may help him to identify the correct course of action to improve performance within the system. The use of the same indicator over time is important because it assists in identifying trends that may need to be reverted before the remedial measures become too expensive or too complex (Brelle & Dressayre, 2014).

A detailed procedure for planning irrigation rehabilitations was produced by Cornish & Skutsch (1997) after their work in Yogyakarta and Central Sulawesi in Indonesia. The procedure was developed mainly to identify the factors, which cause under-performance of schemes, to evaluate the condition and fitness of scheme components and to prioritize structures for improvement.

Infrastructure Condition Assessment (ICA) is a continuous process that involves systematic gathering of information through observation, investigation, direct monitoring and reporting. The need for this research is to determine the current condition of the irrigation infrastructure and identifying root causes for the deterioration of infrastructures through analysis of relative causal index method (David et al., 2007).

Other physical indicators to review broad assessment of the performance of irrigation include relative number of operational irrigated schemes, which is the ratio of aggregated number of successfully operating irrigation schemes to the total developed irrigation schemes in the country. The second indicator is relative irrigated area defined as total area under irrigation versus total designed command areas of already implemented irrigation projects during a particular year or averaged over years in the country or region. The third indicator is beneficiaries target performance; defined as the ratio of actual number of beneficiaries using irrigation schemes and planned or targeted number of beneficiaries. Causes of underperformance of small-scale irrigation, structural (hardware) & management (social and institutional) factors can be analyzed. The research made in Ethiopia indicated that irrigation schemes are not functioning at their optimal capacity. Lack of adequate extension to advice agronomic practices, lack of responsible managing institutions, low technical and financial capacity for sustained operation and management of schemes, post-harvest storage, processing and marketing, weakness of support services are found to be crucial challenges (Sileshi & Mekonen, 2011).

In the evaluation of hydraulic performance for Hare community managed irrigation scheme in Southern, Ethiopia about nine selected performance indicators were used. Out of these indicators, maintenance performance indicators considered the parameters of water surface elevation ratio. Water surface elevation ratio is the ratio of actual water surface elevation at Full Supply Level (FSL) to intended water surface elevation at FSL. The other indicator is effectiveness of infrastructure, which is defined as the ratio of the number of functioning structure to number of infrastructure initially installed. In addition to these indicators, sustainability of irrigated area (measured as the ratio of existing area under irrigation to the planned irrigated area) were included to evaluate the hydraulic performance of the scheme. The result indicated that the maintenance performance of the system was very poor. Some parts of the structures were affected by sedimentation; weed growth, flooding and erosion problems. In the same way investigating the hydraulic performance of the other schemes are very important to improve its performance (Mamuye and Mekonen, 2015).

The hydraulic performance of Amibara irrigation scheme had been declining from time to time due to different challenges in the area, mainly salinity; flash flooding and lack of irrigation management, In this research, causes and effects for the system failure were identified with recommendation for system rehabilitation. Possible constraints for the underperformance of the Amibara irrigation scheme were analyzed. The investigations were done to identify the factors for possible constraints through four categories namely, agricultural and economic, system design and operation, deterioration of system infrastructures, land degradation and consistent under supply at the headwork. Check lists, households' questionnaire, interview with operational staffs and relevant stakeholders and review the existing documents, design criteria and related literatures were used as basic information gathering technics for the analysis. Root causes for the deterioration of system infrastructures were also analyzed and remedial measures were recommended accordingly.

1.2. Statement of the Problem

As far as water scarcity and the resulting competition for limited water resources becomes the sectorial challenge, improving performance irrigated agriculture becoming mandatory to provide additional food to globally growing population Boss et al. (2005). Hashemy and Monem (2011) stated that improving the performance of irrigation canal networks become one of the most important factors in saving limited water resources. To achieve this purpose, improving the operation and maintenance (O&M) activities of irrigation networks is necessary.

Condition assessment of irrigation structures at any level, helps the management at that level to whether the structures performance is satisfactory or whether it can be improved. Through investigation and evaluation of condition assessment of irrigation structures (and the associated process of diagnostic analysis) the scheme managers are able to identify areas where performance can be enhanced (Burton, 2010). However, Hashemy and Monem (2011) stated that most current O&M approaches do not consider the spatial differentiation of networks.

Performance of Amibara irrigation scheme was declining from time to time and users complaining on its management. Many farms and investors had left command areas due to surface and ground water inundation in the vicinity. This study evaluated the condition of the conveyance, storage and water control infrastructures of the scheme, the issues of governance and legal frameworks for further research for sustainability of the scheme. Main factors that contributed to infrastructure deteriorations and the root causes for declining of scheme performance were identified.

1.3. Significance of the Study

The key benefits of investigating and condition assessment of irrigation structures is that it allows utilities to understand risk and determine when to intervene in the deterioration process to avoid failures that impose unacceptable costs or consequences. The consequences may be social, environmental or economic. The benefits of investigation & condition assessment of irrigation infrastructure can only be realized if interventions that can reduce the probability of asset failure are implemented (David *et al*., 2007).

The magnitude of the benefits derived from any new assessment programs will depend on the actual current physical state of the existing assets (probability of failure), the failure consequences associated with assets and the value derived from the enhanced level of information that is gathered beyond that already available. Direct benefits considered those benefits not realized if the assessments are not undertaken (David *et al*., 2007).

In this research, the major causes of the observed problems were identified and future consequences were indicated. Maintenance & rehabilitation investments were also prioritized with provided alternatives for better future development.

1.4.Objectives

1.4.1. General objective

The Primary objective of this research is to evaluate the condition of the existing water conveyance, storage and control infrastructures of the Amibara Irrigation Scheme, with the following specific objectives.

1.4.2.Specific objectives

i. To evaluate the current status of irrigation hydraulic structures of the scheme and determine the level of their functionality;
ii. To identify the factors that lead the scheme to perform below expectations;
iii. To evaluate causes of failure, identify remedial measures set priorities for improvement of existing hydraulic structures

1.5. Scope of the Study

This study addressed the investigation and condition assessment of the whole gravity fed 10,300 ha of irrigation system from headwork to tertiary canals of the Amibara irrigation scheme. This include the headwork, 25.5 k.m gravity main canal, selected secondary canals, off take structures & Head Regulator (HR) from main canal to secondary canals, controlled check drops along the main canal, and flow measurement and regulating structure on the secondary and tertiary canals. About 6,582 ha (64% of total area) was investigated which includes 7 secondary canals out of 10, 10 tertiary canals and whole length of the main canal with 7 out of 10 off taking & regulating structures, all the 6 controlled check drops on the main canal. The sampled irrigation structures were selected from the upper, the middle and the lower reaches of the main, secondary and tertiary canals so that the samples can represent the whole scheme.

The areal scope of this investigation was limited to the storage and conveyance system of the gravity fed irrigation scheme that had been studied under the consultancy of Sir William Halcrow and Partners in 1983. Detailed sampling methods and sample size were discussed in Materials and Methods part.

CHAPTER 2. LITRATURE REVIEW

2.1. Evaluation of the Current Condition of Hydraulic Structures

Yuli and Suprapto (2018) did assessment of irrigation network performance and assessment of the physical condition of the irrigation network infrastructure in addition to other performance evaluation in Tlatak irrigation scheme in East Java's Magetan regency. The assessments of physical condition and functionality metrics were used to establish the performance index value of the irrigation system. The performance index value was used to identify sections that need maintenance and to define the level of damage that has adversely influence the irrigation network infrastructure. The results showed that the Tlatak irrigation system was categorized as 'Poor' and Needing Attention.

Condition assessment of irrigation infrastructures helps to understand how irrigation schemes functions, to identify root causes of problems. Moreover, the assessment helps to identify opportunities for performance gains in order that action can be taken to improve irrigation water management. Condition assessments are carried out when difficult problems are identified through routine monitoring, or when stakeholders are not satisfied with the existing levels of performance achieved and desire a change & supports both operational performance monitoring and strategic planning (Bos *et al*., 2005).

Organizations managing water infrastructures have to make decisions regarding what new infrastructures are needed, which are to be renewed, rehabilitated or what maintenance activities should be performed. Mallebreranet *et al*. (2019) used Infrastructure Value Index (IVI) as the first indicator & Asset Sustainability Index (ASI) as the second during investigation & condition assessment of water infrastructures in Spain, applied to Segura River Basin. The two indicators represent value-based condition assessment & maintenance-based condition assessment respectively. The results with IVI show an overall fair condition for the assets by year 2015, but a lack of maintenance was indicated for 15–20 years before the end of the service life.

Investigation and condition assessment of the existing water control infrastructure for two irrigation schemes (Tugela irrigation scheme and Mooi river irrigation scheme) in South

Africa by Dirwai *et al*. (2019), had been investigated using condition scoring method to undergo Infrastructure Condition Assessment (ICA) for the schemes. The investigators used multi- criteria assessment through deterministic and interrelated infrastructure parameters such as structural adequacy, structural efficiency, structural soundness and structural integrity. Infrastructure condition assessment rating values were 0.2, 0.4, 0.6, 0.8 & 1 representing very bad, bad, fair, good & excellent in the respective orders.

2.2. Factors that Lead the Scheme to Perform Below Expectation

Poor maintenance, repetitive rehabilitation and low collection of water charges are the main causes for the decline of performance of irrigation schemes. The remedy to shift to a virtuous circle is in most cases found in changes in the institutional arrangements with participation of the water users association in management (Plusquellec, 2019). The review of institutional reforms in the irrigation sector for sustainable agricultural water management undertaken in 14 countries and regions concluded that the major challenges for institutional and Public Private Partnership (PPP), towards implementing sustainable agricultural water management practices are the formation and functioning of Water Users Association, aging of irrigation infrastructures and its operation and management (Hamond *et al*., 1993). The investigation on water-resource-related challenges faced by water users association and local farmers in Kashkadarya Province in Uzbekistan, indicated that outdated infrastructure, poor governance, and farmers' non-payment of irrigation service fees become the major challenges for sustainable water management (Kakhramon *et al*., 2017).

Government management of irrigation infrastructure and services has failed in developing countries. Currently, there is a general tendency to transfer the management of such infrastructure and services to local farmer organizations (also known as water user associations) in an exercise technically known as Irrigation Management Transfer (IMT). The research at West Kano irrigation scheme in Kenya, shows an attempt at implementation of the IMT that has achieved mixed results. It indicated that that IMT has not been completely successful as it faces both internal weaknesses and external obstacles (Owiti, 2016).

Study on the current irrigation system management features in Azerbaijan Republic, indicated that the newly created water users association are still weak and the majority of them do not fully understand their tasks and responsibilities. In some cases there is unhealthy relation between the farmers and operational service organizations due to complaints about the water distribution and statements about corruption. Consequently, there is a lack of interest by the farmers to take responsibility for expenses supporting the parts of the system beyond their own boundary. This weak management of operation of irrigation system, results in losses of water, rising of the groundwater level, worsening of soil conditions. These factors cause reduced productivity of the farm (Agarza, 2007). If the scheme-managing agency is not willing to adopt performance-oriented management techniques, all the best management advice in the world will have little or no impact. Performance-oriented management requires a set of incentives and commensurate accountability throughout the management structure (Hamond *et al*., 1993).

According to Sileshi & Mekonen (2011), the major cause for structural failures is the watershed degradation followed by erosion and sedimentation of water control and conveyance structures. The authors stated that lack of sustainable funding, extension of agronomic practice, and post-harvest technologies are identified as the top management-related problems.

David *et al.* (2007) stated that recent infrastructure studies undertaken in the United Kingdom, Australia and the United States have shown a common cause for concern there is widespread deterioration of critical water infrastructure assets, with significant shortfalls in the renewal/replacement investment required to ensure that water utilities can deliver sustainable services to their communities. The author underlined that maintaining water infrastructures to a satisfactory level of service is much better than replacing them with limited funds.

Water service pricing or tariff in irrigation systems is a matter of policy, which must comply with objectives of equity, affordability by farmers (i.e. proportionate to farm gross revenue), and incentives for the efficient use of water. Farmers are ready to pay water fee provided that the tariff is affordable and amount and quality of service is delivered properly. Empowering water users association in operation, maintenance and fee collection is an attractive alternative to public management and delegation to a private company. Optimizing water service costs could be achieved through an adequate combination of public, private and end users' respective skills and capacities (Brelle & Dressayre, 2014).

However, in the case of Amibara irrigation scheme, the water service tariff amount is very minimal (3 Birr for 1000m^3) which cannot cover annual operation & maintenance cost of the scheme. Following the change in organizational structure of responsible Governmental agency in 2007 followed by irrigation management transfer from government to users, there is no seasonal operation & maintenance of irrigation infrastructures. As a result, the current condition of the irrigation infrastructures of the scheme is at high failure risk. Furthermore, in the contrary to the fact that Awash River Basin is characterized by its disastrous flooding especially in the middle valley where Amibara irrigation scheme is located, there is no legally responsible institution for flood protection works since establishment of Awash Basin Authority (Regulation No 156/2008).

Lack of confidence for flood protection and deterioration of the scheme infrastructures become discouraging and confusing matter for the irrigation developers. During the establishment of the new institution namely the Federal Democratic Republic of Ethiopia (FDRE) Irrigation Development Commission (IDC) through Regulation No 444/2018, the operation and maintenance of irrigation infrastructures was not included in its mandate. There is no clear legal framework that indicates who will undertake operation and maintenance of infrastructures and flood protection works. So, the question becomes do these small holders can afford the annual maintenance cost of the infrastructures. On the other hand, it had been found the possibility of salinity expansion to take place in near future at faster rate than ever seen before (Frew et al., 2015).

In this research, the factors that in turn become the root cause for deterioration of infrastructures were identified. Relevant questioners can help to identify some of the causes of poor performance and indicates possible ways through which management performance could be improved. Condition assessments activity falls into two parts; evaluation of the degree to which initial objectives and targets were met, setting priority attention for activities that can improve performance of the scheme. For irrigation schemes, the ideal level of performance can only be achieved when targets were achieved, objectives were fulfilled, and there was an efficient use of available resources (Hamond.D et al., 1993).

An asset were assessed using a standard questionnaire requiring a YES or NO response to each question where questions are all formulated such that a YES response indicates a defect; a NO response implies no defect. To help subsequent analysis to put priorities on works, fixed scores (Appendix 3A) have been assigned to any "Yes" response, while "No" responses all score 100. The Condition Index (CI) is the score associated with the element in worst condition (Cornish & Skutsch, 1997).

The priority of works was established by combining the assessed condition of a component of a system with a measure of its strategic importance and the area served, in an overall score and ranking. The cropped area served by an element is considered to be a rough proxy for its economic value to the system, and it is therefore included in the priority-setting process. After completion of inventory of irrigation infrastructures condition, the priority of works is based on the benefit actually, or potentially, foregone. Priority Index which takes into account asset condition, a measure of area served by the asset relative to the total area of the scheme and indicator directing to the strategic importance of the asset (Cornish & Skutsch, 1997).

The irrigation development potential of the Amibara area was first studied by FAO/SOGREAH in 1964/65. This study proposed irrigation development of 31,000ha in the Melka Sedi, Amibara and Angelele area through gravity water diversion from the Awash River. Irrigation development of the Amibara area started almost immediately with the establishment of the 300ha Melka Warer Research Station. Following this, several small farming enterprises developed irrigated agriculture in the Middle Awash though with little proper planning and design. These farming enterprises included: (i) Ambash Private Limited Company (1967); (ii) Algeta Private Limited Company; (iii) Ethiopian Farm Development Company; and (iv) Melka Sedi Agricultural Estate Share Company (MAESCo). These enterprises operated from early 1965 until 1976 and developed a total irrigated area of about 5,000 ha.

Following the ending of the feudal system and deposal of the Emperor by the Derg in 1974 these farms were nationalized in 1975 and merged to form the Middle Awash Agricultural

Development Enterprise () under the Awash Agricultural Development Corporation of the Ministry of State Farms. The first technical and economic feasibility study of the Amibara Irrigation Project carried out by Italconsult (1969-71) recommended a 14,600ha project. The study proposed two weirs / dams, one at Melka Sadi to divert water to land developed by MAESCo and a second at Melka Werer to divert water to Amibara, Bolhamo and Angelele. A syphon under the Awash River would deliver water to Bolhamo on the left bank.

Halcrow (1993) prepared a report in which design options were reviewed. The report recommended single barrage type headworks at Melka Sadi to supply both Melka Sadi and Amibara (Melka Werer), with possible later extension to supply Angelele and Bolhamo. Detailed designs were prepared in 1974/75. However the designed scheme referred to as Amibara Irrigation Project I (AIP) was deemed too expensive. Redesign for a reduced cost scheme with a cheaper rock fill weir headworks at Melka Sadi, AIP II, was carried out and construction started in 1978 and was completed in 1984. AIP II developed 10,300ha comprising the state farms of Melka Sadi (4,600ha) and Melka Werer (5,700ha). The project increased the net irrigation area at Amibara to about 13,600ha made up of (i) 10,300ha in the two state farms; (ii) about 3,000ha in the Amibara Settlement project; and (iii) about 300ha in the Melka Werer Research farm. Farms in the Settlement project as well as the Research farm receive water pumped directly from the Awash River as well as some gravity supply.

Under AIP II surface drainage was also provided for about 9,000ha. With technical assistance from Mott MacDonalds a subsurface drainage system for the whole area was designed and phase I of planned two-phase project implemented. Phase I installed 3,820ha of subsurface drainage and deepened the southern part of the main drain, and realigned it in the north so that it no longer followed the eastern dyke. Phase II however was never built, so that the subsurface drains were never properly functional (Sir. William Halcrow & Partners, 2008).

The weir was designed for a return period of 200 year and design discharge of 1,200m3/s. The weir is submerged type with crest length of 110m and crest level at 749.00 m above mean sea level. (Sir. William Halcrow & Partners, 2008). The intake was provided with a trash rack on its river face and triangular shaped screens at its entrance. The screens act as a first defense or trees & debris carried down by the Awash River from blocking the trash rack (Sir. William Halcrow & Partners, 2008).

The scour sluice was designed to remove the bed load and heavy silt that enters the intake by discharging them back into the river downstream of the river. The scour sluice was provided with a radial gate of 1.5 m wide to completely shut-off the scour culvert, which is 1.5m*1.5m. Tower is located halfway between the intake and exit of the scour culvert for operation of the radial gate. This structure is also submerged except the operation tower and Access Bridge which connect the tower to the head regulator. Twin supply culverts from the intake each have dimensions of 1.65 m wide x 1.5 m height supply the head regulator. The discharge control is operated by two vertical slide gates installed separate chambers. The two slide gates discharge into twin barrels 1.5m x1.5m which end in a common stilling basin. The main canal is 25.6 k.m long having six controlled check drops and six uncontrolled drops. The uncontrolled drops were provided where the natural slope of the land exceeds the slope of the canal (Sir. William Halcrow & Partners, 2008).

The six controlled check drops are provided with overshot gates to maintain the irrigation water in the main canal upstream of a gate at full supply level. The discharge over the gates passes to the downstream users. A staff gauge is provided in the main canal, just upstream of the check drop, to indicate the water level in the canal. The overshot gates are installed on the downstream face of the crest. On top of each gate is welded a steel pointer, which gives a direct reading on a scale, fixed on top of the gate frame. The gauge riding indicates the height of the gate above the crest of the drop. Check drops 1 to 5 have two drop gates of total length 6m while check drop 6 has only one gate of length 3m. Gate height vs. design discharge rating table was prepared for operation (Sir. William Halcrow & Partners, 2008).

The offtakes to the eleven secondary and one tertiary fed from the canal had been fitted with constant head orifices to measure water delivered to entities. The offtakes are located just upstream of the each check drops. The constant head orifice is a combination of a regulating and measuring device. The rate of flow is estimated by using the principle that the submerged orifice of a give size requires a differential head across the orifice and this is maintained at a constant value by adjusting the downstream regulating gate (Sir. William Halcrow & Partners, 2008). Figure 2.1 below indicated the schematic drawing of an offtakes structures.

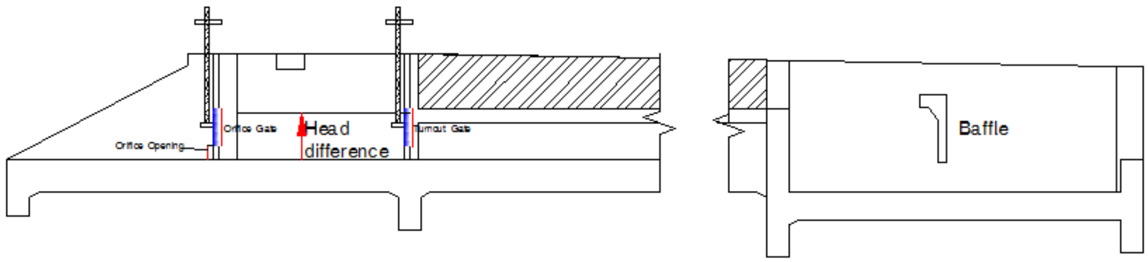

Figure 2.1: Schematic view of constant head orifice turnouts (Sir. William Halcrow & Partners, 2008)

From the reviewed literatures, there is no defined & single way causing the deterioration of irrigation infrastructures. Most of the scholars agreed that there is no well-defined structural link between the irrigation water users and governmental institutions in management of irrigation infrastructures. There is a question raised here; why irrigation water users like Water Users Association (WUAs) lose willingness to take the responsibility of seasonal maintenance of infrastructures? This is the question to be answered in this research.

CHAPTER 3. MATERIALS & METHODS

3.1. General Description of the Study Area

Amibara irrigation scheme is located within the Ethiopian Rift Valley in the Middle Awash, adjacent to the Awash-Mille highway, 265 kilometers (km) away from Addis Ababa as shown in Fig 1 below. The climate of the study area is semi-arid with a bimodal rainfall of 533 millimeters (mm) annually with the long rainy season occurring from July to September accounts for 49 percent of this rainfall (264 mm) and the short rainy season from February to April (156 mm) accounts for 29 percent. The rainfall pattern is characterized by inter-seasonal and inter-annual variations. The mean minimum temperature is 15.2^0C in December and 23^0C in June, while the mean maximum temperature is 32^0 C in December and 38^0 C in June. Mean relative humidity is lowest in June at 36 percent and highest in August at 58 percent. The average daily sunshine hours are 8.5 with an average solar radiation of 536 calories per square centimeter per day (cal/cm_2/day) (Michael & Sileshi, 2007).

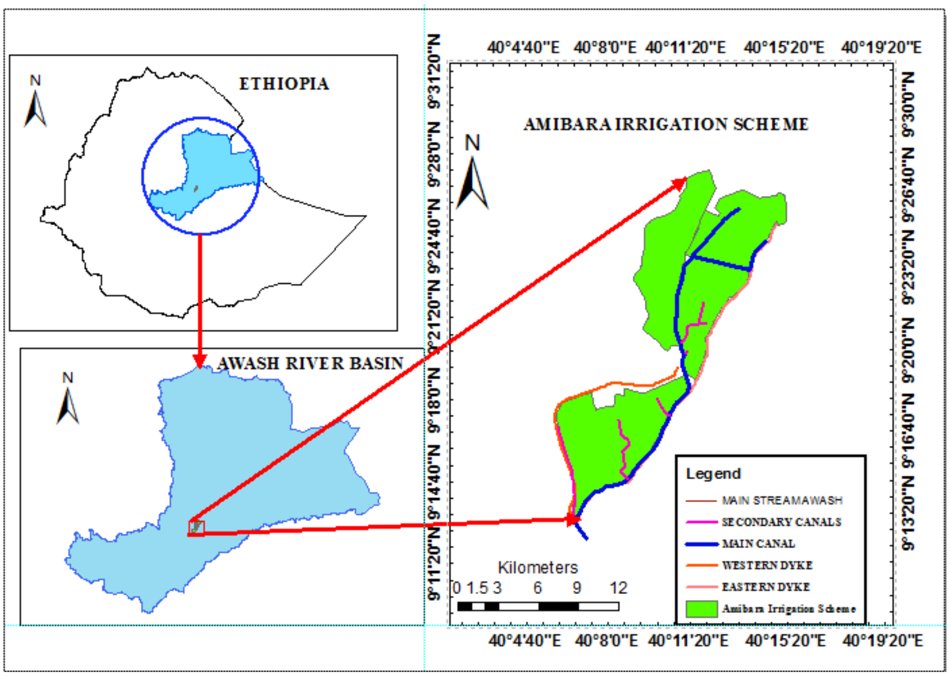

Figure 3.1: Location of Amibara Irrigation Scheme, Ethiopia

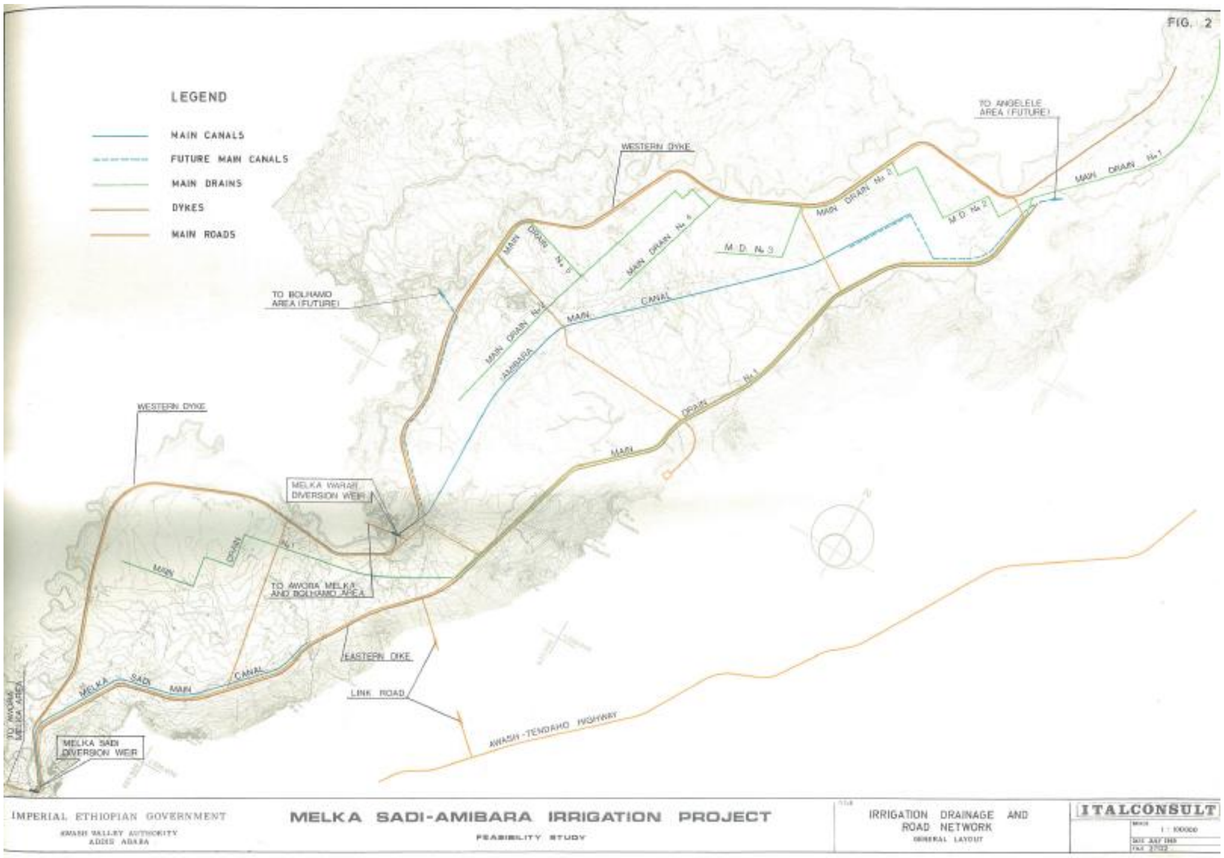

Figure 3.2: Melkasedi-Amibara Irrigation Scheme Layout

3.2. Data Collection

The investigation and condition assessment of scheme hydraulic structures were done through predefined questionnaires, field assessment, interviews with operational staffs and literature review on the scheme background. There were no well-organized data for the scheme since the last ten years. Most information was gathered through interviews and questionnaires at field level.

The questions in the five parts of the checklist adapted from Cornish & Skutsch (1997) Appendix 1, were used as the basis for structured interviews with households & operation staffs Appendix_2 to collect the primary data. The questionnaires were printed and distributed to 9 farm owners or their representatives who were using the selected 7 Secondary Canals (SC), namely SC1, SC2 SC3, SC7, SC8, SC10 and SC11 including their respective Tertiary Canals (TC) ,TC1/1, TC1/3, TC3/1, TC3/3, TC7/2, TC7/4, TC10/2, TC10/4, TC11/2 and

TC11/4. Attention was given during deciding the sample size so that the selected samples can represent the whole scheme. The sample secondary canals were selected through stratifying the main canal as upstream, middle and downstream reaches. Accordingly SC1, SC2 & SC3 represented the upstream, SC7 & SC8 represented the middle and finally SC10 and SC11 represented the downstream users

The households' questionnaire was used to get farmers perceptions regarding effects on farming of a range of factors including agricultural and economic factors, system design and operation, deterioration of system infrastructures, land degradation and consistent water supply at the headwork. The procedure in this research did not cover the investigations required to formulate non-engineering components to the scheme.

On the other hand, the study and detail design documents of the scheme prepared by Halcrow & Partners (1993) were used as secondary data and basic reference for condition assessments of hydraulic structures through selected samples. Secondary data collection was realized through literature review including the scheme design papers, previous investigations and modifications.

Investigation and condition assessment of hydraulic structures were done through predefined procedures developed by (Cornish & Skutsch, 1997). The investigation included the headwork, comprising the diversion weir, the scour sluice, the intake and the head regulator. The whole length of main canal, all the 6 gated check drops along the main canal, 7 out of 10 secondary canals, 10 out of 42 tertiary canals, 10 out of 13 gated offtakes along the main canal were also investigated in this research. The main canal was stratified in to 7 parts taking the gated check drops as starting point for the lower reach and ending for the upper reach of the selected canal length. The guiding principles provided by Cornish & Skutsch (1997) were used to minimize biasness during judgment. Each the selected secondary and tertiary canals were investigated in two locations, one at the upstream and the other at the downstream for best representation of the canals characteristics.

3.3. Identification of the Factors that Lead the Scheme to Perform Below Expectations;

Checklist to define possible performance constraints and households' questionnaire that were relevant to this research were selected & prepared from Cornish & Skutsch (1997) to identify factors that lead the scheme to perform below expectations. The check list indicated the need for further analysis and specialist studies in hydrology, agriculture, management and economics issues. It was used to list down issues which potentially affect the scheme performance after which detailed investigations were carried out. The questions in the check list address the five possible constraints, agricultural and economic factors, system design and operation, deterioration of system infrastructure, land degradation or consistent under-supply at headwork.

However, detailed investigation of non-engineering problems was out of the scope of this research. Those which are relevant for the research were included and prioritized based on their level of significance

3.3.1. Agricultural and economic factors

The agricultural and economic factors include the production inputs such as fertilizers, pesticides, selected seeds, labor, water supply, change in land use land cover, existing organizational/institutional structure and so on. Those non-engineering parameters that were out of the scope of this research were not considered. Among parameters under this category, the investigation of the existing institution was considered through collected information from literature review, the households' questionnaire and interviews with operation staffs

3.3.2. System design and operation

System design and operation factors include method of flow control, operational practice, compatibility between design and operation, staff numbers and variation from design assumptions. The impact of scheme operation on cropping intensity and/or yields, and the variations that exist between intended and actual practice, the flow control methods and water delivery pattern for which the scheme was originally designed were included. Information was collected through discussions with operational staffs, from the observation of structures and water levels in the field, from review of operation manuals, and original design criteria and assumptions.

3.3.3. Deterioration of system infrastructure

Detailed information on deterioration of infrastructure, and its likely impact on hydraulic performance, was obtained using the condition assessment procedure. Early, discussions with operations staff can indicate the location of problems arising from structural deterioration. Information obtained in this way was cross-checked through the condition assessment procedure and localized studies of hydraulic performance, where these are required.

3.3.4. Land degradation

The impact of flooding, shallow ground water table, land fragmentation, erosion & salinization on performance of the scheme was assessed through field investigation, household’s questionnaires distributed to 9 farm owners/representatives who were using the sampled secondary and tertiary canals for irrigating land. The households freely include their perceptions on the space provided in the questionnaire.

3.3.5. Consistent under supply at the headwork

Under this tittle, the adverse effects of variation from design discharge, command area less than design, reduced conveyance capacity of the system deterioration of supply and unrealistic design hydrology are included.

Possible performance constraints and households Questionnaire that are relevant to this research were adapted from Cornish & Skutsch (1997) were used to identify factors that lead the scheme to perform below expectations. The check list indicated the need for further analysis and specialist studies in hydrology, agriculture, management and economics issues. It was used to list down issues which potentially affect the scheme performance after which detailed investigations were carried out. The questions in the check list address the five possible constraints as agricultural and economic factors, system design and operation, deterioration of system infrastructure, land degradation or consistent under-supply at headwork.

Information was gathered through questionnaires and households' interview and level of significance of each parameter was analyzed based on the facts and ground truth. Each factor in the list was checked in one of five classes, Very high, High, Medium, Low and Very Low which show the level of significance of the parameters to alter the scheme performance.

With minor modifications, guiding points by Cornish & Skutsch (1997) were adopted to reduce subjectivity during judgment of conditions of infrastructures. The guiding points include how frequent the factor affect the scheme and how long does it last?, What was the areal extent of the problem? How severe it was? was performance deteriorate further if action is not taken. With minor modifications, the guidance adopted from Cornish & Skutsch (1997) was used as reference in assigning responses or observations to the categories "Major" and "Minor" was set out below:

Very High Significance-households from around 25% of the command area report a particular factor regularly limits crop yields or area in one or more seasons per year.

AND/OR

Operations staff, field inspection and/or operations records indicate that the factor regularly causes under - supply reduction in yield or irrigated area on around 25% of the command area.

High Significance - Farmers in less than, say, 20% of the command area report a particular factor regularly limits crop yield or area in one or more seasons per year.

AND/OR

Operations staff, field inspection and/or operations records indicate that the factor causes under-supply, reduction in yield or irrigated area on less than 20% of the command area.

Medium Significance - Farmers in less than, say, 15% of the command area report a particular factor regularly limits crop yield or area in one or more seasons per year.

AND/OR

Operations staff, field inspection and/or operations records indicate that the factor causes under-supply, reduction in yield or irrigated area on less than 15% of the command area.

Low Significance - Farmers in less than, say, 10% of the command area report a particular factor regularly limits crop yield or area in one or more seasons per year.

AND/OR

Operations staff, field inspection and/or operations records indicate that the factor causes under-supply, reduction in yield or irrigated area on less than 10% of the command area.

Very Low significance; the factor does not appear to limit performance.

Level of significance of each parameter with respect to its effect on the scheme performance was determined through 9 household questionnaires at farm level and interview made with operational staffs, condition assessment of irrigation hydraulic structures, review previous documents. The possible constraints were identified and their level of significance to affect the scheme performance was judged as very low, low, medium, high and very high. After prioritizing level of significance checklist for possible constraints of the scheme for relevant parameters, selected households were interviewed for comparing their sayings with the check results. The overall purpose of the check list and the households' questionnaire were to characterize scheme performance, identify key constraints and to allow priorities to be established. The scheme was stratified to three categories based on location relative to the head of the scheme and main canal. In this regard, the upstream, the middle and the tail reaches of the main canal were selected for households' interview.

The questionnaire was very helpful to assist in the diagnosis of the scheme rather than to provide a broad survey of the socio-economic conditions of housholds. The information obtained by the questionnaire indicated the effects on farming of a range of factors including water supply, flooding, and agricultural inputs.

3.4. Evaluation of the Current Status of Irrigation Hydraulic Structures

Field investigations were undertaken to assess both the structural integrity of system components and their fitness to control and/or convey flows as compared to the design values. The designed values were taken from water management manual that had been prepared during the design of the scheme by William & Partners (2008). Two-stage procedure was adopted for the investigation of the condition of the infrastructure. The first assessment was done by relatively unskilled staffs through standard questionnaire requiring a YES or NO response to each question (Cornish & Skutsch 1997). The questions were all formulated such that a YES response indicates a defect; a NO response implies No defect.

Based on the YES or NO responses of the first stage assessment, fixed scores (Appendix 4) had been assigned by Cornish & Skutsch (1997) to any "Yes" response, while "No" responses all score 100. These fixed scores were used for subsequent analysis to put priorities on works. The (CI) is the score associated with the element in worst condition. Second stage detailed assessment was undertaken for the components which were rated as "poor" or "very poor" class.

According to the definition of Cornish & Skutsch (1997), the CI is combined with measures of the percentage command area served and the importance of the asset type, to arrive at an indicator of priority for improvement. It is a measure of the benefits which would be foregone if the asset were not improved. Cornish & Skutsch (1997), defined the range of Condition Index Status for the elements of structures.

Accordingly,

100 - 81 Good - A YES response returned for a question (s) related to a minor fault. No significant structural deterioration or loss of hydraulic function.

70 - 80 Fair -. indicates partial loss of function and/or some risk to the integrity of the structure. Action not immediately urgent in this case.

51 - 69 Poor - A serious loss of function and/or potentially serious threat to structural integrity. Action needs to be taken to prevent progressive failure.

< 50 Very poor - Effective failure.

Based on the above guiding principles, the selected samples were investigated and the level of their functionality was evaluated using predefined questioners adopted from (Cornish & Skutsch, 1997).

3.4.1. Diversion Weir

The current condition of the weir was investigated according the questionnaires prepared by (Cornish & Skutsch, 1997). The investigation was done to ensure if it was seriously damaged, whether it was capable to maintain the designed water level. The condition of upstream and downstream siltation, structural stability and cracks, the downstream apron and the status of gauging stations were also considered during the investigation of the diversion weir.

3.4.2. Intake

The intake structure was not visible during the investigation because of their submergence in the river. However, deep divers, who are working regularly the clearing of debris and trees from the trash rack, were interviewed at field level to judge the condition of the intake structure.

3.4.3. Scour sluice

During the investigation, only the operation tower was observed and status of the structure and its structural integrity was checked through interview of the operational staffs. The investigation through interview at field level and field inspections include if the intake structure was blocked by debris, the level of its damage, stability and crack problems if any.

3.4.4. Head regulator

The head regulator was checked for missing gates, simplicity to open and close the gates, if reading gauges are functioning, if it had developed serious corrosion and so on. The interview with operational staffs and gate operators added additional information about the structure.

3.4.5. Main canal

The main canal was investigated all over its length in such a way that the reach between each controlled check drops taken independently. Stratification of the main canal was done as shown in table 3.1.

Table 3.1: Assessment Reaches of Main Canal

Main Canal Reaches	From	To	Length
Main Canal (00-1+934)	HR	CD_1	1934
Main Canal (1+934-7+179)	CD_1	CD_2	5245
Main Canal (7+179-11+704)	CD_2	CD_3	4525
Main Canal (11+704-17+169)	CD_3	CD_4	5465
Main Canal (17+169-19+264)	CD_4	CD_5	2095
Main Canal (19+264-20+716)	CD_5	CD_6	1452
Main Canal (20+716-22+500)	CD_6	2400m	1784
Main Canal (22+500-25+500)	2400m	2700	3000

The investigation, through the predefined questionnaires and field inspection, the canal was checked if it was blocked by illegal users, condition of siltation and weeds grow on canal section, if there was bank slippage.

3.4.6. Controlled check drops

All the elements of the 6 check drops were assessed to investigate if any gates were missed, the simplicity of opening and closing the gates and stability and damage conditions of the check drops. The predefined questionnaires adopted from Cornish & Skutsch (1997) were used to collect these information.

3.4.7. Constant head orifice offtakes

The questionnaires adopted from Cornish & Skutsc (1997), were used to determine the overall conditions of sampled irrigation hydraulic structures. Were used to check if gates were missed, cracks, stability and cracks of the gated offtakes.

The questionnaires responding “YES” or “NO” were used for all selected samples of irrigation structure with little deference of the questionnaires for one structure type to the other. For a response of “YES” or “NO” to each questionnaires in the table, the asset is classified ass very good, good, poor or very poor. For each of the classes from very poor to very good, fixed scores adapted from Cornish & Skutsch (1997) were used to assign the corresponding structural effectiveness in percent for the structure under consideration. The numerical value for the overall condition of the asset was then found by averaging the results for each questionnaire in the table. Based on the numerical value of overall condition of the asset, its general class, from “very poor” to “very good” was determined depending on the predefined range established by (Cornish & Skutsch, 1997).

3.5. Evaluation of causes for failure and setting prioritization for rehabilitation of irrigation structures

Structured questionnaires adapted from Cornish & Skutsch (1997) were distributed to 9 households at farm level and operational experts. Technical experts were interviewed to evaluate the questionnaire based on their professional judgment. The technical staffs used their long year experience to evaluate if the failure of the scheme was caused institutional arrangement, lack of skilled manpower, policies, maintenance or environment. The questionnaires were very useful to capture farmer’s perception on which factors had been dominantly causing the deterioration of infrastructure of the scheme.

In addition to reviewed literatures, interviews and questionnaires, local community, surrounding institutions and the operational staffs were communicated in formal and informal ways to get the historical background of the scheme management. There are a number of formal reports, design documents, manuals and guidelines regarding the technical operations of the scheme. However it was difficult to get well organized institutional profile regarding the transfer of operation and maintenance of scheme infrastructure.

After condition assessment of hydraulic infrastructures, priority index has been set for decision of improvement & rehabilitation of the infrastructures. The priority index takes into account, asset condition, as calculated from the inspection during the first assessment by the delegated staffs, a measure of the area served by that particular asset relative to the total area and the indicator reflecting the strategic importance of the asset.

As per Cornish & Skutsch (1997), strategic importance for each asset type was given on a scale of 1 to 4 as shown in table 3 below. The score was intended to reflect the importance of its function, hazard in the event of failure, and relative cost of rebuilding.

Table 3.2: Strategic Importance of Assets adapted from (Cornish & Skutsch, 1997)

Score=1	Score=2	Score=3	Score=4
Measurement structure	Canal reach	Cross drainage culvert	Diversion weir*
	Drain	Aqueduct	Embankment dam*
	Head regulator/	Syphon	Barrage*
	Gated offtakes		Intake works
	Cross regulator		
	Drop/chute		
	Inspection road		

The Priority Index was calculated from the following formula:

$$\text{Priority Index (PI)} = (100\text{-CI}) \text{ X } \left(\sqrt{\frac{a}{A}}\right) \text{ x Is}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where: CI= Condition Index

a= the area served by, or dependent on, the asset

A= Command area of the scheme

Is= Importance score

The asset with larger value of priority index takes the first priority and vice versa. The calculation of the Priority Index for ranking was done using excel spreadsheet by linking the data of inspection in the first phase of assessment with the predefined class and fixed scores from appendix-4. The values of priority index were used to prioritize the rehabilitation and maintenance measures.

The conceptual framework adopted from Cornish & Skutsch (1997) with little modification was used to evaluate determinants of performance and guidance for the diagnostic methods.

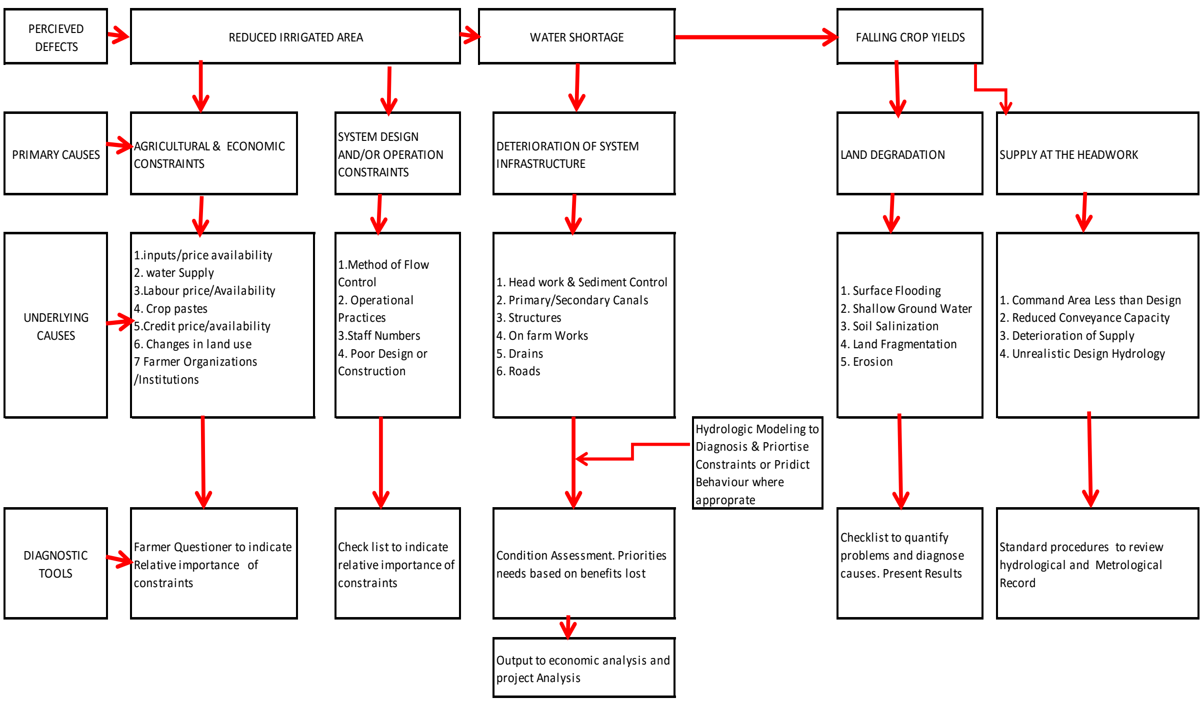

Figure 3.3: Conceptual framework of the process adapted from Cornish & Skutsch (1997).

3.6. Data Analysis

Data analysis to determine the overall condition of hydraulic structures was done using if statement and nested if statements in Microsoft excel 2010. The primary input for the analysis was the level of significance of individual infrastructure components according to its effect on system performance. Cornish & Skutsch (1997) catagorized the level of significance as major, minor and no significance dependin on the effect of individual infrastructure on the irrigation scheme. In this research minor modification was done to minimize generalization of judgment among the three catagories namely major, minor and no significance. Instead the catagories were taken as very high, high, medium, low and very low to indicate the effect of individual structure on the system performance. The results of first phase condition assessment which responds “Yes” or “No” for the predefined questionnaires were used for subsequent analysis to put priorities on rehabilitation works of the scheme. Fixed scores had been assigned, to any “Yes” response while “No” responses all score 100. These fixed scores were adapted from Cornish & Skutsch (1997) and samples were annexed as (Appendix 4). The condition index (CI) is the score associated with the element in worst condition. It include classes as very good, good, poor and very poor with values of CI 100-81, 70-80, 51-69 and <50 respectively.

The if statement was used to respond very good, good, poor & very poor for any excel cell with “yes” or “No” values. The predefined excel program involved the following logical tests where numerical results displayed on the selected cell.

IF(condition, value_if_true1, IF(condition2, value_if_true2, value_if_false2))

The following if statements, directly copied from the formula bar of excel sheet during utilizing it, indicated some of the analysis used during condition index analysis

```
=IF(D20="Yes","Very poor",IF(D20="No","Very Good"))

=IF(D24="Yes","Fair", IF(D24="No", "Very Good"))
```

Where D20 & D24 were the cell for which the condition test is applied.

After the condition index determined as good, fair, poor and very poor, the corresponding effect of deterioration of each element on overall effectiveness was judged and fixed score values were allotted that represent the remaining percentage effectiveness of that specific element. The if statement was used to assign predefined numerical values for the terms “Good”, “Fair”, “Poor” and “Very Poor” as shown sample below.

```
=IF(Headwork!E26="Good".90.IF(Headwork!E26="Good".75.IF(Headwork!E26="Poor".60.IF(Headwork!E26="Verv Poor".40))))
```

The predefined numerical values of condition index adapted from Cornish & Skutsch (1997) were averaged and allotted for each condition status (very good, good, poor and very poor) and tabulated as shown in the above sample. The overall condition of specific infrastructure element was then determined by taking the average value of the whole questionnaires responding “Yes” and “No” responses and the analysis results for each infrastructure element were indicated in Appendix 1. Under the condition classification system adopted from (ornish & Skutsch (1997), classes Good and Fair require only minor work, not urgent at present, which could be addressed under a program of minor maintenance. Works defined as Poor or Very Poor require imminent actions of the concerned institutions. The overall condition of assets was analyzed nested if statement to consider the range as shown in sample below.

```
=IF(F13<=50,"Very oor",IF(AND(51<F13,F13<70),"Poor",IF(AND(71<=F13,F13<=80),"Good", IF(AND(F13>80, F13<100), "Good"))))
```

According to Cornish & Skutsch (1997), ppriority ranking was set based on three elements: the condition of a component (CI), the area served by the structure under consideration, and a measure of strategic importance of the component table 3. The priority ranking method produces priorities which are independent of each other, in other words, there is no direct link to ensure that all components needed to produce an anticipated improvement in performance are ranked together.

Priority Index was calculated using equation1 on excel spreadsheet to produce a ranking of works. The results were arranged in descending order where the larger value of (PI) takes the first priority for action and vice versa.

conceptual framework adopted from Cornish & Skutsch (1997) with little modification was used to evaluate determinants of performance and guidance for the diagnostic methods

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1. Identification of the Factors that Lead the Scheme to Perform Below Expectations

4.1.1. Agricultural and economic factors

From households' interview, it was found that there was neither responsible institution nor organized water users association for operation and maintenance of the scheme infrastructures for the last ten years. As a result, it was observed that bad control/operation of the main canal system, blocked drainage system, salinization of land, surface flooding and malfunctioning of irrigation structures were the major factors that lead the scheme to perform below expectations.

4.1.2. System design and operation

According to operational staffs, there are significant differences between design and actual water control practices. Traditional and illegal diversions became common for the last ten years with no defined institution to monitor such issues. Most of the irrigation and drainage structures were being operated out of the criteria in their design. Headwork and sediment exclusion and/or flushing structures had been failed to effectively operate and to minimize sediment entry to the canal system. The operation staffs witnessed that canals had been fully loaded with sediment every rainy season and there was no responsible body for regular maintenance. It was also found that change in river morphology and increased sediment load in the river call for significant change in the assumptions during the design of the scheme and actual conditions.

4.1.3. Deterioration of system infrastructures

Detailed information on deterioration of infrastructure, and its likely impact on hydraulic performance, was obtained through field investigation and condition assessment procedure of the sampled hydraulic structures. The results of the procedure were discussed in detail in section 4.2 below.

4.1.4. Land degradation

From households' questionnaire, field assessment and interviews, it was found that surface flooding regularly affected part of the command area causing yields to be depressed and land to be left uncultivated. Thirteen years command area data collected from Middle Awash Agricultural Enterprise, indicated that command area was reduced from one year to another due surface flooding, shallow ground water and salinity problems. Some of command areas with significant reduction were shown in figure 5 below. From the graph, the command areas irrigated through tertiary canals 10/1 and 3/2 remained costnat after the year 2007 while tertiary 3/1 continued in decreasing command area up to the 2012. It was observed that T3/1 was near the Awash River where the river escaped from its course and flowing near the dyke. This situation caused the rise in ground water table and salinization of the area gradually increased.

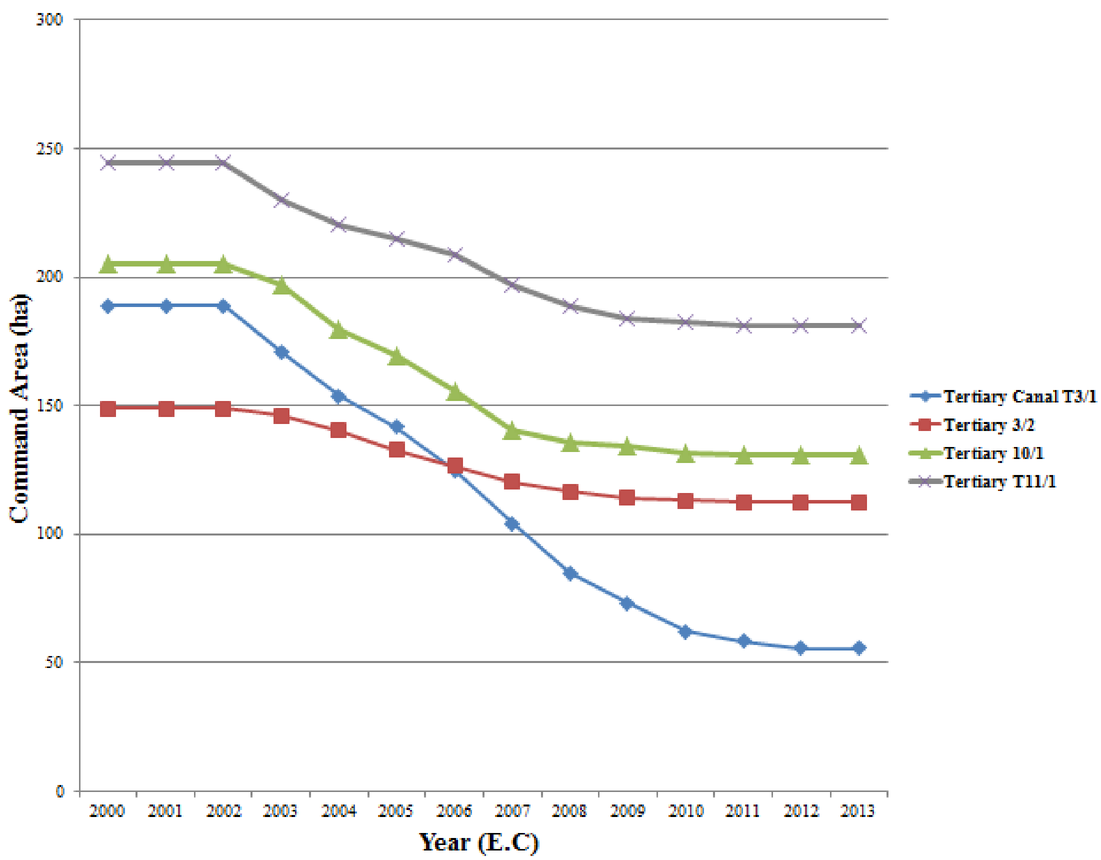

Figure 4.1: Command Area Reduction

4.1.5. Consistent under supply at the headwork

Level of significance of each parameter was analyzed based on the facts and information gathered through questionnaires and households' interview and the results were tabulated in table below. After detailed discussions with technical staffs, level of significance of each parameter for affecting the scheme performance was defined as shown in table 4.1 below.

Table 4.1: Level of Significance for Factors Affecting Performance of Irrigation Scheme

Parameters	**Category**	**Level of Significance**
Existing organizations/institutions	Agriculture and Economics	Very High
Condition of assets	Deterioration of system infrastructure	Very High
Headwork & sediment exclusion	Deterioration of system infrastructure	Very High
Head regulators	Deterioration of system infrastructure	Very High
Drains	Deterioration of system infrastructure	Very High
Reduced conveyance capacity	Supply at the headwork	Very High
Deterioration of supply	Supply at the head work	Very High
Operational practices	System design and operation	Very High
Design/operation compatibility	System design and operation	Very High
Variation from design assumptions	System design and operation	Very High
Water supply	Agriculture and Economics	High
Land out of command	Agriculture and Economics	High
Primary canals	Deterioration of system infrastructure	High
Secondary canals	Deterioration of system infrastructure	High
Off-takes	Deterioration of system infrastructure	High
Surface flooding	Land degradation	High
Shallow groundwater table	Land degradation	High
Soil salinization	Land degradation	High
Variation from design discharge	Supply at the headwork	High

4.2. Evaluation of Current Status og Hydraulic Structures

4.2.1. Headwork

The survey data during the investigation indicated that river bed had been significantly raised over the weir, invert levels of the scour sluice and the intake. During the interview session, the operation staffs stated that diversion of water to the main canal is very difficult and almost impossible during high water level in the river. The reason is that the sediment load and debris directly enters in to the intake and block the flow to the canal. Divers are trying to disturb around the intake by using compressor and long reach excavator to open the intake. As the water level increases, the divers stop on the excavator bucket and send the pressure hose to the intake. But they may not get the exact location of the sediment deposit. This operation is very tedious and tiresome with probability of failure to meet the objective. According to the operational staffs, there had been a number of emergency works, especially during rainy seasons to deliver the river water for the irrigation scheme. Most of the alternatives were not successful with some trials caused flooding.

Over time, a new free intake was constructed about 25m upstream of the existing head works, and operates when the water level is high. Although sited on the outside of the river bend, there is no scour sluice or sediment exclusion facility at this new intake, so that high sediment loads are directly drawn into the main canal. This alternative intake structure also doesn't solve the problem. It can deliver water when the river water level reaches 753m a.s.l and above. The operational staffs added that sometimes both the old and the alternative structures do not function well. On the other hand, the head regulator was observed that it is difficult to operate as per the design. Rather, the gates are always opened and closed using machine and labor forces. Due to considerable increase of riverbed level, the intake structure was overtopped in May, 2017.

Therefore, the condition assessment in general indicated that the headwork faced multiple problems which can collapse the scheme at any an expected time. No structures, the weir, the intake, the scour sluice and the head regulators were in a condition of delivering their duties in appropriate way.

The analysis results of the headwork generally indicated that, the overall condition of the intake structure and the scour sluice fall under very poor condition with priority index of 180 whereas the weir and the head regulator were found to be under poor condition with priority index value of 75 and 120 respectively.

Figure 4.2: Current condition of scouring sluice

4.2.2. Main canal

There is no formal institution taking the responsibility of operation and maintenance of the scheme. Consequently, there is no regular maintenance of all structures including the main canal. During the investigation, the main canal was found with dense weeds of *prosopis juliflora* on its left and right banks and partially filled with sediment load. The canal was blocked illegally at a number of spots by debris, sand bags and other materials.

Figure 4.3: Illegal Diversion from main canal (reach CD1-CD2)

Figure 4.4: Current condition of main canal before disilting

The operation staffs and farmers reported that the main canal repeatedly filled with sediment and no proper disilting work executed. Sometimes some of irrigation users with relatively large irrigation command area tried to maintain the canal by themselves just in front of their farm. This operation hadn't solved the problem because of inconsistent canal bed slope. As a result the canal reach that had been by the users immediately filled with silt load after delivery of irrigation water.

4.2.3. Secondary canals

The main problems of the secondary canals were the diminished section due to sediment load and weed growth on the banks. As reported by the operational staffs, the maintenance of secondary canals had been covered by the irrigation water users. However, there is no cross check if they did the maintenance to standard. The disilting works are mostly done randomly without surveying work to minimize the operational cost. As a result, the canals had lost their shape and capacity to carry the required discharge. The following pictures indicate the current condition of selected secondary canals.The analysis results of the secondary canals indicated that most of their current condition falls under fair condition with minor maintenance and rehabilitation works. The illegal blockage of the canals and restriction in water supply due weeds and sediment in the sections of the canals were the major problems found during investigation.

4.2.4. Gated cross regulators

The gated cross regulators across the main canal are six in number. During the investigation, it was observed that almost all the gates are not functioning; they are difficult to open or close. The reading gauges are distorted or missed whereas downstream aprons are damaged. The concrete structures are almost in good condition with minor maintenance demand. All the gates should be dismantled and replaced by new ones.

Figure 4.5: Current condition of CD $_3$

4.2.5. Gated offtakes

The main problems observed on the gated offtakes were the difficulty to open and close the gates, corrosion of the gates, and blockage of intakes by sediment load and debris. The reinforced concrete structures are more or less in good condition.

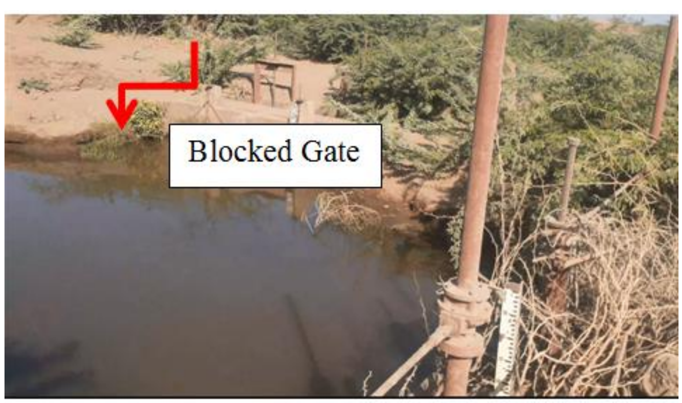

Figure 4.6: Current condition of gated offtake 2 (PO_2)

4.2.6. Tertiary canals

The problems observed with tertiary canals during the investigation were, restricted cross-sections due silt and weeds, limitation of irrigation water due to poor irrigation management, an authorized users from the canals.

The result summary of overall condition and the values of priority index of each investigated hydraulic structures were shown in tables 5.

Table 4.2: Summary of Overall Condition of Irrigation Hydraulic structures

Category	Type of Structure / Structural Element	Effectivenes s %)	Over all Condition
Head Work	Intake Structure	49.00	Very Poor
Head Work	Scour Sluice	50.00	Very Poor
Main Canal Reaches	Head work to CD_1	43.00	Very Poor
Head Work	Head Regulator	61.00	Poor
Gated Check Drops	Check Drop one (CD_1)	63.00	Poor
Gated Check Drops	Check Drop one (CD_2)	61.00	Poor
Gated Check Drops	Check Drop one (CD_3)	61.00	Poor
Gated Check Drops	Check Drop one (CD_4)	61.00	Poor
Gated Check Drops	Check Drop one (CD_5)	61.00	Poor
Gated Check Drops	Check Drop one (CD_6)	61.00	Poor
Main Canal Reaches	CD_1 to CD_2	56.25	Poor
Main Canal Reaches	CD_2 to CD_3	54.00	Poor
Main Canal Reaches	CD_3 to CD_4	69.29	Poor
Main Canal Reaches	CD_4 to CD_5	67.50	Poor
Secondary Canals	Secondary Canal eleven (S_{11})	68.44	Poor
Gated Offtakes	Primary Offtake two PO_2	67.00	Poor
Gated Offtakes	Primary Offtake three PO_3	59.00	Poor
Gated Offtakes	Primary Offtake seven PO_7	63.75	Poor
Gated Offtakes	Primary Offtake eight PO_8	59.00	Poor
Gated Offtakes	Primary Offtake ten PO_{10}	59.00	Poor
Gated Offtakes	Primary Offtake eleven PO_{11}	59.00	Poor

After the overall condition of irrigation structures had been evaluated and determined, the priority index was calculated using equation (1) arranged tabulated in descending order such that the first element need the first priority and vice versa. Table 9 below described the index values of the sampled infrastructures.

Table 4.3. Priority index values

Asset List	Category	Area Sereved (ha)	Area Ratio (a/A)	Importance	Condition Index (CI)	Priority Index
Intake Structure	Head Work	10,300.00	100.00%	3	40	180.00
Scour Sluice	Head Work	10,300.00	100.00%	3	40	180.00
Head Regulator	Head Work	10,300.00	100.00%	3	60	120.00
Main Canal (00-1+934) (HR to CD_1	Main Canal	10,300.00	100.00%	2	40	120.00
Check Drop 1 (CD_1)	Gated Cross Regulator	10,300.00	100.00%	2	60	80.00
Diversion Weir	Head Work	10,300.00	100.00%	3	75	75.00
Check Drop 2 (CD_2)	Gated Cross Regulator	7,743.00	75.17%	2	60	69.36
Main Canal (1+934-7+179) (CD_1 to CD_2	Main Canal	7,743.00	75.17%	2	60	69.36
Check Drop 3 (CD_3)	Gated Cross Regulator	6,735.00	65.39%	2	60	64.69
Main Canal (7+179-11+704) (CD_2 to CD_3	Main Canal	6,735.00	65.39%	2	60	64.69
Check Drop 4 (CD_4)	Gated Cross Regulator	6,095.00	59.17%	2	60	61.54
Main Canal (11+704-17+169) (CD_3 to CD_4	Main Canal	6,095.00	59.17%	2	60	61.54
Check Drop 5 (CD_5)	Gated Cross Regulator	5,366.00	52.10%	2	60	57.74
Main Canal (17+169-19+264) (CD_4 to CD_5	Main Canal	5,366.00	52.10%	2	60	57.74
Check Drop 6 (CD_6)	Gated Cross Regulator	4,491.00	43.60%	2	60	52.83

4.3. Evaluating causes of failure and setting priorities for improvement of existing irrigation hydraulic structures

It was found that the significant factors that cause the system deterioration were the sediment load transported to the middle Awash reach of the main river from highlands, frequent institutional changes on scheme management. The existing rock fill weir was completed in 1984 with a weir crest level of +749.0 meters above sea level. The original sediment exclusion arrangements incorporated in the headwork (a single under-sluice about 2m x 2m in size) had been proved unsatisfactory. Consequently, large amount of sediment load gets drawn into the primary canal every year. Since its completion in 1984, the primary canal had been desilted regularly and about 0.5m of silt had been excavated annually from the entire length of the canal and from many reaches of secondary canals. The aggrading riverbed completely buried the weir, the intake and scour sluice with sediment raising the riverbed level to about +750.5, indicating an annual rate of aggradation of 70cm Sir.William Halcrow & Partners (2008).

From the structured interviews, questionnaires and literatures, it was found that the other significant cause for the deterioration of the scheme infrastructure was lack of responsible institution for regular operation and maintenance of scheme infrastructures. There was no formal governmental institution or well organized water users association that can undergo regular operation and maintenance of scheme infrastructures. The scheme had been considered as modern irrigation system that had full facilities of operation since its establishment in 1973. The operation and maintenance of the system had been strictly executed by well-organized institution until the establishment of Awash Basin Authority in November, 2008 which was responsible for operation and maintenance in the previous years. The scheme operation and maintenance activity had been excluded not only from the mandate of the Authority, but also missed from the establishment regulation of the Federal Irrigation Development Commission. Consequently, operation and maintenance activities had been pended for the last thirteen years generated complex situations frustrating irrigation developers.

CHAPTER 5. CONCLUSSIONS AND RECOMMENDATIONS

5.1. Conclusions

The investigation and condition assessment of the Scheme revealed that the headwork, comprising the weir, the intake and the scour sluice had serious hydraulic and structural failure that may cause the collapse of the scheme at any time. It was concluded that the head work cannot be maintained due increased river bed level and submergence of the scour sluice and the intake structures. Redesign and relocation of the headwork become mandatory for suitability of the scheme. From literature review, households' questionnaires and interviews, it was concluded that lack of responsible institutions or well organized water users association for the last ten years aggravated the deterioration of scheme infrastructures. Water logging, flooding, salinization and blocked drainage system were the main challenges that frustrate the irrigation developers. Under all cases, the scheme as a whole was deteriorating from time to time,

Generally it was concluded that the root causes for the deterioration of the scheme infrastructure were heavy river sedimentation and lack of responsible institution for operation and maintenance of the scheme infrastructures.

5.2. Recommendations

It is not advisable to maintain the headwork which is almost impossible due to high river bed level. This research recommended the implementation of relocation of the headwork to the upstream which had been studied & designed by WWDSE, (2017).

The study by WWDSE (2017) had recommended diversion structure (weir) just upstream of the current intake with geographical location UTM 622851E and 1017615N. This structure not only solves the diversion problem, but also it enables the flood protection works at the current headwork. The proposed intake structure does not change the alignment and shape of the current conveyance system except minor modification to the most upstream part of the main canal. The consultant had estimated the construction cost of the structure as 274,296,126.00 at that time (2017) which may increase due to inflation at this time. The hydraulic and structural integrity of main canal, check drops, gated offtakes, secondary canals, tertiary canals and related structures need rehabilitation as per their priority index values in table 4.2 above.

Therefore, the Ministry of Water Irrigation and Energy (MoWIE) has to take the responsibility to draft and get approval of government to restructure the sector in which responsible governmental institution assigned for operation and maintenance of irrigation schemes. On the other hand, Organizing and capacity building for irrigation water users must be considered to have their own share on operation and maintenance of the scheme. This research recommended that the operation and maintenance of the headwork and the main canal including gated check drops and gated offtakes should be handled by governmental institution. The users, after capacitating their knowledge through short term training, can take the responsibility of operation & maintenance from secondary canals to field canals.

However, rehabilitation of overall scheme including construction of new diversion structure is mandatory before sharing responsibilities of operation and maintenance activities among water users and governmental institutions.

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APPENDICES

Appendix 1: Record Summary Sheet of Possible Performance Constraints

1	System design and operation	Significance					Remark
		Very High	High	Medium	Low	Very Low	
1.1	Method of flow control						
1.2	Design delivery pattern						
1.3	Operational practices						
1.4	Design/operation compatibility						
1.5	Staff numbers						
1.6	Variation from design assumptions						
1.7	Inappropriate design						
2	Deterioration of system infrastructure						
2.1	Condition of assets						
2.1.1	Headwork & sediment exclusion						
2.1.2	Primary canals						
2.1.3	Secondary canals						
2.1.4	Head regulators						
2.1.5	Cross regulators						
2.1.6	Off-takes						
2.1.7	Distribution works below off takes						
2.1.8	Drains						
2.1.9 2.1.10	Roads Others						

Appendix 2: Questionnaire: Farmers' View on System

Constraints and rehabilitation needs

Date: ______________ Interviewer: __________________________

Scheme Name: ____

Type of interview:

Single farmer ☐ name: _________________________

Group of farmers ☐

Location and water source

Village name: ____

Canal name: ___________ Tertiary off-take name/s: _______________

Most irrigation water is taken from:

Authorized off-take……. ☐

Unauthorized off-take…. ☐

Re-use from drains……. ☐

Wells ………………..… ☐

Notes: ____

Cropping intensity

Do you regularly leave land un-planted in one season or more per year?

Yes ☐ No ☐

If "Yes", why do you not plant in those seasons?

Lack of water……………………………………………………… ☐

Land is flooded …………………………………………………… ☐

Poor supply of other inputs -labor, seed, fertilizer, pesticides….. ☐

Prefer to spend time in other activities…………………………… ☐

High risk of pest attack ……………………………………….. ☐

Other ______________________________________

Have you been able to irrigate more land or plant more crops per year in the past?

Yes ☐ No ☐

If "Yes", what has caused the change?

Lack of water……………………………………………………….... ☐

Land is flooded …………………………………………………………………………… ☐

Less land available (land use changed)………………………………………………………… ☐

Poor supply of other inputs - labor, seed, fertilizer, pesticides…... ……………………….. ☐

No need/desire to work for another crop ……………………………………….. ☐

Prefer to spend time in other activities ……………………………………………… ☐

Other ______________________________

Notes: ____

____

____

CROPPING - YIELDS

Do farmers think their yields are normally?

	Good	Average	Poor
First Season			
(Month of harvest_____________)	☐	☐	☐
Second Season			
(Month of harvest_____________)	☐	☐	☐

If yields are poor then what, in the farmers' opinion, is the cause?

Water supply ………… ☐

Seed type…………… ☐

Time of planting…… ☐

Soil fertility………… ☐

Weeds……………….. ☐

Crop pests ……………. ☐

Drainage …………….. ☐

Other ______________________________

Notes: ____

A Water supply

Was/is the rainfall amount:

	More than Average	Avarae	Less than Average
Present season	☐	☐	☐
Last season	☐	☐	☐

Was the rainfall higher in the past?

Yes ☐ No ☐

Is the irrigation supply normally good, i.e. enough water and a regular supply?

In First Season Yes ☐ No ☐

In Second Season Yes ☐ No ☐

If the supply is not good, do farmers describe the supply as:

	First Season	2nd. Season
Insufficient all through the season …..	☐	☐
Insufficient at times of peak…………..	☐	☐
Demand (land prep)……………………	☐	☐

If the supply is not good then what, in the farmers' opinion, is the cause?

	First Season	2nd. Season
Not enough water in the river or reservoir ……………………	☐	☐
Bad control/operation of the main canal system……………..	☐	☐
Other farmers take too much water……………….………….	☐	☐
The condition of the main canal system……………………….	☐	☐
Distribution/control of water below……………………………	☐	☐
The tertiary off-take ………………………………………….	☐	☐

Other ____

Notes: ____

____

____

Flooding

Does flooding around this area ever prevent planting or cause damage to crops?

Yes ☐ No ☐

If "Yes", then:

In which month or months is flooding a problem?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

For how long is the land flooded?

____

Does flooding prevent cropping or reduce yield:

Every year ☐

Most years ☐

Occasionally ☐

Farmers think the cause is:

Blocked drains ☐

No drains ☐

Other ____________________________________

Notes: ____

____

On-farm structures and water distribution

Does the off-take from the main system, or the canal and structures below it, cause problems of water supply for any farmers in the block?

Yes ☐ No ☐

If yes, describe the problem ___________________________________

____

Priorities for change

What is the most serious problem that limits crop production in:

First Season? ____

____

Second Season?

____

____

Notes

Note any unusual and short term constraints influencing production or farmer perceptions at the time of carrying out the interview of farmers

____

____

Appendix 3A: First Phase Condition assessment

Structure type: Intake (Or Head Regulator)

	Yes	No	Not Assessed
1. Are any of the gates missing? ………………………………	☐	☐	☐
2. Is it difficult to fully open or close any of the gates? ………	☐	☐	☐
3. Is any gate seriously corroded or rotting? …………………	☐	☐	☐
4. Are there serious cracks or movement in any part of the structure?	☐	☐	☐
5. Is any part of the structure blocked by sediment? ………………….	☐	☐	☐
6. Is seepage occurring around the structure? ………………………..	☐	☐	☐
7. Is the d/s apron seriously damaged or undercut? …………………..	☐	☐	☐
8. Is it difficult to read the u/s or d/s gauge boards? ………………….	☐	☐	☐
9. Does the overall condition concern you? …………………………	☐	☐	☐

Structure type: GATED CROSS REGULATOR

	Yes	No	Not Assessed
1. Are any of the gates missing? ………………………………………..	☐	☐	☐
2. Is it difficult to fully open or close any gate? ………………………	☐	☐	☐
3. Is any gate seriously corroded or rotting? …………………………..	☐	☐	☐
4. Are there serious cracks or movement in any part of the structure? …	☐	☐	☐
5. Is leakage occurring around the structure? …………………………..	☐	☐	☐
6. Is the d/s apron seriously damaged or undercut? …………………….	☐	☐	☐
7. Is it difficult to read the u/s or d/s gauge boards?................................	☐	☐	☐
8. Does the overall condition concern you?...	☐	☐	☐

Structure type: CANAL REACH

	Yes	No	Not Assessed
1. Is the canal partially blocked at any location by illegal weirs or debris?	☐	☐	☐
2. Is there serious siltation at any location? …………………………………	☐	☐	☐
3. Is there serious weed growth at any location? ……………………………	☐	☐	☐
4. Do farmers and/or staff report the canal capacity restricts water supply? ..	☐	☐	☐
5. Where the reach is in fill, has the water level been dangerously near the canal top at any point? 6. Are there problems of serious bank slippage or erosion?	☐	☐	☐
7. If lined - Is there important damage to lining?..	☐	☐	☐ ☐

8. Are there any unauthorized off-takes? ……………………………………… ☐ ☐

9. Is seepage a problem in the reach? ……………………………………….. ☐ ☐ ☐

10. Does the overall condition concern you? ……………………………….. ☐ ☐ ☐

Structure type: INSPECTION ROAD

	Yes	No	Not Assessed
1. Does limited track width prevent vehicle access at any point? ………	☐	☐	☐
2. Do surface unevenness and pot holes make driving difficult?.............	☐	☐	☐
3. Are cross drainage culverts seriously damaged or exposed at any point?..	☐	☐	☐
4. Are sides slopes seriously eroded or showing signs of serious slippage?...	☐	☐	☐
5. Is access difficult at any time of year? ……………………………………	☐	☐	☐
6. Does the overall condition concern you? …………………………………	☐	☐	☐

Structure type: FLOW MEASUREMENT STRUCTURE

	Yes	No	Not Assessed
1. Are there silt, weeds or rubbish within 5m u/s or d/s of the structure? ……………………………………………..	☐	☐	☐
2. Is the measurement structure drowned? ……………………….......	☐	☐	☐
3. Is there serious damage to any part of the structure? …………….	☐	☐	☐
4. Is leakage occurring around the structure? ……………………….	☐	☐	☐
5. Is the d/s apron seriously damaged or undercut? ………………….	☐	☐	☐
6. Is it difficult to read the u/s or d/s gauge boards? …………………	☐	☐	☐
7. Does the overall condition concern you? …………………………	☐	☐	☐

Structure type: GATED OFFTAKE

	Yes	No	Not Assessed
1. Are any of the gates missing? ………………………………………	☐	☐	☐
2. Is it difficult to fully open or close any of the gates? …………………	☐	☐	☐
3. Is any gate seriously corroded or rotting? ……………………………	☐	☐	☐
4. Are there serious cracks or movement ………………………………	☐	☐	☐
in any part of the structure? …………………………………………	☐	☐	☐
5. Is any part of the structure blocked by sediment?................................	☐	☐	☐
6. Is seepage occurring around the structure? ………………………....	☐	☐	☐

7. Is the d/s apron seriously damaged or undercut? ……………………….
8. Is it difficult to read the u/s or d/s gauge board? ……………………….
9. Does the overall condition concern you? ……………………………

Structure type: DRAIN

Yes No Not Assessed

1. Is the flow seriously limited at any location by silt, weeds or debris?
2. Are there any signs that water has overtopped the drain?...........
3. Is there evidence of water logging (salts, mud, reeds) in this area?..
4. Is there serious bank slippage at any location?.....................................
5. Are any structures in this reach seriously deteriorated? ……………
6. Does the overall condition concern you? …………………………

Structure type: DROP/CHUTE

Yes No Not Assessed

1. Are there serious cracks or movement in any
part of the structure? …………………………………..
2. Is leakage occurring around the structure? …………………
3. Is the d/s structure - stilling basin/apron –seriously
damaged or undercut?...
4. Is the d/s bed or channel section seriously eroded?....
5. Does the overall condition concern you?...................

Structure type: CROSS DRAINAGE CULVERT

Yes No Not Assessed

1. Are there serious cracks or movement in any part of the structure? …
2. Is the canal visibly leaking into the culvert?.......................................
3. Do farmers or staff say the culvert fails to effectively carry peak flow?.
4. Does the culvert appear blocked? …………………………………..
5. Is there serious erosion around the entry or exit of the culvert? ……..
6. Does the overall condition concern you? ……………………………..

Structure type: AQUEDUCT / FLUME

	Yes	No	Not Assessed
1. Are there serious cracks or movement in any part of the structure?...	☐	☐	☐
2. Is there any serious separation of the backfill & structure? …………..	☐	☐	☐
3. Does the aqueduct leak at the union with u/s or d/s reach? ……………	☐	☐	☐
4. Are there important leaks from the aqueduct itself? ………………..	☐	☐	☐
5. Is there evidence of overtopping in the aqueduct or immediately u/s?..	☐	☐	☐
6. Is there evidence of serious damage, to supporting piers and/or superstructure?	☐	☐	☐
7. Does the overall condition concern you? ………………………………	☐	☐	☐

Structure type: SIDE WEIR/ESCAPE

	Yes	No	Not Assessed
1. Is any part of the structure blocked? ……………………………….	☐	☐	☐
2. Are there serious cracks or movement in any part of the structure?.	☐	☐	☐
3. Is seepage occurring around the structure? ………………………..	☐	☐	☐
4. Is there serious separation of the backfill & structure? …………..	☐	☐	☐
5. Is the d/s protection seriously damaged or undercut? …………….	☐	☐	☐
6. Does the overall condition concern you? …………………………	☐	☐	☐

Appendix 3B: Second Phase Condition assessment

Engineering Inspection – Canal Reach Page 1

Canal Name: __________________ Reach ID___________________

Design Parameters:

Discharge_____________________ Flow depth _________________

Bed width ____________________ Freeboard __________________

Bed slope _____________________

A A. Hydraulic functions: Percentage of design

	Value	(125 - 80%)	(79 - 70%)	(69 - 50%)	(<50%)
Estimated discharge	_____	_ _____	__ _		
Average depth	______	____	____	__	
Average clear bed width	_____	____	__________	_	__

Do d/s conditions create backwater problems?

Yes* ☐ No ☐ Don't know* ☐

*Describe d/s condition at section D

B. Chanel condition

	Good (None/minimal)	Fair (Minor)	Poor (Serious)	Very Poor Serious)
Siltation	☐	☐	☐	☐
Weeds	☐	☐	☐	☐
Freeboard	☐	☐		☐
C. Bank condition:		☐	☐	☐
Slips	☐			
Erosion	☐	☐	☐	☐
Seepage	☐	☐	☐	☐

Condition summary:

Most serious defect____

Overall classification Good / Fair / Poor / Very poor

Engineering Inspection – Canal Reach Page 2

D. Notes on Sections A and B:______________________________________

____

F. Is any condition expected to become Poor or Very Poor within 12 months, if not already so?

____

G. Required action:

None …………………….. ☐

Repair…………………… ☐

Demolish & rebuild……… ☐

Demolish & redesign…….. ☐

Define scope of detailed site survey/investigations, if these are required:

____

____

____

Rough estimate of quantities/materials required:

____

____

____

Engineering Inspection – Structure Page 1

For hydraulic structures complete Sections A and B.

Structure type ________________ Structure ID _______________

A. A Hydraulic functions

	Good	Fair	Poor	Very Poor
Conveyance capacity …....	☐	☐	☐	☐
Where relevant………………	☐	☐	☐	☐
Control of discharge/level……	☐	☐	☐	☐
Discharge measurement ……..	☐	☐	☐	☐
Water tightess………………..	☐	☐	☐	☐

B. Structural Condition

	Good (None/minimal)	Fair (Minor)	Poor (Serious)	Very Poor (Very Serious)
Movement settlement) Displacement/heave/rotation)	☐	☐	☐	☐
Scour damage to structure	☐	☐	☐	☐
Scour damage to channel	☐	☐	☐	☐
Joint condition	☐	☐	☐	☐
Condition of structural elements (Cracking, etc.)	☐	☐	☐	☐
Surface condition (Spalling, rust, damaged coatings)	☐	☐	☐	☐
Stability of slopes/retained soil) ¨	☐	☐	☐	☐

Condition summary:

Most serious defect____

Overall classification   Good / Fair / Poor / Very poor

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C. **Notes on Sections A and B** :_____________________________________

____

D. Is any condition expected to become Poor or Very Poor within 12 months, if not already so?

____

G. Required action:

None …………………….. ☐

Repair…………………… ☐

Demolish & rebuild……… ☐

Demolish & redesign…….. ☐

Define scope of detailed site survey/investigations, if these are required:

____

____

____

Rough estimate of quantities/materials required:

____

____

____

Appendix 4: Condition Assessment Score

Ratings : > 80 = Good 51 - 70 = Poor

71 - 80 = Fair ≤ 50 = V. Poor

Note Questions correspond to those in the Overseers Inspection forms - Appendix 3A. Scores/Class are used in subsequent analysis to determine priorities, and have been set on the basis of reasonable engineering judgments.

Sr. No	Structure Type: Intake/Head Regulator	Hydraulic	Structural	Class	% Effective
1	Are any of the gates missing?	■		V.Poor	45
2	Is it difficult to fully open or close any of the gates?	■		V.Poor	45
3	Is any gate seriously corroded or rotting?		■	Poor	70
4	Are there serious cracks or movement in any part of the Structure		■	Poor	60
5	Is any part of the structure blocked by sediment?	■		Fair	75
6	Is seepage occurring around the structure?		■	Poor	60
7	Is the d/s apron seriously damaged or undercut?		■	V.Poor	40
8	Is it difficult to read the u/s or d/s gauge board?	■		Good	90

Sr. No	Structure Type: Gated Cross Regulator	Hydraulic	Structural	Class	% Effective
1	Are any of the gates missing?	■		V.Poor	45
2	Is it difficult to fully open or close any of the gates?	■		V.Poor	45
3	Is any gate seriously corroded or rotting?		■	Poor	70
4	Are there serious cracks or movement in any part of the Structure		■	Poor	60
5	Is leakage occurring around the structure?		■	Fair	75
6	Is the d/s apron seriously damaged or undercut??		■	Poor	60
7	Is it difficult to read the u/s or d/s gauge board?	■		Good	90

Sr. No	Structure Type: Canal Reach	Hydraulic	Structural	Class	% Effective
1	Is the canal partially blocked at any location by illegal weirs or debris?	■		Good	85
2	Is there serious siltation at any location?	■		Poor	55
3	Is there serious weed growth at any location?	■		Poor	55
4	Do farmers and/or staff report the canal capacity restricts water supply?	■		Poor	60
5	Where the reach is in fill, has the water level been dangerously near the canal top at any point?		■	V.Poor	40
6	Are there problems of serious bank slippage or erosion?		■	V.Poor	45
7	If lined - Is there important damage to lining?		■	Poor	55
8	Are there any unauthorised offtakes?		■	Good	90
9	Is seepage a problem in the reach?	■		Poor	60

Sr. No	Structure Type: Inspection Road	Hydraulic	Structural	Class	% Effective
1	Does limited track width prevent vehicle access at any point?		■	V.Poor	45
2	Do surface unevenness and pot holes making driving difficult?		■	Fair	75
3	Are cross drainage culverts seriously damaged		■	Poor	60
4	Are sides slopes seriously eroded or showing signs of serious slippage?		■	Poor	55
5	Is access difficult at any time of year? • Poor		■	Poor	60
Sr. No	**Structure Type: Flow Measurement Structures**	**Hydraulic**	**Structural**	**Class**	**% Effective**
1	Are there silt, weeds or rubbish within 5m u/s or d/s of the structure?	■		Fair	75
2	Is the measurement structure drowned	■		V.Poor	50
3	Is there serious damage to any part of the structure?		■	Poor	55
4	Is leakage occurring around the structure?		■	Poor	55
5	Is the d/s apron seriously damaged or undercut?		■	Poor	55
6	Is it difficult to read the u/s or d/s gauge boards?	■		Fair	75
Sr. No	**Structure Type: Gated Offtake**	**Hydraulic**	**Structural**	**Class**	**% Effective**
1	Are any of the gates missing?	■		V.Poor	40
2	Is it difficult to fully open or close any of the gates?	■		V.Poor	45
3	Is any gate seriously corroded or rotting?		■	Poor	70
4	Are there serious cracks or movement in any part of the structure?		■	Poor	60
5	Is any part of the structure blocked by sediment?	■		Fair	75
6	Is seepage occurring around the structure?		■	Poor	60
7	Is the d/s apron seriously damaged or undercut?		■	V.Poor	40

8	Is it difficult to read the u/s or d/s gauge board?	■		Good	90
Sr. No	Structure Type: Drain	Hydraulic	Structural	Class	% Effective
1	Is the flow seriously limited at any location by silt, weeds or debris?	■		V.Poor	50
2	Are there any signs that water has overtopped the drain?	■		Fair	75
3	Is there evidence of water logging (salts, mud, reeds in the area?	■		Poor	55
4	Is there serious bank slippage at any location?		■	Poor	60
5	Are any structures associated with this drain		■	Fair	75
Sr. No	Structure Type: Drop/Chute	Hydraulic	Structural	Class	% Effective
1	Are there serious cracks or movement in any part of the structure?		■	Poor	60
2	Is leakage occurring around the structure?		■	Poor	60
3	Is the d/s apron seriously damaged or undercut?		■	V.Poor	40
4	Is the d/s bed or channel section eroded?		■	Fair	75
Sr. No	Structure Type: Cross Drainage Culvert	Hydraulic	Structural	Class	% Effective
1	Are there serious cracks or movementin any part of the structure?		■	V.Poor	40
2	Is the canal visibly leaking into the culvert?	■		Fair	75
3	Do farmers/staff say the culvert fails to effectively carry peak flows?	■		Poor	55
4	Does the culvert appear to be blocked?	■		V.Poor	45
5	Is there serious erosion around the entry or exit of the culvert?		■	Poor	50
Sr. No	Structure Type: Aqueduct/Flume	Hydraulic	Structural	Class	% Effective
1	Are there serious cracks or movement in any part of the structure?		■	V.Poor	40
2	Is there any serious separation of the		■	Fair	75

	backfill and structure?				
3	Does the aqueduct leak at the union with u/s or d/s reach?		■	Poor	65
4	Are there important leaks from the aqueduct itself?		■	Poor	70
5	Is there evidence of overtopping in the aqueduct or immediately u/s?	■		V.Poor	50
6	Is there evidence of serious damage to supporting piers and/or super structure?		■	Poor	55
Sr. No	Structure Type: Side Weir/Escape	Hydraulic	Structural	Class	% Effective
1	Is any part of the structure blocked?	■		V.Poor	50
2	Are there serious cracks or movement in any part of the structure?		■	Fair	75
3	Is seepage occurring around the structure?		■	Poor	55
4	Is there any serious separation		■	Poor	60
5	Is the d/s protection seriously damaged or undercut?		■	Fair	75

Appendix 5: Condition Relative Importance of Different Assets

Sr. No	Structure Type: Intake	Hydraulic Impairment	Hydraulic Impairment
1	Are any of the gates missing?	40	0
2	Is it difficult to fully open or close any gate?	35	0
3	Is any gate seriously corroded or rotting?	0	25
4	Serious cracks/damage or movement in any part of the structure?	0	35
5	Is seepage occurring around the structure	0	35
Sr. No	Structure Type: Gated Cross Regulator	Hydraulic Impairment	Hydraulic Impairment
1	Are any of the gates missing?	40	0
2	Is it difficult to fully open or close any gate?	35	0
3	Is any gate seriously corroded or rotting?	0	25
4	Serious cracks/damage or movement in any part of the structure?	0	35
5	Is seepage occurring around the structure?	0	35
6	Is the d/s apron seriously damaged or undercut?	0	50
7	Is it difficult to read the u/s or d/s gauge boards?	15	0
Sr. No	Structure Type: Canal Reach	Hydraulic Impairment	Hydraulic Impairment
1	Is the canal partially blocked at any location by illegal weirs or debris?	10	0
2	Is there serious siltation at any location?	20	0
3	Is there serious weed growth at any location?	20	0
4	Do farmers and/or staff report the canal capacity restricts water supply?	30	0
5	Water level been dangerously near the canal top at any point?	25	35
6	Are there problems of serious bank slippage or erosion?	0	35
7	If lined - Is there important damage to lining?	15	20
8	Are there any unauthorized off-takes?	5	0
9	Is seepage a problem in the reach?	15	20

Sr. No	Structure Type: Inspection Road	Hydraulic Impairment	Hydraulic Impairment
1	Has the road become too narrow to pass necessary traffic?		40
2	Is driving difficult because of surface unevenness and pot holes?		10
3	Are any cross drainage culverts seriously damaged or exposed?		30
4	Are sides slopes seriously eroded or showing signs of slippage?		30
5	Is access difficult during the rainy season?		0
Sr. No	Structure Type: Flow Measurement Structure	Hydraulic Impairment	Hydraulic Impairment
1	Are there silt, weeds or rubbish within 5m u/s or d/s of the structure?	20	0
2	Is the measurement structure drowned?	35	0
3	Is there serious damage to any part of the structure?	0	35
4	Is seepage occurring around the structure?	0	35
5	Is the d/s apron seriously damaged or undercut?	0	25
6	Is it difficult to read the u/s or d/s gauge boards	20	0
Sr. No	Structure Type: Drain	Hydraulic Impairment	Hydraulic Impairment
1	Is the drain flow seriously limited at any location by silt, weeds or debris?	35	0
2	Are there any signs that water has overtopped the drain?	20	0
3	Is there evidence of water logging (salts, mud, reeds) in this area?	25	0
4	Is there serious bank slippage at any location?	0	30
5	Are any structures in the reach seriously deteriorated?	0	25
Sr. No	Structure Type: Cross Check / Drop / Chute	Hydraulic Impairment	Hydraulic Impairment
1	Are there serious cracks or movement in any part of the structure?	0	25
2	Is seepage occurring around the structure?	0	40
3	Is the d/s structure - stilling basin/apron - seriously damaged or undercut?	0	50
4	Is the d/s bed or channel section seriously eroded	10	25

Sr. No	Structure Type: Cross Drainage Culvert	Hydraulic Impairment	Hydraulic Impairment
1	Are there serious cracks or movement in any part of the structure?	0	35
2	Is the canal leaking into the culvert?	100	15
3	Do farmers or staff say the culvert fails to effectively carry peak flows?	35	0
4	Does the culvert appear to be blocked?	40	0
5	Is there serious erosion around the entry or exit of the culvert?	0	35
Sr. No	Structure type: Aqueduct / Flume	Hydraulic Impairment	Hydraulic Impairment
1	Are there serious cracks in any part of the structure?	0	35
2	Is there any serious separation of the backfill and structure?	0	20
3	Does the aqueduct leak at the union with u/s or d/s reach?	15	35
4	Are there leaks from the aqueduct itself?	15	20
5	Is there evidence of overtopping in the aqueduct or immediately u/s?	40	0
6	Is there evidence of significant damage or corrosion to supporting piers?	0	30
Sr. No	Structure Type: Side Weir	Hydraulic Impairment	Hydraulic Impairment
1	Is any part of the structure blocked?	40	0
2	Are there serious cracks or movement in any part of the structure?	0	25
3	Is seepage occurring around the structure? 0	0	35
4	Can gaps be seen between the structure and the backfill?	0	20
5	Is the d/s protection seriously damaged or undercut?	0	35