Performance Evaluation of Irrigation System
(Welenchity Surface Irrigation Scheme)

Author: Alemayehu Serbessa Godana

Advisor: Dr. Daneal F/Selassie

A Thesis submitted to The School of Graduate Studies of
Addis Ababa University

Prepared in partial fulfillment of the requirements for the Degree
of Master of Science in Civil and Environmental Engineering

(Major in Hydraulic Engineering)

Addis Ababa University
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This is to certify that the Thesis prepared by **Alemayehu Serbessa** entitled "**Performance Evaluation of Irrigation System (Welenchity Surface Irrigation Scheme)**" in partial fulfillment of the requirements for the degree of Master of Science (Hydraulic Engineering) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

By

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Declaration

I, the undersigned person, hereby declare that this thesis is my original work and all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, all sources of materials that are not original to this work have been duly acknowledged.

Name: Alemayehu Serbessa Godana

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Abstract

Water scarcity is a potential constraint to produce more foods to meet the demands of increasing world population. One possible approach to conserve this scarce resource might be through improving the performance of existing irrigation schemes. However, in Ethiopia performance evaluation of irrigation schemes is rarely conducted in the past. Welenchity Surface Irrigation Scheme is among the schemes in Ethiopia which do not have a sound performance studies before in order to check and sustain efficient water delivery system in the scheme. This study is therefore a useful start for improving overall irrigation water management, distribution and delivery in the scheme. Accordingly evaluating hydraulic (water delivery) performance and proposing necessary improvements for enhancing operation in order to save irrigation water are the key objectives to be achieved in this study. The Discharge were observed and recorded at seven selected monitoring sites for determining water delivery performance parameters like adequacy, efficiency, equity and dependability which are used to evaluate the performance of Welenchity Irrigation System. Discharge was measured and monitored using a 'Discharge App' which is one of the quickest and easiest ways of acquiring water flow measurements in streams and channels within few minutes using a Smartphone's Camera. The primary canal hydraulic flow characteristics were modeled using HEC-RAS to detect the effect that will result to the secondary and tertiary offtakes due to change in flow at the source/primary canal. The crop water requirement was verified by CROPWAT by the use of designers' scenarios. The performance evaluation of Welenchity Surface Irrigation Scheme reveals that the overall Efficiency and Equity of water distribution of the system are 'poor' and the adequacy of water distribution and dependability of the water supplied in the system is rated as 'Good' and 'Fair' respectively. The parameter of average WSER at head, middle and tail reaches of the main canal during the monitoring period is generally less than one, thus it shows that the main canal has a sedimentation problem. Thus, for their long term sustainability, water distribution equity, reliability and water saving; continuous monitoring and maintenance is required. Nevertheless, the results of the study can be considered in proposed water saving plans for improving the performances of the scheme. It provides to the system managers, farm staffs and policy makers a better understanding of how a system can be operated.

Key Words: ***Water-delivery Performance, Operational Performance, Performance Indicators, Canal Flow Simulation/Hydraulic Models, HEC-RAS, Discharge App***

Contents

List of tables

List of figures

List of Symbols and Acronyms

%	percent
L/s	Liters per second
Ha	hectare
CV	Coefficient of variation
CRM	Coefficient of Residual Mass
DPR	Delivery Performance Ratio
FAO	Food and Agriculture Organization
MAE	Mean Absolute Error
MCM	Million Cubic Meter
ME	Maximum Error
P_A	Adequacy indicator
P_D	Dependability indicator
P_E	Equity indicator
P_F	Efficiency indicator
Q	Discharge
Q_D	Delivered discharge
Q_R	Required or intend discharge
RWS	Relative Water Supply
SIS	Surface Irrigation Scheme
TE	Total Error
SMta	Total available soil moisture content
FC	Field Capacity
PWP	Permanent Wilting Point
WSIS	Welenchity Surface Irrigation Scheme

1 Introduction

In the 21st century, agriculture continues to be a fundamental instrument for sustainable development and poverty reduction. Agriculture alone will not be enough to massively reduce poverty, but it has proven to be uniquely powerful for that task. In the agriculture-based countries, which include most of Sub-Saharan Africa, agriculture and its associated industries are essential to growth and to reducing mass poverty and food insecurity. On the other hand, water scarcity is a potential constraint to produce more foods to meet the demands of increasing world population. One possible approach to conserve this scarce resource might be through improving the performance of existing irrigation schemes (L.E. Small 1992). As is known, Agriculture is by far the largest user of water, contributing to water scarcity. Increasing the productivity of water in Agriculture will play a vital role in easing competition for scarce resources, prevention of environmental degradation and provision of food security: by growing more food with less water, more water will be available for other natural and human uses. It was identified that globally 60% of the diverted fresh water for agriculture does not contribute directly to food production. This amount of water is discharged because of poor water control, inefficient irrigation systems with leaky conveyance and distribution, poor on-farm water management practices, etc. (World Agriculture Forum, 2009). It depicts that only about 40% global fresh water abstracted for irrigation is being effectively used for consumptive use in agriculture. Part of the amount of the discharged water of these systems is lost to saline groundwater or to poor quality drainage water. Performance based management is a principal approach to improve the scheme performances.

Ethiopia has presently embarked to an accelerated irrigation development plan, in which the irrigated land is planned to be increased to three folds in five years (Zeleke Agide Dejen 2014). Apparently, expansion of irrigated land through new irrigation developments is relevant in Ethiopia in view of its underutilized potentials of land and water. However, in Ethiopia performance evaluation of irrigation schemes is rarely conducted among which Welenchity Surface Irrigation Scheme is the one.

(Imbenzi J. Serede 2015), identified that Hydraulic simulation models could be suitable tools for understanding the hydraulic characteristics of irrigation during his study on Mwea Irrigation system, Kenya. He also witnessed that Due to its minimal estimation errors, HEC-RAS model would be appropriate in evaluation of canal hydraulics steady state conditions to improve on scheme performance. (Mamuye Tebebal 2005); As MSc Thesis, evaluated Hydraulic performance of Hare Community Managed Irrigation Scheme, Southern; Ethiopia by nine process performance indicators. (Ziagham Habib 1998), made an assessment on the Water Regulation and Distribution System in the Chishtian Sub-division at the Main and Secondary Canal Levels. (Zeleke Agide Dejen 2014), as PhD Thesis, made a research which concerned with the performance of two large-scale and two community managed irrigation schemes in Ethiopia. The large-scale schemes are known as Wonji-Shoa and Metahara, while Golgota and Wedecha are the community managed schemes. (M. A. Shahrokhnia 2005), applied HEC-RAS for evaluation of Ordibehesht Canal at the Doroodzan irrigation network, northwest of Fars province in the southern Iran. Discharge reduction of offtakes due to discharge reductions at system source were evaluated by the model. (Dr. Jaafar S. Maatooq 2016), applied HEC-RAS model to analysis the actual operation of irrigation canal and evaluated indicators of Al-Ibrahim Irrigation Canal in the South of Iraq.

Awash River Basin, where the scheme of this study is located is a basin of huge socio-economic significance in Ethiopia owing to its agro-climatic and demographic conditions. The river along with its tributaries directly supports millions of people in the region for all kinds of water needs including agriculture, domestic, and livestock. In this regard, the existing irrigation schemes would have to implement a water saving strategy in their operation in order to ensure sustainable water utilization. Concerns about scarcity of water have focused attention on irrigation, the largest water using sector worldwide. Improvement of the efficiency and distribution uniformity of irrigated agriculture can minimize the gap between potential crop water requirements and actual water use. In consequence, it will lead to more crop with less drop and ultimately lead to the improvement of the livelihood of people. In order to minimize the water losses in irrigation systems, a performance assessment should be carried out to check the state of health of the systems and also the level of water use. However, there were no sound studies in the past on performance assessment of Welenchity Surface Irrigation Scheme for checking and sustaining efficient water delivery system in the scheme. This study is therefore a useful start for improving overall irrigation water management, distribution and delivery in the scheme.

Water use and management in agriculture cross many scales: crops, fields, farms, delivery systems, basins, nations and the globe. This research deals with one scale that is the delivery systems. At delivery system scale processes of interest include allocation, distribution of water to farms, operation and maintenance, conflict resolution and drainage. In the past, there have been two major approaches to evaluating the overall performance of irrigation systems: its gross production or return on investment and its efficiency of water use. Recently two major approaches to performance evaluation have been to consider (1) how well service is delivered, and (2) the outcomes of irrigation in terms of efficiency and productivity of resource use (Molden & Clemmens, 2007). The second approaches were followed in this study that is evaluation of water delivery performance and efficiency of water use. The Discharge were observed and recorded at seven selected monitoring sites for determining water delivery performance parameters like adequacy, efficiency, equity and dependability which are used to evaluate the performance of Welenchity Irrigation System. The primary canal hydraulic flow characteristics were also modeled using HEC-RAS to detect the effect that will result to the secondary and tertiary offtakes due to change in flow at the source/primary canal.

1.1 Statement of the Problem

The large numbers of irrigation projects have been constructed for a reliable water supply for agriculture. Evaluation reports indicate that the water delivery and application efficiencies, and cropping intensities have not fulfilled planner’s expectations due to poor water management. The major irrigation projects in Asia are reported to perform at low overall efficiency of 30-35%. The crop yields, both per hectare and per cubic meter of water, are much lower than international benchmarks, and much lower even than in neighboring areas of India (World Bank, 2006). A gap exists between irrigation potential created and that utilized. Thus in future irrigation has to become more efficient and produce more per unit volume of water. This realization has shifted the attention of the researchers and policy makers to focus on improving the performance of the irrigation systems.

Owing to its agro-climatic and demographic conditions, Awash River Basin, where the scheme of this study is located is a basin of huge socio-economic significance in Ethiopia. The river along with its tributaries directly supports millions of people in the region for all kinds of water needs including agriculture, domestic, and livestock. In this regard, the existing irrigation schemes would have to implement a water saving strategy in their operation in order to ensure sustainable water utilization. The river flows in the semi-arid and arid region of Ethiopia characterized by high year round temperatures as high as 40°C. Rainfall distribution in the basin is variable ranging between 1,500 to less than 200 mm per annual. Over 70% of the basin is semi-arid or arid with annual rainfall between 150 mm and 600 mm. In the basin, on average 70% of the annual rainfall is lost by evaporation (Taddese 2007). In addition to the natural causes of water stress in the basin, the upper Awash Basin and its major tributaries have been subjected to major human-induced environmental stress.

Inadequate operation of surface irrigation schemes have highly affected the benefits expected from these schemes. The first and most apparent consequence of ineffective operation is inequity in water delivery at head, middle, and tail reaches of the system. This results in over-supply in some parts of the scheme and under-supply in other parts, which brings about differences in irrigation services among different groups of water users/irrigation blocks/. The second consequence of ineffective operation is loss of significant quantity of water either as over application or run off losses at tail end, which results in low water use efficiencies. This in turn results in low water productivity and puts limitations on the water resources available to irrigate more lands to meet rising food demands. The third consequence of ineffective operation is related to non-sustainability of the schemes due to waterlogging and salinization. This is a typical problem particularly in surface irrigation schemes in arid and semi-arid regions with poorly drained soils but this is not the case in Welenchity irrigation scheme as it is dominated with a well-drained soils.

Due to this there is a general consensus that the trends of water use in the schemes of the basin would not continue in the same way like what it has been in the past. Effective and sound system operation rules are believed to be potential water management interventions, which would ensure equity and efficiency of water distribution and water saving while ensuring sustainability. Accordingly, the research questions which arose for these schemes are:

- How do the total water diversions into these schemes relate to demands and basin-wide water management?
- How does the existing operation and hydraulic features of structures affect the spatial and temporal water delivery performance (equity, adequacy, efficiency, reliability) in these schemes?
- Will an alternative operation rule, based on a thorough hydrodynamic simulation, enhance effective operation, hydraulic performance and efforts in water saving at Welenchity Scheme?

The hydrodynamic behavior of traditional manually operated surface irrigation systems is often less understood by operators and managers, while it plays a major role in water distribution and delivery. The Hypothesis of this study is that thorough investigation of the water delivery performance of the scheme and consequent modification in operation enhances the water delivery performance and can save significant amount of water in this scheme.

1.2 Objective of the Study

1.2.1 General Objective

Evaluating hydraulic (water delivery) performance and proposing necessary improvements for enhancing operation in order to save irrigation water are the key objectives to be achieved in this study.

1.2.2 Specific Objectives

1. to carry out thorough assessment of irrigation demand versus water diversion trends in this scheme
2. to evaluate water delivery performance indicators in spatial, temporal scales using routinely monitored offtake discharges under the existing operation rules

3. Identify the underlying major operational as well as hydraulic factors contributing to result of number 2 above;
4. to simulate the flow in the main water conveyance system of Welenchity Scheme using a hydraulic model HEC-RAS
5. to Model the effect of discharge reduction at system source on offtakes discharge

1.3 Significance of the Study

The evaluation of the performances of the scheme based on identifying the problems associated with water ineffective use and its remedial solutions will help in planning the overall project management for productivity of the scheme, especially the results of the study can be considered in proposed water saving plans for improving the performances of the scheme. It provides to the system managers, farm staffs and policy makers a better understanding of how a system can be operated.

The study work is helpful as:

- the methods used, the analyses and results obtained and the subsequent recommendations made could be of useful contributions to the ongoing efforts by the Wonji-Shoa Sugar Estates in general and Welenchity Scheme in particular;
- the final results of this study is useful for effective and sound system operation which would ensure equity and efficiency of water distribution and water saving which reduces the water stress in the basin as well.

- It also tries to find an alternative that minimizes consequence of ineffective operation which is related to non-sustainability of the schemes due to waterlogging and salinization, and ensures sustainability even though currently this is not the case in Welenchity Surface Irrigation Scheme as it is dominated by well drained soils.

2 Literature Review:

2.1 Introduction

Water is a natural resource of strategic importance which directly affects economic and social development. As competition for water increases, the irrigation sector is often blamed for its high and inefficient use of water and is commonly held responsible for urban water shortages.

Performance assessment has been an integral part of irrigation since man first started harnessing water to improve crop production. Performance evaluation of irrigation schemes has specially been an important and active field of research during the last few decades. Several approaches and methodologies have been developed for assessing irrigation performance from different perspectives. With limited water and land resources availability for the required global increase in food production, improving the productivity of existing irrigation schemes has got an increasing attention. Global cereal production has to duplicate in the next 25 to 30 years, while 80-90% of this increase would have to be realized from the existing agricultural land. This would be through increasing land and water productivity by various interventions as intensifying irrigation, employing water saving mechanisms, innovating irrigation management, improved drainage, etc. All these have to improve the performance of the existing irrigation and drainage schemes in order for these schemes to achieve the objectives.

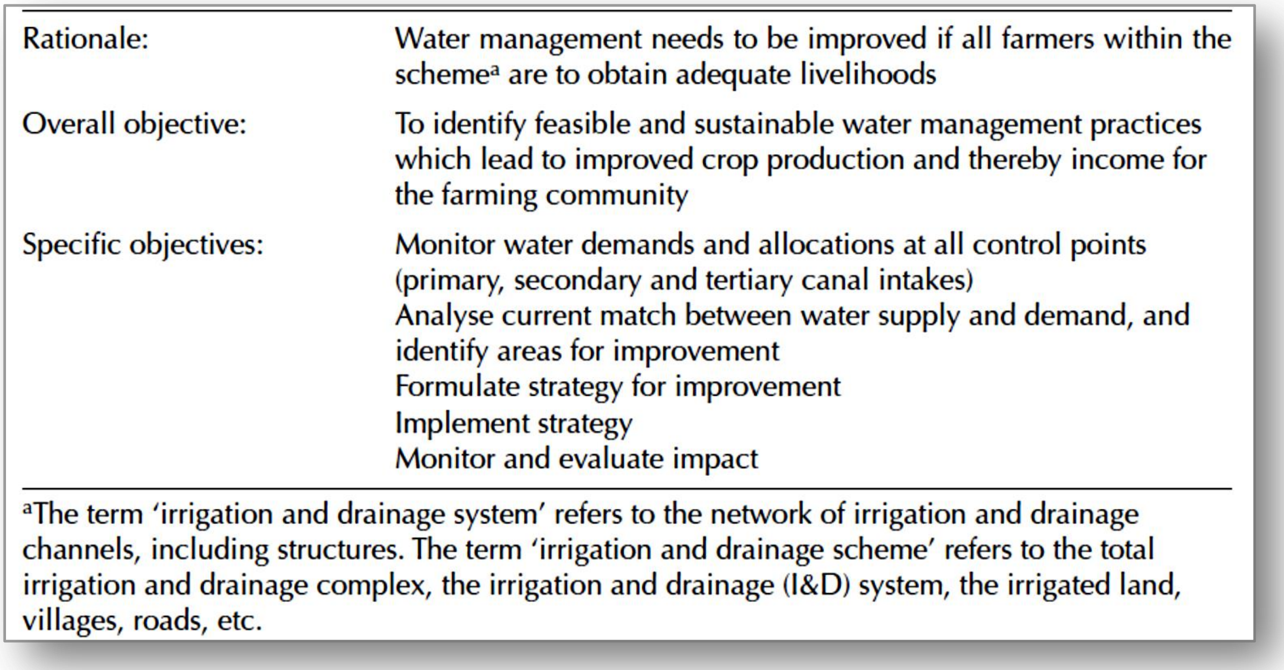
A considerable amount of work has been undertaken in the past 10 years to develop a framework for irrigation performance assessment. Irrigation performance indicators cover the traditional aspects related to adequacy, equity and reliability of the water service. The framework of performance indicators thus included environmental sustainability features to evaluate the longer-term effects irrigation has on the environment such as groundwater table changes (as summarized by W.G.M. Bastiaanssen & M.G. Bos, 1999). The concern of this study is bounded to the performance assessment built up on the indicators related to water delivery and sustainability.

(M.G. Bos 2005), defined the rationale of a performance assessment programme, overall objective and the specific objectives as articulated in Table 2-1.

The ultimate purpose of performance assessment is to achieve an efficient and effective use of resources by providing relevant feedback to management at all levels. Therefore, it may assist the system management in determining whether the performance is satisfactory and, if not, which and where corrective or different actions need to be taken in order to remedy the situation.

In this regard, the existing large-scale irrigation schemes would have to implement a water saving strategy in their operation in order to ensure sustainable water utilization. There were no sound studies in the past on Performance of Welenchity Irrigation Scheme to address scheme water demand versus diversion. Moreover, water delivery performance monitoring within the scheme is absent. ***Thus Performance Evaluation of Irrigation System (Welenchity Surface Irrigation Scheme)*** was implicit to be a useful start for improving overall irrigation water management, distribution and delivery in the scheme.

Table 2-1: Example of the rationale and a set of objectives for a performance assessment programme (M.G. Bos 2005)



Rationale:	Water management needs to be improved if all farmers within the scheme[a] are to obtain adequate livelihoods
Overall objective:	To identify feasible and sustainable water management practices which lead to improved crop production and thereby income for the farming community
Specific objectives:	Monitor water demands and allocations at all control points (primary, secondary and tertiary canal intakes) Analyse current match between water supply and demand, and identify areas for improvement Formulate strategy for improvement Implement strategy Monitor and evaluate impact

[a] The term 'irrigation and drainage system' refers to the network of irrigation and drainage channels, including structures. The term 'irrigation and drainage scheme' refers to the total irrigation and drainage complex, the irrigation and drainage (I&D) system, the irrigated land, villages, roads, etc.

2.2 Framework for Performance Assessment

Irrigation performance indicators cover the traditional aspects related to adequacy, equity and reliability of the water service (D.H. Murray-Rust 1993), after reviewing significant work, suggested a list of indicators being related to the performance of (i) the water delivery system, (ii) the environment and (iii) the irrigated agricultural economic system. The framework of performance indicators thus included environmental sustainability features to evaluate the longer-term effects irrigation has on the environment such as groundwater table changes.

Irrigation system performance assessment needs a framework to adequately guide the work and for the stakeholders to effectively use the outcomes from performance assessment. The purpose of the framework is to form a link between repeated actions in such a way as to provide a learning experience for the manager that allows things to be done better at a later successive iteration. The framework defines why the performance assessment is needed, what data are required, what methods of analysis will be used, who is the performance assessment for, etc. Without a suitable framework the performance assessment program may fail to collect the necessary data, and may not provide the required information and understanding to the user. Performance assessment is based on collection, analysis and interpretation of data related to irrigation management and irrigation service delivery.

Performance assessment of irrigation management can be viewed from two perspectives: operational performance and strategic performance. Operational performance evaluation help irrigation management to address the question ‘Am I doing things right?’ while strategic performance assessment addresses the question ‘Am I doing the right thing’? This study is concerned with operational performance evaluation.

2.3 Water Delivery Performance in Irrigation Schemes

Irrigation systems are ideally designed to meet field irrigation requirements uniformly in full, without wasting water. However, due to technical and operational reasons, irrigation systems often do not meet the design objectives. Hydraulic performance refers to adequacy of conveyance, distribution and delivery of irrigation water in spatial and temporal scales. Hydraulic performance is generally measured against some criteria, for which indicators can be developed. Factors such as adequacy, operational efficiency, equity, reliability, timeliness, delivery performance ratio (DPR), etc. have been proposed and used by a large number of researchers, including Molden et al. (1998). In many large-scale manually operated gravity irrigation schemes in least developed and emerging countries, poor hydraulic performance remains a major challenge. This is largely associated with lack of knowledge and information regarding the complex hydraulic behavior of the systems. Effective canal operation for adequate hydraulic performance requires knowledge of when, where and how operations should be made, and understanding the effects of operational decisions.

Operation of canal irrigation systems involves decision making on operation of flow control and delivery structures (offtakes and water level regulators) and anticipation of the resulting hydraulic responses (outputs). Operation is an external perturbation (input), while results, like change in discharge or water levels, are outputs. Thorough knowledge of the relationship between inputs and outputs is basic for effectiveness of operation. Hydraulic principles govern the way each component of the system is being affected by a perturbation. However, canal systems are complex, and their interactive operation and hydraulic behavior are often less understood by operators. Thus, there is a need for relatively easier means to aid effective canal operation.

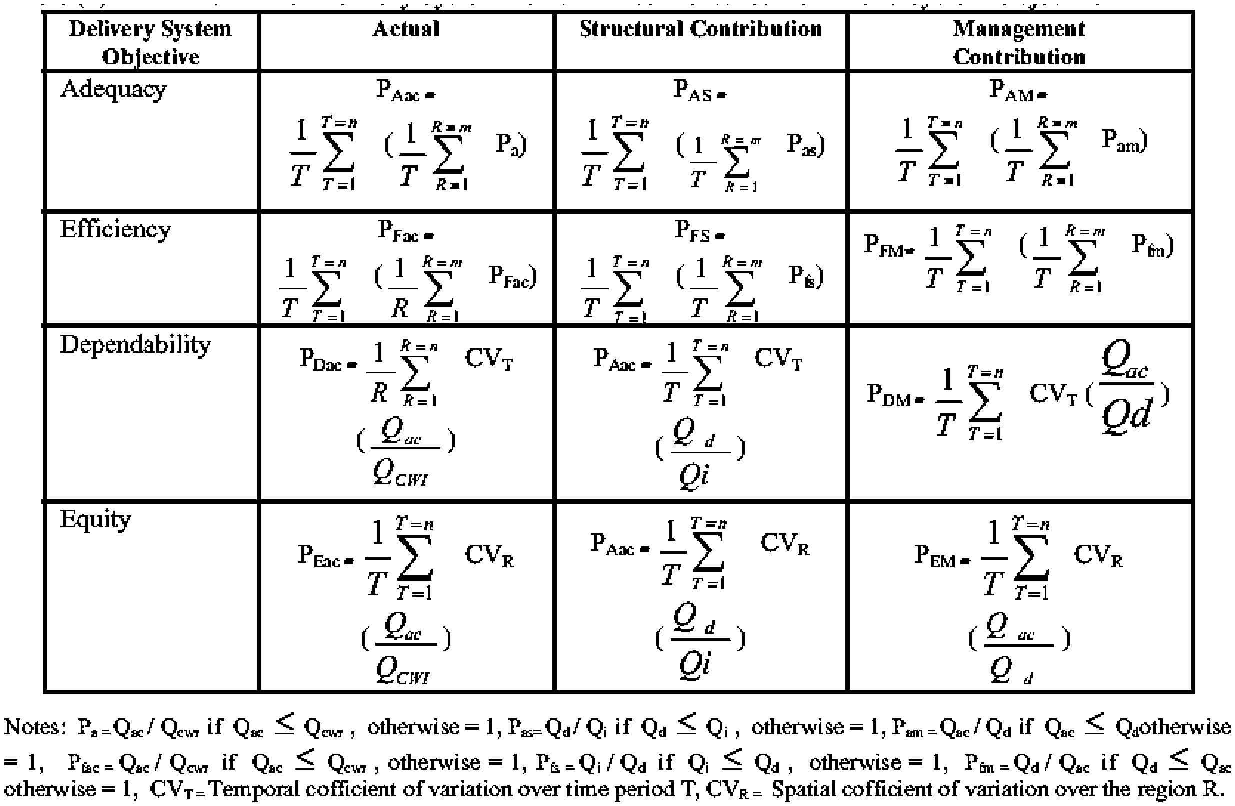
Hydraulic simulation during the last two decades, has contributed a lot to the evaluation of complex hydraulic performances and to decision making in irrigation system operation. Hydraulic modeling has been used and verified to be of useful tools to assist operational decision making in large-scale irrigation systems by researchers. Some of the useful hydraulic models developed and have been in use during the past two decades for simulation of flows in irrigation networks include CANALMAN, SIC, CARIMA, MODIS, USM, DUFLOW, HEC-RAS, etc. In this study, HEC-RAS will be applied as a tool for simulating the flow for different operational setups.

Due to its minimal estimation errors, HEC-RAS model would be appropriate in evaluation of canal hydraulics in steady state conditions to improve on scheme performance. HEC-RAS supports Steady and Unsteady Flow Water Surface Profiling calculations; (Imbenzi J. Serede 2015). Adequacy (relative delivery), efficiency, equity and reliability were used as criteria for hydraulic (water delivery) performance evaluation and corresponding indicators were employed.

2.3.1 Performance Indicators

Performance is measured through the use of indicators, for which data are collected and recorded. The analysis of the indicators then informs us on the level of performance (M.G. Bos 2005). Twelve performance measures are defined relative to four objectives of water delivery system (adequacy, efficiency, dependability, and equity). The suggested performance indicators are depicted in Table 2-2.

Table 2-2: Matrix of Water Delivery System Performance Measures Relative to System Objective



Delivery System Objective	Actual	Structural Contribution	Management Contribution
Adequacy	$P_{Aac} = \frac{1}{T}\sum_{T=1}^{T=n}\left(\frac{1}{T}\sum_{R=1}^{R=m} P_a\right)$	$P_{AS} = \frac{1}{T}\sum_{T=1}^{T=n}\left(\frac{1}{T}\sum_{R=1}^{R=m} P_{as}\right)$	$P_{AM} = \frac{1}{T}\sum_{T=1}^{T=n}\left(\frac{1}{T}\sum_{R=1}^{R=m} P_{am}\right)$
Efficiency	$P_{Fac} = \frac{1}{T}\sum_{T=1}^{T=n}\left(\frac{1}{R}\sum_{R=1}^{R=m} P_{Fac}\right)$	$P_{FS} = \frac{1}{T}\sum_{T=1}^{T=n}\left(\frac{1}{T}\sum_{R=1}^{R=m} P_{fs}\right)$	$P_{FM} = \frac{1}{T}\sum_{T=1}^{T=n}\left(\frac{1}{T}\sum_{R=1}^{R=m} P_{fm}\right)$
Dependability	$P_{Dac} = \frac{1}{R}\sum_{R=1}^{R=n} CV_T \left(\frac{Q_{ac}}{Q_{CWI}}\right)$	$P_{Aac} = \frac{1}{T}\sum_{T=1}^{T=n} CV_T \left(\frac{Q_d}{Qi}\right)$	$P_{DM} = \frac{1}{T}\sum_{T=1}^{T=n} CV_T \left(\frac{Q_{ac}}{Qd}\right)$
Equity	$P_{Eac} = \frac{1}{T}\sum_{T=1}^{T=n} CV_R \left(\frac{Q_{ac}}{Q_{CWI}}\right)$	$P_{Aac} = \frac{1}{T}\sum_{T=1}^{T=n} CV_R \left(\frac{Q_d}{Qi}\right)$	$P_{EM} = \frac{1}{T}\sum_{T=1}^{T=n} CV_R \left(\frac{Q_{ac}}{Q_d}\right)$

Notes: $P_a = Q_{ac} / Q_{cwr}$ if $Q_{ac} \leq Q_{cwr}$, otherwise = 1, $P_{as} = Q_d / Q_i$ if $Q_d \leq Q_i$, otherwise = 1, $P_{am} = Q_{ac} / Q_d$ if $Q_{ac} \leq Q_d$ otherwise = 1, $P_{fac} = Q_{ac} / Q_{cwr}$ if $Q_{ac} \leq Q_{cwr}$, otherwise = 1, $P_{fs} = Q_i / Q_d$ if $Q_i \leq Q_d$, otherwise = 1, $P_{fm} = Q_d / Q_{ac}$ if $Q_d \leq Q_{ac}$ otherwise = 1, CV_T = Temporal cofficient of variation over time period T, CV_R = Spatial cofficient of variation over the region R.

Indicators appropriate to address the performance of the system with reference to targets of *equitable, adequate, timely and reliable* water supply to the farmers will be used to assess the water delivery performance (Ziagham Habib 1998).

2.3.2 Sustainability of Irrigated Area

Sustainability of irrigated area is the ratio of currently irrigated area to initially irrigated area when designed (M.G. Bos 2005). It is a useful indicator for assessing the sustainability of irrigated agriculture. Lower values of this indicator would mean abandonment of lands which were initially irrigated; and hence, indicate contraction of irrigated area over time. On the other hand, values higher than unity indicate expansion of irrigated area and would imply more sustainable irrigation.

2.4 HEC-RAS Steady Model

Hydrologic Engineering Center-River Analysis System (HEC-RAS) is designed by U.S. Army Corps of Engineers to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. Water surface profiles are computed from one cross section to the next by solving the energy equation with an iterative procedure called the standard step method. The effects of various obstructions such as bridges, culverts, weirs and gates can be considered in the computations (Brunner 2016). HEC-RAS is one of the most commonly used models to calculate water-surface profiles and energy grade lines in 1-D, steady-state, gradually-varied flow analysis (Imbenzi J. Serede 2015).

2.4.1 Model Setup and Calibration

The setup preparation for the HEC-RAS model involves specifications of canal cross-sections, layout of the canal network, regulators, upstream and downstream boundary conditions. Data on geometry of the canal and hydraulic structures were collected from state farm or site research Centre. The geometry of structures which is necessary for model includes type of gate, number and width of gate, sill levels and discharge coefficients. The boundary condition includes the discharge at system source, Manning's "n" at every location and rating curve or normal depth or critical depth, or known water level at downstream end of every branch. The comparisons between observed and simulated values were made using following criteria proposed by Jabro et al. (1998).

The maximum error (ME) is a measure of the maximum error between any pair of simulated and measured values. The lower limit and the best value of ME is zero.

$$\text{ME} = Max|M_i - S_i|_{i=1}^{n} \quad (2.1)$$

The root mean square error (RMSE) provides a percentage for the total difference between simulated and measured values proportioned against the mean observed values. The lower limit for RMSE is zero and indicates a more accurate simulation.

$$\text{RMSE} = \left[\frac{1}{n}\sum_{i=0}^{n}(M_i - S_i)^2\right]^{0.5}\left(\frac{100}{M}\right) \quad (2.2)$$

The modeling efficiency (EF) is a measure for assessing the accuracy of simulations. The maximum value for EF is one, which occurs when the simulated values match the measured values perfectly.

$$\text{EF} = \frac{\sum_{i=0}^{n}(M_i - M)^2 - \sum_{i=0}^{n}(M_i - S_i)^2}{\sum_{i=0}^{n}(M_i - M)^2} \quad (2.3)$$

The coefficient of residual mass (CRM) is an indication of the consistent errors in the distribution of all simulated values across all measurements with no consideration of the order of the measurements. A CRM value of zero denotes no bias in the distribution of simulated values with respect to measured values.

$$\text{CRM} = \frac{\sum_{i=0}^{n} M_i - \sum_{i=0}^{n} S_i}{\sum_{i=0}^{n} M_i} \quad (2.4)$$

The other important parameter for comparing the estimated and measured values is the mean absolute error of estimation. MAE is the mean absolute error of estimation, which is better to be close to zero.

$$\text{MAE} = \frac{1}{n}\sum_{i=0}^{n} |S_i - M_i| \quad (2.5)$$

3 Performance Assessment of Irrigation Systems

Population increase and the improvement of living standards brought about by development will result in a sharp increase in food demand during the next decades. Twice as many people-the same amount of water. It is expected that agricultural production from irrigated lands would need to increase by about 13% per decade during the next few decades to feed the increasing world population (FAO, 2003). Several studies show that the contribution of expanding agricultural land for the required increase in production is relatively low; and the contribution of cultivated lands, particularly that of irrigated lands will be much higher. Although there are various views on the speed of the required increase in agricultural production, the major part of the increase (80-90%) would by and large have to come from already cultivated lands; among other means, by improved irrigation practices, increased intensity, improved drainage practices, and increase in storage.

In the following sections it is presented the importance of performance assessment, particularly water delivery performance and the respective indicators. Further, the application of hydraulic models particularly HEC-RAS in performance assessment is discussed.

3.1 Need for Performance Assessment

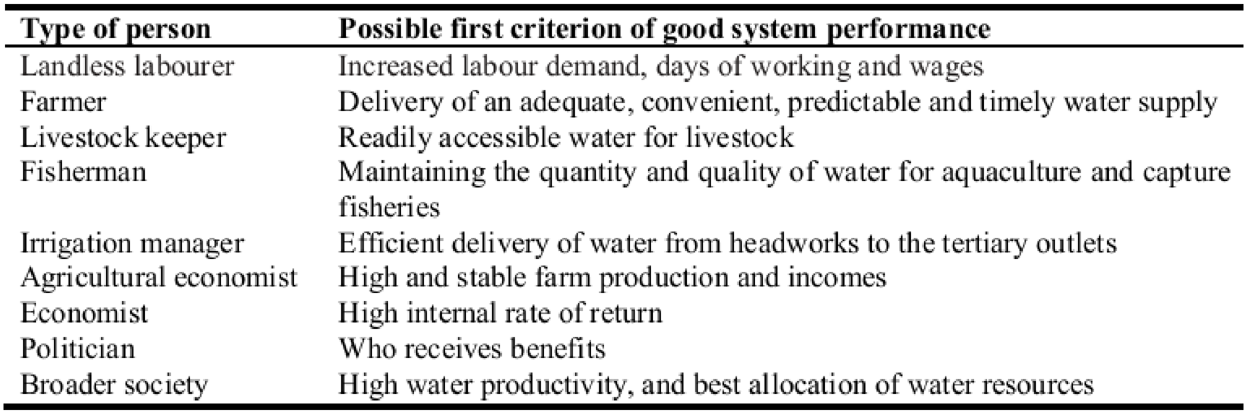
Performance analysis is an essential part of management, it is needed to target and monitor actual achievements in operation and take appropriate actions if required.

Performance of an irrigation system could be assessed for a number of reasons; (Molden 1998) such as: i) to assess progress against strategic goals of a system, ii) to improve operations, iii) to evaluate impact of water delivery service on overall performance of the agricultural sector, iv) to understand cost effectiveness and financial viability of the system, v) for comparison of the system with other irrigation systems.

For this study, the main reasons for performance assessments are to evaluate the general condition of the system regarding to water delivery and improve system operation.

Different stakeholders will have different perceptions about irrigation performance (see Table 3-1).

Table 3-1: Possible criteria of good system performance for different types of users



Type of person	Possible first criterion of good system performance
Landless labourer	Increased labour demand, days of working and wages
Farmer	Delivery of an adequate, convenient, predictable and timely water supply
Livestock keeper	Readily accessible water for livestock
Fisherman	Maintaining the quantity and quality of water for aquaculture and capture fisheries
Irrigation manager	Efficient delivery of water from headworks to the tertiary outlets
Agricultural economist	High and stable farm production and incomes
Economist	High internal rate of return
Politician	Who receives benefits
Broader society	High water productivity, and best allocation of water resources

Molden *et al (2007)*

Livestock keepers and fishermen, while perhaps not considered in the original design of irrigation systems, often become dependent on irrigation water. Politicians may be keenly concerned about who receives the benefit and what this means to their political power base, while farmers value a system that delivers a reliable, timely and adequate irrigation water supply.

3.2 Water Delivery System Performance

The success of an irrigation water- delivery system can be measured by how well it meets the objectives of delivering an adequate and dependable supply of water in an equitable, efficient manner to users served by the system. If water does not arrive at farms in an adequate and timely amount, crop yields may suffer and farm net returns may decrease. Also, it is important that each farmer receives a fair, while not excessive, amount of water.

To evaluate how well an irrigation-water-delivery system is functioning, and to make decisions about designing or rehabilitating a system, requires definition of measures for system performance and standards for assessing the values of those measures. Performance measures should be functions of state variables that have a direct impact on the fulfillment of system objectives, should be intuitively easy to interpret, and should be relatively easy to measure or predict (Molden and Gates 1990). The major state variables that determine water-delivery-system performance may be defined in terms of an amount of water Q, which may refer to rate, volume, frequency, or duration of water delivery.

4 Materials and Methods

4.1 Description of the Study Area

The Welenchity Surface Irrigation System, the focal study area of this research is located within the Awash River Basin. In this section, first, the location and climatic features, water resources infrastructure and water scarcity situation in the Awash River Basin will be discussed. Then, a detailed description of Welenchity Surface Irrigation System will be presented.

The Welenchity Project area is part of the upper Awash River Basin located in the Oromia National Regional State, East Shoa Zone, about 115 km southeast of Addis Ababa (See **Error! Reference source not found.**). The Project Area is situated on the left side of the Awash River and has an altitude of to 1,500 m above sea level (a.s.l). In terms of geographic coordinates, the Welenchity Project area lies between 39°20' & 39°30' East longitude and 8°24' & 8°42' North latitude. Annual rainfall in the area ranges from 697mm at Sodere and Dera to 910mm at Welenchity. Mean annual maximum temperature is 27.5°C, with mean annual minimum temperature being 14.5°C. The average annual evaporation is 1,577.60 mm. Welenchity was initially designed to be an integrated irrigation scheme consisting both surface (1,078.51ha) and pressurized (sprinkler, 449.3ha) system. However, pressurized part was currently abandoned due to social problem. Thus, this study considers the surface irrigation system which is the only part currently under operation. The command area of the scheme reduced from the designed 1,078.51ha to 945ha.

The present access to the water abstraction Intake structure and settling basin is via the national highway Addis Ababa – Adama towards Asela town at Melkasa Dam. The command area is accessed via Addis Ababa – Adama highway towards Metehara town (see Figure 4-1).

4.1.1 Climate

The rainfall data of Welenchity were based on the arithmetic mean rainfall data of Welenchity, Nazareth and Wonji; The arithmetic mean data of temperature, relative humidity and sunshine hours of Wonji and Nazareth adopted for Welenchity; and The Average of Wonji & Melkasa wind data was used as representative of Welenchity wind run, given the similarity in climate and altitude among the three sites (WWDSE 2008).

For the purpose of estimating ETo, the average wind speed of Wonji and Melkasa was used, as recommended by the WWDSE. Based on the climatic data provided in

Table 4-1, the mean monthly evapotranspiration (ETo) has been calculated according to FAO's CROPWAT 8 software.

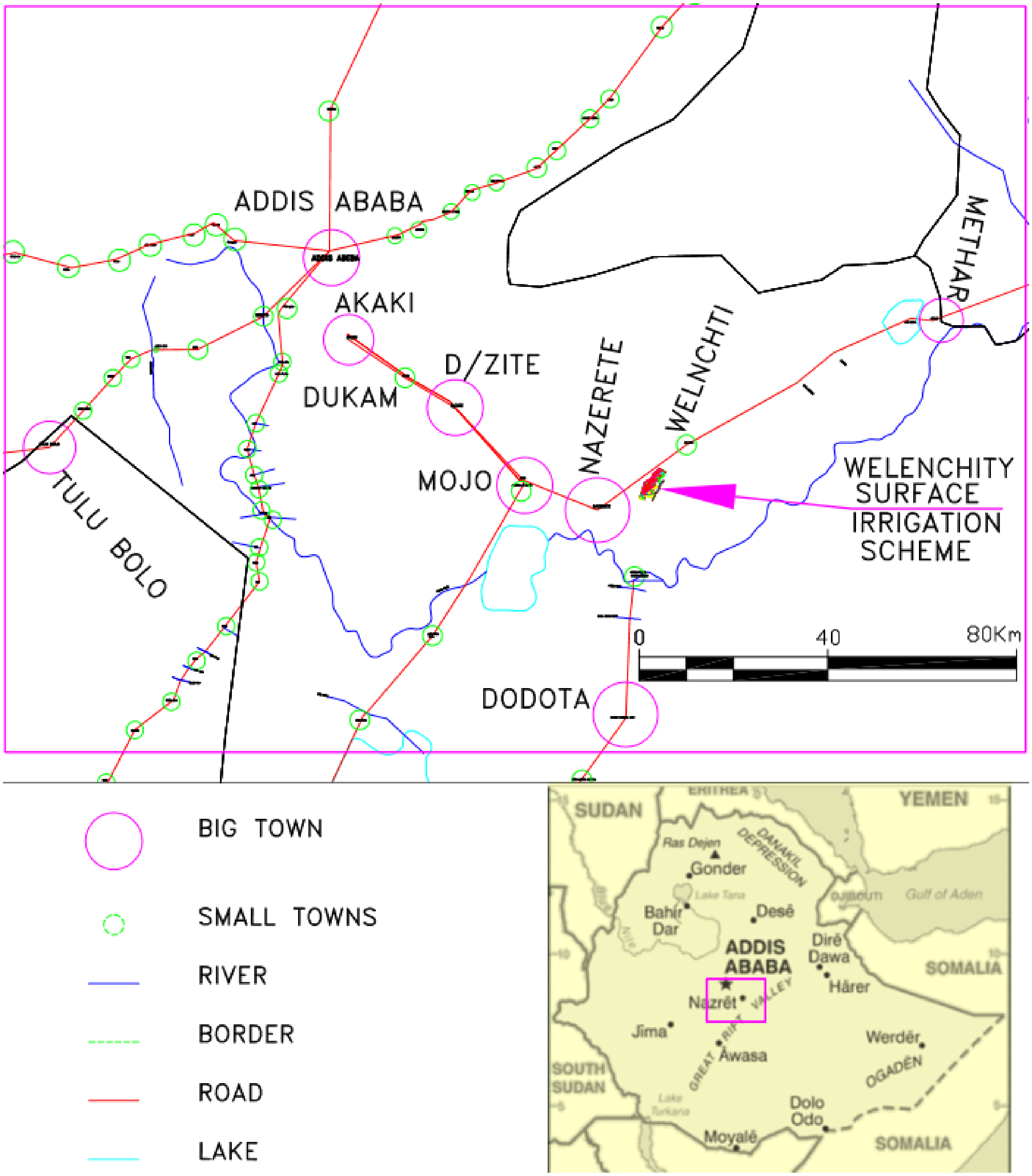


Figure 4-1: Location Map of Welenchity Irrigation Scheme

Table 4-1*:* Mean Monthly Climatic Data of the Project Area (1979-2006)

Month	Rain Fall (mm)	Maximum temp (^{0}C)	Minimum temp (^{0}C)	**Relative Humidity (%)**	Avg.Wind speed of Wonji&Melkasa(Km/day)	Sunshine (Hours)
January	19.2	26.5	12.6	52.5	198	8.8
February	33.3	27.8	14.2	50.5	194	8.4
March	59.7	29.0	15.1	51.1	194	8.3
April	62.1	29.2	15.5	54.0	171	8.1
May	56.9	29.9	16.1	51.9	153	8.8
June	68.3	29.1	17.2	55.4	201	8.4
July	215.7	26.0	16.4	65.0	204	6.8
August	223.5	25.6	16.2	67.6	158	6.9
September	98.1	26.8	15.4	64.6	105	7.3
October	34.2	27.3	12.6	53.1	140	8.7
November	11.0	26.6	11.8	50.5	182	9.3
December	8.7	26.1	11.4	51.5	195	9.1
Average		**27.5**	**14.6**	**55.6**	**174.6**	**8.2**
Total	**890.7**					

Source: (WWDSE, 2008)

4.2 Soils

Most soils of the project area are somewhat structure less, especially the topsoils of loamy sand soils. The weak structures of most soils in the project area are a reflection of immature soil formation, with low content of organic matter and coarse soil textures. Clay and clay loam soils in the project area, on the other hand, have moderate to strong structure (WWDSE 2008).

According to WWDSE report, the soils of the project area found to have quite high infiltration rates that vary from 2.1 cm/hr. in clay soils to 25.3 cm/hr. in sandy loam soils. The majority of the infiltration test results range from 2.1 to 10.3 cm/hr. The very high infiltration rate in some test pits is attributed to the underlying pumice layer up to a depth of 105 cm.

Available Water Holding Capacity (WHC) is defined as the quantity of water held in the soil between field capacity and wilting point. The available soil moisture ranges from 138-190 mm/m in fine-textured soils (an average of 168 mm/m), 197 - 246 mm/m for medium-textured soils (an average of 221 mm/m), and 86 – 134 mm/m for moderately coarse-textured soils (an average of 110 mm/m) (WWDSE, 2008).

Figure 4-2: Welenchity Surface Irrigation Scheme under Sugar Cane Plantation (Source: Google Earth)

4.3 Methods

According to the objectives of this study, data on canal operation, climate and cropping pattern practiced in Welenchity irrigation scheme is required. The Primary Canal (PC-2) delivers the required water to the whole System of Welenchity Irrigation Scheme. This Canal has a length of 13.2km with five offtakes; three of them deliver water directly to the system network and two of them divert water to ponds and then the system under these offtakes gets water from the stored water in ponds during night time plus day time flow. The Primary Canal (PC-2) together with its water control structures and Offtakes will be evaluated during this study.

In general, the irrigation canals are designed for a capacity determined by the maximum irrigation requirements. In case of Welenchity, for most of the time, the canal flows less than the maximum flow and it is necessary to control the discharge and the water levels by means of structures. The main objective of the flow control system is to deliver a discharge (i) in the right amount i.e., at the right flow rate, frequency, and duration, (ii) with sufficient head, (iii) equitable and at the right place (iv) at the right period in time and (v) in a reliable and assured way.

Ideally, the objective of a primary irrigation delivery system, or "main system", is to convey water through canals to farmlands in a manner which optimizes both individual field and overall agriculture production.

Welenchity Irrigation Scheme has no Cross Regulator gates except the temporary horizontally sliding leaking gate at Offtake SC 2-2 constructed by the client himself. However, PC-2 Canal was equipped with speeds break (see Figure 4-3) together with head regulators for assuring the right head and flow rate instead. Accurate flow measurement is a basic requirement for improving the efficiency of water deliveries. The following describes the method used in brief.

i. The Discharge were observed and recorded at seven selected monitoring sites for determining water delivery performance parameters like adequacy, efficiency, equity and dependability which are used to evaluate the performance of Welenchity Irrigation System. The sites are selected near the offtakes. The numbers of discharge monitoring sites were based on the number of offtakes. Since the secondary are closed conduits and not equipped with flow measuring device, the inflow discharge upstream and outflow discharge downstream of each secondary offtakes were recorded to compute the offtake discharge as the difference of the two.
ii. Discharge and Water Depth was measured and monitored using a ‘Discharge App’ which is one of the quickest and easiest ways of acquiring

water flow measurements in streams and channels within few minutes using a Smartphone's Camera.

iii. The primary canal hydraulic flow characteristics were modeled using HEC-RAS to detect the effect that will result to the secondary and tertiary offtakes due to change in flow at the source/primary canal.

iv. The tentative irrigation scheduling recommended by designer, WWDSE (2008), for furrow irrigated fields currently in use was blamed for creating water stress by Wonji/Shoa sugar estate. Thus, the crop water requirement was verified by CROPWAT 8.0 by the use of designers' scenarios. All calculation procedures used in CROPWAT 8.0 are based on the two FAO publications namely no. 56 and no. 33. For more details and to see the governing equations please refer to chapter 6 of this research paper.

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Figure 4-3: Existing Speeds Break at Offtake TC 2-3-1&2 used as cross regulator

One way to achieve water management improvements in irrigation systems is through the use of advanced technologies to improve the operation of irrigation systems, and consequently, the management of water therein. With regard to improvements concerning the operation of irrigation system, there are many available models for large scale water management of conveyance and distribution networks.

4.1 Performance of Gated Division Systems with Little Cross-Regulation

Gated systems provide much greater flexibility in operations than ungated ones, and therefore tend to have lower maintenance requirements. This flexibility means that there are fewer limitations on the objectives, and it is possible to manage the system for a wide variety of combinations of adequacy, reliability and equity.

This flexibility is, however, a double-edged weapon. Sliding gates can be just as easily abused as used and well-planned water distribution patterns can be disrupted due to improper, illegal or merely malicious gate operations by field staff and farmers alike.

This chapter looks at three different variations of this type of design. The common thread is that each offtake along the Primary canal 2 and each offtake along secondary canals is provided with a gate that provides a great deal of operational flexibility. The distinction between the three systems comes in the opportunities to control water level in the main and secondary canals on the upstream side of the offtake gate.

Because these systems have considerable control capacity it is common to split performance assessment into two parts: assessment of main and secondary canals, and assessment of tertiary-level operations.

4.1.1 Systems with Little Cross-Regulation

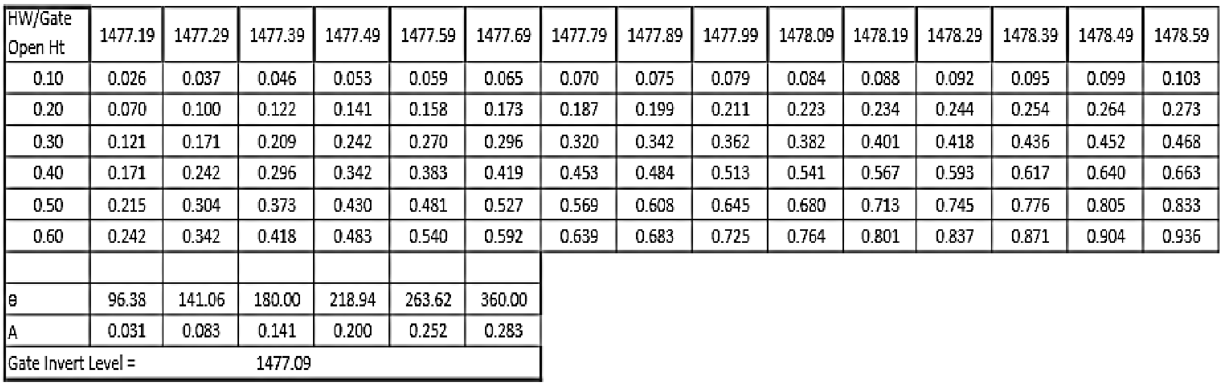
This design type is characteristic of older irrigation systems in relatively flat areas where it is comparatively easy to design long canal sections and still achieve appropriate water levels upstream of each offtake.

Operational inputs at the head of the canal are essential to achieve reliable and dependable water supplies in systems with little or no canal cross- regulation capacity. Each fluctuation in discharge into the head of the canal will result in changes in water surface elevation on the upstream side of each offtake structure; these changes, in turn, necessitate a change in the setting of the offtake gate if uniform discharge is to be maintained through the offtake climate, and crop patterns.

4.1.2 Gate Opening

The head regulator slide gates of Welenchity Irrigation Project differs in operation from the usual sluice gates in that it open to the buried pipes systems. Thus a user defined curve option is used to make the modeling a real representation of the actual scheme (See Table 4-2). The gate opening height was initially iterate manually using solver program and then optimized by HEC-RAS inbuilt system by turning on the optimization flag. The gate opening height was initially iterated for 80% Design Discharge, for Design Discharge and for 15% increase in Design Discharge (See Table 4-2).

Table 4-2: User defined curve (610ha Offtake)



HW/Gate Open Ht	1477.19	1477.29	1477.39	1477.49	1477.59	1477.69	1477.79	1477.89	1477.99	1478.09	1478.19	1478.29	1478.39	1478.49	1478.59
0.10	0.026	0.037	0.046	0.053	0.059	0.065	0.070	0.075	0.079	0.084	0.088	0.092	0.095	0.099	0.103
0.20	0.070	0.100	0.122	0.141	0.158	0.173	0.187	0.199	0.211	0.223	0.234	0.244	0.254	0.264	0.273
0.30	0.121	0.171	0.209	0.242	0.270	0.296	0.320	0.342	0.362	0.382	0.401	0.418	0.436	0.452	0.468
0.40	0.171	0.242	0.296	0.342	0.383	0.419	0.453	0.484	0.513	0.541	0.567	0.593	0.617	0.640	0.663
0.50	0.215	0.304	0.373	0.430	0.481	0.527	0.569	0.608	0.645	0.680	0.713	0.745	0.776	0.805	0.833
0.60	0.242	0.342	0.418	0.483	0.540	0.592	0.639	0.683	0.725	0.764	0.801	0.837	0.871	0.904	0.936
ɵ	96.38	141.06	180.00	218.94	263.62	360.00									
A	0.031	0.083	0.141	0.200	0.252	0.283									
Gate Invert Level =			1477.09												

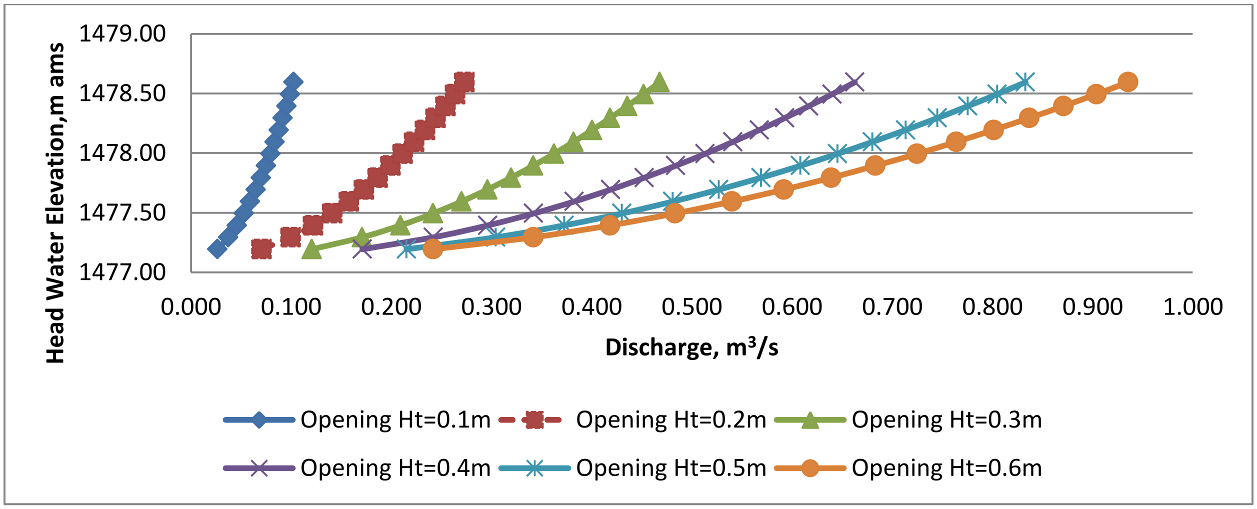


Figure 4-4: Head versus Discharge Curve (610ha Offtake)

Table 4-3: Iterated Optimum Gate Open Height for a discharge of 80% Design Discharge, Design Discharge, and for 15% increase in Design Discharge

Initial Gate Open Height with Solver						
1.15*Qd = 1.18m^3/s						
		610ha	SC 2-1	SC 2-2	SC 2-3-1&2	SC 2-3
Target Values		3.265	1.443	2.181	1.738	1.769
Opt	1.769					
X	138.969					
ɵ		183.54	127.89	151.93	137.95	138.97
Gate Open Height		0.309	0.168	0.227	0.192	0.195
Qd =1.03m^3/s						
		610ha	SC 2-1	SC 2-2	SC 2-3-1&2	SC 2-3
Target Values		2.839	1.255	1.897	1.511	1.538
Opt	1.538					
X	131.219					
ɵ		171.31	121.01	143.10	130.28	131.22
Gate Open Height		0.277	0.152	0.205	0.174	0.176
0.8*Qd = 0.82m^3/s						
		610ha	SC 2-1	SC 2-2	SC 2-3-1&2	SC 2-3
Target Values		2.271	1.004	1.518	1.209	1.230
	1.230					
X	120.062					
ɵ		154.65	111.01	130.53	119.26	120.06
Gate Open Height		0.234	0.130	0.174	0.148	0.150

Where: Qd is Design Discharge

The model was calibrated for the Manning and discharge coefficients of 0.012 and 0.8, respectively.

The existing gate operation rules for management of Welenchity Surface Irrigation System show some differences between delivered and required discharges. Therefore, the gate operation rules proposed by the network designers were simulated by the model, and discharges were computed.

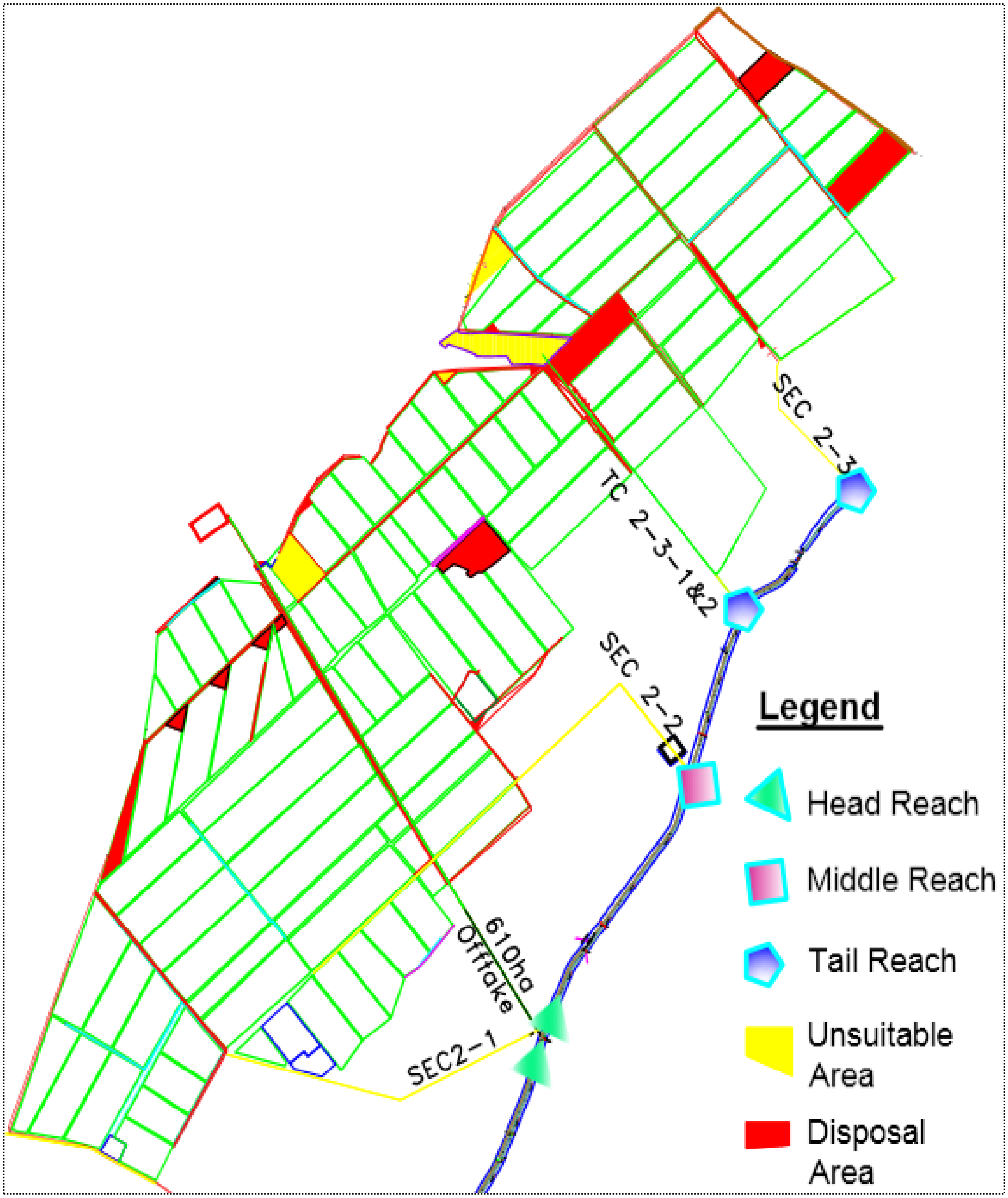


Figure 4-5: Welenchity Scheme Layout with Discharge Monitoring Locations in Head, Middle and Tail Reaches.

4.2 Data Sources and Methods of Data Collection

In this study the data were collected from primary and secondary sources. The primary data were collected in direct measurement from fields. Such activity includes: measurements of discharging through the branch off take canals, measurement of actual water surface elevation in the main canal, field observations.

The secondary data were collected from Ethiopian Sugar Corporation Research and Training Center and Wonji Shoa Sugar Factory are major data which were utilized in the study.

4.2.1 Discharge App (Optical Technology for Measuring Discharge)

Accurate flow measurement is a basic requirement for improving the efficiency of water deliveries. Many modern methods for operating canals in a more efficient manner rely upon real-time knowledge of flow rates throughout a canal system and require the ability to quickly and easily adjust flow rates at various locations throughout a system. Discharge App is one of the quickest and easiest ways of acquiring water flow measurements in streams and channels within few minutes using a Smartphone’s Camera and it is used as a discharge measurement and monitoring tool in this study.

The Discharge app is a non-intrusive, optical flow measurement tool, suited for natural water streams, irrigation furrows and water channels. The app is fully integrated in the web platform ‘discharge.ch’. At dedicated measurement sites the app can accurately determine water level and discharge. The discharge is calculated either via rating curve, or via surface velocity that is measured by the app. All calculations are performed directly on the smartphone, such that the app can operate in offline mode.

An operational site requires 4 reference markers and a known cross sectional profile. Discharge App version 1.4.1 built on Jul 24, 2017 by Hydrosolutions ltd is available on Google Play Store. Search for “Discharge River” and download the application at (https://play.google.com/store/apps/details?id=ch.photrack.discharge&hl=en).

Special features and benefits Optical technology for measuring discharge

- Simple and cost - efficient installation
- Flexible positioning of the measuring equipment
- No flow tracers required
- Representative and non- intrusive measurement
- On- site evaluation
- A smart alarm management system
- Autonomy, Robust, weather insensitive, precise

- Remote transmission of measurement data, videos and images (evidence photos)

Measuring Overviews

Input parameters (defined):

- cross sectional profile
- reference markers, Approximately 4

Measured parameters (optically captured):

- water level h
- surface velocity

Modeled parameters:

- vertical velocity profiles

Calculated parameters:

- mean velocity
- discharge

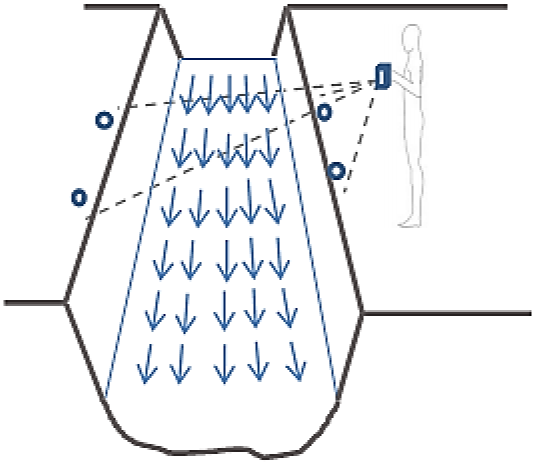


Figure 4-6: Recording Position and Markers for Discharge App

Results/Output:

- ✓ **Water level h**
- ✓ **Mean surface velocity v_m**
- ✓ **Discharge Q**

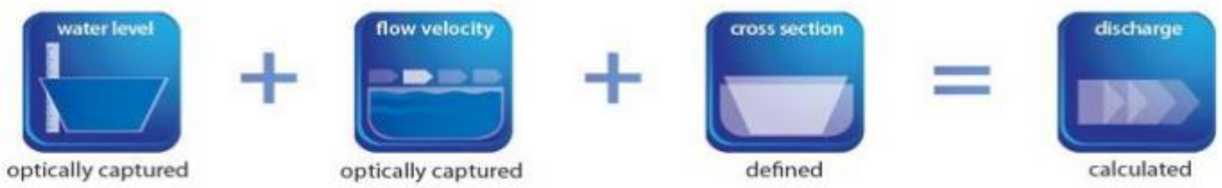


Figure 4-7: Schematically representation of the discharge app Process

Procedures

- Draw two markers on each bank and measure their position relative to the cross sectional profile. The markers need to be close the corners of your camera view in portrait mode.
- For standard geometries the app is guiding you through the steps, for more complex geometries refer to manual on discharge.ch/help.
- Create your site either in the mobile app or with the web-based tool of discharge.ch and enter and verify your site measurements.
- Perform the measurements using your smartphone's camera by recording a small video of seconds' length.

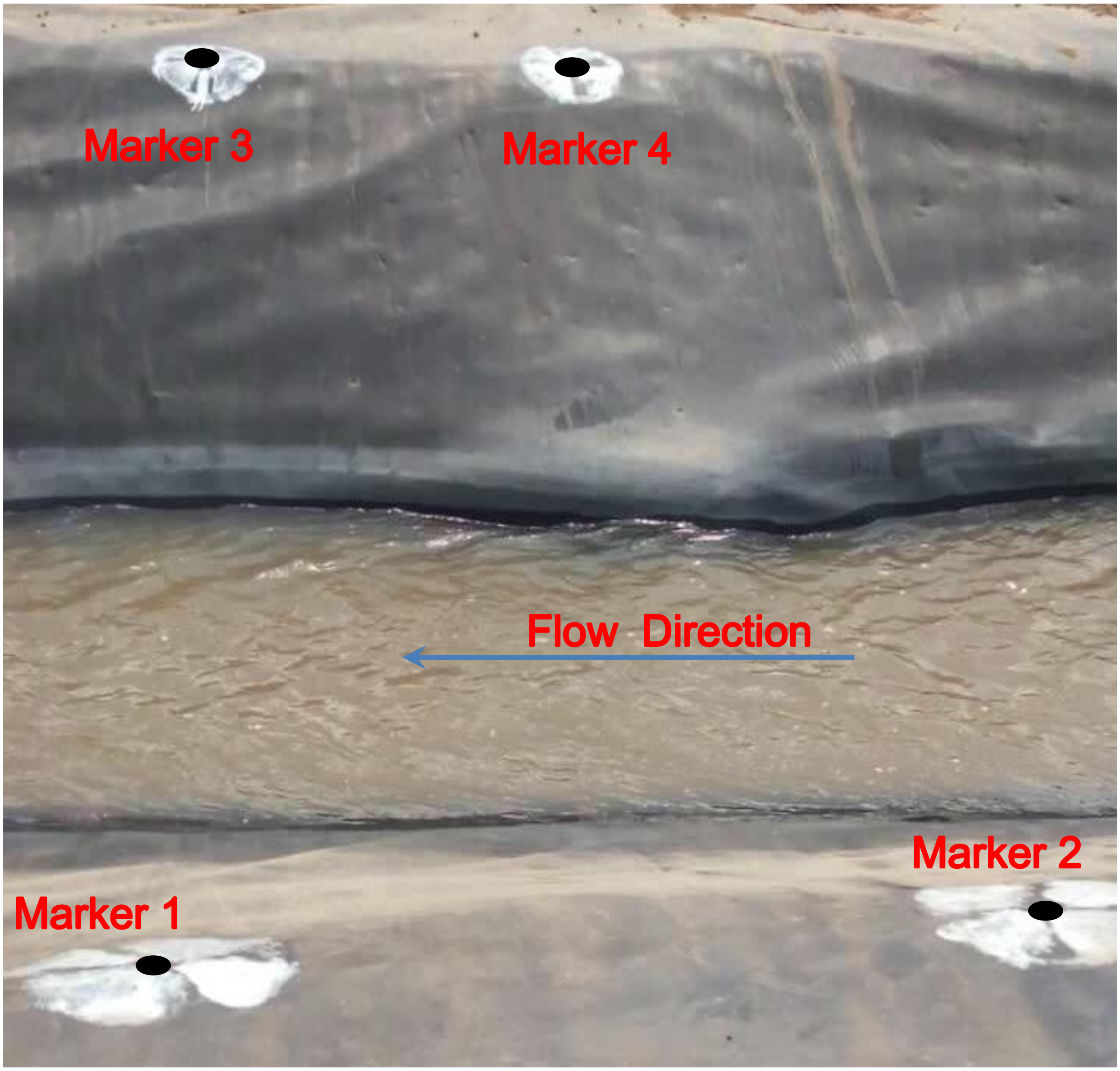
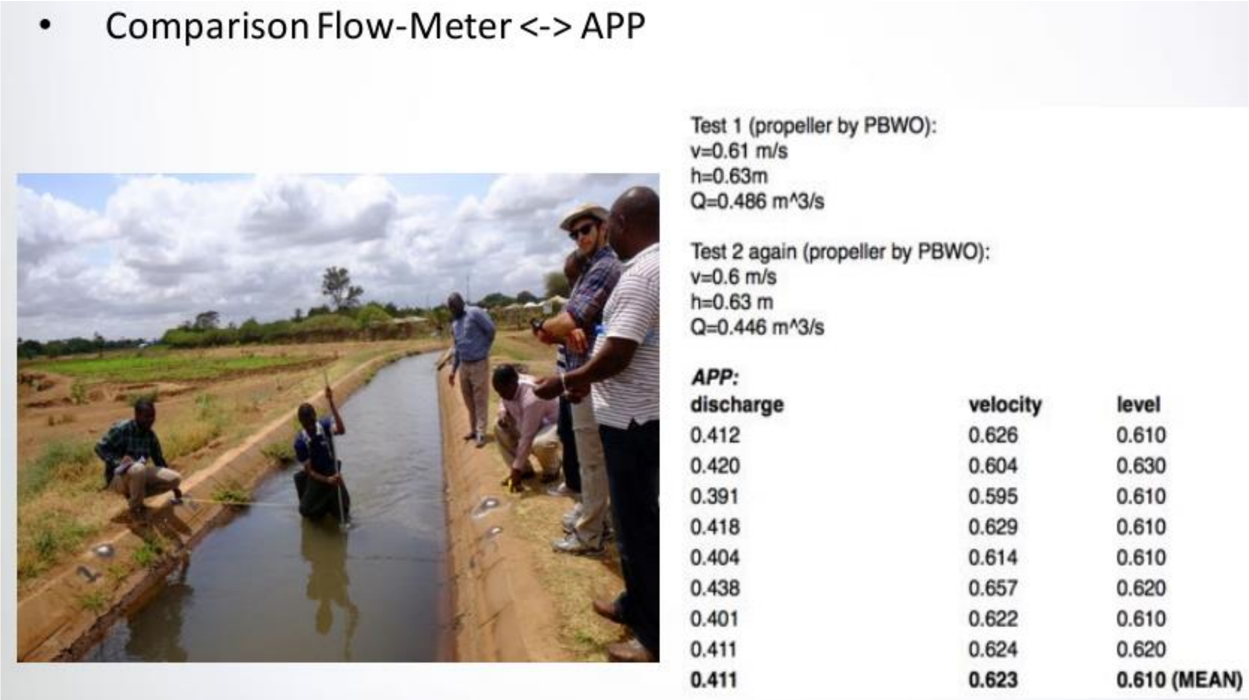


Figure 4-8: Discharge Monitoring Location Downstream of SC 2-1 Offtake

The application Discharge is available on android devices with the following requirements:

- Android 4.1 or higher
- Smartphone Camera: 25 fps video
- ARM Processor



- Comparison Flow-Meter <-> APP

Test 1 (propeller by PBWO):
v=0.61 m/s
h=0.63m
Q=0.486 m^3/s

Test 2 again (propeller by PBWO):
v=0.6 m/s
h=0.63 m
Q=0.446 m^3/s

APP:

discharge	**velocity**	**level**
0.412	0.626	0.610
0.420	0.604	0.630
0.391	0.595	0.610
0.418	0.629	0.610
0.404	0.614	0.610
0.438	0.657	0.620
0.401	0.622	0.610
0.411	0.624	0.620
0.411	**0.623**	**0.610 (MEAN)**

Figure 4-9: Comparison of Flow-Meter and Discharge APP (By photrack Ltd & SEBA Hydrometry)

4.2.1.1 Water Surface Elevation Measurements (WSE)

Water surface elevation of the canal will be measured in the reaches of the canal in the head, middle and tail reaches. It is measured using graduated staff with reference to the elevation of as-built structures and reference Bench Marks.

4.3 Data analysis and interpretation

Operational deficiencies can arise from differences between system design criteria and expected water distribution capacity and flexibility. Many existing irrigation systems have been designed based on steady state, peak flow criteria which preclude the ability to operate the system according to actual expectancies. Additional operational problems often associated with the delivery of water to irrigated areas include: (1) water level fluctuations in the main system; (2) sluggish system response to changing demands; (3) inequitable distribution of water among the users, particularly between users on the upstream end of the system and users on the downstream end of the system; and (4) too much or too little available water with respect to user needs at any given time.

"The performance of a system is represented by its measured levels of achievements in terms of one, or several, parameters that are chosen as indicators of the system's goals." Thus performance of the irrigation system was evaluated using performance indicators. Performance evaluation using process indicators consists specifically measuring the extent to which the goals and required benefits are being achieved. A water delivery performance was designated to evaluate on a canal at head, middle and tail reaches.

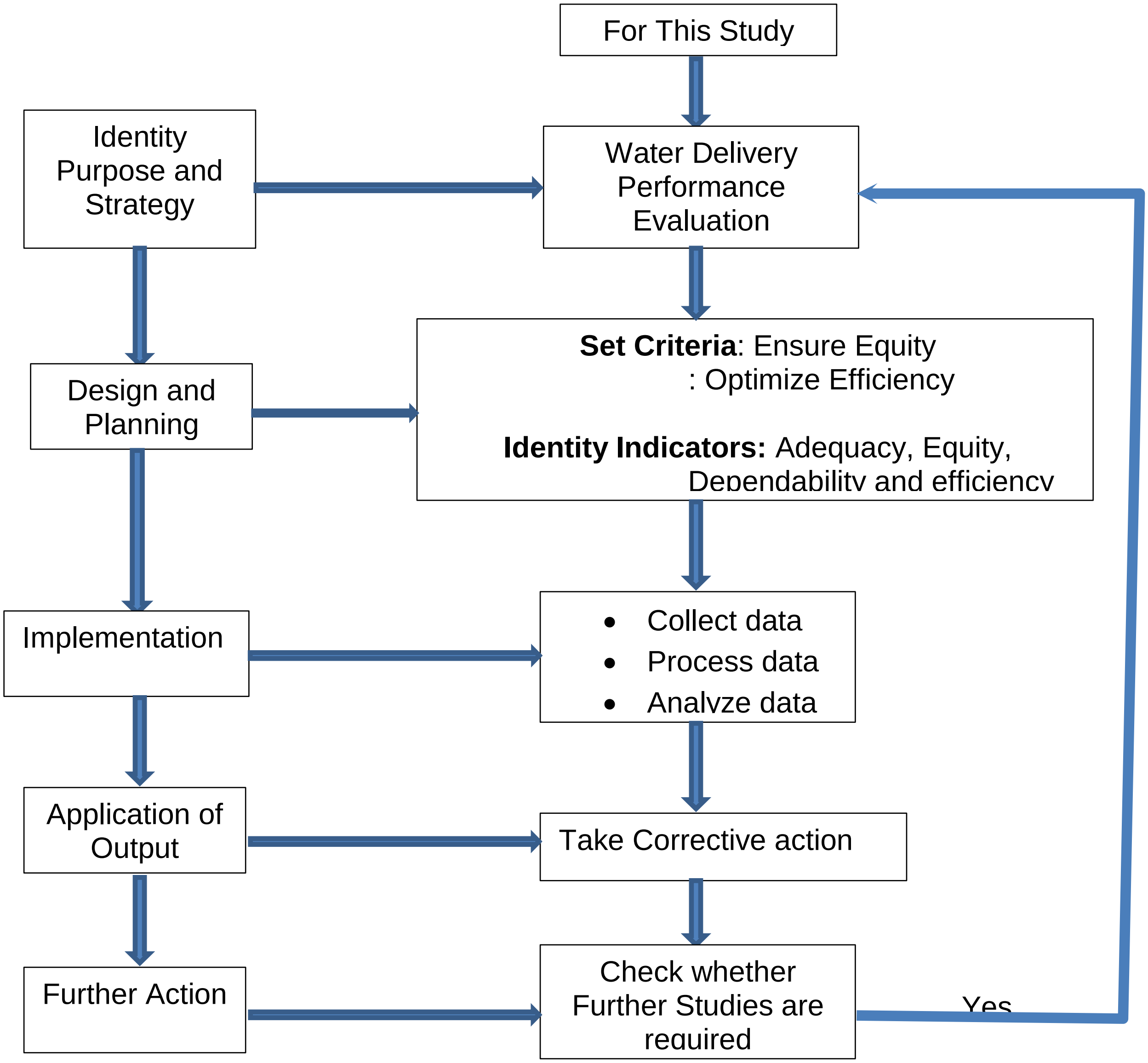


Figure 4-10: Framework for Performance Assessment of Irrigation Schemes

4.3.1 Selection of Indicators

It is necessary to emphasize here that the concept of performance is closely linked to the existence of goals and targets for achievement (Seckler et al. 1988; Abernethy 1989).The goals may be explicit or implied; but the choice of any parameter as an indicator of performance is based on the premise that enhancement of the parameter is a desirable thing.

Different performance indicators were employed for various systems like irrigation water delivery system, irrigated agriculture system and agriculture economic system in the framework of (L.E. Small 1992). However, the scope of this study was limited to performance evaluation of irrigation water delivery system.

4.3.1.1 Water Delivery System

There appears to be reasonable agreement in the literature that the irrigation water delivery should be evaluated on the dimensions of *adequacy, timeliness, and equity*. Sometimes, other terms are also used: efficiency in water use, predictability and reliability of water supply. These are, however, not separate but associated with adequacy and timeliness. Water quality may be an additional important dimension in some systems, but it is not the case in this study.

Indicators of the three characteristics--adequacy, timeliness, equity—should enable us to answer, in respect of any given irrigation system, three questions framed on the following lines (Abernethy 1989):

- To what extent does the quantity of water provided suffice for the growth needs of the crops that are planted?
- Does the timing of the water deliveries match the growth needs of the crops and the expectations of the farmers?
- Is the water distributed fairly among the multiple users of the system?

4.3.2 Computation of performance indicators

To evaluate how well the water delivery system in **Welenchity** Irrigation System is functioning, measures of system performance has to be defined. Molden (2007) have concluded that performance measures so developed facilitated analysis of irrigation water delivery systems in terms of adequacy, efficiency, dependability, and equity of water delivery. In calculating these indicators, the values of Demand (Q_D) and Required (Q_R) for each irrigation were taken as basic variables; the number of irrigations in one season (T) was taken as the time period; and the number of fields (R) was taken as the sub-region (N. Korkmaz 2012).The performance measures provided a quantitative assessment not only of overall system performance. Spatial and temporal distributions of required, scheduled, deliverable and delivered water were used to calculate the performance measures. These variables may be estimated by a combination of field measurement and simulation techniques.

According to Molden and Gates, 1990 the performance of the system was classified as good, fair or poor.

4.3.2.1 Adequacy

A fundamental concern of water-delivery systems is to deliver the amount of water required to adequately irrigate crops. To meet the water requirements of crops is a basic obligation of the farming system. Without a good knowledge of the net water availability and demand in the system, no improvement for the optimal utilization of the water resources can be suggested. In the framework of the study, canal supplies are the primary resource. In this study, an effort is made to compute the adequacy of the present supplies.

Adequacy of delivery is dependent on water supply, specified delivery schedules, the capacity of hydraulic structures to deliver water according to the schedules, and the operation and maintenance of the hydraulic structures.

The adequacy can be estimated for an irrigation system as a whole, or for subsystems and sub-command areas. Locally, for an offtake, the adequacy is simply the ratio of actual to required delivery. The adequacy is computed using the equation (4.1) and the values lower than 1 shows the inadequate delivered water while the values higher than 1 show that the delivered water is more than enough.

$$P_A = \frac{1}{T}\sum_T \left(\frac{1}{R}\sum_R p_A\right); \qquad p_A = \frac{Q_D}{Q_R} \quad if \quad Q_D \leq Q_R \text{ ,} otherwise \;\; p_A = 1 \tag{4-1}$$

Where:

P_A - the performance measure relative to adequacy at subsystem or system level;

p_A - adequacy for a single point (e.g. offtake) or simply delivery performance ratio;

Q_D - the actual amount of delivered water;

Q_R - the intended (required) amount of water;

R - region served by the system (secondary canals for this study);

T - time period (irrigation season).

Note that the adequacy value becomes 1 if the delivered discharge is higher than the targeted or required discharge, showing that this indicator will not penalize the water user for receiving more water than intended. But this may also create an environmental problem and efficiency problem

4.3.2.2 Delivery Performance Ratio (DPR)

Water delivery performance is generally defined as the amount of actual water delivered by the channel compared to the target amount. Supplies from the main canal to the secondary stem should follow the pattern of the scheduling during all circumstances of flow shortage, or excessiveness. In actual operations, there are long and short-term perturbations, caused by the operations at upstream nodes, inappropriate water delivery schedules, limitation of the physical system, etc. These factors create a noise in the system, which should minimally influence the planned operations of the system, if the historical flow hydrograph and the constant factors are properly considered in the planning.

The ratio of supply with respect to target discharge (design) would be equal to unity if the target is 100% achieved whatever the actual supply to the canal is.

Otherwise, its value represents the degree to which the target has been achieved. Nevertheless, a major generic problem of these systems is the inconsistency of the targets, which are either not fixed for all units of the system, or not specified during all periods of a season.

For Welenchity Irrigation System, the design discharge of each offtaking canal from the primary (PC-2) is a target discharge. Thus, Delivery Performance Ratio (DPR) is defined as:

$$DPR = \text{Actual } Q/\text{Design } Q$$

This set of graph exhibit the potential of the Delivery Performance Ratio indicator for evaluating the manager’s target and equitable distribution of water among different offtakes over a time interval.

4.3.2.3 Assessment of the Managerial Performance by the Total Error (TE) Index

The Total Error (TE) Index was defined as (Thiels Formula):

$$TE = \frac{\sqrt{\sum(Targeted\,Value - Achieved\,Value)^2}}{\sqrt{\sum(Targeted\,Value)^2}}$$

The major assumption in these computations is the equal weightage to the positive and negative deviation from the target (absolute values), while a higher weightage is given to the bigger values (squaring of the values).

For the management of the delivery system, the best quantitatively expressible internal target is DPR. As discussed in the pervious sections, the targeted value of this ratio is one.

Using TE as an index to compute the effectiveness of the management for achieving the design delivery performance ratio on the seasonal bases, gives a percentage error which means a management effectiveness is 100% minus the error.

Important to note is that the computed error value (or performance index) depends upon the realization of the objectives and their quantitative representation.

The Total Error (TE) idex gives a good overall picture of the gross deviation from the targets and is easy to use.

4.3.2.4 Efficiency

Efficiency embodies the ability to conserve water by matching irrigation application with crop water requirements. A water delivery system that delivers more water than adequate does not conserve water resources and promotes other problems such as waterlogging. The objective of water delivery efficiency is to conserve water by matching water deliveries with water requirements.

The objective of water delivery efficiency is to conserve water by matching water deliveries with water requirements. A measure of this objective would be the spatial and temporal average of the ratio of Q_R to Q_D see equation (4.2).

$$P_F = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R p_F\right); \qquad p_F = \frac{Q_R}{Q_D} \quad if \quad Q_R \le Q_D \;\; otherwise \;\; p_F = 1 \qquad 4\text{-}2$$

Where:

P_F - the performance measure relative to efficiency at subsystem or system level;

p_F – efficiency for a single point (e.g. offtake);

Q_D - the actual amount of delivered water;

Q_R - the required amount of water

R - region served by the system

T - time period (irrigation season)

Efficiency is lower than 1.0 when actual deliveries are greater than required. A system under water stress ($Q_R > Q_D$) always has a level of efficiency equal to 1.0.

4.3.2.5 Equity

Equity, as related to water-delivery systems, can be defined as the delivery of a fair share of water to users throughout a system. Equity expresses the degree of variability in relative water delivery from point to point over the irrigated area (N. Korkmaz 2012). The first and most apparent consequence of ineffective operation is inequity in water delivery at head, middle, and tail reaches of the system. This results in over-supply in some parts of the scheme and under-supply in other parts, which brings about differences in irrigation services among different groups of water users/irrigation blocks/. In turn this result in yield reduction in under irrigated parts of the scheme while the source discharge is sufficient for the whole field sees **Error! Reference source not found.**. The second consequence of ineffective operation is loss of significant quantity of water either as over application or run off losses at tail end, which results in low water use efficiencies. This in order results in low water productivity and puts limitations on the water resources available to irrigate more lands to meet rising food demands.

Several alternative definitions of water-delivery equity have been suggested but in the present study, equity is defined as being spatial uniformity of the ratio of the delivered amount of water to the required or scheduled amount (Molden and Gates 1990) see Equation (4.3).

$$P_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_D}{Q_R}\right) \qquad \text{4-3}$$

Where:

P_E - the performance measure relative to equity;

$CV_R\frac{Q_D}{Q_R}$- Spatial coefficient of variation (ratio of standard deviation to mean) of the ratio QD/QR (relative water delivery) at delivery points over the hydraulic level or reaches R. As the value of PE is close to zero, the degree of equity in water delivery would be higher.

Figure 4-11: Effect of inequity in water distribution at Welenchity Surface Irrigation Scheme

4.3.2.5.1 Equity Ratio for Head and Tail (ERHT)

This indicator focused on the equity of water distribution for head and tail at different levels of a system. It can assist to identify head and tail difference at the level of the system; and to address problems as a result. The ratio is defined as:

$$\text{ERHT (MDR)}=\frac{\frac{1}{n}\sum_{t=1}^{t=n} MDR(head)}{\frac{1}{n}\sum_{t=1}^{t=n} MDR(tail)} \qquad (3.5)$$

The value of MDR is described as the ratio of QD with QR, n is the number of periods monitored.

4.3.2.6 Dependability

Dependability is defined as temporal uniformity of the ratio of the amount of water delivered to that required to irrigate the crops.

$$P_D = \frac{1}{R}\sum_R CV_T\left(\frac{Q_D}{Q_R}\right) \qquad 4\text{-}4$$

Where: `

P_D - performance measure relative to dependability or reliability;

$CV_T\frac{Q_D}{Q_R}$- Temporal coefficient of variation of the ratio of Q_D/Q_R over time period T.

The degree of temporal variability can be qualified by the value of indicator P_D. The closer the value of this indicator is to zero, the more reliable the relative delivery becomes over time.

4.3.2.6.1 Timeliness of Canal Supplies

In its generic meanings, the term timeliness is a measure of correlation between crop water requirements and actual deliveries to the command area. This is different to adequacy, which determines a quantitative ratio for supply and demand, and from reliability, which indicates a much between the actual and expected supply. “Timeliness” can be considered on the basis of the accuracy of fit between two time history curves, one of which represents the evapotranspiration needs of the crop throughout its season, and the other, the actual deliveries of water.

Timeliness is an important parameter from the farmer’s prospective because it ensures availability of water when it is most required.

4.3.2.7 Deficiency

The value of deficiency is a quantitative measure of the dissatisfaction’s of users/irrigators. The parameter will help the system managers and users/irrigators to take corrective measurements for system improvements in deficit areas. A measure of deficiency is given as the ratio of temporal and spatial average of water deficiency to the required amount (Q_R).

$$PDF = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R \frac{Q_R - Q_D}{Q_R}\right) \qquad 4\text{-}5$$

Where:

$PDF = \frac{Q_R - Q_D}{Q_R}$, *If*$Q_R > Q_R$, *otherwise =0*

4.3.2.8 Maintenance Indicators

Maintenance requirements of the system were observed according to the maintenance indicators of water surface elevation ratio, effectiveness of infrastructure, delivery duration ratio and sustainability of irrigable area. The physical structures in its operational condition were categorized as operative, nearly operative, nearly inoperative and inoperative. If at least one of the following conditions are in effect: broken and damaging of the structure, change of canal cross-section, scouring of canal section, missing of flow control and measuring structures, sedimentation and weed growth (M. Samad and D. Vermillion, 1998).

$$EI = \frac{Number\ of\ functioning\ Structures}{Total\ Numbers\ of\ Structures\ initially\ installed}$$

$$WSER = \frac{Actual\ Water\ Surface\ Elevation\ at\ FSL}{Design\ Water\ Surface\ Elevation\ at\ FSL}$$

$$DD = \frac{Actual\ Duration}{Designed\ Duration}$$

$$SI = \frac{Actual\ Irrigated\ Area}{Designed\ Irrigated\ Area}$$

Where:

EI = Effectiveness of infrastructure
WSER = Water surface elevation ratio
DDR = Delivery Duration Ratio
SI = Sustainability of irrigated area

4.3.2.9 Amount of Water Required in the Irrigation System

The amount of water needed for the irrigated crop fields was obtained from Wonji Shoa Sugar Factory which was rechecked by using CROPWAT version 8.0 programs. Crop water requirements, irrigation requirements (IR) and scheme water supply for varying crop patterns were estimated based on the soil type.

5 Application of the Hydrodynamic Model HEC-RAS

5.1 Why Hydraulic Simulation Model is required for Performance Assessment

Hydraulic simulation models are fundamental tools for understanding the hydraulic flow characteristics of irrigation systems.

Some of the useful hydraulic models developed and have been in use during the past two decades for simulation of flows in irrigation networks include CANALMAN, SIC, CARIMA, MODIS, USM, DUFLOW, HEC-RAS, etc. In this study, HEC-RAS will be applied as a tool for simulating the flow for different operational setups.

Due to its minimal estimation errors, HEC-RAS model would be appropriate in evaluation of canal hydraulics in steady state conditions to improve on scheme performance; (Imbenzi J. Serede 2015).

HEC-RAS was developed by the Hydrologic Engineering Center, a research group for the U.S. Army Corp of Engineers. The program is freely distributable and can be obtained from the HEC web site: www.hec.uasce.army.mil.

The study of 'Performance assessment of Doroodzan irrigation network by steady state hydraulic modeling' shows that HEC-RAS model can be used successfully for a large and complex irrigation system for evaluation of its performance in the absence of observed flow data and improvement of irrigation management plans.

Discharge deviations at the source of an irrigation canal cause changes in the discharge of lateral canals or tertiaries. However, there is an important question. How the discharge deviation in the tertiary canals is affected by discharge deviation at the system source? To find a proper answer to this question, dis-charge reductions at tertiaries due to discharge reductions at system source were evaluated using the model for the reach under study.

5.2 Fundamental Functions of the HEC-RAS Model

The HEC-RAS system has the capability to perform one-dimensional surface profile hydraulic analysis in both steady state and unsteady conditions.

The steady flow computational procedure is based on the solution of the one dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include hydraulic structures. The effects of various obstructions such as culverts, weirs and other structures can be considered in the computations (Mark Jensen 2004).

Losses between cross sections in steady flow analysis are the sum of the friction losses and contraction expansion losses. In subcritical analysis, the computations start at the downstream boundary and proceed upstream. The water surface at the next cross section is computed such that the energy loss between the sections is the sum of the friction losses and the contraction and expansion losses. Friction losses are computed with a friction slope from Manning's equation and the contraction/expansion losses are computed a coefficient times the change in velocity head. The friction slope is a conveyance weighted average between the sections.

The fundamental hydraulic equations that govern 1-D, steady-state and gradually-varied flow analysis comprise the continuity, energy and flow resistance equations.

$$\text{Continuity Equation: } Q = V_1A_1 = V_2A_2$$

$$\text{Energy Equation: } H = Z+y+\frac{\alpha v^2}{2g};\ Z_A+y_A+\frac{\alpha v^2}{2g} = Z_B+y_B+\frac{\alpha v^2}{2g}+H_L$$

$$\text{Flow Resistance Equation: } Q = K\, S_f^{1/2}$$

$$K = {}^{1}/_{n}\, A\, R^{2/3}$$

5.3 Development of the Welenchity PC-2 Canal HEC-RAS model

Geometric Data

The layout and geometry of the physical features of the Welenchity PC-2 Canal were taken from several sources including Final Design and Tender Document Report Volume IV (Drawing Album) by WWDSE, September 2008; As-built Drawings and a profile spreadsheet data submitted to Wonji Shoa Sugar Factory during handing over.

The Welenchity PC-2 Canal was modeled as one reach, with a specified flow distribution and downstream boundary conditions (normal depth). There were 72 user entered cross sections to describe the physical system and 60 interpolated sections to get the computation distance below 90m. The modelling results vary depending on the number of cross-sections. Typically, it is suggested that cross-sections to be spaced in the order of 90 m to 150 m apart (May et al., 2000).

The Drop structures can be modeled with the *inline weir option* or as a *series of cross sections*. However, if one is just interested in getting the water surface upstream and downstream of the drop structure, then the inline weir option would probably be the most appropriate alternative. Thus, in this study, the weir option method was adopted for modeling the drop structures.

Steady Flow Data

- Flow rate for each profile
- Boundary condition
    - The discharge at the source and rating curves at downstream of every offtake was chosen as upstream and down-stream boundary conditions.
    - Manning's "n" and discharge coefficients used for calibration of model.
- Gate elevation setting/Gate opening height

5.3.1 HEC-RAS Output

- profile plot including the water elevation that represented the actual water surface profile depth
- simulated flows at canal offtakes

5.3.2 Model Operation

With the geometry and flow files established, the HEC-RAS model was executed. This was achieved by selecting Simulate/ Steady Flow Analysis from the project window. The calibration procedure gave the actual Manning's of the canal which was further optimized.

5.3.3 Model Calibration and Validation

5.3.3.1 Model Calibration

In an effort to ensure a higher level of Model accuracy, the user can calibrate the Model when a reliable data is available. Often times the primary focus of calibration is the adjustment of Manning's n Values (Gary W. Brunner 2016). Thus, during calibration, Manning's coefficient "n" and flow roughness coefficients were changed iteratively until the differences between simulated and observed values of water levels were within the allowable criteria ranges as per the selected statistical criteria (Imbenzi J. Serede 2015). The calibration procedure gave the actual Manning's of the canal and discharge coefficients of the gates (see Figure 5-1).

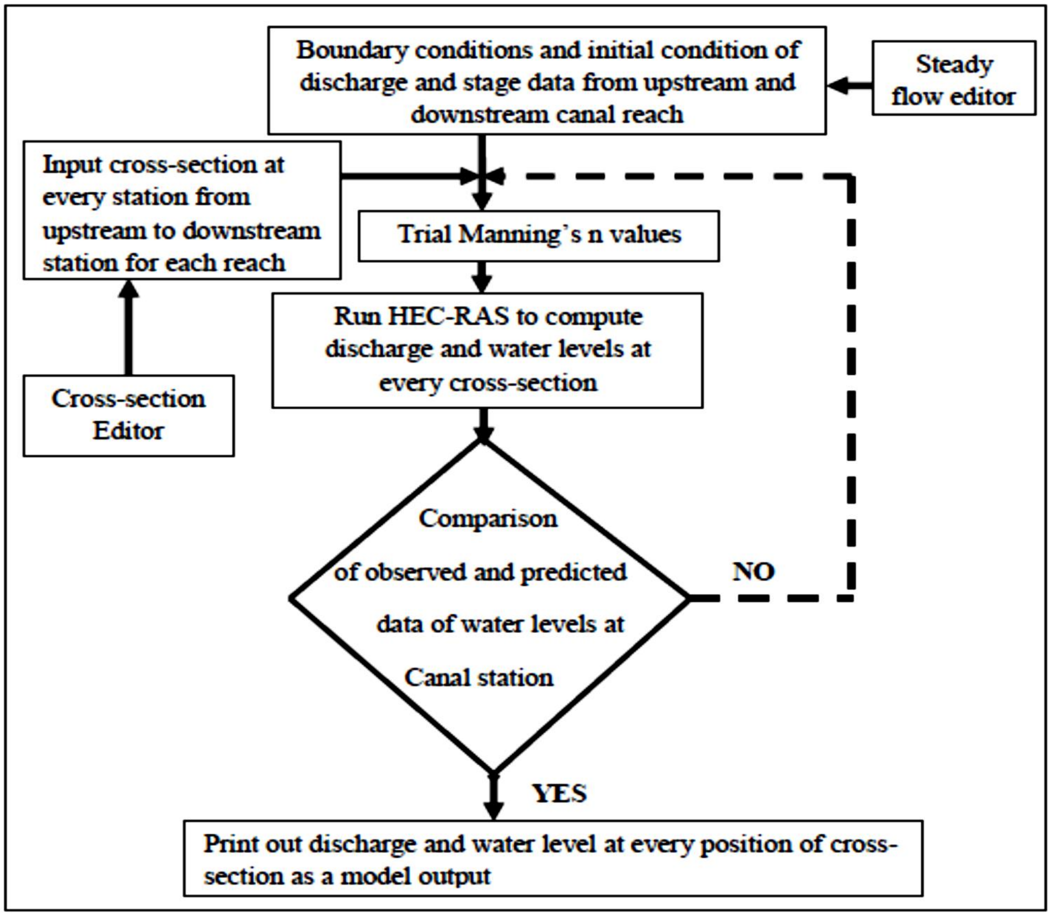


Figure 5-1: Flow chart of conceptual framework for HEC-RAS Model calibration

The setup preparation for the HEC-RAS model involves specifications of canal cross-sections, layout of the canal network, regulators, upstream and downstream boundary conditions. Data on geometry of the canal and hydraulic structures were collected from Wonji Shoa Sugar Factory. The cross-section data are available at discrete points along the canal system. The geometry of structures which is necessary for model includes type of gate, number and width of gate, sill levels and discharge coefficients. The boundary condition includes the discharge at system source, Manning's "n" at every location and rating curve or normal depth or critical depth, or known water level at downstream end of every branch.

The Canal flow data, gate opening data during the measurement, and water surface elevations were directly measured on site which is used for Model Calibration and Validation.

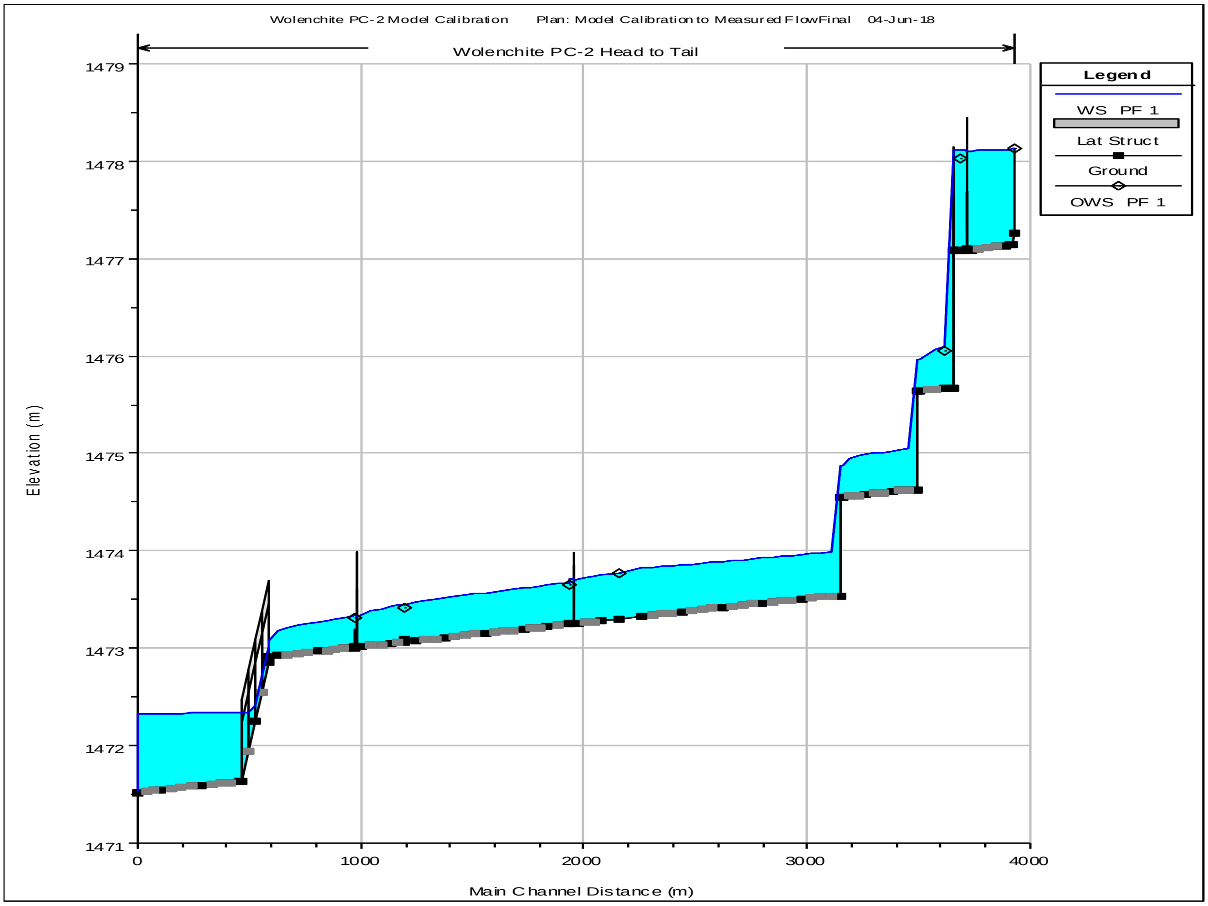


Figure 5-2: PC-2 Canal Profile Calibrated with the first observed data

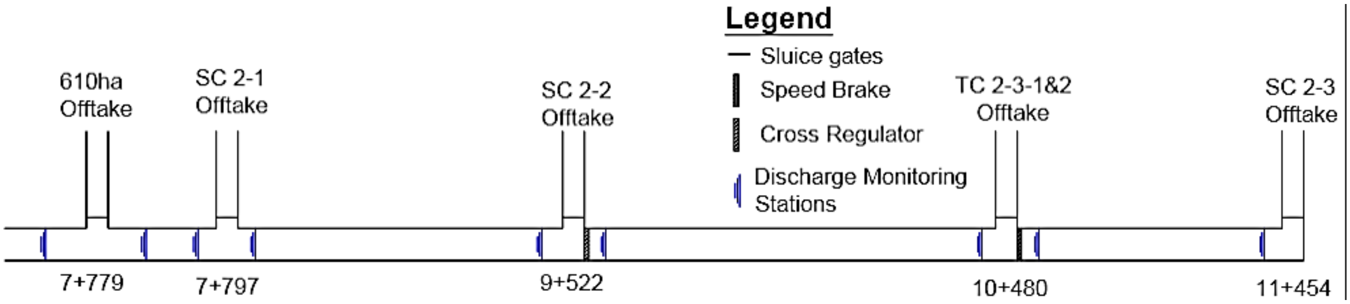


Figure 5-3: Schematic Representation of Welenchity PC-2 Canal and Related Control Structures

The comparisons between observed and simulated values were made using following criteria proposed by Jabro et al (1998).

The maximum error (ME) is a measure of the maximum error between any pair of simulated and measured values. The lower limit and the best value of ME is zero.

$$\text{ME} = Max|M_i - S_i|_{i=1}^{n} \qquad \text{5-1}$$

The root mean square error (RMSE) provides a percentage for the total difference between simulated and measured values proportioned against the mean observed values. The lower limit for RMSE is zero and indicates a more accurate simulation.

$$\text{RMSE} = \left[\frac{1}{n}\sum_{i=0}^{n}(M_i - S_i)^2\right]^{0.5}\left(\frac{100}{M}\right) \qquad \text{5-2}$$

The modeling efficiency (EF) is a measure for assessing the accuracy of simulations. The maximum value for EF is one, which occurs when the simulated values match the measured values perfectly.

$$\text{EF} = \frac{\sum_{i=0}^{n}(M_i - M)^2 - \sum_{i=0}^{n}(M_i - S_i)^2}{\sum_{i=0}^{n}(M_i - M)^2} \qquad \text{5-3}$$

The coefficient of residual mass (CRM) is an indication of the consistent errors in the distribution of all simulated values across all measurements with no consideration of the order of the measurements. A CRM value of zero denotes no bias in the distribution of simulated values with respect to measured values.

$$\text{CRM} = \frac{\sum_{i=0}^{n} M_i - \sum_{i=0}^{n} S_i}{\sum_{i=0}^{n} M_i} \qquad \text{5-4}$$

The other important parameter for comparing the estimated and measured values is the mean absolute error of estimation. MAE is the mean absolute error of estimation, which is better to be close to zero.

$$\text{MAE} = \frac{1}{n}\sum_{i=0}^{n} |S_i - M_i| \qquad \text{5-5}$$

Where Si , Mi and M are the simulated, measured (observed) and average of measured values, respectively.

In this study, the Primary Canal PC-2 water delivery performance of the Welenchity Surface Irrigation Scheme was evaluated. The discharge at the source and the normal depth (slope) at downstream was chosen as upstream boundary conditions. Two sets of measured data were used for model calibration and validation. These data include measured discharge and water surface elevation at various locations along the canal. After the model was calibrated and validated, it was used for simulation of other desired conditions. To calibrate the model, an initial run was made with default global values of Manning's roughness coefficient "n" and gate discharge coefficients. Later these parameters were adjusted manually and the model was rerun. Based on the comparison, the model parameters were adjusted. This process was continued until the observed and simulated values were in close agreements. To validate the calibrated model, the second set of discharges and water levels along this canal were used. If the observed and simulated values were still in close agreement without any changes in model calibration parameters, it could be concluded that the model was valid for the intended purpose.

The required or target discharges which are on the basis of crop water requirements were obtained from Wonji Shoa Sugar Factory which was after rechecked with CROPWAT tool.

Table 5-1: Measured Flow and Water Surface Elevation Data for Model Calibration and Validation

Offtakes	**Water Depth, m**		**Discharge, m3/s**		**Water Surface Elevation, m asl**		**Gate Open Height**		**Offtake invert level**
	Calibration	Validation	Calibration	Validation	Calibration	Validation	Calibration	Validation	
610ha	0.87	0.74	2.02	1.71	1478.135	1478.005	0.2	0.31	1477.265
SC 2-1 us	0.99	0.85	1.37	0.57	1478.075	1477.935	0.6	0.28	1477.085
SC 2-1 ds	0.39	0.25	0.756	0.377	1476.060	1475.920			1475.670
SC 2-2 us	0.47	0.28	0.731	0.369	1473.775	1473.585	0.23	0.14	1473.305
SC 2-2 ds	0.41	0.25	0.449	0.238	1473.660	1473.500			1473.250
TC 2-3-1&2 us	0.32	0.19	0.44	0.207	1473.410	1473.280	0.24	0.17	1473.090
TC 2-3-1&2 ds	0.3	0.12	0.257	0.121	1473.310	1473.130			1473.010

During the model calibration, the value of Manning's n that resulted in the closest agreement between observed data and results of hydraulic simulation is determined by trial and error to be (n=0.012) for both over bank and main channel. The calibrated values then are used to verify the model predicted results with a set of data not used in the calibration.

5.3.3.2 Model Validation

The accuracy of calibrated parameters will be tested using the differences between second set of observed data and the new simulated values. This will validate the model (Imbenzi J. Serede 2015).

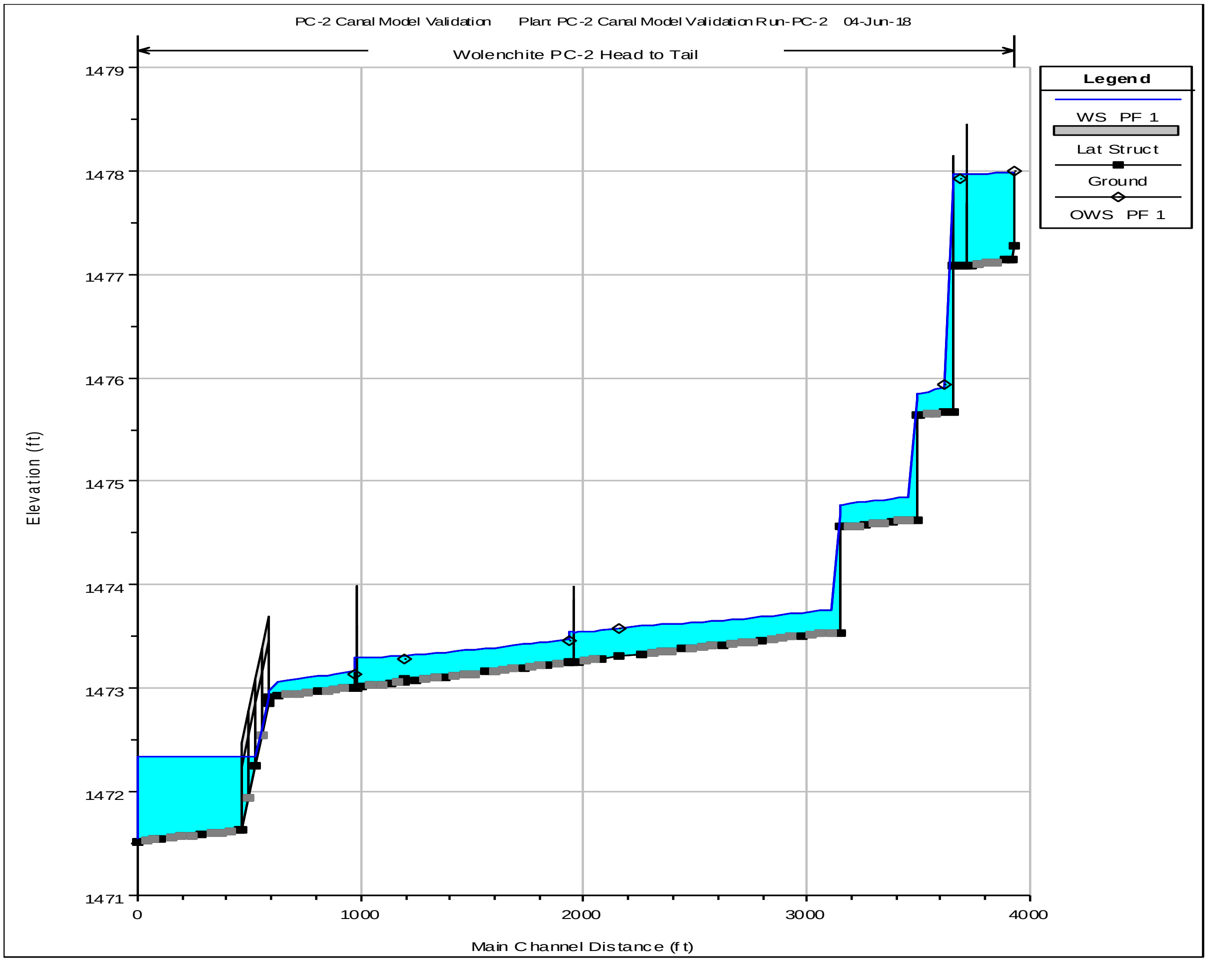


Figure 5-4: PC-2 Canal Profile Calibrated with the Secondly Observed Data

The head regulator slide gates of Welenchity Irrigation Project differs in operation from the usual sluice gates in that it open to the buried pipes systems. Thus a user defined curve option is used to make the modeling a real representation of the actual scheme (See Table 4-2). The gate opening height was initially iterate manually using solver program and then optimized by HEC-RAS inbuilt system by turning on the optimization flag. The gate opening height was initially iterated for 80% Design Discharge, for Design Discharge and for 15% increase in Design Discharge (See Table 4-2).

5.3.3.3 Evaluation of the Offtakes Discharge Changes

The discharge deviation at system source influences the water level and discharges due to each offtake and inline check structure. These changes were evaluated by running the model for different discharges at system source.

Discharge deviations at the source of an irrigation canal cause changes in the discharge of lateral canals or tertiaries. However, there is an important question. How the discharge deviation in the tertiary canals is affected by discharge deviation at the system source? To find a proper answer to this question, dis-charge reductions at tertiaries due to discharge reductions at system source were evaluated using the model for the reach under study. For this purpose, the gate openings in the model were set with several run of model on the basis of required discharges in the tertiary canals.

To meet the desired discharges in Secondary or tertiary canals two gate operation rule can be considered:

- First rule is to open both checks and offtakes with minimum openings. This way, water level at upstream of checks and offtakes will be at their maximum level and the canal will run full. However, for the case of Welenchity only one horizontally sliding mal-functioning check gate was available at offtake of SC 2-2. Thus rule cannot be applied to the case of Welenchity.
- Second rule is to open checks and offtakes for their maximum setting. This will result in a decrease of water level in the canal. Thus, this second option rule was modeled for PC-2 canal with the help of HEC-RAS for this study.

By trial and error, the best gate openings that meet the required discharges in Secondary or tertiary canals were assessed.

Changes in the discharge at the system source will change the discharge and water surface level along the main and tertiary canals. For evaluation of these changes the HEC-RAS model was run for Canal under different discharges at the system source and the discharges where computed in tertiary canals.

The first rule which is based on the design levels used when a higher head is required for the offtakes. The second rule is a rule could be considered to decrease some of the operation problems in the study area. By blocking the downstream section of the canal at offtakes point with trash, the farmers increase upstream water level which was common in Welenchity. This increases the offtaking discharge and as a result decreases the equity of water delivery, and causes water spill over the canal. Using the second rule makes trashes pass easily through the gate opening and prevents water spill over the weirs. Opening the offtakes at their maximum heights prevents farmers from destroying the gates since inflicting damages to the gates will have no benefits for them. The second rule also increases the possibility of passing more discharges whenever needed. In both of the above conditions some discharge reductions were assumed at the beginning of the canal under study and the reduction of discharge at secondary or tertiary canals were estimated and evaluated. Then, the changes in equity indicator were calculated and evaluated using the relation proposed by Molden and Gates (1990).

6 Water Demand and Scheduling of the Command Area

6.1 Background

Sugarcane being a long duration crop producing huge amounts of biomass is classed among those plants having a high water requirement and yet it is drought tolerant. It is mostly grown as an irrigated crop.

The purpose of irrigation scheduling is to determine the exact amount of water to apply to the field and the exact timing for application. The importance of irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve the goal. This increases irrigation efficiency. To achieve high water use efficiencies and high production, the irrigation schedules should follow the variation in crop water needs during the growing season. Correct irrigation scheduling adds value and achieves more effective use of limited water resources.

Irrigation water is used most efficiently when crop requirement is defined accurately and water is applied to meet this demand both fully and at precisely the right time. Uniform water distribution across the field is important to derive the maximum benefits from irrigation scheduling and management.

Welenchity irrigation and agricultural expansion project under Wonji/Shoa sugar estate was designed to covers 1,527.81ha of land for sugarcane production. From this, 1,078.51ha of land is planned to be irrigated by furrow irrigation (currently actual command area is 945 ha) and the remaining has been planned to be irrigated by dragline sprinkler system (which was abandoned due to social problem). WWDSE (2008) recommended tentative irrigation scheduling for furrow irrigated fields based on only the soil textural classes (Appendix 2) which was blamed for creating water stress by Wonji/Shoa sugar estate. Thus, the crop water requirement was verified through CROPWAT by the use of designers' scenarios.

6.2 Water Demand

Climatic data (rainfall, maximum and minimum temperature) and five years sunshine hour, relative humidity and wind speed data from Adama metrological station were used for the analysis. The climatic data were used to determine the reference evapotranspiration and the effective rainfall. The effective rain fall was estimated using Dependable Rainfall Formula which also recommended by FAO using CROPWAT model. The reference evapotranspiration (ETo) was estimated using CROPWAT computer program based on the recommended Penman-Monteith equation (Allen et al., 1998). The Penman-Monteith equation utilizes standard weather data to give estimates of evapotranspiration that are more consistent with actual crop water usage. Then the sugarcane water use (crop evapotranspiration (ETc) was estimated from reference evapotranspiration and crop coefficient (Kc) as follow.

$$ETc = Kc * ETo \qquad (1)$$

The crop parameters needed are sugarcane growth stages, crop coefficients and sugarcane root depth. Information related to sugarcane growth stages and crop coefficients were used from literatures as they are not yet determined for local conditions; but cane rooting depth survey result at Finchaa was used with some modification.

Table 6-1: Major growing stages of sugarcane

Cane age group (month)	Canopy cover estimated (%)	Crop coefficient, K_c
0-3	0-25	0.55
3-6	25-100	0.9
6-15	100	1.05
15 and above	100	0.7

Source: Doorenbos and Pruitt (1996) and Doorenbos and Kassam (1996)

The soil data was used to calculate the irrigation depth. The data used were moisture content at field capacity and permanent wilting point, and depletion level. The soil classification and their properties generated by WWDSE (2008) were used. Then depth of application was determined using the following formula:

$$Dn = TAW * \rho * Dr \qquad (2)$$

Where, TAW = total available water (mm/m),

ρ = allowable depletion (fraction),
Dr = effective root depth (m),
Dn = Net depth of application (mm),

Irrigation water application strategy of refilling depletion at 60% of total soil moisture depletion was considered as recommended by FAO (Doorenbos and Kassam, 1996). The experience of survey result at Finchaa sugar estate by Habib (2001) was adopted for root depth of sugarcane with some modification. The maximum root depth of 65cm was used for Welenchity.

Table 6-2: Root depths at different growth stages

Age (Months)	0-3	3-6	6-15	≥15
Root depth (cm)	30	45	60	60

6.3 Crop Water Requirements Using CROPWAT

CROPWAT 8.0 is a decision support tool developed by Joss Swennenhuis for the Water Resources Development and Management Service of FAO, having as main functions:

- **to calculate**: reference evapotranspiration, crop water requirements, crop irrigation requirements;
- **to develop:** irrigation schedules under various management conditions, scheme water supply;

CROPWAT Answers the Three Fundamental Questions of Irrigation

- How to irrigate?
- How much to irrigate?
- When to irrigate?

Fundamental/ Governing Equations

All calculation procedures used in CROPWAT 8.0 are based on the two FAO publications of the Irrigation and Drainage Series, namely no. 56 “Crop Evapotranspiration- Guidelines for Computing Crop p Water Requirements” and no. 33 entitled “Crop Yield Response to water”. The Fundamental Equations are:

1. FAO **Penman-Monteith method** to estimate ETo (Richard G. ALLEN 2006)

$$\mathbf{ET_o} = \frac{0.408\,\Delta(\mathbf{R_n} - \mathbf{G}) + \gamma\dfrac{900}{\mathbf{T}+273}\mathbf{u_2}\,(\mathbf{e_s} - \mathbf{e_a})}{\Delta + \gamma(1+0.34\,\mathbf{u_2})}$$

Where	ET_o	reference evapotranspiration (mm/day),
	R_n	net radiation at the crop surface (MJ/ m^2/day),
	G	soil heat flux density (MJ m-2 day-1),
	T	mean daily air temperature at 2 m height (°C),
	u_2	wind speed at 2 m height (m/s),
	e_s	saturation vapour pressure (kPa),
	e_a	actual vapour pressure (kPa),
	e_s-e_a	saturation vapour pressure deficit (kPa),
	Δ	slope vapour pressure curve (kPa/ °C),
	γ	psychrometric constant (kPa/°C).

2. **Crop yield and water use** (Pasquale Steduto 2012)

$$\left(1-\frac{Y_a}{Y_x}\right)=K_y\left(1-\frac{ET_a}{ET_x}\right)$$

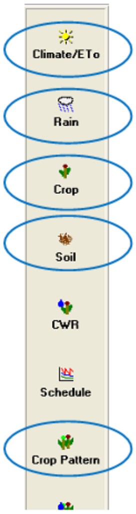
Where Y_x and Y_a are the maximum and actual yields, ET_x and ET_a are the maximum and actual evapotranspiration, and K_y is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses.

Program Structure

- five data input modules
- three calculation modules

The Input Modules

- **Climate/Eto**
- **Rain**
- **Crop**
- **Soil**
- **Crop Pattern**



The water balance method is used for calculation of irrigation schedules in CROPWAT, which means that the incoming and outgoing water flows from the soil profile are monitored (Saab 2015).

Effective Rainfall

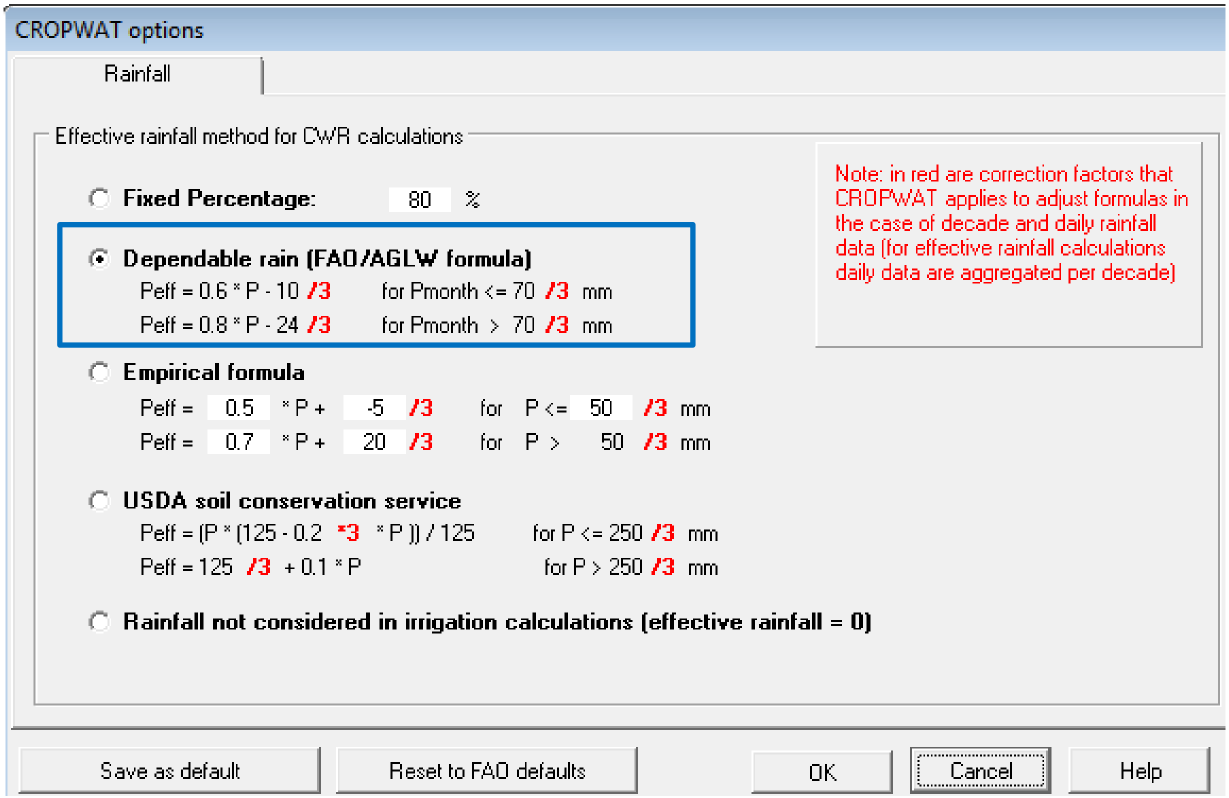
To account for the losses due to runoff or percolation, a choice can be made of one of the four methods given in CROPWAT 8.0 (Fixed percentage, Dependable rain, Empirical formula, USDA Soil Conservation Service).

In general, the efficiency of rainfall will decrease with increasing rainfall. For most rainfall values below 100 mm/month, the efficiency will be approximately 80%. Unless more detailed information is available for local conditions, it is suggested to select the Option “Fixed percentage” and give 80% as requested value. However, for this study

'Dependable Rainfall' Formula which is statistically predictable and also recommended by FAO is used.

In the water balance calculations included in the irrigation scheduling part of CROPWAT, a possibility exists to evaluate actual Efficiency values for different crops and soil conditions.

Effective Rainfall



Effective rainfall method for CWR calculations

○ **Fixed Percentage:** 80 %

● **Dependable rain (FAO/AGLW formula)**
Peff = 0.6 * P - 10 /3 for Pmonth <= 70 /3 mm
Peff = 0.8 * P - 24 /3 for Pmonth > 70 /3 mm

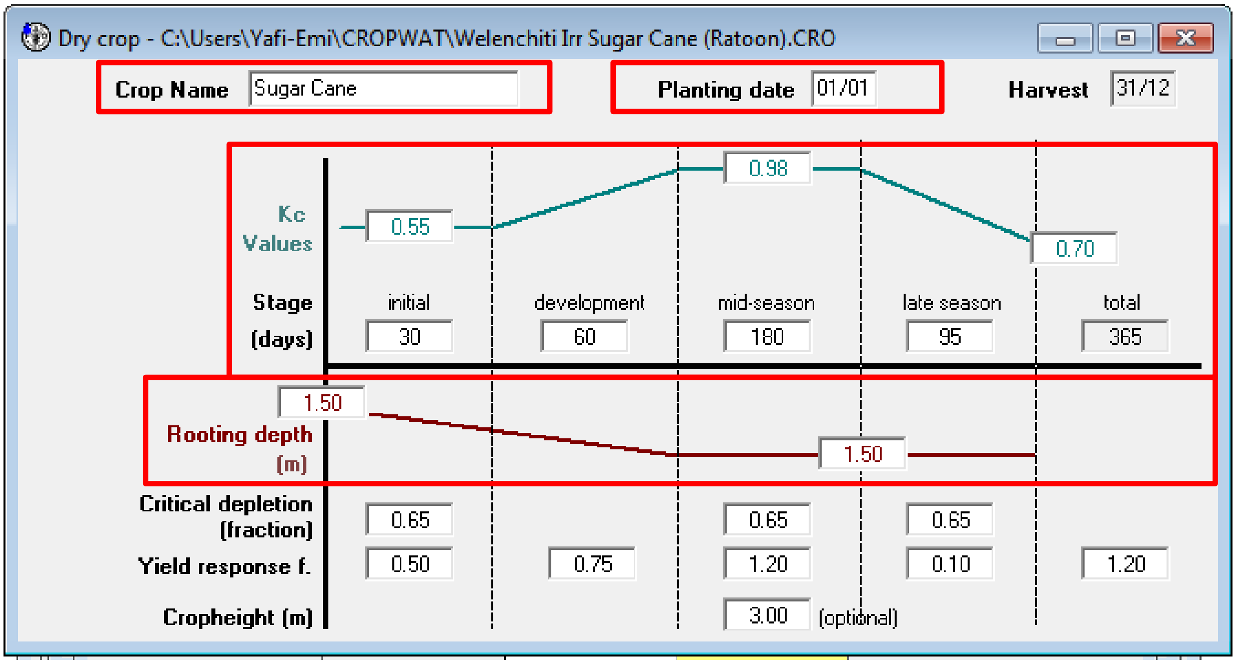
○ **Empirical formula**
Peff = 0.5 * P + -5 /3 for P <= 50 /3 mm
Peff = 0.7 * P + 20 /3 for P > 50 /3 mm

○ **USDA soil conservation service**
Peff = (P * (125 - 0.2 *3 * P)) / 125 for P <= 250 /3 mm
Peff = 125 /3 + 0.1 * P for P > 250 /3 mm

○ **Rainfall not considered in irrigation calculations (effective rainfall = 0)**

Note: in red are correction factors that CROPWAT applies to adjust formulas in the case of decade and daily rainfall data (for effective rainfall calculations daily data are aggregated per decade)

Crop Module



Dry crop - C:\Users\Yafi-Emi\CROPWAT\Welenchiti Irr Sugar Cane (Ratoon).CRO

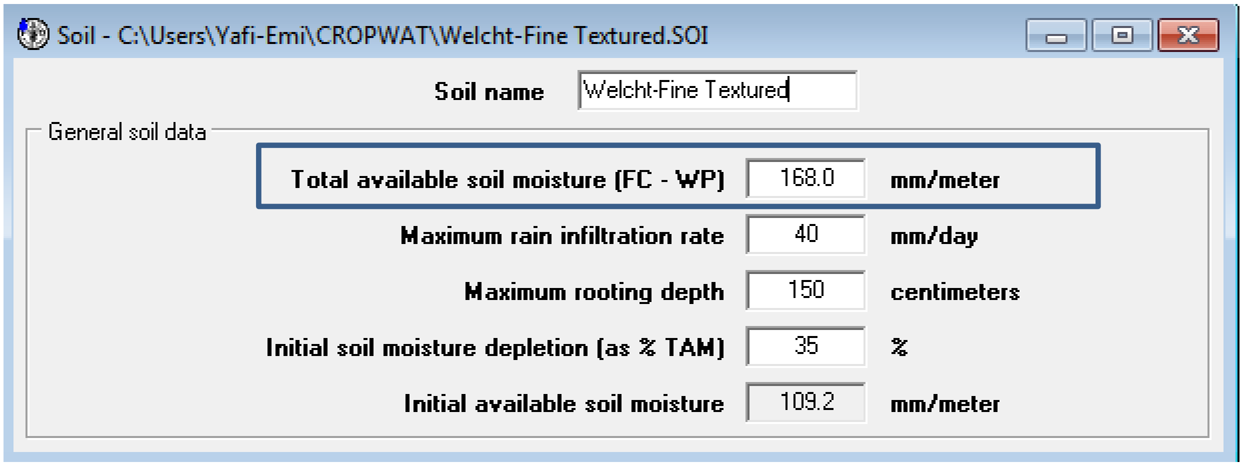
Crop Name Sugar Cane

Planting date 01/01

Harvest 31/12

Stage	initial	development	mid-season	late season	total
Kc Values	0.55		0.98	0.70	
(days)	30	60	180	95	365
Rooting depth (m)	1.50		1.50		
Critical depletion (fraction)	0.65		0.65	0.65	
Yield response f.	0.50	0.75	1.20	0.10	1.20
Cropheight (m)			3.00	(optional)	

Soil Data



Soil - C:\Users\Yafi-Emi\CROPWAT\Welcht-Fine Textured.SOI

Soil name Welcht-Fine Textured

General soil data

Total available soil moisture (FC - WP)	168.0	mm/meter
Maximum rain infiltration rate	40	mm/day
Maximum rooting depth	150	centimeters
Initial soil moisture depletion (as % TAM)	35	%
Initial available soil moisture	109.2	mm/meter

The soil parameters necessary for irrigation scheduling for CROPWAT program are:

1. Total available soil moisture content (SMta), defined as the difference in soil moisture content between field capacity (FC) and wilting point (PWP). This is the total amount of water available to the crop and depends on texture, structure and organic matter content;

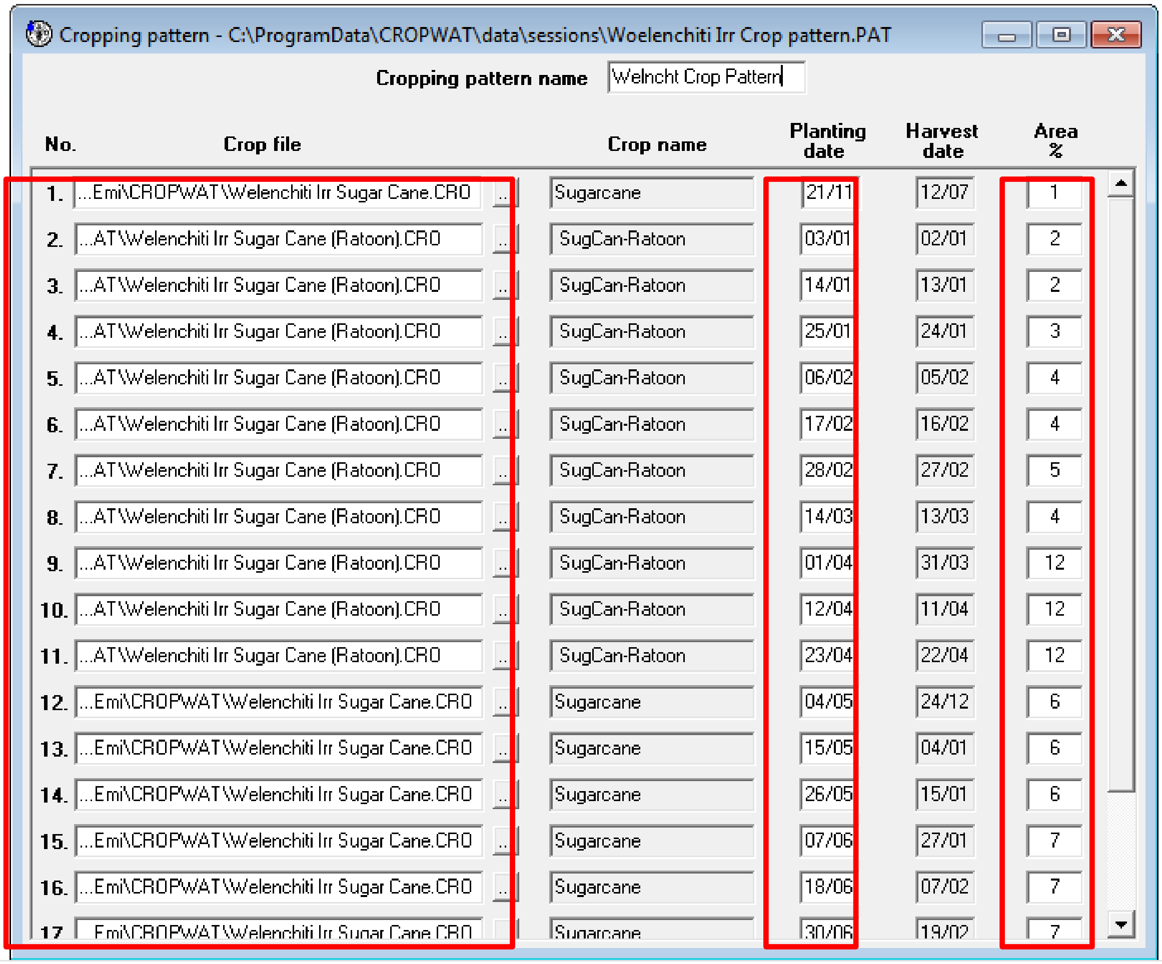
2. Initial soil moisture depletion indicates the dryness of the soil at the start of irrigation. This is expressed as a depletion percentage from FC;

3. Maximum rooting depth will in most cases be determined by the genetic characteristics of the plant. In some cases the root depth can be restricted by limiting layers;

4. Maximum rain infiltration rate allows for an estimate of the surface runoff for the effective rain calculation. This is a function of rain intensity, soil type and slope class.

Crop Pattern Module

Scheme Water Supply is calculated according to the cropping pattern defined by the user, which can be include up to 20 crops. For this study cropping pattern was adopted from Wonji/Shoa cane composition report.



Cropping pattern - C:\ProgramData\CROPWAT\data\sessions\Woelenchiti Irr Crop pattern.PAT

Cropping pattern name: Welncht Crop Pattern

No.	Crop file	Crop name	Planting date	Harvest date	Area %
1.	...Emi\CROPWAT\Welenchiti Irr Sugar Cane.CRO	Sugarcane	21/11	12/07	1
2.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	03/01	02/01	2
3.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	14/01	13/01	2
4.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	25/01	24/01	3
5.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	06/02	05/02	4
6.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	17/02	16/02	4
7.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	28/02	27/02	5
8.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	14/03	13/03	4
9.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	01/04	31/03	12
10.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	12/04	11/04	12
11.	...AT\Welenchiti Irr Sugar Cane (Ratoon).CRO	SugCan-Ratoon	23/04	22/04	12
12.	...Emi\CROPWAT\Welenchiti Irr Sugar Cane.CRO	Sugarcane	04/05	24/12	6
13.	...Emi\CROPWAT\Welenchiti Irr Sugar Cane.CRO	Sugarcane	15/05	04/01	6
14.	...Emi\CROPWAT\Welenchiti Irr Sugar Cane.CRO	Sugarcane	26/05	15/01	6
15.	...Emi\CROPWAT\Welenchiti Irr Sugar Cane.CRO	Sugarcane	07/06	27/01	7
16.	...Emi\CROPWAT\Welenchiti Irr Sugar Cane.CRO	Sugarcane	18/06	07/02	7
17	...Emi\CROPWAT\Welenchiti Irr Sugar Cane.CRO	Sugarcane	30/06	19/02	7

e

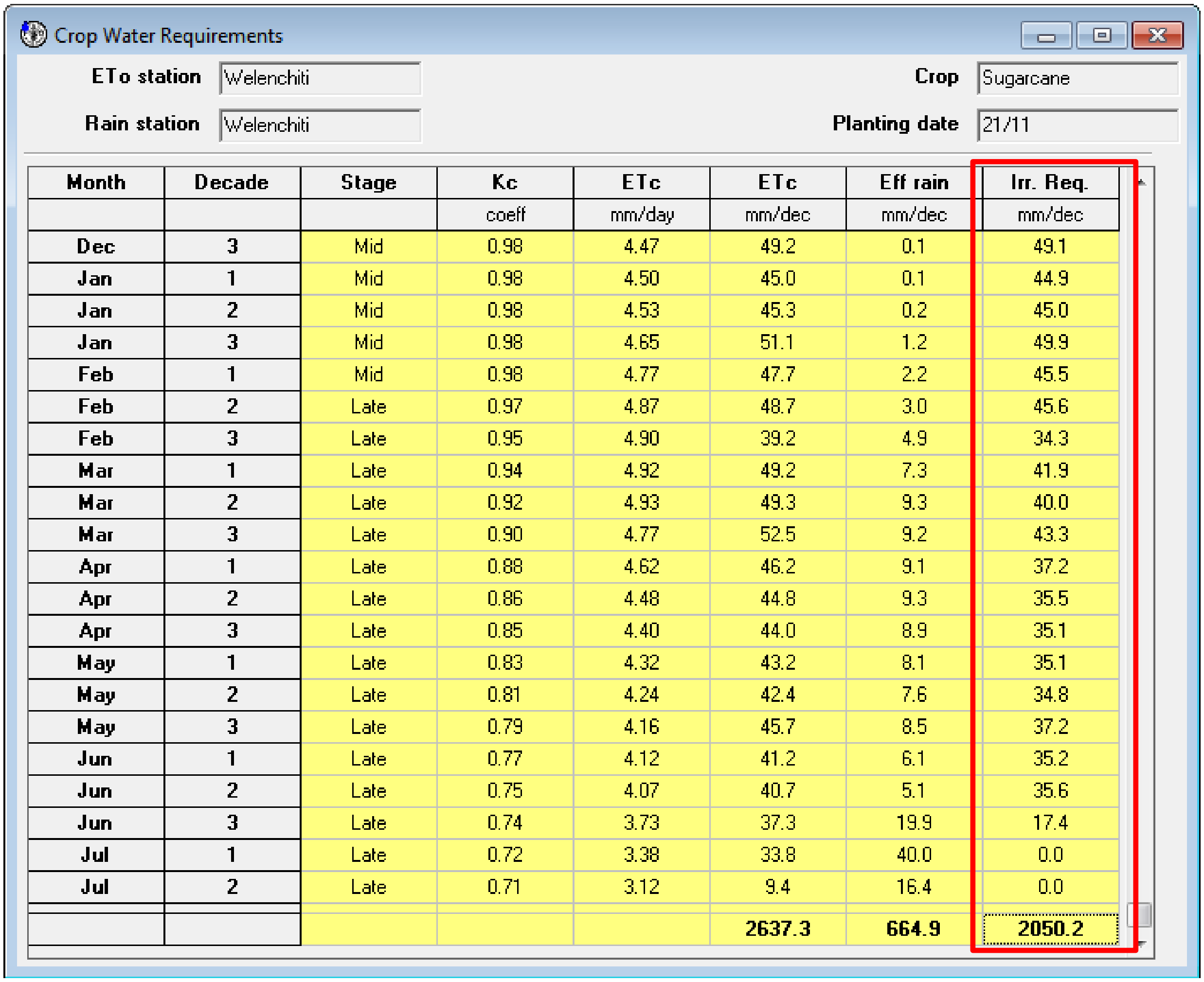
6.1 Irrigation Scheduling

The irrigation scheduling was determined based on soil, crop and climatic data which were collected from secondary sources. Two methods (calculating evapotranspiration losses and feel methods) are used to schedule irrigation.

The irrigation interval (I) in days was estimated using the following formula:

$$I = Dn/ETc \qquad (3)$$

Crop Water Requirement



ETo station Welenchiti

Rain station Welenchiti

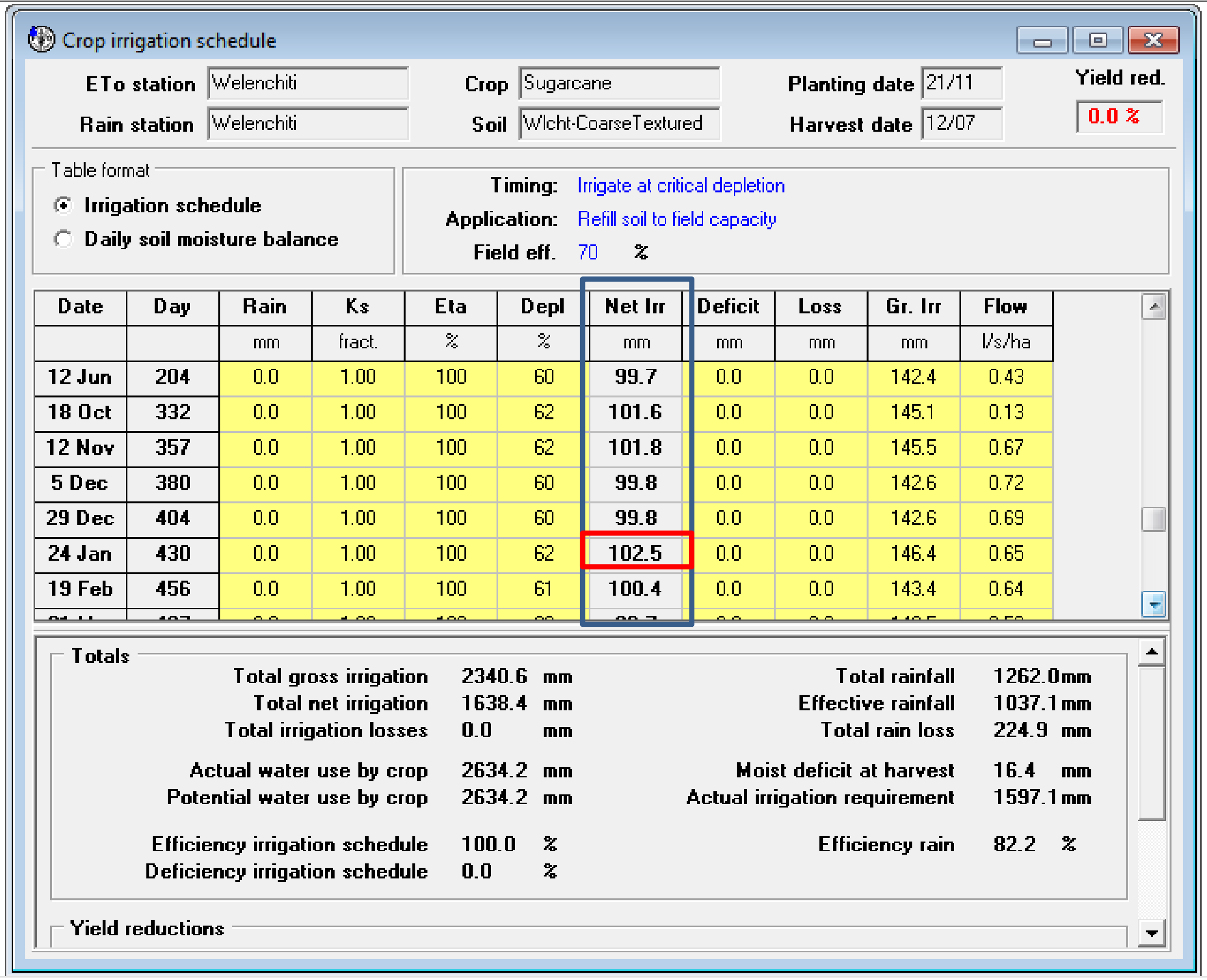
Crop Sugarcane

Planting date 21/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	3	Mid	0.98	4.47	49.2	0.1	49.1
Jan	1	Mid	0.98	4.50	45.0	0.1	44.9
Jan	2	Mid	0.98	4.53	45.3	0.2	45.0
Jan	3	Mid	0.98	4.65	51.1	1.2	49.9
Feb	1	Mid	0.98	4.77	47.7	2.2	45.5
Feb	2	Late	0.97	4.87	48.7	3.0	45.6
Feb	3	Late	0.95	4.90	39.2	4.9	34.3
Mar	1	Late	0.94	4.92	49.2	7.3	41.9
Mar	2	Late	0.92	4.93	49.3	9.3	40.0
Mar	3	Late	0.90	4.77	52.5	9.2	43.3
Apr	1	Late	0.88	4.62	46.2	9.1	37.2
Apr	2	Late	0.86	4.48	44.8	9.3	35.5
Apr	3	Late	0.85	4.40	44.0	8.9	35.1
May	1	Late	0.83	4.32	43.2	8.1	35.1
May	2	Late	0.81	4.24	42.4	7.6	34.8
May	3	Late	0.79	4.16	45.7	8.5	37.2
Jun	1	Late	0.77	4.12	41.2	6.1	35.2
Jun	2	Late	0.75	4.07	40.7	5.1	35.6
Jun	3	Late	0.74	3.73	37.3	19.9	17.4
Jul	1	Late	0.72	3.38	33.8	40.0	0.0
Jul	2	Late	0.71	3.12	9.4	16.4	0.0
					2637.3	**664.9**	**2050.2**

Ideally, at the beginning of the growing season, the amount of water given per irrigation application, also called the irrigation depth, is small and given frequently. This is due to the low evapotranspiration of the young plants and their shallow root depth. During the mid-season, the irrigation depth should be larger and given less frequently due to high evapotranspiration and maximum root depth. Thus, ideally, the irrigation depth and/or the irrigation interval (or frequency) varies with the crop development.

Schedule



ETo station: Welenchiti
Rain station: Welenchiti
Crop: Sugarcane
Soil: Wlcht-CoarseTextured
Planting date: 21/11
Harvest date: 12/07
Yield red.: 0.0 %

Table format
● Irrigation schedule
○ Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
		mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
12 Jun	204	0.0	1.00	100	60	99.7	0.0	0.0	142.4	0.43
18 Oct	332	0.0	1.00	100	62	101.6	0.0	0.0	145.1	0.13
12 Nov	357	0.0	1.00	100	62	101.8	0.0	0.0	145.5	0.67
5 Dec	380	0.0	1.00	100	60	99.8	0.0	0.0	142.6	0.72
29 Dec	404	0.0	1.00	100	60	99.8	0.0	0.0	142.6	0.69
24 Jan	430	0.0	1.00	100	62	102.5	0.0	0.0	146.4	0.65
19 Feb	456	0.0	1.00	100	61	100.4	0.0	0.0	143.4	0.64

Totals

Total gross irrigation	2340.6	mm	Total rainfall	1262.0	mm
Total net irrigation	1638.4	mm	Effective rainfall	1037.1	mm
Total irrigation losses	0.0	mm	Total rain loss	224.9	mm
Actual water use by crop	2634.2	mm	Moist deficit at harvest	16.4	mm
Potential water use by crop	2634.2	mm	Actual irrigation requirement	1597.1	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	82.2	%
Deficiency irrigation schedule	0.0	%			

Yield reductions

When sprinkler and drip irrigation methods are used, it may be possible and practical to vary both the irrigation depth and interval during the growing season. When surface irrigation methods are used, however, it is not very practical to vary the irrigation depth. With surface irrigation, variations in irrigation depth are only possible within limits. Irrigating cane fields by varying the depth of application based on the growth stage is not also practiced in the Wonji Shoa Sugar Factory due to its difficulty for management.

The depth of application for respective growth stages were calculated for the three soil textural groups and used for the calculation of determining the theoretical irrigation interval.

Table 6-3 **:** Scheme Water Requirement

ETo station: Welenchity Cropping Pattern: Welenchity Crop Pattern

Rain station: Welenchity

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Sugarcane	140	126	125	107.8	107	88.2	0	1.5	70.6	130	138	139
2. SugCan-Ratoon	59.2	80.5	115	125	134	123	6	1.5	70.5	122	117	105
3. SugCan-Ratoon	69.5	71.9	102	122.1	134	123	6	1.5	70.5	126	122	109
4. SugCan-Ratoon	79.2	67.5	89.1	114.8	134	123	6	1.5	70.5	129	127	114
5. SugCan-Ratoon	106	58	75.9	102.3	134	123	6	1.5	70.5	130	132	119
6. SugCan-Ratoon	111	69.8	68	90.2	129	123	6	1.5	70.5	130	136	124
7. SugCan-Ratoon	116	87.5	64.7	78	120	123	6	1.5	70.5	130	138	129
8. SugCan-Ratoon	122	97	59	65	104	120.9	6	1.5	70.5	130	138	135
9. SugCan-Ratoon	130	105	94.1	58.7	83.6	107.7	6	1.5	70.5	130	138	138
10. SugCan-Ratoon	135	109	99.6	50.9	73	95.4	4.5	1.5	70.5	130	138	139
11. SugCan-Ratoon	138	114	105	63.7	66.8	83.1	0.8	1.5	70.5	130	138	139
12. Sugarcane	140	127	135	125.1	134	123.1	6	0	58.9	109	110	79.8
13. Sugarcane	108	127	135	125.1	134	123.1	6	0	61.4	112	112	105
14. Sugarcane	99.3	127	135	125.1	134	123.1	6	0.8	64	114	115	108
15. Sugarcane	90	127	135	125.1	134	123.1	6	1.5	66.8	117	118	111
16. Sugarcane	106	103	135	125.1	134	123.1	6	1.5	69	120	121	114
17. Sugarcane	109	97.7	135	125.1	134	123.1	6	1.5	70.3	123	124	117
Net scheme irr.re												
in mm/day	3.8	3.7	3.5	3.1	3.6	3.8	0.2	0	2.3	4	4.3	3.9
in mm/month	116	105	108	93.3	110	112.7	5.1	1.3	68.5	124	128	122
in l/s/h	0.43	0.43	0.4	0.36	0.41	0.43	0.02	0	0.26	0.46	0.50	0.46
Irrigated area (% of total area)	100	100	100	100	100	100	99	88	100	100	100	100
Irr.re for actual area (l/s/h)	0.43	0.43	0.4	0.36	0.41	0.43	0.02	0	0.26	0.46	0.50	0.46

Table 6-4: Net depth of application for respective growth stages and soil textures

Soil texture	Initial	Development	Mid-season	Late-season
Fine	30.3	45.5	60.6	65.7
Medium	39.9	59.8	79.7	86.4
Coarse	19.8	29.7	39.6	42.9

The net depth of application or perceived application depth (targeting 65cm rooting depth), the required gross application depth, and cut off time (at 5lit/sec inflow rate to each furrow, 100m furrow and its design application efficiency of 75%) estimated were tabulated below.

Table 6-5: Net and gross depth of application for 100m furrow at 75% application efficiency

Soil texture	Net depth(mm)	Gross depth (mm)	Cut off time (Min)
Fine	66	88	42
Medium	86	115	56
Coarse	43	57	28

The net depth of application for medium texture soils is somewhat high (86mm) as compared to fine and coarse textured soil. This is because of the high water holding capacity of the soil type. The cut off time is also direct relation to the depth of application.

Soil moisture monitoring by feel method using drilling test is a common practice in the Ethiopian sugar industry. Drilling test could be limited in top 30cm starting from three-leaf stage to 4 month growth stage starting from planting and in top 60 cm depth after wards. However, for crop stage below three leaves stage of cane, the soil moisture monitoring shall be confined only in top 15cm soil layer. In ratoons, similar irrigation interval and soil moisture monitoring could be used with that of corresponding growth stage of plant cane.

The theoretical irrigation intervals are estimates for sugarcane production based on assumptions. Actual crop water requirements of sugarcane may be higher or lower than the theoretical irrigation intervals. Therefore it is advisable to start soil moisture monitoring before three days of the theoretical irrigation interval.

7 Analysis and Results

7.1 Irrigation supply and demand

Results of this study are based on daily discharge measurements at upstream and downstream of each Secondary or Tertiary Offtakes categorized under head, middle and tail reaches of the distributaries. A Discharge App which is an Optical Technology for discharge measurement with the use of a smart phone is adopted for quantifying flow rate at seven selected sites in the scheme. These outcomes are the averages of three consecutive month i.e, March, April and May 2018. Results show that the distributary belong to 610ha Offtake received more than 33% of designed supplies other four distributaries also received in excess or equal to their designed discharges. The demand of the scheme was computed using CROPWAT 8.0 which was then compared with the designed discharge.

7.2 Water delivery/hydraulic performance

Spatial and temporal scales were used to determine performance of water delivery of a system. The spatial indicators determine the water delivery performance at head, middle and tail reaches of the distributaries in its command area (A), while the temporal indicators are used to determine water delivery performance in time (T).

7.2.1 Spatial and Temporal performance indicators

To determine spatial performance, the indicators such as efficiency and equity were taken into account. The observed equity indicator (PE) for all the distributaries was compared with performance standard given by Molden and Gates, (1990) (see Table 7-1. Data show that the observed equity levels for different distributaries were rated as ‘poor’. Dependability indicator involves probability and irregularity; where probability deals with consistency of the timing and the irregularity accounts for the variable amount of water available in the system. It was observed that flow of water at each reach was extremely anticipated, because middle reach receives the maximum flow even more than their share, while head and tail reach gets less water as compared to middle reach but in some cases both reaches received more than their due share. However, the tail reaches receive minimum share. As a result head and middle were getting excessive flows consistently over time than the designed one, while tail reaches suffer from shortage of water especially during months with minimum flows in the system.

There were many different factors that affect irrigation water deliveries in the study area. The community in Welenchity Surface Irrigation Scheme both irrigation beneficiaries and non-beneficiaries use water from the Primary canal (PC-2) and the other in field systems of the irrigation scheme for all water demand purposes including livestock and household demands particularly in the dry period (Figure 7-1).

Table 7-1: Performance standards for indicators of quality of irrigation service

Indicators	**Scale**		
	Good	**Fair**	**Poor**
P_A	0.90-1.0	0.8-0.89	<0.80
P_F	0.85-1.0	0.70-0.84	<0.70
P_D	0.00-0.1	0.11-0.20	>0.20
P_E	0.00-0.10	0.11-0.25	>0.25

Source: Molden and Gates (1990)

As a result, loss of irrigation water from the intended purpose was high in this irrigation scheme. Based on the investigation, from March to May, 2018 the average values of actual monitored discharge and required in the secondary and Some Tertiary offtake canals are summarized in Table 7-2 and

Table 7-3 respectively.

Table 7-2: Average required (Q_R) and delivered (Q_D) Discharge on the Primary (PC-2) canal (m^3/s)

Month	**Head**				**Middle**		**Tail**			
	610ha Offtake		SC 2-1		SC 2-2		TC 2-3-1&2		SC 2-3	
	Q_R	**Q_D**	**Q_R**	**Q_D**	**Q_R**	**Q_D**	**Q_R**	**Q_D**	**Q_R**	**Q_D**
March	1.18	1.89	0.43	1.07	0.31	0.7	0.19	0.43	0.1	0.15
Apr	1.18	1.28	0.43	0.63	0.31	0.37	0.19	0.2	0.1	0.11
May	1.18	1.58	0.43	0.78	0.31	0.67	0.19	0.36	0.1	0.15

The Discharge were observed and recorded at seven monitoring site with the use of optical technology for measuring discharge with the use of Smart Phone.

Table 7-3: Average delivered and required discharge in the branch off-take canals (m3/s)

Reach	**Head**				**Middle**		**Tail**			
	610ha Offtake		**SC 2-1**		**SC 2-2**		**TC 2-3-1&2**		SC 2-3	
Month	**Q_R**	**Q_D**	**Q_R**	**Q_D**	**Q_R**	**Q_D**	**Q_R**	**Q_D**	**Q_R**	**Q_D**
March	0.76	0.81	0.12	0.38	0.12	0.25	0.08	0.21	0.10	0.15
Apr	0.76	0.85	0.12	0.24	0.12	0.37	0.08	0.22	0.10	0.11
May	0.76	0.83	0.12	0.31	0.12	0.31	0.08	0.21	0.10	0.15

Figure 7-1: Water used for other purpose than irrigation.

Adequacy indicator (P_A)

The adequacy of irrigation water at Welenchity Surface irrigation scheme expressed as average temporal value of adequacy is 1 at head; middle and tail reach of the system respectively which categorizes it in a **Good** performance range (see Table 7-4). Thus it shows that adequate water is available at the system source throughout the study period.

Table 7-4: Average adequacy of water distribution on the system

Month	**Head**		**Middle**	**Tail**		**Spatial Average (P_A)**
	610ha Offtake	**SC 2-1**	**SC 2-2**	**TC 2-3-1&2**	**SC 2-3**	
March	1	1	1	1	1	**1.00**
Apr	1	1	1	1	1	**1.00**
May	1	1	1	1	1	**1.00**
Average (Temporal)	1.00	1.00	1.00	1.00	1.00	**1.00**
Average Reach (P_A)		**1.00**	**1.00**		**1**	**1.00**

Since the irrigation water was diverted in excess of the required supply throughout the study period, the PC-2 (Primary) Canal was modeled with HEC-RAS to see the effect that it brings on adequacy if the system is supplied with the required discharge or if there is a deficit of water in case. The model was first calibrated and validated before use. Then, the model was run for design discharge and for additional reduced discharge (i.e from 0 to 40% reduced design discharge) to see the effect; the result is tabulated in Table 7-5). The temporal and spatial average of adequacy as modeled by HEC-RAS were in the range of Fair to Good in head and tail where as it is 1 at middle which shows that the middle reach will not affected in either of the cases. The overall average adequacy of the system was 0.9 (in the range of Good performance).

Table 7-5: Effect of Discharge change at source on the adequacy of distribution

Reduced discharge	**Head**		**Middle**	**Tail**		**Spatial Average (P_A)**
Percentage of Designed Discharge	**610ha Offtake**	**SC 2-1**	**SC 2-2**	**TC 2-3-1&2**	**SC 2-3**	
100	1	1	1	1	1	**1.00**
95	0.95	1	1	1	0.9	**0.97**
90	0.90	1	1	1	0.9	**0.96**
85	0.85	1	1	1	0.8	**0.93**
80	0.80	1	1	1	0.7	**0.90**
75	0.75	0.98	1	1	0.6	**0.87**
70	0.70	0.93	1	1	0.6	**0.85**
65	0.65	0.86	1	0.95	0.5	**0.79**
60	0.60	0.81	1	0.89	0.4	**0.74**
Average (Temporal) P_A	0.80	0.95	1.00	0.98	0.71	**0.89**
Average Reach (P_A)		**0.88**	**1.00**		**0.85**	**0.91**

Equity

The obtained results as presented in Table 7-6 shows that equity of water distribution in Welenchity Surface irrigation scheme averaged over all months was 0.4 which is categorized in a **poor** performance range. Absence of cross regulators and sufficient water measuring gauges within the system is among the possible reason for this.

Table 7-6: Average dependability of water supplied and Equity of water distribution on the system

Month	**Head**		**Middle**	**Tail**		**Spatial Average**	**STDEV**	**CV_R (P_E)**
	610ha Offtake	**SC 2-1**	**SC 2-2**	**TC 2-3-1&2**	**SC 2-3**			
March	1.07	3.17	2.08	2.63	1.50	**2.09**	0.84	**0.40**
Apr	1.12	2.00	3.08	2.75	1.10	**2.01**	0.91	**0.45**
May	1.09	2.58	2.58	2.63	1.50	**2.08**	0.73	**0.35**
Average (Temporal)	1.09	2.58	2.58	2.67	1.37	**2.06**		
Average Reach		**1.84**	**2.58**		**2.02**	**2.15**		
STDEV	0.03	0.58	0.50	0.07	0.23	0.04		
CV_T (P_D)	0.02	0.23	0.19	0.03	0.17			
Ave.CV_T (P_D)		**0.12**	**0.19**		**0.10**	**0.14**		**0.40**

Table 7-7: Equity ratio for Head and Tail (ERHT (MDR)) reach of the system

Month	Head		Tail		ERHT(MDR)
	610ha Offtake	SC 2-1	TC 2-3-1&2	SC 2-3	
	MDR	MDR	MDR	MDR	
October	0.94	0.32	0.38	0.67	1.80
November	0.89	0.50	0.36	0.91	1.64
December	0.92	0.39	0.38	0.67	1.87
Average					1.77

Dependability

Generally, the dependability value of Welenchity Surface irrigation scheme lay within fair range (0.11-0.20). The average dependability values at the head, middle and tail reach of the system are 0.12, 0.19 and 0.10 respectively with an overall average dependability of 0.14 (Table 7-6). Similar results were obtained by (Efriem Tariku Kassa 2017).

Gorantiwar and Smout (2005) explained that farmers may be happier with a water delivery system in the irrigation scheme that delivers an inadequate supply which is reliable, than with the adequate supply which is not reliable. If the farmers are sure that the deliveries are according to the schedule communicated to them, they can plan their activities accordingly resulting in higher productivity.

Efficiency

Irrigation performance efficiency which is stated as ‘irrigation efficiency’ on a number of research journals differs from the design stage efficiencies (application efficiency, conveyance efficiency or distribution efficiency). The latter is used to determine the water demand whereas the former is used to compare and contrast the already established demand against the actual water diversion in the scheme during operation stage. Thus also in this research paper the term ‘irrigation efficiency’ is used to mean irrigation performance efficiency.

For Welenchity irrigation scheme the spatial and temporal average values of irrigation performance efficiency (PF) are illustrated in Table 7-8. Both the spatial and temporal irrigation efficiency was categorized in poor performance range at the head, middle and tail reaches in all months throughout the irrigation scheme. This problem was happened due absence of properly constructed cross regulator gates. Initially the canal was designed taking in to account a command area of more than 1,500 ha. However, currently the irrigated land was reduced to less than half of the design command (721 ha). Thus, to raise water head to meet the required head at each offtakes, irrigators usually release water in excess of the required. Besides, they usually construct trash at downstream of each offtakes to increase water head.

Generally, similar results were found from different sites; for example, Dejen (2015) aggregated all monthly efficiency indicators values concern the tendency of the whole system to save water for the downstream off-takes. Moreover, Tebebal and Ayana (2015) found similar results at the middle and tail reach of the system over the observation period; while the efficiency of water supplied in the head reach was poor.

Table 7-8: Average spatial and temporal irrigation efficiency

Month	**Head**		**Middle**	**Tail**		**Spatial Av. P_F**
	610ha Offtake	**SC 2-1**	**SC 2-2**	**TC 2-3-1&2**	**SC 2-3**	
March	0.94	0.32	0.48	0.38	0.67	**0.56**
April	0.89	0.50	0.32	0.36	0.91	**0.60**
May	0.92	0.39	0.39	0.38	0.67	**0.55**
Average P_F	0.92	0.40	0.40	0.38	0.75	
Temporal Av. P_F		**0.66**	**0.40**	**0.56**		**0.57**

Deficiency

There is no deficiency with respect of supply of each offtake when the design demand is concerned. However, irrigators always claim for the inadequacy of water regulation structures especially for the absence of cross regulator gates within the scheme. The irrigators and farmers usually use the trashes (waterlogged boot) at the downstream of almost all oftakes in order to divert sufficient water towards the offtakes. The only exceptional is SC 2-1 offtake which acquires required water supply with the use of the provided speed break checks. The canal was modeled with HEC-RAS to demonstrate the resulting deficiency at secondary and tertiary offtakes as a consequence of possible Discharge change at source canal (PC-2). The detected and demonstrated effects were tabulated in Table 7-9

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Table 7-9: The resulting offtake discharge Deficiency (PDF) as a consequence of Discharge change at source

Reduced discharge	Head		Middle	Tail		Spatial Avg. PDF
% of Designed Discharge	610ha Offtake	SC 2-1	SC 2-2	TC 2-3-1&2	SC 2-3	
100	0.17	0.33	0.00	0.00	0.00	0.10
95	0.21	0.33	0.00	0.00	0.10	0.13
90	0.26	0.42	0.00	0.00	0.10	0.16
85	0.32	0.42	0.00	0.00	0.20	0.19
80	0.36	0.58	0.00	0.00	0.30	0.25
75	0.38	0.58	0.00	0.00	0.40	0.27
70	0.43	0.58	0.00	0.00	0.40	0.28
65	0.47	0.67	0.00	0.00	0.50	0.33
60	0.53	0.67	0.00	0.00	0.60	0.36
Temporal Avg. PDF	0.35	0.51	0.00	0.00	0.29	**0.23**
Average PDF		**0.43**	**0.00**		**0.14**	**0.19**

The data are from the HEC-RAS Simulation of Effect of Discharge change at source on the secondary or tertiary offtakes

Note: For a decrease of 5% discharge, there is an immediate change for **610ha offtake** and **SC2-3** whereas there is no significant change at **SC 2-1, SC 2-2** and **TC 2-3-1&2.** This is due to the absence of cross regulator structure at 610ha offtake whereas the others are equipped with speed breaks and **SC 2-3** is at canal end. These caused, **610ha offtake** and **SC 2-3** sensitive and **SC 2-1** is less sensitive whereas **SC 2-2** and **TC 2-3-1&2** insensitive to discharge change at primary canal.

Surplus Water

According to the three months monitoring result on average 0.352m^3/s surplus water was released every time when the gate opened for irrigation. This surplus amounts to 8.4Mm^3 of water annually. Thus, if this amount of water is saved by improving the current performance level of Welenchity Surface Irrigation Scheme, it could irrigate an additional land of 258.8 ha.

7.2.2 Effectiveness of infrastructure

In Welenchity Surface irrigation scheme, no failure was observed at the primary Canal (PC-2) and beyond the mal-functionality of the Cross Regulator gates and the three of the Speed Break Checks along (see Table 7-10).

Based on the design document, the total number of structures that were constructed in Welenchity Surface Irrigation scheme Offtakes, offtake gates, Speed break checks, and other irrigation structures built on the primary (PC-2) canal were 42, however only 37 structures are (See Table 7-10). The values of effectiveness of infrastructures estimated to be 88.10%. This value suggests that the maintenance activity of the system was fair. Similar results and expression given by Tebebal and Ayana, (2015) in Hare irrigation scheme, SNNPR, Ethiopia from 113 constructed irrigation structures only 18 structures were functional and its position was 15.9%.

Table 7-10: Functional and mal-functioned irrigation structures

Welenchity Irrigation Scheme

S/N	Infrastructures	Functional	Mal-functioned	Total No. of infrastructure	Effectiveness of infrastructure (%)
1	Drop structures	22	0	22	100
2	Off-take	5	0	5	100
3	Sluice gate at the off-take	7	0	7	100
4	Cross Regulator	2	0	2	100
5	gate at Cross Regulator	0	2	2	0.0
6	Speed Break Check	1	3	4	25.0
7	Total	37	5	42	70.83
8	Position (%)	**88.10**	11.90		

Water surface elevation ratio (WSER)

The parameter of average WSER at head, middle and tail reaches of the main canal during the monitoring period is generally less than one, thus it shows that the main canal has a sedimentation problem Table 7-11.

Delivery Duration Ratio (DDR)

As per the design document the intended duration of water delivery was 24 hours per day. Thus there is no possibility to elongated irrigation time. Since the main canal was sized and designed to accommodate a discharge for more than two fold of the current irrigated land it can compensate for a shortage incurred due to silting up of the canal system, malfunctioning of control structure and defective of ender main and secondary canals without requiring elongated irrigation duration.

Table 7-11: Water surface elevation ratio (WSER)

Linear distance (m)	Head				Linear distance (m)	Middle				Linear distance (m)	Tail				Overall	
	IWSE (m)	AWSE (m)	DEV. WSE	WSER		IWSE (m)	AWSE (m)	DEV. WSE	WSER		IWSE (m)	AWSE (m)	DEV. WSE	WSER	DEV. WSE	WSER
7520	1.02	0.99	0.03	0.97	9280	0.42	0.39	0.03	0.93	10240	0.36	0.32	0.04	0.89		
7760	0.87	0.87	0	1.00	9480	0.47	0.47	0	1.00	10460	0.33	0.30	0.03	0.91		
7821	0.42	0.39	0.03	0.93												
Average		0.75	0.02	0.97			0.43	0.02	0.96			0.31	0.04	0.90	**0.02**	**0.94**
Maximum		0.99	0.03	1.00			0.47	0.03	1.00			0.32	0.04	0.91		

7.2.3 Physical (area based) sustainability indicators

Irrigation ratio (IR) in Welenchity Surface irrigation scheme from the total irrigable land about 47% was irrigated (see Table 7-12). This is because the irrigable land includes an integration of Surfaces (1,078.5ha) and pressurized (Sprinkler, 449.3ha). However according to the focus group discussion the pressurized part were abandoned due to the dominance of this area with a pumice soil which is not suitable for irrigation together with social problems that is lack of thrust on the project from the farmers' side. This soil and the social problem accounted for shrinkage of irrigated land to 67%. Besides, there is no irrigation water fee that promotes farmers to use the irrigation water efficiently so as to increase the irrigable land in the scheme.

Dejen et al. (2012) have similar reasons for the greater irrigation ratio found at Golgota which could be explained by three factors; these are, generous water availability, absence of irrigation water fee and better land productivity encouraging farmers to invest on more areas.

Table 7-12: Environmental sustainability of irrigation scheme

Irrigation Scheme	Irrigable area (ha)	Design capacity (ha)	Irrigated land (ha)	IR	SIA
WSIS	1527.8**	1078.5**	721.18*	**0.47**	**0.67**

** Source WWDSE Design Report

Managerial Performance

The overflow of canal sections or excessive canal discharge due to information gap between irrigators and overhead personnel on one hand and due to some un-resolved problems related with the compensation fee for non-beneficiary displaced farmers from the command area on the other hand is considered as managerial performance druse.

Table 7-13: Assessment of managerial performance by the Total Error (TE) index

Average Target Discharge (m^3/s)	Average Achieved Value (m^3/s)	(Targeted Value-Achieved Value)^2	(Targeted Value)^2
1.18	1.58	0.16	1.39
0.43	0.83	0.16	0.18
0.31	0.58	0.07	0.10
0.19	0.33	0.02	0.04
0.1	0.14	0.00	0.01
Total		**0.41**	**1.72**
TE			**0.49**

Figure 7-2: Waterlogged boots as a cross regulator constructed by irrigators/farmers

Figure 7-3: Excessive canal discharge in February, 2018

7.2.4 Overall water delivery indicators

The overall water delivery indicators for the three months are shown in Table 7-14. Data reveal that the overall efficiency (P_F) and Equity (P_E) are ‘poor’. This shows that the water supplied to each distributary was in excess of the required but it is not distributed judicially among the end users. Conversely, the adequacy (P_A) of water distribution and dependability (P_D) of the water supplied in the system is rated as ‘Good’ and ‘Fair’ respectively. Thus, efficiency and equity indicators suggest that system is not functioning properly and need proper attention so that its efficiency could be improved.

Table 7-14: The overall result of water delivery indicators for the three months

Indicators	Standard Scale (Molden 1990)			Welenchity SIS	
	Good	Fair	Poor	Scale Value	Status
P_A	0.9-1.0	0.80-0.89	< 0.80	0.9*	Good
P_F	0.85-1.0	0.70-0.84	< 0.70	0.56	Poor
P_D	0.00-0.10	0.11-0.20	> 0.20	0.14	Fair
P_E	0.00-0.10	0.11-0.25	> 0.25	0.4	Poor

* From HEC-RAS Model Result (the result of measured data was 1.0)

7.3 HEC-RAS Model Result

The model was calibrated for the Manning and discharge coefficients of 0.012 and 0.61, respectively. Table 7-15 shows the differences (residuals) between observed and estimated water surface levels for model calibration and validation in several points along the reach. It is observed that differences between simulated and observed values of water surface levels are small. The average and maximum differences between observed and simulated water levels is 3, 4 cm for both calibration and validation. Table 3 shows the statistical parameters used for model calibration and validation. High values of EF and low values of ME, MAE, CRM, and RMSE show that the model was calibrated accurately and is valid for other simulations.

Table 7-15: Differences between predicted and observed water levels (cm)

Distance from canal beginning (m)		**7520**	**7760**	**7821**	**9,280**	**9,480**	**10,240**	**10,460**
Calibration	Measured	0.88	0.99	0.39	0.47	0.41	0.32	0.30
	Predicted	0.87	1.02	0.42	0.47	0.45	0.36	0.33
Validation	Measured	0.74	0.85	0.25	0.28	0.25	0.19	0.12
	Predicted	0.71	0.88	0.23	0.27	0.29	0.23	0.16
Difference (cm)	Calibration	1	-4	-3	-1	-4	-4	-3
	Validation	3	-4	2	1	-4	-4	-4

Table 7-16: Statistical parameters for HEC-RAS validation and calibration

Statistical parameters	**Calibration**	**Validation**
ME (m)	0.04	0.04
RMSE	0.06	0.08
EF	0.986	0.986
CRM	-0.05	-0.04
MAE (%)	2.71	2.93

Similar results were obtained by (M. A. Shahrokhnia 2005).

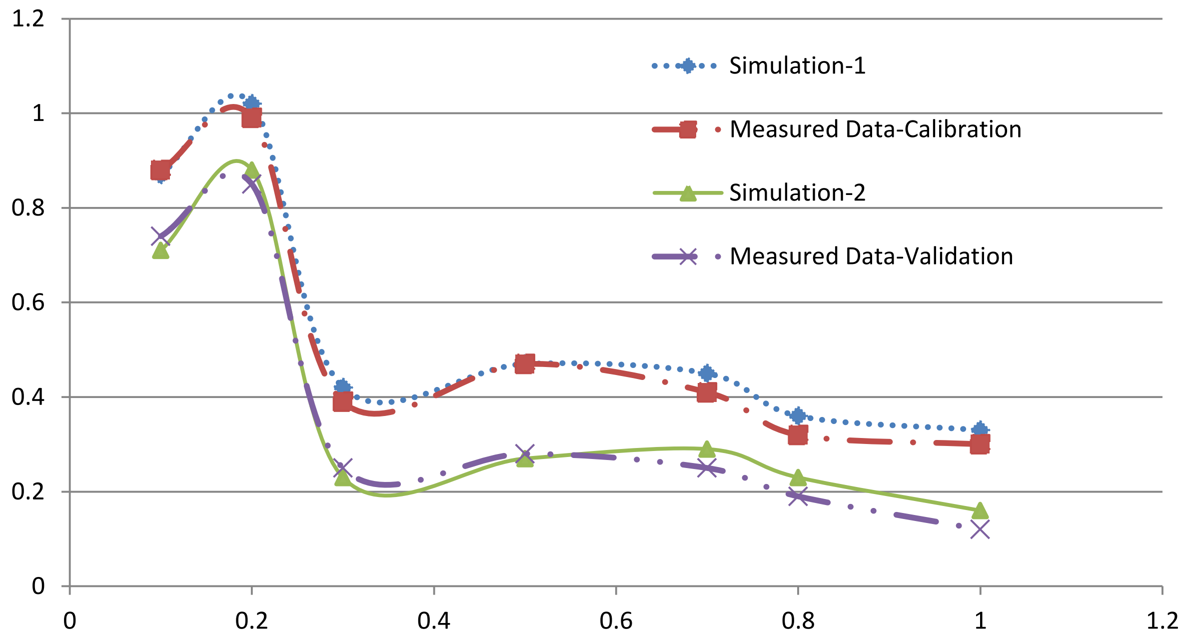

Figure 7-4: Measured versus Simulated data for Calibration and Validation

Discharge changes at the system source due to different reasons. These changes in the discharge at the system source canal will change the discharge along the secondary and tertiary canals. For evaluation of these changes the HEC-RAS model was run for PC-2 Canal under different discharges at the system source and the discharges where computed in secondary and tertiary canals. As previously mentioned, two kinds of rules can be applied for having constant discharges in secondary or tertiaries. However for the case of Welenchity only the second rule was applicable and thus a model run for this option with a half gate open condition scenario to test for the subsequent resulting discharge changes at each offtakes. Figure 7-6 shows the relation between the percent deviation (decrease) of discharge at the system source and the percent deviation (decrease) of discharge in the tertiary canals. Figure 7-7 shows the changes in adequacy or DPR in tertiary canals due to discharge reduction at system source. The deviation of equity indicator due to discharge reduction at system source is plotted in Figure 7-8, too. According to Figure 7-6 upstream tertiary canals are more sensitive than the downstream tertiaries.

Table 7-17: Average Diverted and Required Discharge at Source and Offtakes

Offtake Name	Diverted Discharge		Required Discharge	
	Source	Offtake	Source	Offtake
610ha	1.535	0.824	1.184	0.758
SC 2-1	0.856	0.308	0.426	0.116
SC 2-2	0.548	0.207	0.311	0.123
TC 2-3-1&2	0.322	0.164	0.188	0.084
SC 2-3	0.123	0.123	0.103	0.103

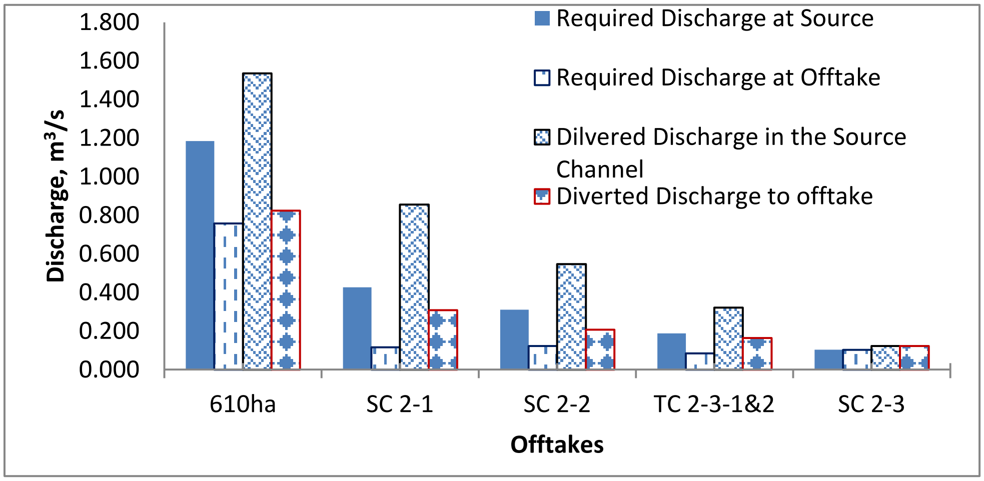

Figure 7-5: Comparison between required and actual discharges passing through secondary/tertiary offtakes

Table 7-18: Decreased rate of flow at source to detect its effect at distributary canals

Required Discharge 1.18	m^3/s
Percent of Source Discharge	Discharge, m^3/s
100	1.18
95	1.121
90	1.062
85	1.003
80	0.944
75	0.885
70	0.826
65	0.767
60	0.708

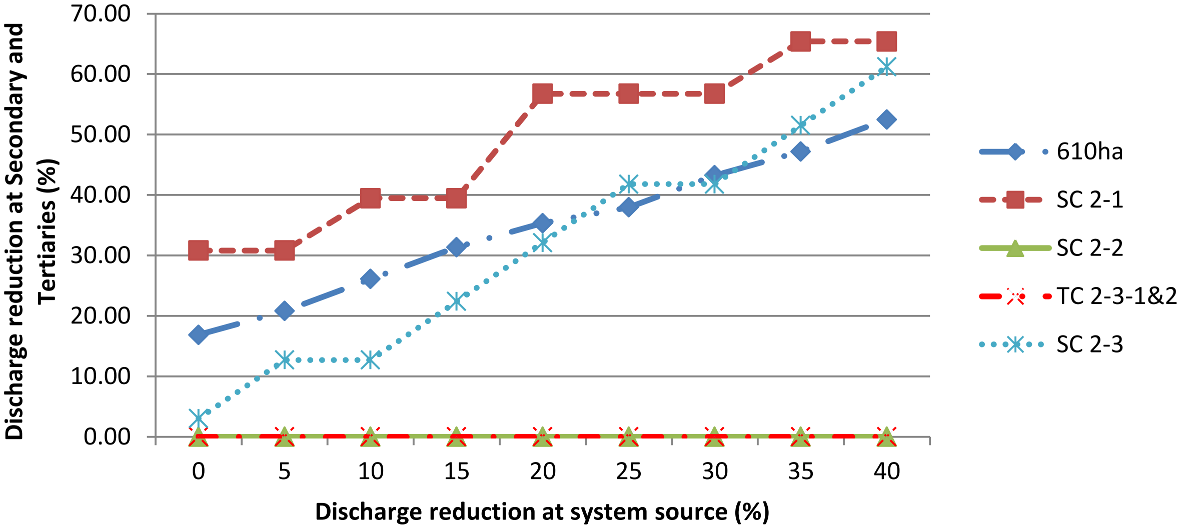

Figure 7-6: Discharge reduction at offtakes due to discharge reduction at system source

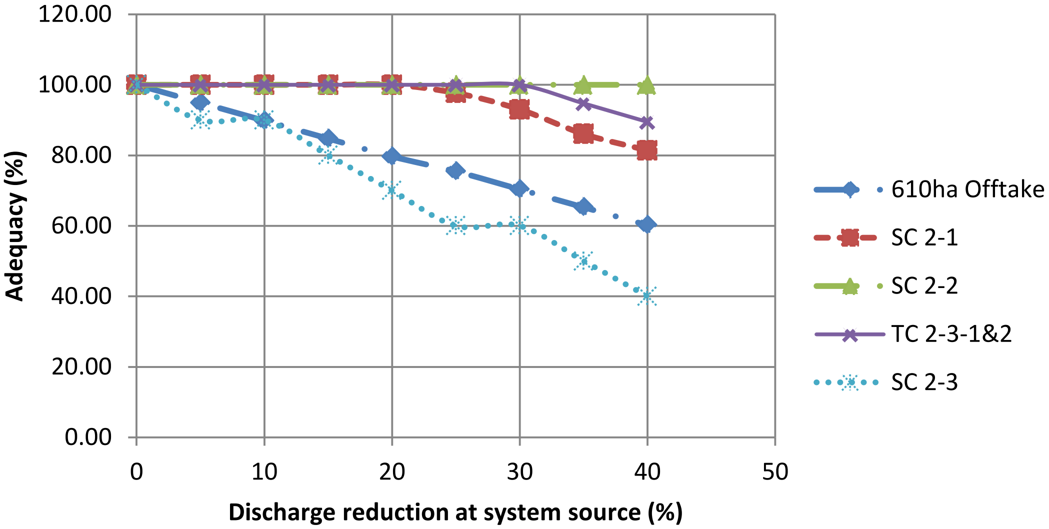

Figure 7-7: Adequacy changes at offtakes due to discharge reduction at system source for the first rule

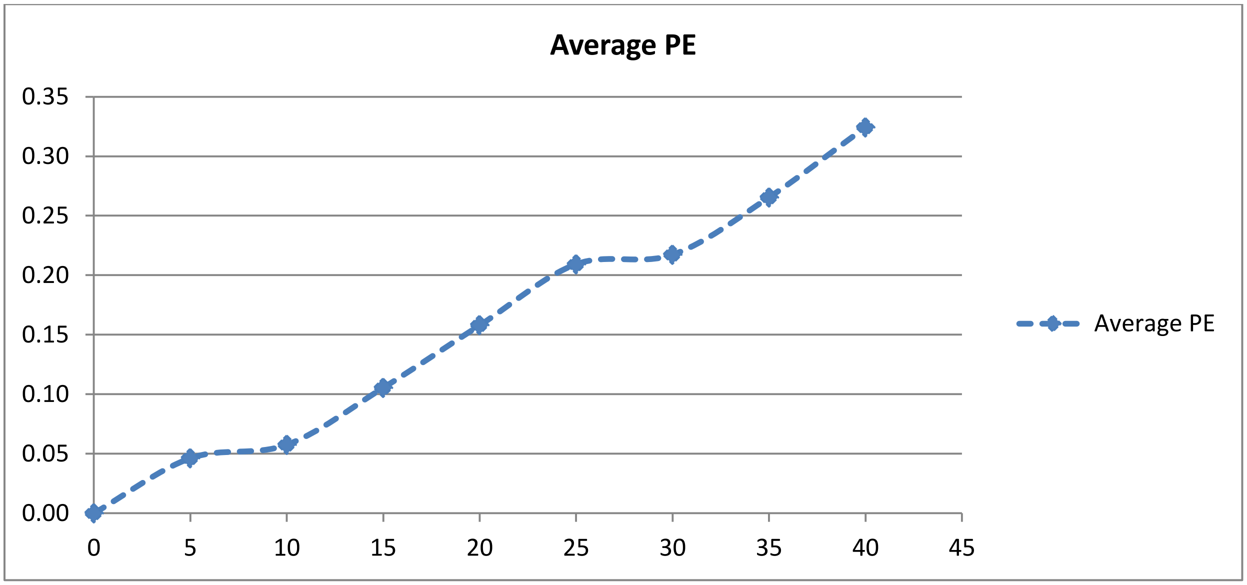

Figure 7-8: Equity changes at offtakes due to discharge reduction at system source

Conclusions and Recommendations

Conclusions

The evaluations of this study reveal that the overall efficiency (PF) and Equity (PE) are 'poor'. This shows that the water supplied to each distributary was in excess of the required but it is not distributed judicially among the end users. Conversely, the adequacy (P_A) of water distribution and dependability (P_D) of the water supplied in the system is rated as 'Good' and 'Fair' respectively.

These suggest that system is not functioning properly and need proper attention so that its efficiency could be improved.

The parameter of average WSER at head, middle and tail reaches of the primary canal during the monitoring period is generally less than one, thus it shows that the Primary canal (PC-2) has a sedimentation Problem.

The overall assessment of this study reveals that water delivery performance of irrigation system requires the quickest and easiest ways of acquiring water flow measurements in order to manage and keep equitable water distribution among the fields and water users.

Thus Discharge App which is not only the quickest way of obtaining flow measurement but also simple and cost effective is better to be adopted for flow measurement. It enables the one to quickly and easily adjust flow rates at various locations throughout a system as all calculations are performed directly on the site using smartphone that also can operate in offline mode.

The HEC-RAS Model result shows that the middle reach was less sensitive for discharge change at primary canal and will gain the designed flow even if the source canal flow is reduced to 40%.

Whereas the Tail reach is very sensitive to discharge reduction at source and Head reach was less sensitive when compared with Tail reach.

According to the three months monitoring result on average 0.352m3/s surplus water was released every time when the gate opened for irrigation. Thus, if this amount of water is saved by improving the current performance level it could irrigate an additional land of 258.8 ha.

Physical (area based) sustainability indicators shows a shrinkage of irrigated land to 67% of the designed command area.

Thus, for their long term sustainability, water distribution equity, reliability and water saving; continuous monitoring and maintenance is required.

Recommendations

Improving water delivery performance

Optimum utilization of limited water resources is very important to attain the maximum beneficial use. This could be done through improvement in water delivery systems. The adequate supply of water should be mandatory in the delivery systems. The water should be equally distributed among end users as per their share. The system should be operated efficiently and water availability, required amount and timing must be reliable. Results on the water delivery performance of five distributaries suggest that there is a need to make significant operational changes in the distribution system. The crop water requirement varies according to its growth stages; hence the rotation shall be based on crop water demands in the area. The physical restoration and implementation of new management technique must be included in the operational changes.

Remodeling of Distributaries and Outlet structures

The type of structure and water controlling systems were altered during the Construction period and with the passage of time as well. Accordingly hydraulic characteristics of some distributaries in the study area have been differed and need proper remodeling. They must be redesigned in such a way that their water delivery improves. They must provide required amount to each outlet according to its designed discharge. Similarly, some of the outlets structures have been altered during the construction and later during operation. Thus, some of them draw more water while others take fewer shares. The outlet structures must be remodeled so that each should operate properly and take its share according to its design.

Proper Management and Operation

The hydraulic characteristics of flow at head middle and tail reaches play a vital role in equal distribution and delivery of irrigation water (M. U. Mirjat 2017). Effective management and proper operation of system is another issue that needs to be addressed for better performance. As the time goes, the aging of distributaries and their improper maintenance is a major limitation to operative management. Thus, distributaries must be managed and maintained to ensure proportional distribution of water during excessive or under flow conditions in canal supply.

Continuous Flow Monitoring and Measurement

Continuous flow measurement at middle and tail reaches is absent at these distributaries. Flow measurement is not being made at head reach as well; just gauge readings are continuously monitored by Wonji/Shoa Sugar Factory employee on daily basis before. Currently even such recording was ceased. Installation and proper management and monitoring of head, middle and tail reaches would improve water delivery equity. Thus, re-calibration of these gauges must be done after each de-silting activity or after every season.

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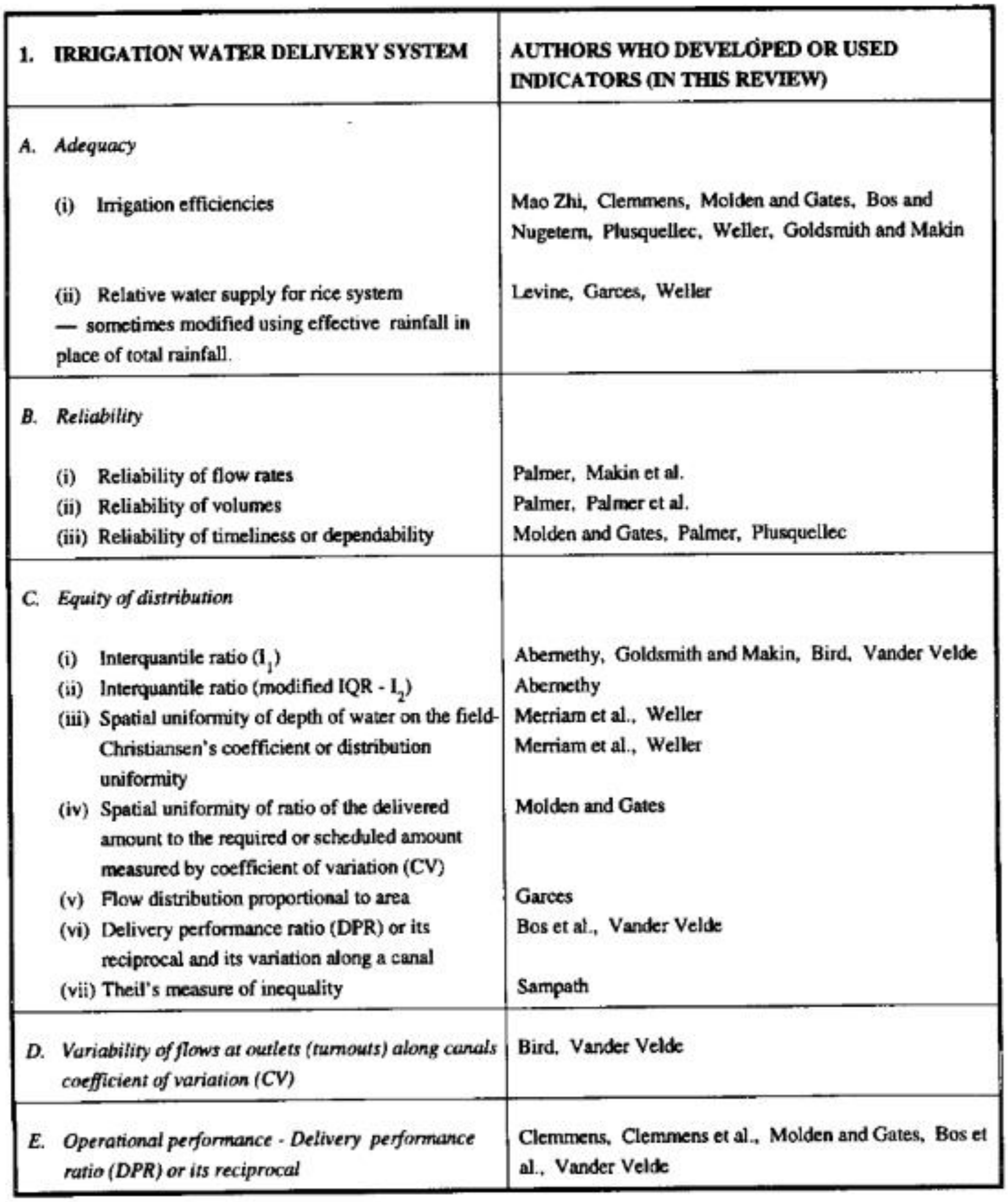
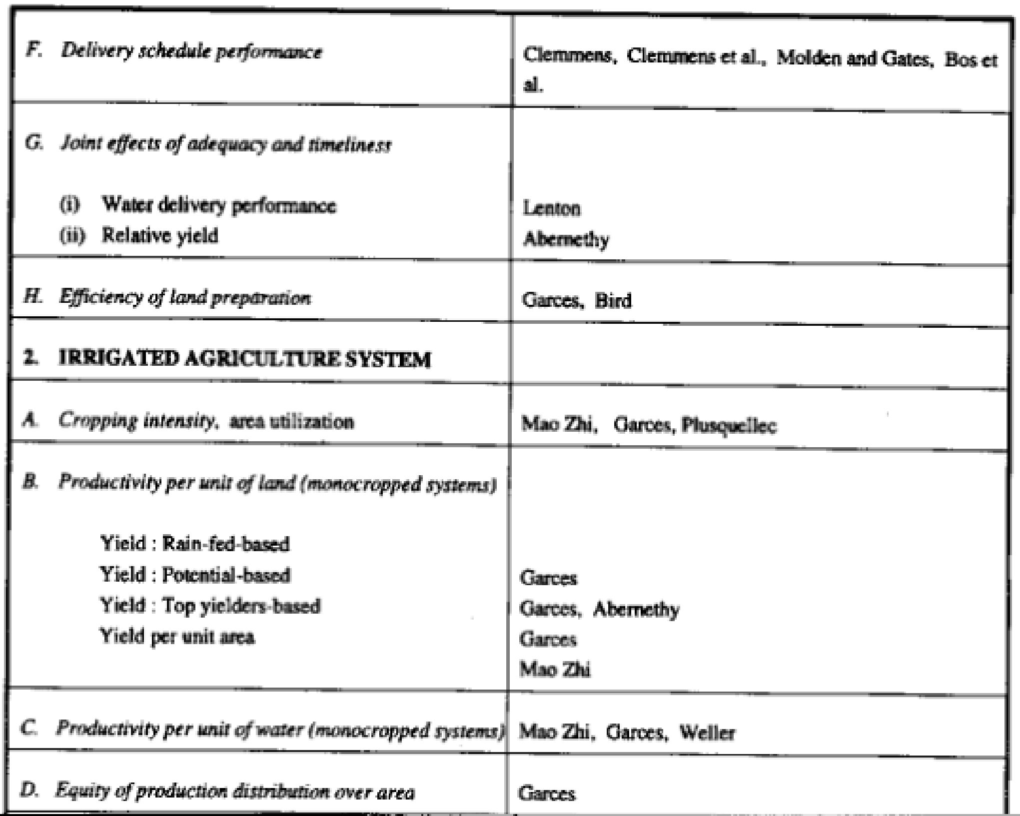
A. Appendix

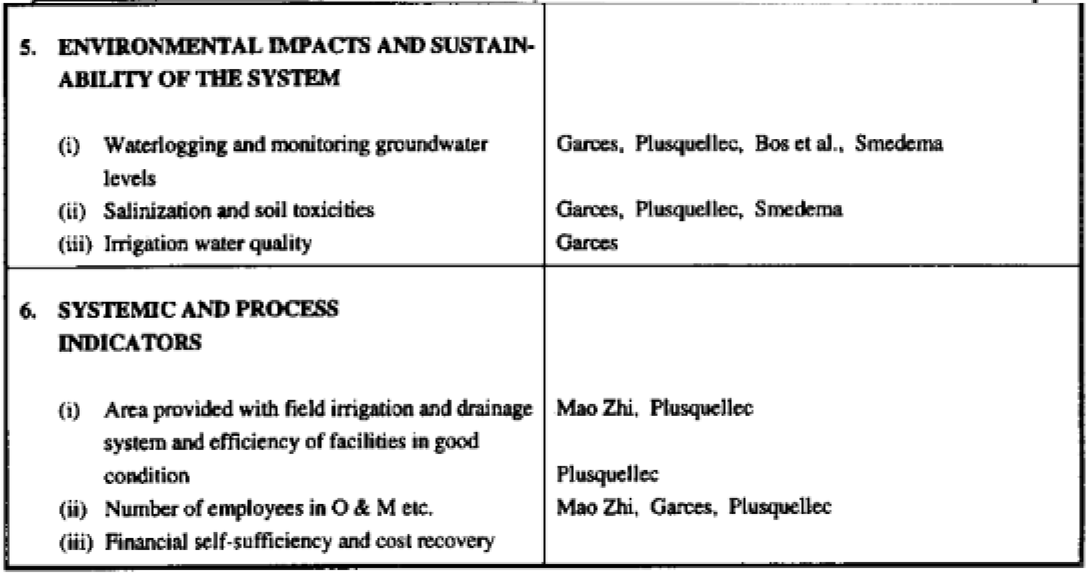
Table A-1: Types of Indicators used for various Systems in the framework of Small and Svendsen (1990, 1992) together with the Authors of Publications who used them



1. IRRIGATION WATER DELIVERY SYSTEM	**AUTHORS WHO DEVELOPED OR USED INDICATORS (IN THIS REVIEW)**
A. *Adequacy*	
(i) Irrigation efficiencies	Mao Zhi, Clemmens, Molden and Gates, Bos and Nugetem, Plusquellec, Weller, Goldsmith and Makin
(ii) Relative water supply for rice system — sometimes modified using effective rainfall in place of total rainfall.	Levine, Garces, Weller
B. *Reliability*	
(i) Reliability of flow rates	Palmer, Makin et al.
(ii) Reliability of volumes	Palmer, Palmer et al.
(iii) Reliability of timeliness or dependability	Molden and Gates, Palmer, Plusquellec
C. *Equity of distribution*	
(i) Interquantile ratio (I_1)	Abernethy, Goldsmith and Makin, Bird, Vander Velde
(ii) Interquantile ratio (modified IQR - I_2)	Abernethy
(iii) Spatial uniformity of depth of water on the field-	Merriam et al., Weller
Christiansen's coefficient or distribution uniformity	Merriam et al., Weller
(iv) Spatial uniformity of ratio of the delivered amount to the required or scheduled amount measured by coefficient of variation (CV)	Molden and Gates
(v) Flow distribution proportional to area	Garces
(vi) Delivery performance ratio (DPR) or its reciprocal and its variation along a canal	Bos et al., Vander Velde
(vii) Theil's measure of inequality	Sampath
D. *Variability of flows at outlets (turnouts) along canals coefficient of variation (CV)*	Bird, Vander Velde
E. *Operational performance - Delivery performance ratio (DPR) or its reciprocal*	Clemmens, Clemmens et al., Molden and Gates, Bos et al., Vander Velde

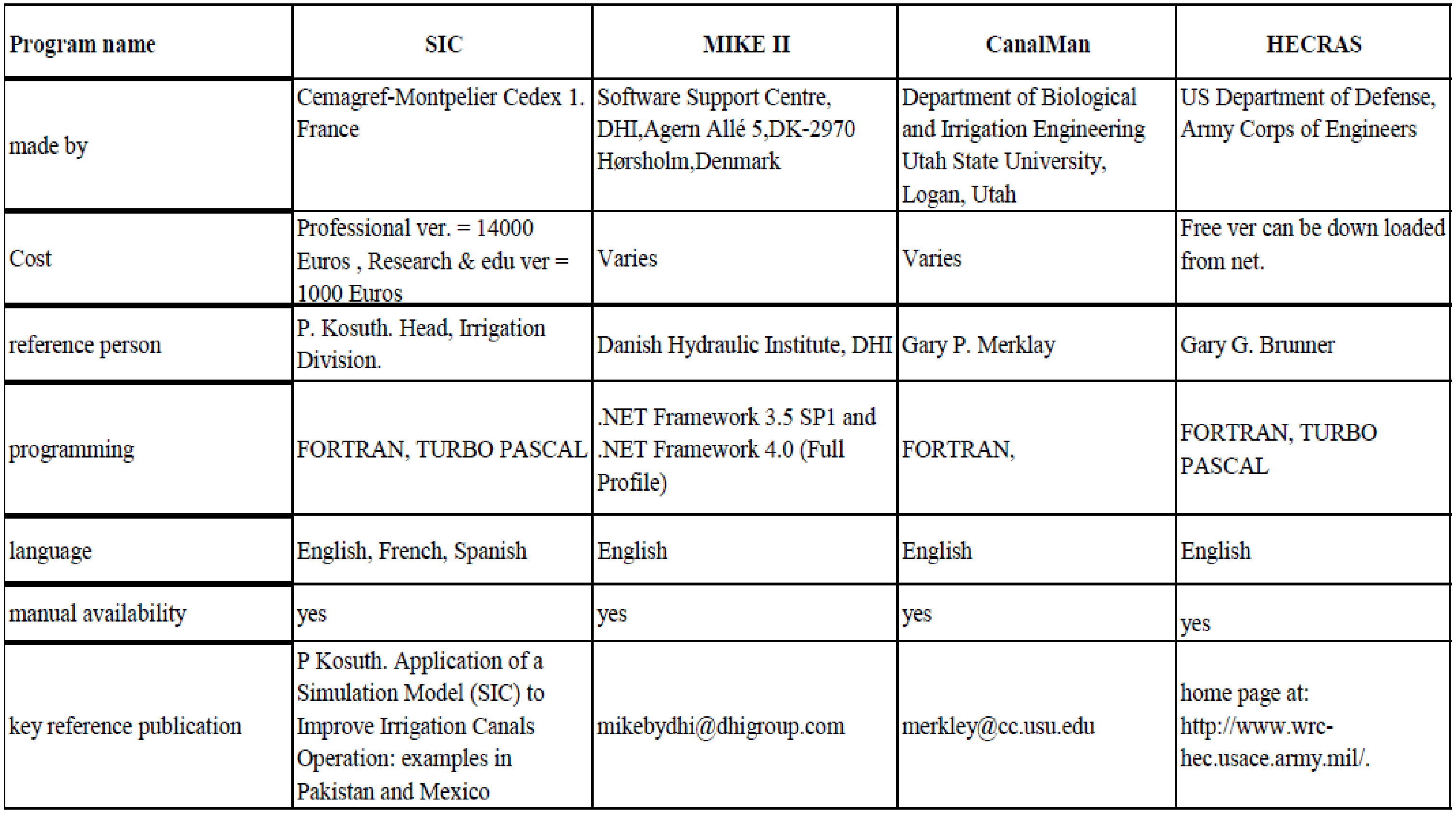


F. Delivery schedule performance	Clemmens, Clemmens et al., Molden and Gates, Bos et al.
G. Joint effects of adequacy and timeliness (i) Water delivery performance (ii) Relative yield	 Lenton Abernethy
H. Efficiency of land preparation	Garces, Bird
2. IRRIGATED AGRICULTURE SYSTEM	
A. Cropping intensity, area utilization	Mao Zhi, Garces, Plusquellec
B. Productivity per unit of land (monocropped systems) Yield : Rain-fed-based Yield : Potential-based Yield : Top yielders-based Yield per unit area	 Garces Garces, Abernethy Garces Mao Zhi
C. Productivity per unit of water (monocropped systems)	Mao Zhi, Garces, Weller
D. Equity of production distribution over area	Garces



5. ENVIRONMENTAL IMPACTS AND SUSTAINABILITY OF THE SYSTEM (i) Waterlogging and monitoring groundwater levels (ii) Salinization and soil toxicities (iii) Irrigation water quality	 Garces, Plusquellec, Bos et al., Smedema Garces, Plusquellec, Smedema Garces
6. SYSTEMIC AND PROCESS INDICATORS (i) Area provided with field irrigation and drainage system and efficiency of facilities in good condition (ii) Number of employees in O & M etc. (iii) Financial self-sufficiency and cost recovery	 Mao Zhi, Plusquellec Plusquellec Mao Zhi, Garces, Plusquellec

Table A-2: General information for evaluation criteria of hydraulic flow models



Program name	**SIC**	**MIKE II**	**CanalMan**	**HECRAS**
made by	Cemagref-Montpelier Cedex 1. France	Software Support Centre, DHI,Agern Allé 5,DK-2970 Hørsholm,Denmark	Department of Biological and Irrigation Engineering Utah State University, Logan, Utah	US Department of Defense, Army Corps of Engineers
Cost	Professional ver. = 14000 Euros , Research & edu ver = 1000 Euros	Varies	Varies	Free ver can be down loaded from net.
reference person	P. Kosuth. Head, Irrigation Division.	Danish Hydraulic Institute, DHI	Gary P. Merklay	Gary G. Brunner
programming	FORTRAN, TURBO PASCAL	.NET Framework 3.5 SP1 and .NET Framework 4.0 (Full Profile)	FORTRAN,	FORTRAN, TURBO PASCAL
language	English, French, Spanish	English	English	English
manual availability	yes	yes	yes	yes
key reference publication	P Kosuth. Application of a Simulation Model (SIC) to Improve Irrigation Canals Operation: examples in Pakistan and Mexico	mikebydhi@dhigroup.com	merkley@cc.usu.edu	home page at: http://www.wrc-hec.usace.army.mil/.

Table A-3: Properties for evaluation criteria of hydraulic flow models

Program name			**SIC**	**MIKE II**	**CanalMan**	**HECRAS**
Qualities	Program qualities	theoretical quality	The model is built around three main computer programs (TALWEG, FLUVIA and SIRENE) that respectively carry out the topography and geometry generation, the steady flow computations and unsteady flow computations. The three units can be run independently or in sequence.	MIKE II is a main computer software package in PASCAL. It is an implicit model. The model can describe super critical as well as sub flow conditions through numerical description.	CanalMan implicitly sloves an integrated form of the Saint-Venant equations of continuity and motion for one dimensional unsteady open channel flow.	For steady flow, HEC RAS is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction and contraction / expansion. The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include hydraulic jumps, hydraulics of bridges, and evaluating profiles at river confluences.
		technical quality	Computational Acuracy, SIC solves the Saint Venant eq.s an duse classical implicit Pressmann scheme. Implicit coeficnet is set to 0.6, the time step can be selecd from 0.01 to 999.99 minutes. The distance step can be chssen by the user. (default 200m) . Numerical Solution criteria, (ASCE Bench marks tets, Mass Conservation Test , Robustness	Implicit coeficnet is set to 0.6, the time step can be selecd from 0.01 to 999.99 minutes. The distance step can be chssen by the user. (default 200m) . Numerical Solution criteria, (ASCE Bench marks tets, Mass Conservation Test , Robustness	Implicit coeficnet is set to 0.6, the default time step is 10mbut it can be changes. The distance step can be chssen by the user. Numerical Solution criteria, (ASCE Bench marks tests)	The distance step can be chssen by the user. (default 200m) . Numerical Solution criteria, (ASCE Bench marks tets, Mass Conservation Test , Robustness
		interface	User-friendly interface	User-friendly interface	User-friendly interface	User-friendly interface
		documentation	yes	yes	yes	yes
		availability	yes	yes	yes	yes

Table A-5: Welenchity Crop Pattern compiled from Wonji/Shoa Sugar Factory-Cane Composition Report

No.	Crop name	Planting date	Harvest date	Area %
1	Sugarcane	21-Nov-2016	12-Jul-2018	1
2	SugCan-Ratoon	3-Jan-2017	2-Jan-2018	2
3	SugCan-Ratoon	14-Jan-2017	13-Jan-2018	2
4	SugCan-Ratoon	25-Jan-2017	24-Jan-2018	3
5	SugCan-Ratoon	6-Feb-2017	5-Feb-2018	4
6	SugCan-Ratoon	17-Feb-2017	16-Feb-2018	4
7	SugCan-Ratoon	28-Feb-2017	27-Feb-2018	5
8	SugCan-Ratoon	14-Mar-2017	13-Mar-2018	4
9	SugCan-Ratoon	1-Apr-2017	31-Mar-2018	12
10	SugCan-Ratoon	12-Apr-2017	11-Apr-2018	12
11	SugCan-Ratoon	23-Apr-2017	22-Apr-2018	12
12	Sugarcane	4-May-2017	24-Dec-2018	6
13	Sugarcane	15-May-2017	4-Jan-2018	6
14	Sugarcane	26-May-2017	15-Jan-2018	6
15	Sugarcane	7-Jun-2017	27-Jan-2018	7
16	Sugarcane	18-Jun-2017	7-Feb-2018	7
17	Sugarcane	30-Jun-2017	19-Feb-2018	7
	Total Area Covered by Sugar Cane is **721.18** hectare			

Source: Compiled from Wonji/Shoa Sugar Factory Cane Composition Report