

**Application of the International Programme for Technology and Research in
Irrigation and Drainage (IPTRID) Benchmarking Indicators in Performance
Assessment of Ahero Irrigation Scheme in Kisumu County, Kenya.
A Comparative Study**

By

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**A Thesis Submitted to the School of Engineering, Department of Civil and
Structural Engineering in Partial Fulfilment of the Requirements for the Award
of the Degree of Masters in Water Engineering**

Moi University

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Declaration

This thesis is my original work and has not been presented for a degree in any other university. No part of it may be reproduced without the prior written permission of the author and/or Moi University.

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Dedication

I dedicate this work to my loving friends and family who came in different ways to support my work by providing resources and steadfast encouragement throughout my studies.

Acknowledgement

I give thanks to the almighty God for providing me with guidance and knowledge that made it possible for me to undertake this research work. Glory be to his name.

I would also like to thank my classmates for their unwavering support, especially the assistance extended to me during the development of my thesis. Their willingness to share ideas and knowledge contributed a lot to my research work.

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Abstract

Ahero Irrigation Scheme in Kenya grows rice under irrigation. The current state of the scheme is unsatisfactory because of poor performance. It is important to evaluate the scheme to come up with measures that will assist the scheme's managers to better understand the system they control to bring about improvements. The main objective of this study was to apply the IPTRID benchmarking indicators in performance assessment of Ahero Irrigation Scheme. The specific objectives were to: determine the hydraulic performance of the irrigation system; evaluate the financial performance of the irrigation system; and assess the rice crop-water productivity performance of the scheme. The research study employed both quantitative and qualitative research designs. The primary and secondary data types were collected. The random sampling technique was employed in data collection. Specialised software was used in data analysis. The hydraulic performance evaluation found that the earthen main canal of length 14.3km lost 16.8% of the irrigation water as conveyance losses. Some of the water control structures like division boxes and sluice gates along the main canal were not functioning properly because they were aged or vandalized. The financial assessment found that the operation and maintenance revenue collected from farmers covered 22.2% of the expenses incurred in offering irrigation and drainage services. The energy cost was the biggest accounting for 54.7% of the total expenditure. The rice crop-water productivity for the scheme was 0.341kg/m^3 and was found as poor because of conveyance losses and field application losses of irrigation water. The study concluded that substantial amount of irrigation water was lost as conveyance losses. The water control structures were not functioning properly. The operation and maintenance revenue collected from farmers could not sustain expenses incurred in offering irrigation and drainage services. The rice crop-water productivity for the scheme was low. This study recommends that; the earthen main canal be lined with impermeable lining, water control structures be rehabilitated, collected revenue be reviewed, alternative or supplementary sources of energy be developed, and irrigation water be supplied via gravity. Further studies should be conducted to determine the effects of sediments carried by pumped irrigation water on performance of the electric pumps.

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Acronyms and Abbreviations

ACA	Athi Catchment Area
BPCA	Benchmarking and Principal Component Analysis
CID	Crop Irrigation Need
CWR	Crop Water Requirements
DE	Distribution Efficiency
ENNCA	Ewaso Ng'iro Catchment Area
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GoK	Government of Kenya
Ha	Hectares
I&D	Irrigation and Drainage
ICID	International Commission on Irrigation and Drainage
IE	Irrigation Efficiency
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
IWMI	International Water Management Institute
IWUA	Irrigation Water Users Association
Kg	Kilograms
KPLC	Kenya Power and Lighting Corporation
Ksh	Kenya Shillings
l/s	Liters per second
LVNCA	Lake Victoria North Catchment Area
LVSCA	Lake Victoria South Catchment Area
MDGs	Millennium Development Goals

M ³	Cubic Meters
mm	Millimetre
NIA	National Irrigation Authority
NWMP 2030	National Water Master Plan 2030
O&M	Operation and maintenance
RVCA	Rift Valley Catchment Area
SDGs	Sustainable Development Goals
SRC	Salaries and Remuneration Commission
TCA	Tana Catchment Area
UN	United Nations
US\$	United States dollars
USDA-SC	United States Department of Agriculture – Soil Conservation
WB	World Bank
WRA	Water Resource Authority
WRUA	Water Resource Users Association

Definition of Terms

Application efficiency

The ratio that relates the amount of water that is directly available to the crop at the root zone compared to the amount of water the irrigation field received from its inlet.

Basin irrigation

Artificial application of water to crops in a levelled field bounded by bunds along its perimeter. The basin is usually flooded with water and has both inlets and outlets.

Command area

The net area of the irrigation scheme in the nominal design provided with irrigation infrastructure less the right of way for the roads, drains, canals, and villages.

Conveyance efficiency

The ratio that relates the quantity of water delivered to the field through transport systems to the quantity of water diverted from an abstraction point.

Conveyance losses

The amount of water lost in a canal through; percolation from the canal's bed, evaporation into the atmosphere, and transpiration by the canal's aquatic weeds.

Crop productivity

The ratio that relates the crop yield to the resources applied in crop production.

Crop water requirement

Total water needed by the crops to transpire from planting to harvesting.

Cropping calendar

A planning irrigation tool in the form of a schedule with timely information starting from land preparation to the harvest of crops.

Effective rainfall

A portion of the total amount of rainfall received that is utilized by the crop to transpire.

Hydraulic

A term that relates to the movement of fluids in a system.

Intermittent irrigation

A type of irrigation in which fields are wetted in cycles. The cycles of irrigation water are applied when the moisture content has fallen below the required amount.

Irrigation efficiency

Product of conveyance and application efficiencies.

Pump discharge capacity

The maximum amount of water a pump discharges as described by the manufacturer.

Pump actual discharge

The amount of water a pump discharges as it operates.

Pump efficiency

The ratio that relates the actual volume a pump discharges to the manufactured discharge capacity.

Sedimentation

A process in which soil particles settle at the bottom of a canal's bed due to the influence of gravitational force on sediments with high specific gravity.

Turbidity

The measure of clarity of a liquid. The optical characteristic of water that describes the level of light scatter

Chapter 1: Introduction

1.1 Background Information

The Kenyan government has heavily invested in the development of public irrigation schemes in the country. According to the economic survey of 2012 in the water sector, the majority of the grants from the government were allocated to irrigation an estimation of 39% of the development expenditure (Ksh 8.0 billion), followed by water supply (GoK, 2013).

Under the national development targets in The National Water Master Plan (NWMP) 2030, the Government of Kenya (GoK) intends by the year 2030 to increase the area of land under irrigation to 1.2 million hectares with an aim of increasing agricultural production of the country. Public (Large scale), smallholder (small scale), and private irrigation schemes are all to be increased according to the plan (GoK, 2013).

The National Irrigation Authority (NIA) is responsible for the management of public irrigation schemes established by the government. Smallholders' irrigation schemes are usually managed by the Water Resource User Associations (WRUAs) which are responsible for conserving, maintaining, and operating irrigation water infrastructure used for conveying water to all its members. WRUAs mostly are formed through; the government, development partners, or farmers themselves. Private irrigation schemes are typically commercial firms or estates owned privately that are engaged in the production of high-value crops. Examples of these high-value crops are; floriculture and horticultural crops largely exported to foreign markets (Ngigi, 2002).

Ahero Irrigation Scheme located in the western part of Kenya is a public scheme under the NIA that predominantly grows rice under irrigation. The water used for irrigation

is abstracted from River Nyando by the use of several electric pumps. The abstracted water is then delivered into the earthen canals for conveyance to the fields for irrigation. The irrigation water flows through the earthen canals from the pumping station to the fields through gravity. The method used to apply water to the crops is surface irrigation. The rice crop is grown in irrigation basins.

1.2 Problem Statement

Kenya is a developing country that is experiencing rapid population increase. Kenya's population is forecasted to reach 57.8 million by the year 2030. This is a rapid increase from a population of 8.6 million in the year 1962 (KNBS, 2019). Population increase comes with challenges of unemployment and increased need for food, clean water, and energy to meet the demands of the growing population. This increase puts pressure on available natural resources, and there is need to utilize these resources in a sustainable manner. Water, food, and energy form a nexus that greatly influence sustainable development (Belaud, et al., 2019).

Sustainable development goals aim to ensure environmental sustainability, and eradication of poverty and hunger. Kenya aims to transform into a middle-income country according to its Vision 2030 development programs that are geared to provide a high quality of life to its citizens in a clean and secure environment. Both sustainable development goals and vision 2030 development programs are geared to promote environmental sustainability and improvement of quality of life through provision of better nutrition and creation of jobs.

Kenya has a high potential of developing new irrigation schemes and expanding already existing ones. According to the set targets outlined in the NWMP 2030, the Government of Kenya (GoK) intends to increase the area of land under irrigation to 1.2 million hectares before the year 2030 (GoK, 2013). Irrigation promises to create jobs and provide food for the ever-growing Kenyan population.

Public irrigation schemes in the Kenya are currently performing poorly. This is attributed to; high cost of operation and maintenance, poor utilization of scarce water resources, poor irrigation technologies used, low crop productivity, and adverse effects brought about by climate change (Ngigi, 2002). It is important for managers of these schemes to address these challenges to ensure the realization of the set targets outlined in the NWMP 2030.

With the demand of expanding existing irrigation schemes and the development of new ones, the government will heavily rely on the experience and knowledge acquired from the management of already established public irrigation schemes in the country that are self-sustaining to act as a benchmark for new upcoming projects.

1.3 Objectives

1.3.1 Broad Objective

To apply the IPTRID benchmarking indicators in performance assessment of Ahero Irrigation Scheme.

1.3.2 Specific Objectives

The specific objectives of the study are to:

- i. Determine the hydraulic performance of the irrigation system
- ii. Evaluate the financial performance of the irrigation system

- iii. Evaluate the rice crop water productivity performance of the irrigation system

1.4 Research Questions

- i. What is the performance of hydraulic infrastructure established by the scheme?
- ii. What is the ratio of revenue generated from the production of crops compared to the expenditure incurred?
- iii. What is the measure of crop production compared to the water resource applied while producing the crop?

1.5 Study Justification

The challenge of poor performance of public irrigation schemes in the country need to be addressed to enable the government realise its set targets of increasing area under irrigation. Performance assessment of public irrigation schemes need to be conducted to identify areas of improvement. A research study on performance assessment of public irrigation schemes in the western part of Kenya was done recently (2018) by Muema and others.

This research study employed the use of the Benchmarking and Principal Component Analysis (BPCA) evaluation technique to assess performance of the irrigation schemes. The study was broad covering three irrigations schemes in the western part of Kenya which are; West Kano, Bunyala, and Ahero. The study evaluated performance indicators under agricultural productivity, water supply, and financial performance categories. Of all performance indicators available in these categories, the study researched only on 11 indicators. The remaining indicators were not researched due of

lack of data (Malano & Burton, 2001; Muema *et al.*, 2018). There is need to fill this gap. More studies need to be conducted to compliment and compare the findings realised from the study undertaken.

The aim of this research study is to conduct a detailed performance assessment of Ahero Irrigation Scheme (AIS) using IPTRID benchmarking indicators and compare the outcome of this study with the findings of the research study done using the BPCA evaluation technique as a comparative reference. This study also aims to fill the gaps left behind from the study conducted using the BPCA evaluation technique.

This comparative research study aims to evaluate the performance of Ahero Irrigation Scheme in terms of; (i) hydraulic, (ii) financial, and (iii) rice crop water productivity performance indicators. Areas that are currently performing poorly will be outlined and the measures to be put in place to improve the performance of the scheme. The measures of improvement outlined in this research study can also be applied to other public irrigation schemes in the country with similar challenges as Ahero Irrigation Scheme.

Chapter 2: Literature Review

2.1 Introduction

It is estimated that the highest yield harvested from irrigation is more than double when compared to the highest yield harvested from rainfed agriculture (FAO, 2016). Irrigation is expensive and because of this most small-scale farmer cannot find adequate resources to sustain irrigation especially in many developing countries. Despite these limitations, irrigation promises to solve challenges related to increasing food production and security if irrigation management is efficiently undertaken.

The income of produce from irrigated agriculture in Kenya is estimated to contribute approximately 3% of the GDP (GoK, 2013). The area under irrigation is approximated as 4% of the total area of land under agriculture and yet it produces 18% of all agricultural produce in our country (GoK, 2013). From these statistics, though limited, irrigated agriculture has the potential of increasing our country's agricultural produce.

Our country's population is ever-increasing each year and our government is faced with salient challenges affecting developing countries. Food security, job creation, and the poor livelihood of people need to be addressed. One way of solving these challenges by the government is through the enhancement of agricultural production through irrigation.

2.2 Sustainable Development Goals

The leaders across the world came together at the start of this millennium with a goal of solving global challenges. From this, The Millennium Development Goals (MDGs) came into existence. In the year 2015, The Millennium Development Goals (MDGs) were replaced with The Sustainable Development Goals (SDGs). Some of the SDGs aim to ensure; no poverty (1), zero hunger (2), good health and well-being (3), clean water and sanitation (6), affordable and clean energy (7), decent work and economic growth (8), sustainable cities and communities (11), responsible consumption and

production (12), life below water (14), life on land (15), and climate action (13) (UN, 2015).

The African Union in the year 2013 developed a 50-year strategic framework for the continent called the Agenda 2063 with an aim of achieving inclusivity and sustainable socio-economic development. One of the aspirations of the Agenda 2063 has priorities targeting to; create jobs, increase income, reduce poverty, prevent hunger, improve health and nutrition, promote economic growth, increase agricultural productivity, sustain natural resources, and prevent climate change (AU, 2024).

Kenya as a country share common visions as those of the SDGs and the Agenda 2063 as indicated in the country's Vision 2030 Development Goals. Kenya intends to transform into a middle-income country by the provision of high-quality life to all its citizens in a clean and secure environment (GoK, 2013).

From these development goals; improvement of quality of life, conservation of the environment, and improvement of agricultural production have been identified as key drivers to bring about positive change towards the realization of set targets. Irrigation engineering promises to; increase food production, conserve the environment, and improve quality of life through improvement of nutrition and job creation.

2.3 Irrigation Potential

Kenya has a big potential to increase the area of land under irrigation by developing new irrigation schemes and expanding existing ones. For example, Lake Victoria South Catchment Area (LVSCA) has a target of increasing the area under irrigation from the current 13,218 ha to 113,206 ha before the year 2030 (GoK, 2013). Figure 2.1 illustrates the potential the country has of increasing the area of land under irrigation by portraying the currently developed area of land under irrigation in relation to the anticipated area of land to be developed under irrigation. Figure 2.2 shows the current

developed irrigated areas of land compared to the expected areas of land to be irrigated in various water catchments in the country.

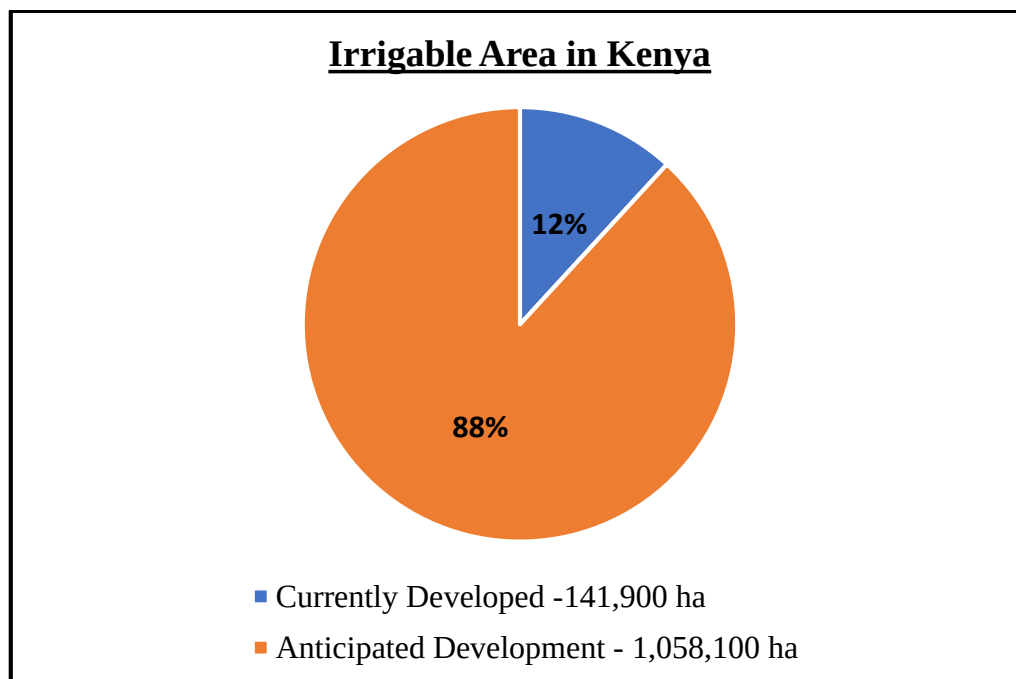


Figure 2.1: Irrigation potential countrywide. Source NWMP 2030

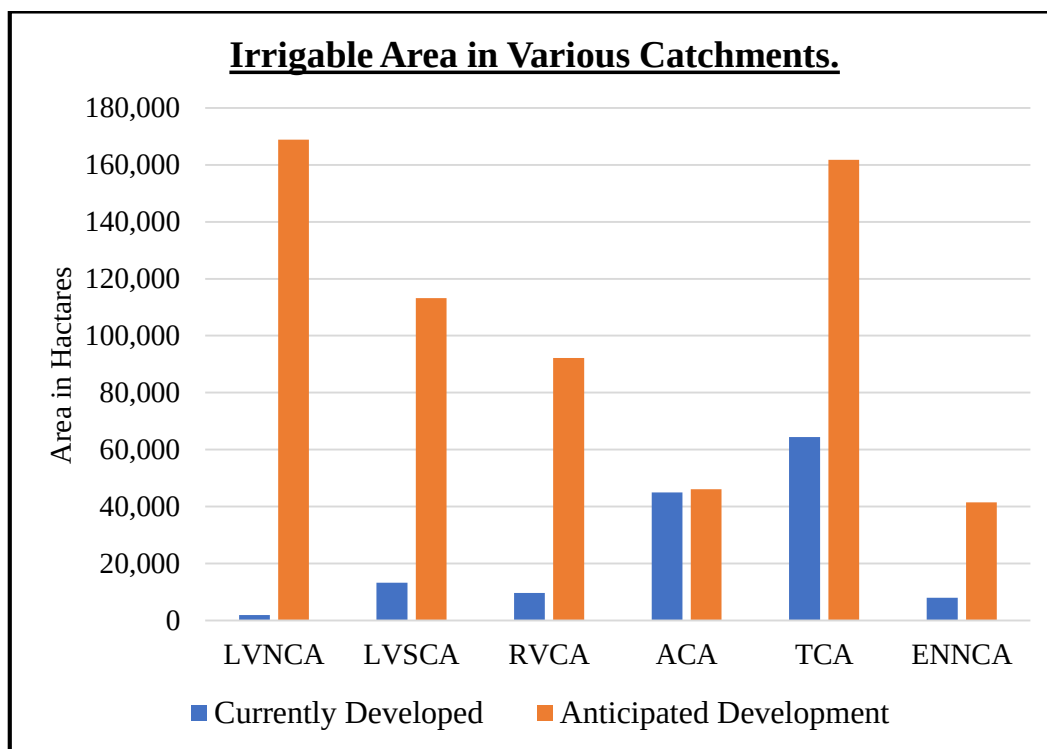


Figure 2.2: Irrigation potential in the catchment areas. Source NWMP 2030

2.4 Current State of Public Irrigation Schemes in the Western Kenya

Public irrigation schemes in Kenya are performing poorly. West Kano, Bunyala, and Ahero are public schemes located in the western part of Kenya. In a recent performance benchmarking exercise, the average performance of West Kano, Bunyala, and Ahero was found to be 49%, 56%, and 48% respectively (Muema *et al.*, 2018). The Benchmarking and Principal Component Analysis evaluation technique was used in the assessment. During the evaluation, it was discovered that the water abstracted to irrigate the crops was limited and therefore could not meet the crop water requirements. The schemes had low water use efficiencies. In addition to these, the schemes were found to be financially lacking because the water fees collected from water users were found to be limited to meet the irrigation costs of management and operations (Ngenoh *et al.*, 2015).

2.5 Strategies for Evaluation of Public Irrigation Schemes

Evaluation of public irrigation schemes is a way of gathering and assessing information that helps managers to better understand the systems they control in order to bring about positive improvements. During an evaluation key aspect that affect performance need to be considered. Examples of these aspects are; maintenance cost, crop productivity, water availability, energy cost, and revenue generation. There is no standard format used in the performance evaluation of irrigation systems but majorly; financial, hydrological, and agricultural performance indicators are mostly used (Muema *et al.*, 2018; Ngenoh *et al.*, 2015).

2.6 Benchmarking Process

Benchmarking is a systematic procedure put in place for the continual improvement that encompasses measuring actual process performance and making comparisons to the set norms and standards (Cornish, 2005; Brandmeier & Rupp, 2024). Benchmarking activities involve; i) mensuration of level of performance a process is operating, ii) making comparisons to the best practices, iii) identification of process performance

gaps, iv) generating measures to be put in place to improve the process, v) implementing the measures generated, and vi) appraising the process performance by making comparison to the initial process performance. Benchmarking is a diagnostic procedure that is carried out in cycles to ensure continual improvement (Malano & Burton, 2001).

2.7 How Rice is Grown

Rice is a water-loving crop, see Figure 2.3. The crop is grown in irrigation basins that have bunds along their perimeter to retain flooded water. The basins have both inlets to draw water in, and outlets to drain water away. Rice is mainly grown in clay and loam soils. Before planting the crop, land preparation is done. The basin is flooded with water to soften the soil and to prevent growth of unwanted weeds. Flooded basins are then ploughed and levelled. Paddy rice is then sowed to nursery beds where they germinate to an appropriate height capable of being transplanted to the flooded field. During transplanting, the young crop is evenly spaced in the basin. As the crop continues to grow; weeding, application of fertilizer, and control of pests and diseases are done. Two weeks before harvesting the flooded basin is drained away to allow for smooth harvesting activities. Harvesting is done either manually by the use of sickles or through mechanization by the use of modern combine harvesters. The harvested paddy rice is then sundried, milled, and packaged for sale (Arraudeau & Vergara, 1988; Yoshida, 1981).



Figure 2.3: Irrigated rice crop.

2.8 Water Resource Scarcity and Allocation Priority in LVSCA

Kenya is a water-scarce country receiving approximately an average annual rainfall of 679 mm/year (GoK, 2013). The northern and eastern parts of the country are majorly classified as semi-arid. Ahero Irrigation Scheme is located in the Lake Victoria South Catchment Area (LVSCA) in the western part of the country. The catchment is estimated to receive an annual rainfall ranging from 1,200mm to 1800mm. Despite the region receiving a high amount of rainfall, the available water resources (rainfall, groundwater, surface water) cannot meet adequately the present and future water demands. Various water subsectors (domestic, industrial, livestock, wildlife, and fisheries) in the catchment are competing for the same scarce water resource (GoK, 2013). The irrigation scheme experiences water shortages mostly in dry months when the area is not receiving rainfall. During dry seasons little water can be abstracted from River Nyando because the river water discharge is too low.

2.9 Sources of Water for Irrigation in Ahero Irrigation Scheme

Ahero Irrigation Scheme receives water for irrigation mainly from two sources; rainfall, and rivers. The area generally receives a good amount of rainfall annually. The

proportion of this rainfall amount that is effectively utilized to meet the crops' water needs can be referred as effective rainfall (Getaneh, 2020). Several methods can be used to calculate the effective rainfall. The USDA-Soil Conservation Method in-built in CROPWAT 8 application is an example of a method that can be used to calculate the effective rainfall. River Nyando is another source of water that the scheme utilizes to irrigate the crop. The amount of water in River Nyando is highly variable throughout the year having high discharges in wet seasons and low discharges in dry spells. The water is abstracted by the use of several electric pumps that divert the water into earthen canals for conveyance to the fields for irrigation.

2.10 IPTRID Assessment Tool

IPTRID assessment tool uses indicators outlined in Table 2.1 to evaluate the performance of irrigation schemes. These indicators are annual that require the research period and the data collected be for a year. The tool was developed in the year 1999 when the World Bank requested the IPTRID Consultative Group to develop guidelines for benchmarking drainage and irrigation projects through research. The research study was conducted as a joint initiative of the; World Bank (WB), the International Programme for Technology and Research in Irrigation and Drainage (IPTRID), the International Commission on Irrigation and Drainage (ICID), the International Water Management Institute (IWMI), and the Food and Agriculture Organization of the United Nations (FAO) (Malano & Burton, 2001).

Table 2.1: IPTRID assessment indicators

No.	Specific Objective	Indicators
1	Determine the hydraulic performance of the irrigation system	1. Total annual volume of irrigation water delivered (m ³) 2. Total annual volume of irrigation water supplied (m ³) 3. Total annual volume of water supplied (m ³) 4. Annual irrigation water supplied per unit command area (m ³ /ha) 5. Annual irrigation water supplied per unit irrigated area (m ³ /ha) 6. Main system water delivery efficiency (%) 7. Annual relative water supply 8. Annual relative irrigation water supply 9. Water delivery capacity of pumps
2	Evaluate the financial performance of the irrigation system	10. Cost recovery ratio 11. Maintenance cost to revenue ratio 12. Total management, operation, and management cost per unit irrigated area (Ksh/ha) 13. Total personnel cost per person employed on water delivered (Ksh/person) 14. Revenue collection performance 15. Total irrigated area managed per person (ha/Persons) 16. The average revenue per cubic meter of irrigation water delivered (Ksh/ m ³) 17. Total management, operation, and maintenance cost per unit volume of water delivered (Ksh/m ³) 18. Total management, operation, and maintenance cost per unit crop production (Ksh/kg) 19. Total annual energy cost per unit crop production (Ksh/kg) 20. Percentage of total annual energy cost to the total management operation cost (%)
3	Evaluate the rice crop water productivity performance of the irrigation system	21. Total annual crop production (tonnes) 22. Total annual value of crop production (Ksh) 23. Output per unit command area (Ksh/ha) 24. Output per unit irrigated area (Ksh/ha) 25. Output per unit irrigation water delivered (Ksh/m ³) 26. Output per unit irrigation water supplied (Ksh/m ³) 27. Output per unit water supplied (Ksh/m ³) 28. Output per unit crop water demand (Ksh/m ³) 29. Total annual volume of water supplied per unit crop production (litres/kg)

2.11 Hydraulic Performance

2.11.1 Pump Efficiencies

Efficiency can be defined or expressed as a ratio of output to the input. Pump efficiency is determined by comparing the actual volume of water a pump discharges in relation to the manufactured discharge capacity. Pump efficiencies reduce with time due to wear and tear of its parts (Glovatski *et al.*, 2021; Serrano *et al.*, 2018).

When the water pressure in a pump falls below the vapour pressure during suction air bubbles are created that later implode with high energy on the surface of impellers located in a high-pressure delivery side of a centrifugal pump. This phenomenon is called cavitation and it leads to wear and tear of impellers (Glovatski *et al.*, 2021; Reinemann *et al.*, 2015).

The presence of sediment particles in pumped water cause abrasion effect on the surfaces of parts in a pump that leads to wear and tear due to erosion. This reduces efficiency and shortens the operational life of a centrifugal pump (Bandi *et al.*, 2023).

2.11.2 Conveyance Efficiencies

Conveyance efficiency is one that relates the quantity of water delivered to the field through the transport systems to the quantity of water diverted from an abstraction point. Earthen canals have low conveyance efficiencies because they are associated with high infiltration losses. The indicative conveyance efficiencies of canals made of clay soils and ones lined with concrete are 80% and 95% respectively for the canals longer than 2000 meters (FAO, 1989).

The canals invaded with aquatic weeds have low conveyance efficiencies. The aquatic weeds growing in the canals' transport systems are opportunistic as they use the water intended to irrigate the crops for their own transpiration. The floating and submerged aquatic weeds also increase the retention time of flowing water through the canals by

reducing the flow velocity. The reduction in flow velocities causes more water to be lost through infiltration and promotes deposition of sediments onto the canals' bed. The aquatic weeds also reduce the canals' capacities and cause blockages (Sytsma & Parker, 1999). The sedimentation in canals is mainly caused by the reduction of the canal's water current as a result of poor maintenance or lack of it (Agunwamba, *et al.*, 2013).

The water control structures are infrastructure put in place along a canal to convey water, divert flow direction, and to maintain appropriate water surface elevation in a canal. Some of the water control structures include; division boxes, culverts, sluice gates, weir etc. Vandalised water control structures hinder effective water resource management practices in the field and contributes to conveyance losses along a canal (Tamirayehu & Amare, 2021).

2.11.3 Application Efficiencies

Application efficiency can be said to be a ratio of the irrigation water that is directly available to the crop at the root zone compared to the amount of irrigation water the irrigated field received from its inlet. Applied irrigation water can be lost through; evaporation from soil, surface runoff, wind drift (in case of sprinklers), and percolation beyond root zone (Howell, 2015; Irmak *et al.*, 2011). Application efficiency (E_a) as a percentage can be calculated from equation 2.1 as;

$$E_a(\%) = 100 * \frac{\text{Volume of water stored in the root zone } (v_s)}{\text{Volume of water delivered to the field } (v_f)} \dots \dots \dots \text{equation 2.1}$$

2.11.4 Distribution Efficiencies

Irrigation distribution efficiency can also be referred as Christiansen's uniformity coefficient. It is a measure of uniformity of water application in terms of depth after irrigation water has been applied to crops. Factors influencing irrigation distribution

efficiency include; type of irrigation method used, type of soil, and the degree of which irrigated fields are levelled – the slope. Christiansen's uniformity coefficient can be expressed from equation 2.2 as (Maroufpoor *et al.*, 2010; Kara *et al.*, 2008);

$$DE = 1 - \left(\frac{\sum_{i=1}^n (Y_{average} - Y_i)^2}{n * Y_{average}^2} \right) \dots \dots \dots \text{equation 2.2}$$

Where; DE is the distribution efficiency, $Y_{average}$ is the mean of irrigation depths, Y_i is the irrigation depths at various points, and n is the number of measurements of irrigation depths.

2.11.5 Irrigation Efficiencies

Irrigation efficiency is a critical measure of performance in irrigation. The performance is measured from the source of irrigation water (abstraction point) to the field level where uniformity of water application is considered. Irrigation efficiencies (IE) take into account both conveyance and application efficiencies and can be calculated from equation 2.3 as;

$$\begin{aligned} & \text{IE (\%)} \\ &= \frac{\text{Conveyance efficiency (\%)} * \text{Application efficiency (\%)}}{100} \dots \dots \text{equation 2.3} \end{aligned}$$

According to the NWMP 2030, the country aspires by the year 2030 to achieve irrigation efficiencies of; surface irrigation - 50%, sprinkler irrigation - 70%, and drip irrigation - 90% (GoK, 2013)

2.12 Financial Performance

Economic analysis is an important diagnostic tool that involves evaluation of benefits and costs in projects. It is useful in decisions related to resources allocation and checking economic viability of projects. Economic analysis involves; i) mensuration of

costs incurred in a project, ii) estimation of benefits gained in a project, and iii) comparison of benefits to the costs incurred (Edomah, 2018). The benefit cost ratio is a profitability indicator that shows relationship between estimated benefits and the costs (Razzaq *et al.*, 2018).

The cost recovery ratio of services offered in irrigation and drainage in many irrigation schemes in Kenya is low. The revenue generated as operation and maintenance fee (O&M) serves to; i) cover the costs incurred in offering irrigation and drainage services, and ii) encourage farmers to use less water which is a scarce resource in crop production. There is low performance in collection of operation and maintenance fees in most of the irrigation schemes in many developing countries that hinders the sustainability of offering irrigation services. Low water collection fees is attributed to; i) lack of farmers participation in project management and planning, ii) lack of transparency between the schemes' management and the farmers, iii) lack of penalties for delayed and non-payment of water charges, iv) corrupt officials engaged in offering irrigation and drainage services, v) low income generated from production of crops that makes it difficult for farmer to contribute the operation and maintenance (O&M) fees, vi) revenue collection exercise has been given less priority, vii) there is a disconnect between the revenue collected by farmers and the funds allocated to irrigation projects to cater for expenses, and viii) poor irrigation water delivery services offered by schemes' management who fail to deliver water on time, in appropriate duration, and in adequate quantity (Easter & Liu, 2005).

2.13 Crop Water Productivity

The rice crop requires a lot of water to grow to maturity. On average, the crop water requirement for rice to meet evapotranspiration needs is 1,432 litres to produce 1kg of

paddy rice (equivalent of 0.6983kg/m^3). In real life situation, depending upon efficiencies of irrigation infrastructure established in the schemes, the rice crop will require approximately (2,500 – 5,000) litres of water to produce 1kg of paddy rice (equivalent of 0.2kg/m^3 - 0.4kg/m^3) depending on the water application efficiency that takes into account factors such as seepage, percolation, and conveyance losses (Bouman, 2009).

2.14 Irrigation Water Management Models

A model can be described as a tool that represents an approximation of a field situation. It is a virtual representation of a physical system that investigates a certain phenomenon or predicts its behaviour over time. CROPWAT 8.0 software is an example of an application model developed by FAO used in management of irrigation water. With limited resources such as water and land, irrigation is becoming an act of precision whereby all resources need to be used in an optimal way (Díaz *et al.*, 2020). Modelling with CROPWAT 8.0 software facilitates decision making by managers in charge of irrigation projects. The model has the following capabilities; i) calculation of evapotranspiration from climate data, ii) estimation of effective rainfall, iii) computation of crop water requirements, iv) determination of irrigation schedules, and v) generation of cropping patterns (Getaneh, 2020).

Evapotranspiration is a collective word used to refer to the amount of water lost from the soil surface through evaporation and the amount of water lost from the surface of leaves as transpiration. Effective rainfall is a portion of rainfall received which is directly useful to the crops to meet the water requirements needs. Irrigation scheduling is a process of establishing the appropriate frequency, the amount, and the duration which irrigation water will be applied to the crops. A cropping pattern is a schedule that

indicates the proportion of area of land having various crops that are under irrigation and at what time.

Other software models that have more or less or similar capabilities as CROPWAT 8.0 application include; CLIMWAT application and Aqua Crop application (FAO, 2024). CLIMWAT is limited to calculate the; crop water needs, irrigation schedule, and the cropping pattern. Aqua Crop application interface is less user friendly. This study has used CROPWAT 8.0 application because of its user-friendly interface and its broad capability to calculate; crop water requirements, effective rainfall, irrigation schedule, cropping pattern and reference evapotranspiration (Getaneh, 2020).

2.15 Gaps from previous studies

Currently, there is limited knowledge that describes how well public irrigation schemes in the country are performing in terms of hydraulic, crop productivity, and financial aspects. The high cost of operation and maintenance, low crop productivity, poor utilization of scarce water resource, and poor irrigation technologies used are some of the key challenges facing public irrigation schemes in the country (Ngigi, 2002). This study seeks to research on these topics and shed light on how to bring about improvements. This information will help managers of the scheme to better understand the systems they are in charge. The information will also be valuable to the government in its endeavour to increase the area of land under irrigation according to its set targets.

Currently, there is limited information on whether the existing public irrigation schemes can accommodate future expansions. Assessment of already established irrigation infrastructure and available resources in the irrigation schemes will dictate whether the schemes will be able to accommodate future expansions or not (Elshaikh *et al.*, 2018; GoK, 2013). Some of the irrigation infrastructure and available resources that will greatly influence future expansions of schemes are; i) pumps and their performance, ii)

capacity of canals and their conditions, iii) availability of water resource, and iv) availability of land to accommodate future expansions.

2.16 Comparative studies

Comparative research is a study intended to find similarities and differences of two or more researched cases. The study helps in expanding existing knowledge about cases researched. The study fills gaps in knowledge by opening new opportunities and directions for future research on issues that researchers may have not been aware of previously. Comparative studies aim to recognize weaknesses in research designs that assists to improve the quality of work being studied (Iranifard & Latifnejad, 2022; Zohreh & Seyed, 2019)

Comparative studies can be of two types; quantitative or qualitative. Quantitative comparative research is one whose analysis is variable oriented. Qualitative comparative research is one whose analysis is not variable oriented but of cases (Iranifard & Latifnejad, 2022; Zohreh & Seyed, 2019).

This thesis evaluates performance of Ahero Irrigation Scheme using qualitative comparative method which aims to compare similarities, differences, and gaps of findings realised from my study and the one conducted by Muema and others (2018).

Chapter 3: Research Methods

3.1 Study Area

Ahero Irrigation Scheme is located in the western part of the country in the Kano Plains in between the Nyabondo Plateau and the Nandi Escarpment, see Figure 3.1. The scheme administratively lies in Kisumu County, Muhoroni Sub-County. The area falls in the tropics and can be referenced using GPS coordinates as follows; Latitude (0.125S to 0.175S) and longitude (34.975E to 34.905E). The height above the mean sea level is approximately 1160m. The terrain can be described as plain with gentle slopes.

The construction of the scheme commenced in the year 1966, and the scheme came into operation in the year 1969 (NIA, 2024). The National Irrigation Authority (NIA) is responsible for the management of the public irrigation scheme. The area under irrigation is measured as 2,183 acres. The scheme is currently establishing other extensions such as Mbega, and Kobong'o (NIA, 2024). More than 30,000 farmers are benefiting from this irrigation infrastructure. The scheme is further subdivided into irrigable blocks namely; A, B, C, D, F, G, K, L, M, N, O, P, and Research (R), see Figure 3.2.

The scheme lies in the Lake Victoria South Catchment Area (LVSCA) and the region can be described as sub-humid according to the climatic characteristics (Biamah, 2005). The catchment area averagely receives annual rainfall of 1490mm (Goodess *et al.*, 2021). The maximum temperature range for the region is 28.6°C to 28.7°C while the minimum temperature range is 14.7°C to 18.2°C (Wabwire *et al* 2020). The annual reference evapotranspiration for the region can be approximated as 1736.3mm (Chumo *et al.*, 2011).

Rice crop is predominantly grown in Ahero Irrigation Scheme. IR variety is the most grown type followed by Basmati. Other varieties are grown but in small quantities. Apart from rice, other crops that are grown in the scheme include; soybeans, maize, watermelons, tomatoes, cowpeas, and sorghum.

The irrigation scheme gets its water from two major sources; rainfall and rivers. The area has heavy clay soils suitable for growing rice because little water can be lost through infiltration compared to other types of soils. The scheme practices surface irrigation in which rice crop is grown in irrigation basins. Water is retained by earthen bunds along the perimeter of the irrigated basin. The scheme uses the fully supply / continuous flooding irrigation method to apply water to the crops.

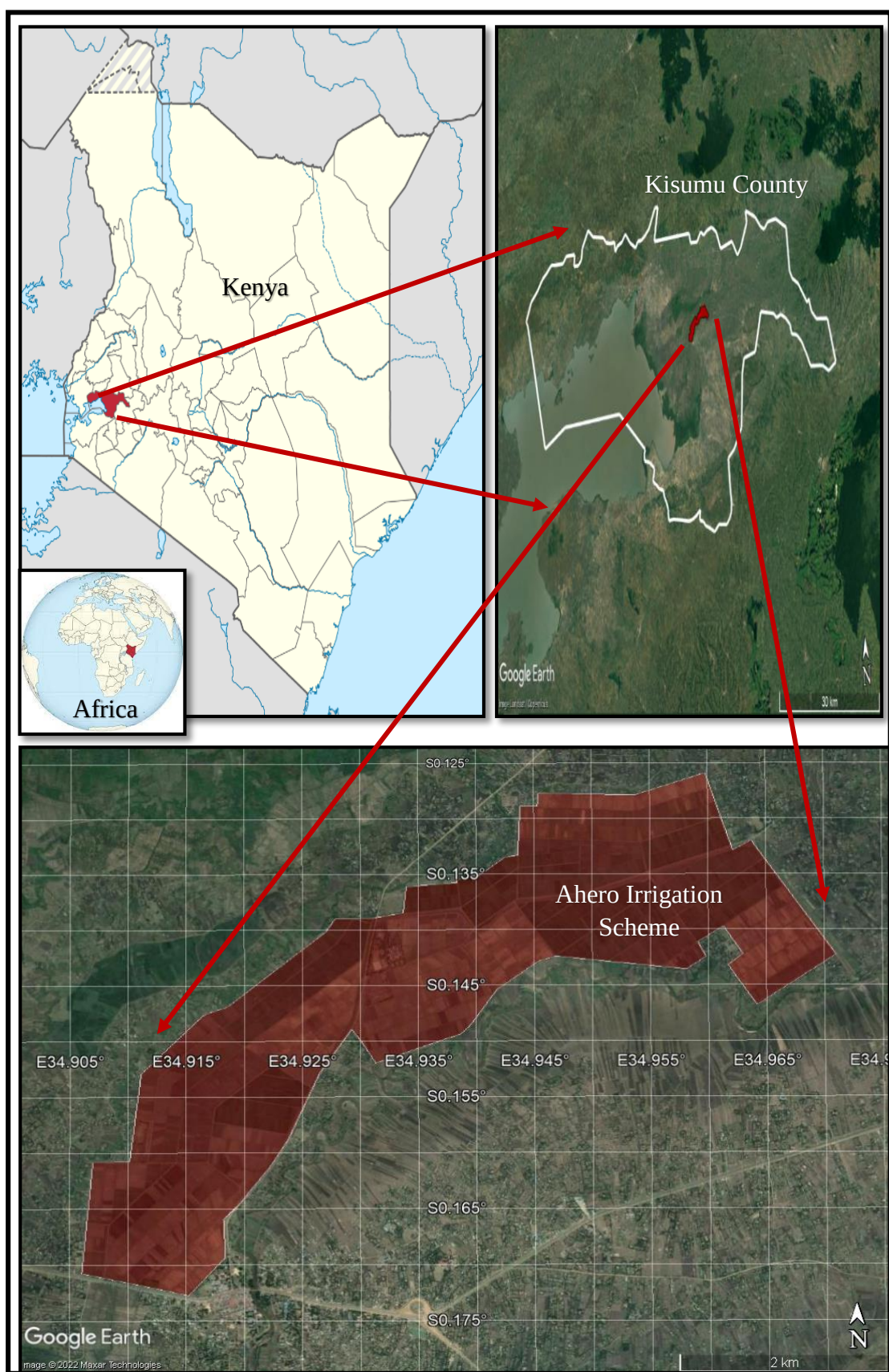


Figure 3.1: Aerial satellite imagery of Ahero Irrigation Scheme (Source; Google Earth, 2022)

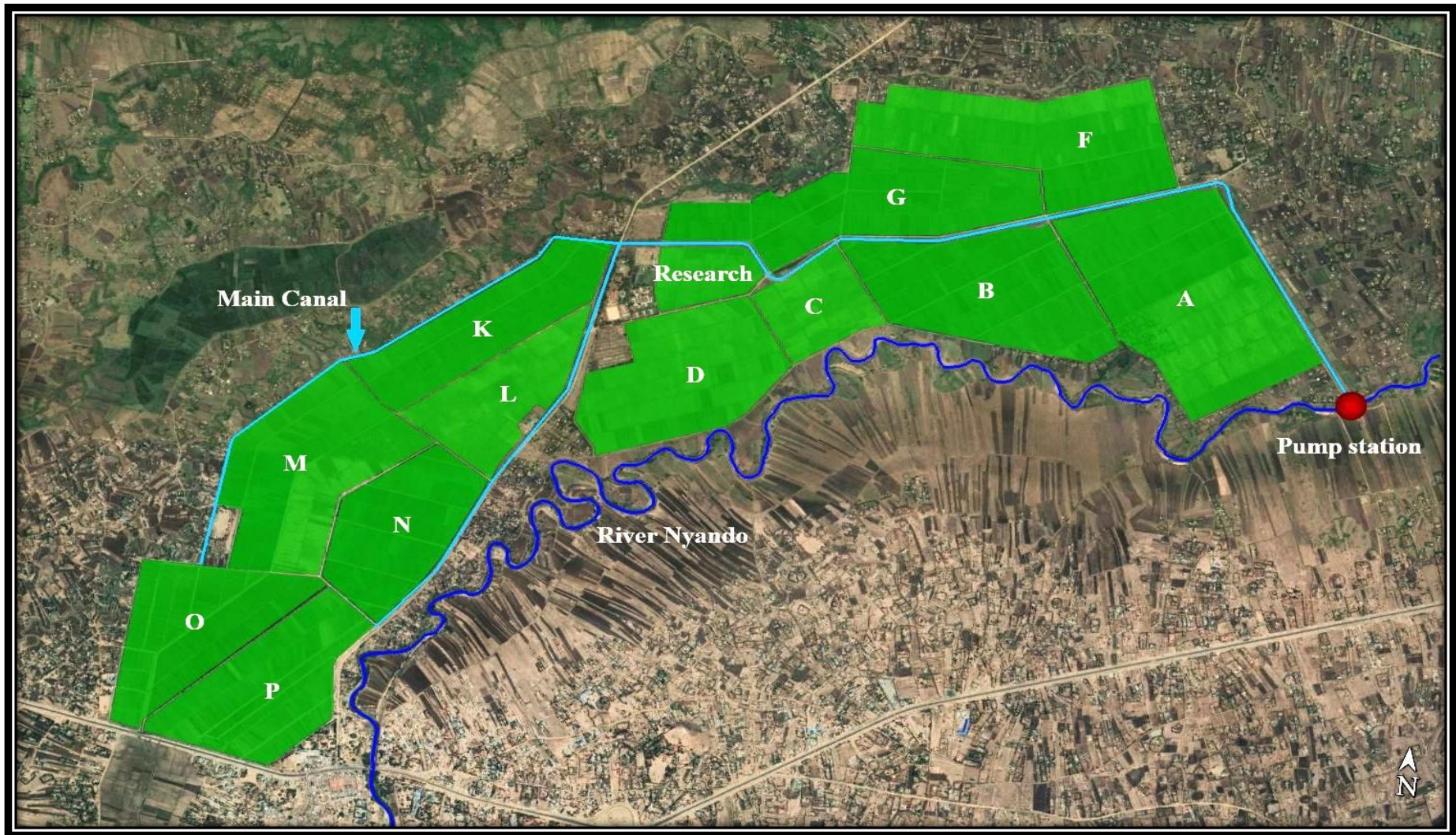


Figure 3.2 Aerial satellite imagery of Ahero Irrigation Scheme – Irrigable Blocks (Source; Google Earth, 2024)

3.2 Hydraulic Indicators

The hydraulic part of the IPTRID assessment tool has indicators that aim to assess the performance of hydraulic infrastructure, effectiveness of water resource management, and the water conveyance efficiency from the abstraction point to the final point of usage. Detailed information describing these hydraulic indicators is presented in Appendix 1, Table A1.1.

The total annual volume of irrigation water delivered (m^3) was measured at the interface between NIA and the water users in the branch canals using discharge measurement equipment, see Appendix 1, Table A1.1, indicator 1. The points along the main canal where discharge measurement was conducted can be referred to Table 3.1 and Figure 3.3. The discharge measurement equipment also helped in evaluating performance of each pump by measuring their actual discharge in the canal when each pump was operating alone. The actual discharges for Pump 1, Pump 2, and Pump 4 are presented in the Appendix 1 in Table A2.4, Table A2.2, and Table A2.8 respectively.

Table 3.1: GPS Coordinates for discharge measurement locations

	Location	Latitude (S)	Longitude (E)
1	Pump Station	-0.144213	34.972498
2	A	-0.132191	34.963703
4	B and C1	-0.135160	34.954868
5	C2	-0.140501	34.940128
6	D	-0.140519	34.940073
7	F	-0.132139	34.963663
8	G	-0.135089	34.954777
9	K, Feeder 1	-0.139290	34.930535
10	K, Feeder 2	-0.139394	34.930522
11.	L	-0.142711	34.930353
12	M	-0.147705	34.916849
13	N	-0.154155	34.925645
14	O, Feeder 1	-0.160839	34.909869
15	O, Feeder 2	-0.160934	34.909716
16	P	-0.163482	34.920149
17	R	-0.140455	34.940066

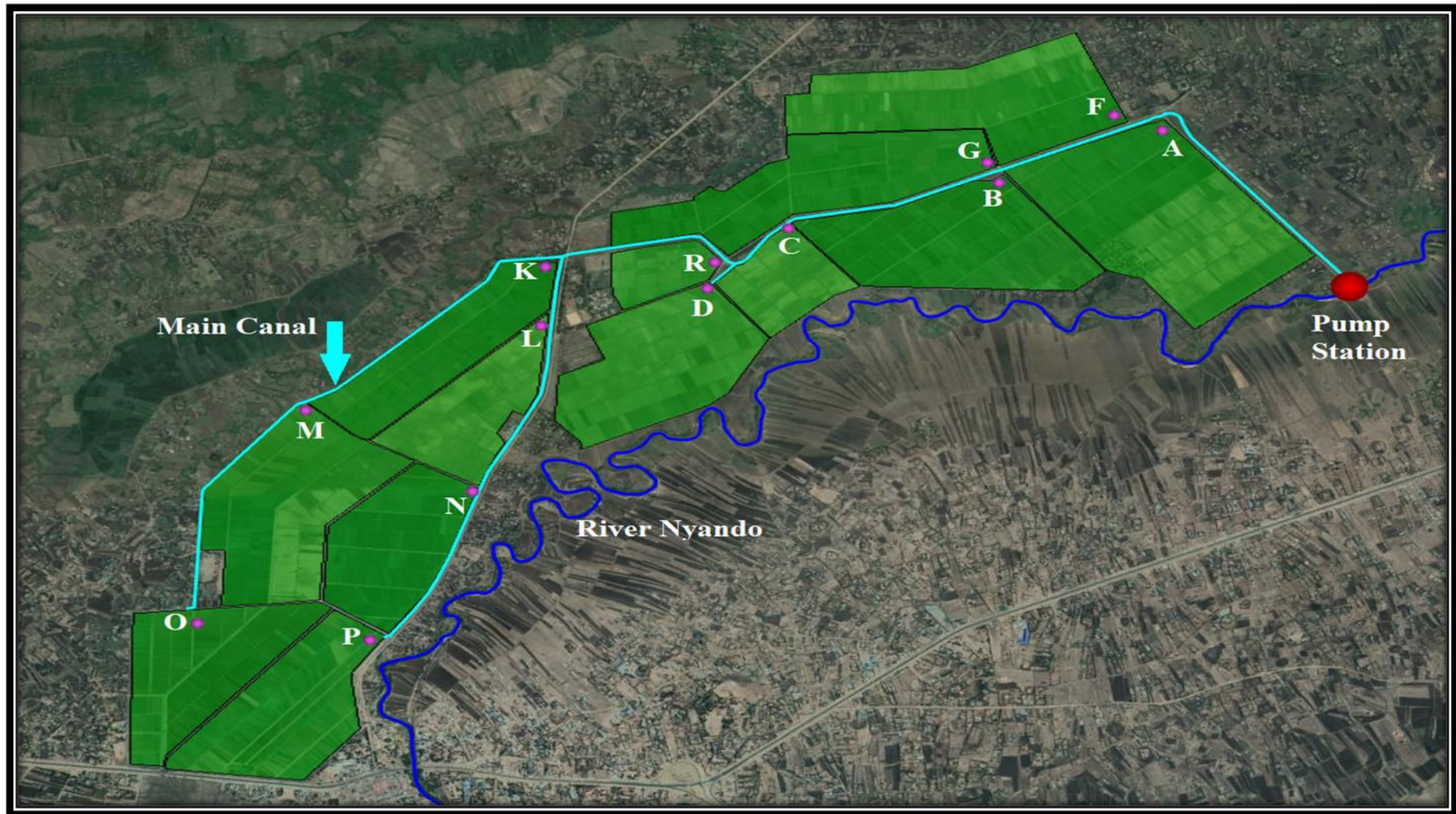


Figure 3.3: Aerial satellite imagery of Ahero Irrigation Scheme – Data collection points (Source; Google Earth, 2023)

The velocity-area method was used to calculate the discharge passing in the canal. A current meter was used to measure flow velocity. An electromagnetic current meter (KENEK model) was used in the measurements, see Figure 3.4. The staff gauges helped in measuring the depths of discharge in the canal, see Figure 3.5. The discharge in the canal was varied by partially opening the sluice gates to specific levels that influenced change of water depths. Using the electromagnetic current meter the quantity of water passing through the canal cross-section was measured at various depths as varied by the sluice gates. The raw discharge data that was collected using electromagnetic current meter was filled in a template that assisted in the computation of discharge passing through the canal cross-section at that depth. Table A2.1 to Table A2.81 in Appendix 2 are discharge measurement calculations at various gauge readings.

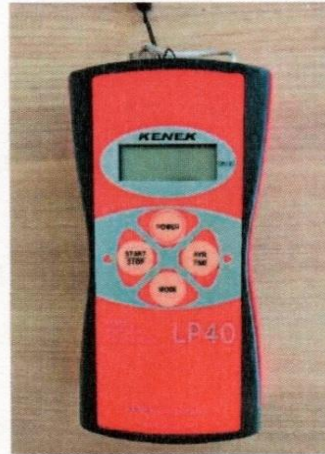
The rating curves were later developed to help quantify continuous discharge passing through the canal at various water depths. Figure A2.1 to Figure A2.16 in Appendix 2 show various rating curves that were developed for various points along the main canal where discharge measurement was carried out. Also presented beside these rating curves is raw data that was used in preparation of the rating curves, see Appendix 2 Figure A2.1 to Figure A2.16.

The daily continuous discharge delivered to water users passing through the canal's sluice gate was quantified by the help of the gauge readings drawn from the staff gauges installed permanently in the canal. This was achieved by multiplying the duration in which the sluice gates were opened and the corresponding discharge rates drawn from the rating curves at specific gauge readings. The irrigation water delivered to various blocks was added to find the cumulative amount of water delivered to farmers in the entire irrigation scheme.

Electromagnetic Current Meter



Electromagnetic Current Meter [KENEK]



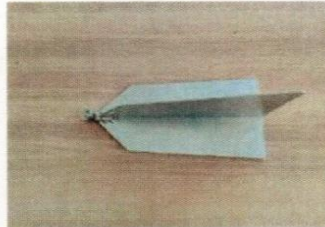
Indicator [LP40]



Detector [LPT-425]



Support Rod (Extendable 0.5m to 1.1m)



Flow Direction Vane



Extension Rod(1.0m)



Angle Adjustment Bracket

Sensor Stopper

Ferrule

Fixing Screw (Spare)

Figure 3.4: A current meter measures the velocity of discharge passing in a canal.



Figure 3.5 Staff gauge aids in measuring the depth of water in the canal

The total annual volume of irrigation water supplied (m^3) was measured at the pumping station as the amount of water diverted from River Nyando, see Appendix 1, Table A1.1, indicator 2. This amount of water was quantified by adding the amount of water pumped daily in a year. The amount of water pumped in a day was measured by finding the product of pumping hours and the pumps' operating discharge rates.

The total annual volume of water supplied (m^3) was found by summing the total annual volume of irrigation water supplied (m^3) with the total volume of effective rainfall (m^3), Appendix 1, Table A1.1, indicator 3. The depth of effective rainfall was calculated by the USDA-Soil Conservation Method in-built in CROPWAT 8 application. The volume of the total effective rainfall was calculated as a product of the depth of effective rainfall and the cropped area.

The annual irrigation water supplied per unit command area (m^3/ha) was calculated as a ratio of the total annual volume of irrigation water supplied (m^3) to the command area in hectares as illustrated in Appendix 1, Table A1.1, indicator 4. The command area was the net area of the irrigation scheme less the areas covered by the canals, roads, and villages.

The annual irrigation water supplied per unit irrigated area (m^3/ha) was calculated as a ratio of the total annual volume of irrigation water supplied (m^3) to the total annual irrigated cropped area as illustrated in Appendix 1, Table A1.1, indicator 5. The extent of land where the crop was grown during the season was the total annual irrigated cropped area.

The main system water delivery efficiency was calculated as a ratio of the total annual volume of irrigation water delivered (m^3) to the total annual volume of irrigation water supplied (m^3) as shown in Appendix 1, Table A1.1, indicator 6.

The annual relative water supplied was calculated as a ratio of the total annual volume of water supplied (m^3) to the total annual volume of crop water demand (m^3) as

illustrated in Appendix 1, Table A1.1, indicator 7. The total annual volume of crop water demand was the amount of water required to meet the evapotranspiration needs for the crops. FAO CROPWAT 8 application was used in the calculation of the amount of water lost through evapotranspiration.

The annual relative irrigation water supplied was calculated as a ratio of the total annual volume of irrigation water supplied (m^3) to the total annual volume of crop irrigation demand as shown in Appendix 1, Table A1.1, indicator 8. The total annual volume of crop irrigation demand was measured by subtracting total annual volume of effective rainfall (m^3) from the total annual volume of crop water demand (m^3).

The water delivery capacity was calculated as a ratio of the pumps' capacity to deliver water at the system head (l/s) to the peak irrigation water consumptive demand (l/s). The pumps' capacity to deliver water at the system head was calculated by summing the pumps' discharge rates (l/s) as illustrated in Appendix 1, Table A1.1, indicator 9. The peak irrigation water consumptive demand was expressed in flow rate (l/s) as the highest amount of water in a month required to meet the crop water requirements. The peak irrigation water consumptive demand (l/s) was calculated using the month with the highest crop water needs.

The hydraulic data was collected both physically in the field and by use of secondary data available from other reliable sources. Data collected physically in the field entailed; (i) discharge measurement in the earthen canals, see Figure 3.6, (ii) discharge measurement at the pumping station, see Figure 3.7, and (iii) rainfall and temperature measurement at the meteorological station, see Figure 3.8. A rain gauge was used to measure the amount of rainfall received, see Figure 3.9. A thermometer was used to measure temperature. A tape measure was used to measure distance.

The cropping calendar was a source of secondary data. The cropping calendar informed; the area of blocks irrigated, and the time of the year in which various blocks were irrigated in the irrigation scheme, see Table 3.2.



Figure 3.6: Discharge measurement in the earthen canal



Figure 3.7: Pumping station: Discharge outlets for Pump 1, Pump 2, Pump 3, and Pump 4



Figure 3.8: Weather station with a thermometer used to measure temperature



Figure 3.9: Rain gauge used to measure rainfall

Table 3.2: Cropping calendar – Acreage irrigated

Cropping Calendar													
Irrigated Blocks	Acreage	Apr 2022	May 2022	Jun 2022	Jul 2022	Aug 2022	Sep 2022	Oct 2022	Nov 2022	Dec 2022	Jan 2023	Feb 2023	Mar 2023
A	285												
B	209												
C	78												
D	183												
F	231												
G	203												
K	149												
L	122												
M	131												
N	238												
O	84												
P	245												
Commercial	25												
Totals	2183	453	738	900	1,253	1,605	1,599	1,314	1,152	930	578	131	131

The analysis of hydraulic data was done after data collection. Both quantitative and qualitative data were collected. Simple arithmetic functions were used in the computation of various indicators. Specialized software were used in the analysis of data. FAO CROPWAT 8 application was used to calculate effective rainfall and evapotranspiration. Google Earth Pro application was used in the production of aerial images of the irrigation scheme. MS Office application was used in simple arithmetic calculations and report production. A camera was used to take images of features in the field as a form of qualitative data. The summary of hydraulic data collection and analysis techniques is illustrated in Table 3.3.

Table 3.3: Hydraulic data collection techniques

Data Management Techniques - Hydraulic Performance				
Type of Data	Data Collected	Collection Techniques	Tools of Data Collection	Data Analysis and Presentation
1. Primary data Quantitative data	Discharge in canals	Direct Measurement	Current meters Staff gauge	Simple arithmetic functions Specialized software (MS Office)
	Rainfall	Direct measurement	Rain gauge	Simple arithmetic functions Specialized software (MS Office)
	Temperature	Direct measurement	Thermometer	Simple arithmetic functions Specialized software (MS Office)
	Area	Direct Measurement & Software's	Tape measure Google Earth Pro App.	Simple arithmetic functions Specialized software (MS Office) Specialized software
2. Primary data Qualitative data	Images	N/A	Camera	N/A
3. Secondary data Quantitative data	Area	Outsource from records	Cropping calendar	Simple arithmetic functions Specialized software (MS Office)

3.3 Financial Indicators

The financial part of the IPTRID assessment tool has indicators that aim to evaluate whether the scheme performs well in terms of finances. Expenses incurred, the income generated, and other resources utilized are compared. The detailed information describing these financial indicators is presented in Appendix 1, Table A1.2.

The cost recovery ratio was computed by dividing the gross revenue collected by the total cost of management, operation, and maintenance as indicated in Appendix 1, Table A1.2, indicator 10. The gross revenue collected was the amount of money collected from the payment of O&M services by water users. The total cost of management, operation, and maintenance was the expense incurred in providing irrigation and drainage services excluding capital expenditure. The components of this cost included; the bulk water cost, the staff cost, the energy cost, the maintenance cost, and the overhead cost.

The bulk water cost paid to the Water Resource Authority (WRA) was determined by multiplying the prevailing water rates charges by the amount of water diverted from River Nyando at the pumping station which is the abstraction point.

The staff cost was found by summing the wages received by personnel directly involved in offering irrigation and drainage services. This was achieved by finding the average of the maximum and minimum gross pay of employees based on their job groups according to the Salaries and Remuneration Commission (SRC) compensation rates. Their monthly average gross pay was added for the twelve months to get the annual staff cost.

The energy cost was determined by assessing the KPLC annual bill statements which informed how much money was paid as electricity bill in every month for a period of one year.

The overhead cost was calculated by adding administrative expenses, insurance, and taxes in a period of one year.

The maintenance cost was calculated by adding the amount money spent in one year paying the contractors engaged in maintenance activities of the canals such as; desilting, and reshaping.

The maintenance cost to revenue ratio was found by dividing the cost of maintenance by the collected gross revenue, see Appendix 1, Table A1.2, indicator 11. The total cost of management, operation, and maintenance per unit irrigated area (Ksh/ha) was computed as a ratio of the total cost of management, operation, and maintenance to the total irrigated area serviced by the irrigation system as indicated in Appendix 1, Table A1.2, indicator 12.

The total personnel cost per person employed on water delivery (Ksh/person) was calculated as a ratio of the total cost of personnel employed in the provision of irrigation and drainage services to the total number of personnel engaged in the provision of irrigation and drainage services as shown in Appendix 1, Table A1.2, indicator 13.

The revenue collection performance was found by dividing the total revenue collected from payment of operation and maintenance fee by water users by the total revenue anticipated to be collected from water users for provision of irrigation and drainage services as indicated in Appendix 1, Table A1.2, indicator 14.

The total irrigated area managed per person (ha/Persons) was computed as a ratio of the total actual area cropped during the year to the total number of personnel employed in the provision of irrigation and drainage services, see Appendix 1, Table A1.2, indicator 15.

The average revenue per cubic meter of irrigation water delivered (Ksh/m³) was found by dividing the gross revenue collected from water users as operation and maintenance fee by the total volume of irrigation water delivered to farmers over the period of one year as illustrated in Appendix 1, Table A1.2, indicator 16.

The total cost of management, operation, and maintenance per unit volume of water delivered (Ksh/m³) was calculated by dividing the total cost of management, operation, and maintenance of providing the irrigation and drainage service by the total volume of irrigation water delivered to the water users over a period of one year, see Appendix 1, Table A1.2, indicator 17.

The total management, operation, and maintenance cost per unit crop production (Ksh/kg) was the ratio of the total management, operation, and maintenance cost to the total annual crop production in kilograms as shown in Appendix 1, Table A1.2, indicator 18.

The total annual energy cost per unit crop production (Ksh/kg) was found by dividing the electricity cost incurred in the operation of the pumps by the total annual crop production in kilograms as illustrated in Appendix 1, Table A1.2, indicator 19.

The percentage of the total annual energy cost to the total cost of management, operation, and maintenance as a percentage was computed by dividing the energy cost incurred by the total cost of management, operation, and maintenance and multiplying the result by 100, see Appendix 1, Table A1.2, indicator 20.

The analysis of financial data was done after data collection. The data collected was in quantitative form. The raw data was outsourced from reliable financial statements. The energy cost of running the electric pumps was outsourced from KPLC bill statements. The salaries paid to persons involved in provision of irrigation and drainage services

was outsourced from the Salaries and Remuneration Commission (SRC) pay scale. The maintenance cost of desilting and reshaping of the canals paid to the external contractors was outsourced from the payment receipts. Simple arithmetic functions and specialized software such as MS Office applications was used in the analysis of various indicators. The summary of financial data collection techniques, sources of data, and methods of analysis are illustrated in Table 3.4.

Table 3.4: Financial data collection techniques

Data Management Techniques - Financial Performance				
Type of Data	Data Collected	Collection Techniques	Source of Data	Data Analysis and Presentation
1. Secondary data Quantitative data	Energy Cost (Electricity)	Outsource from records	KPLC Bill Statements	Simple arithmetic functions Specialized software (MS Office)
	Gross Revenue Collected (O&M)	Outsource from records	NIA - financial statements	Simple arithmetic functions Specialized software (MS Office)
	Bulk Water Fee	Outsource from records	NIA - financial statements	Simple arithmetic functions Specialized software (MS Office)
	Staff cost	Outsource from records	SRC Pay Scale	Simple arithmetic functions Specialized software (MS Office)
	Maintenance Cost	Outsource from records	NIA - financial statements	Simple arithmetic functions Specialized software (MS Office)
	Overhead Cost	Outsource from records	NIA - financial statements	Simple arithmetic functions Specialized software (MS Office)

3.4 Crop Productivity Indicators

The IPTRID assessment tool has crop productivity indicators that aim to assess performance of the scheme by comparing the crop yield to other units of resources applied in crop production such as; money, water, and land. Comprehensive details regarding these crop productivity indicators are outlined in Appendix 1, Table A1.3.

The total annual mass of rice crop production was calculated by summing the produce of various irrigated blocks of the scheme in a year. The amount of crop production was presented in tonnes as shown in Appendix 1, Table A1.3, indicator 21.

The total value of crop production in a year was calculated in monetary value by finding the product of the crop yield in a year and the existing market prices of the crop. The value of the crop production was presented in Kenya shillings as shown in Appendix 1, Table A1.3, indicator 22.

The output per unit command area (Ksh/ha) was calculated as a ratio of the total annual value of crop production to the command area served by irrigation infrastructure as shown in Appendix 1, Table A1.3, indicator 23. The command area is the area in the nominal design provided with irrigation infrastructure less the area covered by the canals, drains, roads and villages.

The output per unit irrigated area (Ksh/ha) was calculated by dividing the total annual value of crop production by the total area in which the rice crop was grown in a year as indicated in Appendix 1, Table A1.3, indicator 24.

The output per unit irrigation water delivered (Ksh/ m³) was computed as a ratio of the total value of crop production in a year to the total volume of irrigation water delivered to farmers in a year measured in the branch canals as described in Appendix 1, Table

A1.3, indicator 25. The branch canals were the interface between the NIA and the water users.

The output per unit irrigation water supplied (Ksh/m³) was calculated by dividing the total value of crop yield received by farmers in a year by the total volume of water diverted into the scheme through pumping at an abstraction point which is the pumping station, see Appendix 1, Table A1.3, indicator 26.

The output per unit water supplied (Ksh/m³) was found by dividing the total value of crop production in a year by the summed amount of volume of water diverted from River Nyando through pumping and the volume of effective rainfall as indicated in Appendix 1, Table A1.3, indicator 27.

The output per unit crop water demand (Ksh/m³) was computed by dividing the total value of crop yield received by farmers in a year with the total volume of water used in a year by the crop to meet the evapotranspiration needs as shown in Appendix 1, Table A1.3, indicator 28.

The total annual volume of water supplied per unit crop production (liters/kg) was computed by dividing the value of summed volume of irrigation water diverted through pumping plus the total volume of effective rainfall by the value of the total crop yield received by the farmers in a year in kilograms as described in Appendix 1, Table A1.3, indicator 29.

The analysis of crop productivity data was done after data collection. Primary, secondary, and quantitative data types were collected. Primary and quantitative data types collected included; (i) Area measurements using; Google Earth Pro specialized software, a tape measure, and a staff gauge, see Figure 3.5, (ii) Rainfall measurements

using a rain gauge, see Figure 3.9, (iii) Discharge measurement in the earthen canals using a current meter and a staff gauge, see Figure 3.6.

Secondary and quantitative data types collected included the crop production data outsourced from reliable production records and the prices of crop produce data gathered through interviews. The data analysis was done by the use of simple arithmetic functions, and specialized software such as MS Office applications. The MS Office application was used in report production. The summary of the data types, data collection techniques, data collection tools, and data analysis techniques are illustrated in Table 3.5.

Table 3.5: Crop productivity data collection techniques

Data Management Techniques – Crop Water Productivity Performance				
Type of Data	Data Collected	Collection Techniques	Tools of Data Collection	Data Analysis and Presentation
1. Primary data Quantitative data	Area	Direct Measurement	Tape measure	Simple arithmetic functions Specialized software (MS Office)
		Software's	Google Earth Pro App.	Specialized software
		Outsource from records	Cropping calendar	Simple arithmetic functions Specialized software (MS Office)
	Rainfall	Direct measurement	Rain gauge	Simple arithmetic functions Specialized software (MS Office)
	Discharge in canals	Direct Measurement	Current meters Staff gauge	Simple arithmetic functions Specialized software (MS Office)
2. Secondary data Quantitative data	Crop Production (kg)	Outsource from records	NIA – Production records	Simple arithmetic functions Specialized software (MS Office)
	Value of Crop Production (Ksh)	Interview	N/A	Simple arithmetic functions Specialized software (MS Office)
	Rice crop water productivity	Direct Measurement Outsource from records	CropWat.8 Application NIA – Production records	Simple arithmetic functions Specialized software (MS Office)

3.5 Research Methods for Comparative Reference Study

Section 3.5 presents data collection techniques and analysis methods of the research study that used BPCA evaluation technique to assess performance of Ahero Irrigation Scheme.

3.5.1 Data Collection

Secondary data was collected for five years starting from the year 2012 to the year 2016 and the average was found to represent annual values. The data was collected from reliable records kept by the management. Rice was the only crop that was considered during the evaluation. The following data were outsourced from records kept by the management; cropped area, command area, paddy rice prices at various periods, revenue collected, invoiced revenue, cost of management, pumping discharge rates, and pumping hours. The meteorological data was outsourced from the weather station in the scheme. Data collection techniques of observation and interviews were employed to collect data on cropping patterns, farming practices, maintenance of the system, and the status of the irrigation system.

3.5.2 Data Analysis

The raw data collected was first processed into useful form that can be used in calculating performance indicators. The following indicators were calculated; total annual volume of irrigation water supplied, annual relative water supply, annual relative irrigation water supply, annual irrigation water supplied per unit irrigated area (m^3/ha), annual irrigation water supplied per unit command area (m^3/ha), gross annual agricultural production (tones), total annual value of agricultural production (US\$), output per unit irrigated area (US\$/ha), output per unit command area (US\$/ha), output per unit water supplied (US\$/ m^3), output per unit irrigation water supplied (US\$/ m^3),

output per unit crop water demand (US\$/m³), water collection fee performance (%), and average revenue per unit irrigation water supplied (US\$/m³).

Using the results of the indicators calculated, the overall performance of the scheme was summarized into a single score as a percentage. The following indicators were omitted while calculating the overall performance score; total agricultural production, total volume of irrigation water supplied, and the annual value of agricultural production. These indicators were omitted because their inclusion in the calculation of the overall score could distort the results. Pearson correlation method was first used to test the indicators for correlation. Only ten indicators with low correlation were used in the calculations. The principal component analysis was used to weight the indicators. The reference to target method was used to normalize the indicators. The linear regression method was finally used to aggregate the results into a single performance score.

Chapter 4: Results and Discussion

4.1 Hydraulic Indicators

4.1.1 Results for hydraulic indicators

The description and results for the 9 hydraulics indicators for assessing hydraulic performance of the irrigation scheme is presented in Appendix 1, Table A1.1.

The total volume of irrigation water delivered to the fields for irrigation through the canal conveyance system of the scheme for a period of one year was measured as 11,572,188.36 m³ as shown in Table 4.1 and Table A1.1, indicator 1 in the Appendix 1.

The total amount of water that was diverted from River Nyando into the scheme for irrigation at the pumping station for a period of one year was measured as 13,908,173.84 m³, see Table 4.2 and Table A1.1, indicator 2 in the Appendix 1. The monthly amount of water diverted from the river was quantified by multiplying the discharge rates of the pumps that were operating with the duration in which the pumps were in operation. The annual amount of irrigation water supplied was found by summing the amount of water supplied in each month as shown in Table 4.2.

The total annual volume of water supplied was calculated as 16,902,351.94 m³ which is a summation of amount of water diverted into the scheme for irrigation at the pumping station and the volume of effective rainfall received, see Table 4.3 and Table A1.1, indicator 3 in the Appendix 1. The monthly volume of effective rainfall was found as a product of the cropped area and the depth of effective rainfall received in a month as calculated by FAO CROPWAT 8 application. The amount of water supplied in the

12 months through pumping and effective rainfall was summed to get the total volume of water supplied in a year as seen in Table 4.3.

The annual irrigation water supplied per unit command area was calculated and found as 15,731.18 m³/ha as indicated in Appendix 1, Table A1.1, indicator 4. The result was computed by dividing the volume of irrigation water supplied through pumping in a year with the command area of the irrigation scheme. The volume of irrigation water supplied used in the calculation was found from Table 4.2. The command area serviced by the irrigation scheme was found from the cropping calendar in Table 3.2 as 2,183 acres an equivalent of 884.115 hectares. The command area was the area in the nominal design served by the irrigation infrastructure less the area covered canals, roads, and villages.

The annual irrigation water supplied per unit irrigated cropped area was calculated and found as 15,731.18 m³/ha as indicated in Appendix 1, Table A1.1, indicator 5. The outcome was calculated by dividing the volume of irrigation water supplied through pumping in a year with the cropped area which was irrigated. The volume of irrigation water supplied used in the computation was found from Table 4.2. The cropped area that received irrigation water was found from the cropping calendar in Table 3.2 as 2183 acres an equivalent of 884.115 hectares. The cropped area was the extent of land on which irrigated crops were grown.

The earthen canal conveyance system efficiency was calculated as 83.2% as shown in Appendix 1, Table A1.1, indicator 6. The result was computed by dividing the volume of irrigation water delivered to water users in a year in the branch canals with the

volume of irrigation water supplied to the scheme in a year diverted at the pump station from River Nyando. The volume of irrigation water delivered to water users in a year in the branch canals was found from Table 4.1. The volume of irrigation water supplied to the scheme in a year diverted from the pump station was found from Table 4.2.

Table 4.1: Total annual volume of irrigation water delivered (m³)

No.	Irrigated Blocks	Duration of opened gates in a season (Hrs)	Gauge Readings ($\times 10^{-1}$ m)	Discharge rate from rating curves (m ³ /s)	Volume of water delivered per irrigated block (m ³)
1	Block A	3240	7	0.19	2,216,160.00
2	Block F	3240	4	0.16	1,866,240.00
3	Block B and C1	3240	6	0.14	1,632,960.00
4	Block G	3240	1.75	0.12	1,399,680.00
5	Block P	3240	2.5	0.09	1,049,760.00
6	Block N	3240	3	0.06	699,840.00
7	Block D	3240	5	0.06	699,840.00
8	Block K, Feeder 1	3240	2	0.024	279,936.00
9	Block K, Feeder 2	3240	4	0.023129	269,772.36
10	Block L	3240	3	0.05	583,200.00
11	Block M	3240	4	0.015	174,960.00
12	Block C2	3240	3	0.01	116,640.00
13	Block O, Feeder 1	3240	3	0.01	116,640.00
14	Block O, Feeder 2	3240	2.5	0.01	116,640.00
15	Research	3240	4	0.03	349,920.00
Total					11,572,188.36

Note: The discharge rates for each irrigable block can be referenced from Appendix 2 starting from Figure A2.1 to Figure A2.16

Table 4.2: Total annual volume of irrigation water supplied (m³)

Period	Pump Name	Discharge Rate (l/s)	Duration (Hrs)	Volume of Pumped Water (m ³)
Apr-22	Pump 1	349.20	222.00	279,080.64
	Pump 2	528.70	232.00	441,570.24
	Pump 4	291.00	215.00	225,234.00
	Total		669.00	945,884.88
May-22	Pump 1	349.20	240.00	301,708.80
	Pump 2	528.70	235.00	447,280.20
	Pump 4	291.00	222.00	232,567.20
	Total		697.00	981,556.20
Jun-22	Pump 1	349.20	252.00	316,794.24
	Pump 2	528.70	226.00	430,150.32
	Pump 4	291.00	189.00	197,996.40
	Total		667.00	944,940.96
Jul-22	Pump 1	349.20	354.00	445,020.48
	Pump 2	528.70	350.00	666,162.00
	Pump 4	291.00	320.00	335,232.00
	Total		1,024.00	1,446,414.48
Aug-22	Pump 1	349.20	337.00	423,649.44
	Pump 2	528.70	329.00	626,192.28
	Pump 4	291.00	188.00	196,948.80
	Total		854.00	1,246,790.52
Sep-22	Pump 1	349.20	328.00	412,335.36
	Pump 2	528.70	311.00	591,932.52
	Total		639.00	1,004,267.88
Oct-22	Pump 1	349.20	381.00	478,962.72
	Pump 2	528.70	394.00	749,908.08
	Pump 4	291.00	101.00	105,807.60
	Total		876.00	1,334,678.40
Nov-22	Pump 1	349.20	337.00	423,649.44
	Pump 2	528.70	341.00	649,032.12
	Pump 4	291.00	310.00	324,756.00
	Total		988.00	1,397,437.56
Dec-22	Pump 1	349.20	314.00	394,735.68
	Pump 2	528.70	311.00	591,932.52
	Pump 4	291.00	215.00	225,234.00
	Total		840.00	1,211,902.20
Jan-23	Pump 1	349.20	395.00	496,562.40
	Pump 2	528.70	400.00	761,328.00
	Pump 4	291.00	136.00	142,473.60
	Total		931.00	1,400,364.00
Feb-23	Pump 1	349.20	374.00	470,162.88
	Pump 2	528.70	378.00	719,454.96
	Pump 4	291.00	57.00	59,713.20
	Total		809.00	1,249,331.04
Mar-23	Pump 1	349.20	235.00	295,423.20
	Pump 2	528.70	236.00	449,183.52
	Total		471.00	744,606.72
Grand Total			9,465.00	13,908,173.84

Note: The actual discharges for Pump 1, Pump 2, and Pump 4 are presented in the Appendix 1 in Table A2.4, Table A2.2, and Table A2.8 respectively. Pump 3 was not operational.

Table 4.3: Total annual volume of water supplied in m³

No.	Months	Volume of water pumped (m ³)	Monthly rainfall (mm)	Effective rainfall (mm)	Cropped Area in (Acres)	Cropped Area in (m ²)	Volume effective rainfall (m ³)	Total monthly volume of water supplied (m ³)
1.	Apr 2022	945,884.88	182.6	129.3	453	1,833,225.77	237,036.09	1,182,920.97
2.	May 2022	981,556.20	119.4	96.6	738	2,986,579.73	288,503.60	1,270,059.80
3.	Jun 2022	944,940.96	105	87.4	900	3,642,170.40	318,325.69	1,263,266.65
4.	Jul 2022	1,446,414.48	29.5	28.1	1253	5,070,710.57	142,486.97	1,588,901.45
5.	Aug 2022	1,246,790.52	69.1	61.5	1605	6,495,203.88	399,455.04	1,646,245.56
6.	Sept 2022	1,004,267.88	97.9	82.6	1599	6,470,922.74	534,498.22	1,538,766.10
7.	Oct 2022	1,334,678.40	28.9	27.6	1314	5,317,568.78	146,764.90	1,481,443.30
8.	Nov 2022	1,397,437.56	121.7	98	1152	4,661,978.11	456,873.85	1,854,311.41
9.	Dec 2022	1,211,901.20	115.5	94.2	930	3,763,576.08	354,528.87	1,566,430.07
10.	Jan 2023	1,400,364.00	16.3	15.9	578	2,339,082.77	37,191.42	1,437,555.42
11.	Feb 2023	1,249,331.04	6.1	6	131	530,138.14	3,180.83	1,252,511.87
Total								16,902,351.94

Note: Volume of water pumped to be referenced from Table 4.2, effective rainfall was calculated with using USDA Soil Conservation Method in CROPWAT 8 application, cropped area to be referenced from Table 3.2.

The annual relative water supply was calculated and found to be 0.734 as shown in Appendix 1, Table A1.1, indicator 7. The outcome was calculated by dividing the volume of water supplied in a year by the volume of crop water demand in a year. The volume of water supplied was found as a sum of volume of water supplied through pumping and the volume of water received as effective rainfall. The volume of water supplied in a year used in the computation was drawn from Table 4.3. The value of volume of crop water demand in a year calculated using FAO CROPWAT 8 application used in the computation was drawn from Table 4.4. The crop water demand was the amount of water required to meet evapotranspiration requirements for the crops. The volume of crop water demand was found as a product of crop evapotranspiration and the cropped area.

The annual relative irrigation water supply was calculated and found to be 0.813 as shown in Appendix 1, Table A1.1, indicator 8. This result was found by dividing the volume of irrigation water supplied in a year by the volume of crop irrigation demand. The volume of irrigation water supplied in a year used in the computation was found from Table 4.2 as amount of water diverted into the irrigation scheme from River Nyando through pumping. The value of volume of crop irrigation demand in a year calculated using FAO CROPWAT 8 application was drawn from Table 4.5. The crop irrigation demand was the volume of crop water demand less the volume of effective rainfall.

The water delivery capacity of the pumps to meet the peak irrigation water demands for the scheme was calculated as 0.8673 as indicated in Appendix 1, Table A1.1, indicator 9. The result was computed by dividing pumps' capacity to deliver water at system head with the peak irrigation water consumptive demand. The pumps' capacity to deliver

water at the system head was calculated by summing pumps' discharge rates. Pump 3 was grounded during the research period. The capacity to supply water at the system head was calculated by adding discharge rates for Pump 1, Pump 2, and Pump 4. The peak irrigation water consumptive demand was expressed as a flow rate of the highest amount of water required in a month to meet the crop water needs. The month of September 2022 had the highest water consumptive demand, see Table 4.4.

Table 4.4: Total annual crop water demand in m³

Name	Acreage	Apr 2022	May 2022	Jun 2022	Jul 2022	Aug 2022	Sep 2022	Oct 2022	Nov 2022	Dec 2022	Jan 2023	Feb 2023	Mar 2023
A	285		543,360	741,234	523,527	567,743	559,661						
B	209						401,280	582,023	436,292	466,588	418,334		
C	78			149,760	198,682	152,119	168,967	154,814					
D	183	351,360	472,286	353,029	347,934	336,427							
F	231				443,520	609,470	485,876	502,314	453,499				
G	203					389,760	563,853	428,590	436,385	413,146			
K	149					288,960	418,029	317,748	313,090	314,038			
L	122				234,240	321,885	256,610	265,291	239,510				
M	131									251,520	367,010	295,253	272,057
N	238						456,960	645,075	468,642	536,908	441,562		
O	84			161,280	213,965	163,820	181,964	166,723					
P	245	470,400	632,296	472,634	465,814	450,408							
R	25	57,000	77,424	57,874	57,038	55,152							
Total		879,360	1,725,366	1,935,811	2,484,720	3,335,745	3,493,199	3,062,579	2,347,419	1,982,199	1,226,996	295,253	272,057

Grand total = 23,040,704**Note:** FAO CROPWAT 8 application was used to calculate the crop water demand for each block in each month

Table 4.5: Total annual crop irrigation demand in m³

Name	Acreage	Apr 2022	May 2022	Jun 2022	Jul 2022	Aug 2022	Sep 2022	Oct 2022	Nov 2022	Dec 2022	Jan 2023	Feb 2023	Mar 2023
A	285		324,658	543,360	459,909	428,507	372,654						
B	209						263,173	535,876	272,436	309,086	391,750		
C	78			95,222	181,147	113,743	117,424	137,592					
D	183	162,065	330,864	225,075	306,796	246,391							
F	231				391,591	495,818	333,231	451,309	272,395				
G	203					289,884	429,710	383,767	277,233	260,165			
K	149					214,914	318,578	284,517	198,905	192,520			
L	122				206,814	261,861	175,992	238,354	143,862				
M	131									152,798	350,346	288,965	127,941
N	238						299,690	592,525	288,069	344,740	411,378		
O	84			102,547	195,082	122,492	126,457	148,176					
P	245	216,972	442,960	301,330	410,738	329,868							
R	25	52,568	54,240	36,898	50,294	40,392							
Total		405,605	1,152,722	1,304,433	2,202,371	2,543,871	2,436,911	2,772,117	1,452,900	1,259,308	1,153,474	288,965	127,941

Grand total = 17,100,616**Note:** FAO CROPWAT 8 application was used to calculate the crop water demand for each block in each month

4.1.2 Discussion of results for hydraulic indicators

There was a significant reduction of amount of water delivered to the fields for irrigation measured at the interface between the NIA and the irrigation water users in the branch canals quantified as 11,572,188.36 m³ compared to the amount of water diverted into the irrigation scheme from River Nyando an estimation of 13,908,173.84 m³ at the pumping station, see Table 4.1 and Table 4.2. This was an indication that the earthen main canal was associated with high conveyance losses. The earthen main canal conveyance system efficiency was calculated as 83.2% as shown in Appendix 1, Table A1.1, indicator 6. The measured length of the earthen main canal was found to be 14.3 km. The canal length was long because the area to be irrigated was fairly large, 2183 acres. This level of conveyance efficiency was found to be low compared to the indicative conveyance efficiency of 95% for the canals lined with concrete (Tamirayehu & Amare, 2021).

The lined canals have a reputation of high conveyance efficiency because irrigation water cannot be lost through infiltration through their impermeable lining. The trapezoidal cross-section is the best geometric design for efficient water conveyance (El-Hazek, 2019). The earthen canals should be properly be maintained to improve conveyance efficiency as a cheaper alternative compared to lining the canals. The following typical maintenance activities are undertaken to improve the irrigation water conveyance efficiency in the earthen canals; i) de-silting of the canal beds, ii) reshaping of the canal's cross-section, and iii) reconstruction of the failing canal's embankments (Gidey & Siri, 2021).

During the research period it was observed that the earthen main canal was invaded by aquatic weeds, see Figure 4.1. The aquatic weeds hinder conveyance of water in the

canal by reducing the flow velocity which increases the retention time of water in the canal promoting more water to be lost through infiltration through the canal's bed. The reduced flow velocities caused by aquatic weeds also promoted sediments deposition onto the canal's bed due to the increased retention time of the canal water (Agunwamba, *et al.*, 2013). The submerged and floating aquatic weeds in the canals were opportunistic in nature because they used the water intended to irrigate the rice crop for their own transpiration. The aquatic weeds also caused blockages in the canals (Sytsma & Parker, 1999). The invasion of aquatic weeds in the canal was attributed to poor maintenance or lack of it (Agunwamba, *et al.*, 2013). The scheme will benefit if the earthen main canal is maintained regularly or lined with impermeable lining that will limit losses from the canal's bed and growth of aquatic weeds. Figure 4.2 is a picture of a well-maintained irrigation canal without aquatic weeds that has high convenience efficiency. Well maintained canals have; limited aquatic weeds, adequate flow velocities, little sedimentation, and little blockages.



Figure 4.1: Poorly maintained irrigation canal with aquatic weeds.



Figure 4.2: Well-maintained irrigation canal without aquatic weeds.

During the research period it was observed that some of the water control structures along the earthen main canal were not functioning properly. Figure 4.3 is a picture of a failing division box that has its wing wall leaning and collapsing towards the earthen main canal hindering the operation of the sluice gate. Figure 4.4 is a picture of a faulty sluice gate. The sluice gate is fully closed but still water passes downstream of the gate. The water control structures were failing because they were aged for the case of the division boxes. The water control structures were vandalized by water users in attempts to abstract more water than what was allocated from the main canal for the case of the sluice gates. The failing water control structures affected the ability to manage the canal water effectively. Inadequate provision of maintenance and over abstraction of water by users promoted deterioration of hydraulic structures along the main canal (Tamirayehu & Amare, 2021).



Figure 4.3: Failing water control structure – Division box

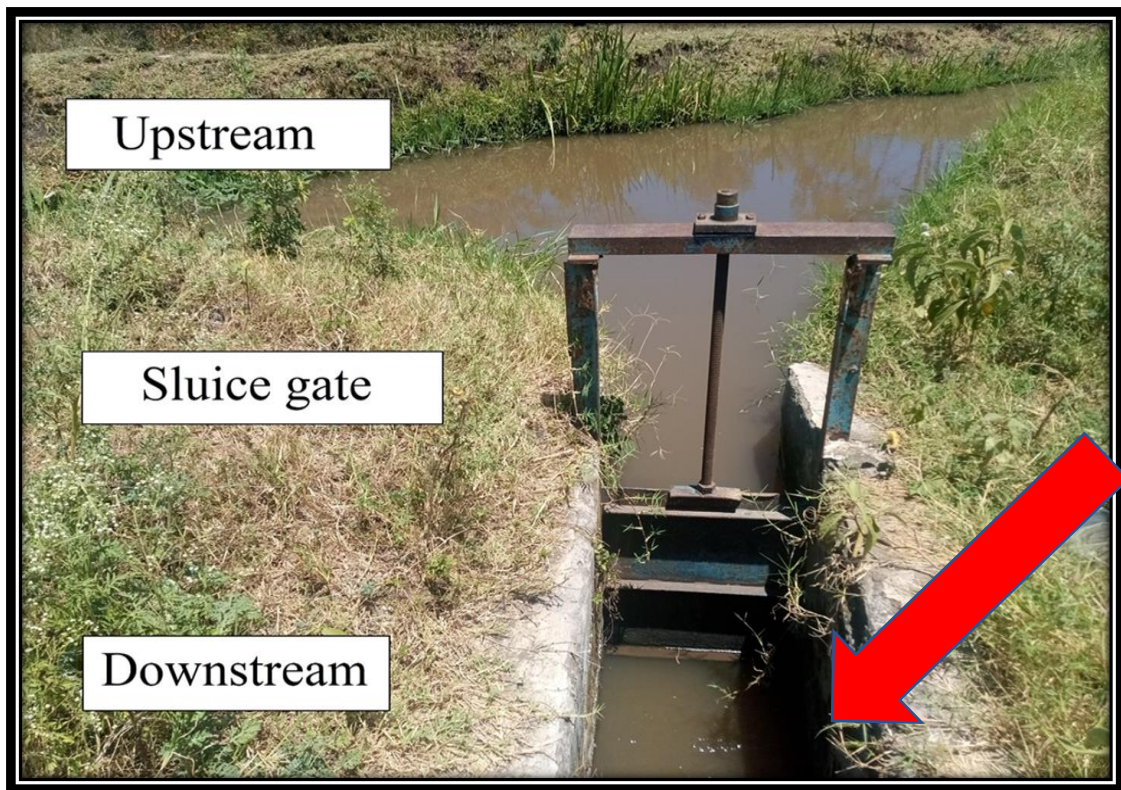


Figure 4.4: Failing water control structure – Sluice gate

There is a significant difference between the total annual volume of water supplied quantified as 16,902,351.94 m³ compared to the total annual volume of irrigation water delivered quantified as 11,572,188.36 m³, see Table 4.1 and Table 4.3. This illustrates that rainfall contributed a significant amount of water to grow the rice crop as effective rainfall an approximation of 31.5%. Rainfall was essential in crop production because rainfall supplemented irrigation water and reduced the irrigation costs (Inocencio, et al., 2007).

Comparing the value of the annual relative water supply quantified as 0.734 to the annual relative irrigation water supply quantified as 0.813 depicts the contribution of effective rainfall towards meeting the crop's evapotranspiration needs, see Appendix 1, Table A1.1, indicator 7 and indicator 8. Water from rainfall was critical to the crop

especially on the growth stage when the crop's water requirement was high (Wang *et al.*, 2009).

During the research period Ahero Irrigation Scheme received significant amount of water from rainfall to supplement irrigation water supplied through pumping diverted from River Nyando at the pumping station. The rainfall reduced irrigation costs of the scheme by supplying water that could otherwise be charged if the water was abstracted from River Nyando. Water Resource Authority (WRA) charges the scheme proportionately to the amount of water diverted into the scheme from River Nyando.

It is prudent to structure the cropping calendar such that the growth stage of the crop with the highest crop water requirements coincide with the period of highest rainfall events according to the rainfall pattern of a region (Wang *et al.*, 2009). From this arrangement, water from rainfall will be adequately utilised. The cropping calendar should also be structured such that the harvesting period of the crop coincide with the dry periods when little moisture is available.

The calculated values of the annual irrigation water supplied per unit command area computed as 15,731.18 m³/ha and the annual irrigation water supplied per unit irrigated area computed as 15,731.18 m³/ha are equal, see Appendix 1, Table A1.1, indicator 4 and indicator 5. This demonstrates that the area in the nominal design provided with irrigation infrastructure intended to grow the rice crop in the scheme was fully utilised (100%) during the research period. Full utilisation of available land resource implies that the scheme employed best land management practices to ensure maximum yields from the fields (Darge, et al., 2018; Tersteeg, 1993). Full utilisation of available land resource also indicates that the irrigation and drainage infrastructure (canals and water

controls structures) were well developed to serve the whole scheme without deficiencies of irrigable lands remaining unserved with irrigation water.

The value of water delivery capacity of 0.8673 indicates that the pumps serving the scheme could not meet the scheme's peak water consumptive demand, see Appendix 1, Table A1.1, indicator 9. The month of September 2022 had the highest water demand and the pumps only supplied 86.73% of the water requirement. The pumps could not supply enough water to meet the demand because they had low performance efficiencies as illustrated in Table 4.6. Additionally, the water level in River Nyando fluctuated in accordance with the rainfall pattern in the catchment. Little water was abstracted during dry spells to meet the high demand of water required by the rice crop – water scarcity.

Table 4.6 Performance efficiencies of the pumps

	Capacity	Measured	Efficiency
Pump 1	1100 l/s	349 l/s	31.7%
Pump 2	1100 l/s	528 l/s	48.0%
Pump 3	660 l/s	425 l/s	64.4%
Pump 4	660 l/s	291 l/s	44.1%
Average			47.05%

The pump's performance efficiency is a ratio that relates the actual volume of a pump discharges to their manufactured discharge capacity. The scheme had four electric pumps with low performance efficiencies because they were at the end of their utility life and were due for replacement. The average performance efficiency of the four pumps serving the scheme was calculated and found to be 47.05% as shown in Table 4.6.

The irrigation scheme had centrifugal pumps installed at the pumping station. The centrifugal pumps are known to be affected with cavitation that causes wear and tear of parts of a pump such as the impeller (Glovatski *et al.*, 2021; Reinemann *et al.*, 2015). The pumped irrigation water with sediment load had abrasive effects on parts of the pumps such as the impellers. The sediments eroded their surfaces (Serrano, *et al.*, 2018; Bandi, *et al.*, 2023). Regular maintenance should be done to improve the performance of the pumps. The worn-out parts should be replaced with new ones. The extent of effects of cavitation on the parts of the centrifugal pumps was not investigated in my research study. The scope of my research study did not investigate the amount of sediments load carried in the irrigation water diverted from River Nyando through pumping and the extent of abrasion the sediments had on parts of the pumps.

Pump 3 was grounded during the research period of one year due to mechanical failure. The pump was not repaired on time because; (i) the pump required replacement of parts that were to be imported from the manufacturer based in South Africa, and (ii) the repair works to be done on the pump were costly. Pump 3 was the newest of the four pumps. The pump had the highest performance efficiency but had broken down sooner than the rest of the pumps. Even though Pump 3 was grounded, the pump was allowed to operate for 1 hour during the research period to measure its actual discharge in the canal for the purpose of collecting data for this research study.

The pumps could not meet the scheme's peak water consumptive demand because the region experienced occasional power outages. The pump serving the scheme used electric energy to run. The pumps were not operational during period of power outages.

The crops did not receive irrigation water during periods of power outages because the pumps were not operational. The scheme should invest in developing alternative sources of energy to run the pumps during power outages. Solar energy is preferred. Solar energy can be transformed and stored in batteries to be used in future in case of power outages. Solar energy is clean and cheaper (Maka & Alabid, 2022).

4.2 Financial Indicators

4.2.1 Results for financial indicators

The description and results for the 11 indicators for evaluating financial performance of the irrigation scheme is presented in Appendix 1, Table A1.2.

The ratio of cost recovery was calculated and found to be 0.22 as shown in Appendix 1, Table A1.2, indicator 10. The result was computed by dividing the gross revenue collected from farmers by the total cost of management, operation, and maintenance. The value of gross revenue collected used in the calculation can be found from Table 4.7. The value of the total management, operation, and maintenance costs used in the computation was calculated by adding; the bulk water costs, staff costs, energy costs, maintenance costs, and overhead costs as shown in Table 4.7.

The maintenance cost to revenue ratio was calculated as 0.071 as shown in Appendix 1, Table A1.2, indicator 11. The value of 0.071 was found by dividing the maintenance cost by the revenue collected. The maintenance cost of desilting and reshaping of the canals was calculated as 600,000 Kenyan shillings as amount of money paid to external contractors to do the work, see Table 4.7. The value of the total cost of management, operation, and maintenance used in the computation was calculated as shown in Table 4.7.

The result of the total cost of management, operation, and maintenance per unit irrigated area was calculated and found to be 28,363.52 Ksh/ha, see Appendix 1, Table A1.2, indicator 12. The outcome was found by dividing the total cost of management, operation, and maintenance by the cropped irrigated area. The value of the total cost of management, operation, and maintenance used in the calculation was drawn from Table 4.7. The rice cropped area that received irrigation water was found from the cropping calendar in Table 3.2 as 2183 acres an equivalent of 884.115 hectares.

The result of the total personnel cost per person employed on water delivery was computed and found to be 321,133.33 Ksh/person as illustrated in Appendix 1, Table A1.2, indicator 13. The result was calculated by dividing the cost of salary paid to the personnel engaged directly in offering irrigation and drainage services by the number of the personnel employed in offering in irrigation and drainage services. The monthly personnel cost was calculated by finding the sum of average of the maximum and minimum gross salaries of employees based on their job groups according to the Salaries and Remuneration Commission (SRC) compensation rates. The monthly personnel cost was added to find the annual cost as shown in Table 4.7. The total number of personnel engaged in offering irrigation and drainage services were counted and found to be 9.

Table 4.7: Revenue generated vs cost of management, operation, and maintenance in Ksh.

No.	Month	Gross Revenue Collected (O&M)	Total Management, Operation, and Maintenance Cost				
			Bulk water fee	Staff cost	Energy cost (Electricity)	Maintenance cost	Overhead cost
1.	April 2022	215,320		240,850	1,733,069		121,960
2.	May 2022	763,300		240,850	1,113,325		414,893
3.	Jun 2022	1,390,460		240,850	1,267,265		264,854
4.	Jul 2022	1,171,800		240,850	1,216,424		161,659
5.	Aug 2022	1,450,150		240,850	1,676,316		204,198
6.	Sep 2022	260,400		240,850	1,499,889		183,088
7.	Oct 2022	1,292,700		240,850	1,189,841		147,234
8.	Nov 2022	1,271,425	10,854,154	240,850	1,783,796	600,000	493,098
9.	Dec 2022	85,000		240,850	2,588,382		134,623
10.	Jan 2023	272,110		240,850	2,557,879		205,021
11.	Feb 2023	211,100		240,850	2,461,463		115,578
12.	Mar 2023	27,900		240,850	1,659,426		288,400
Total		8,411,665	10,954,517	2,890,200	20,747,075	600,000	2,734,606
					37,926,398		

The result of the operation and maintenance revenue collection performance from IWUA members was found as 1.257 as illustrated in Appendix 1, Table A1.2, indicator 14. The outcome was computed by dividing the gross revenue collected by the gross revenue invoiced. The monthly collected operation and maintenance revenue was added together to find the amount collected in a year as shown in Table 4.7. The gross revenue invoiced was the amount of money anticipated to be collected from water users for using irrigation and drainage services. The gross revenue ought to be collected from farmers in a year was calculated by multiplying the cropped area by 3,100 Kenyan shillings. The cropped area was 2,183 acres, see Table 3.2. The farmers were charged 3,100 Kenyan shillings as maintenance costs for every acre of land they used to grow rice.

The value of total irrigated area managed per person was calculated and found to be 98.235 ha/person, see Appendix 1, Table A1.2, indicator 15. The result was found by dividing the total annual irrigated area by the number of persons employed in offering irrigation and drainage services. The irrigated area was found from the cropping calendar in Table 3.2 as 2183 acres an equivalent of 884.115 hectares. The total number of employees engaged in offering irrigation and drainage services were counted as 9.

The result for the average revenue per cubic meter of irrigation water delivered was calculated and found to be 0.727 Ksh/m³ as shown in Appendix 1, Table A1.2, indicator 16. The value was calculated by dividing the revenue collected from water users as operation and maintenance fee by the volume of irrigation water delivered to farmers

measured in the branch canals. The amount of gross revenue collected was calculated as shown in Table 4.7. The irrigation water delivered to farmers was computed as indicated in Table 4.1.

The result for the total cost of management, operation, and maintenance per unit irrigation water delivered was computed and found to be 3.277 Ksh/m³ as illustrated in Appendix 1, Table A1.2, indicator 17. The outcome was realized by dividing the total cost of management, operation, and maintenance by the volume of the irrigation water delivered to farmers measured at various branch canals. The total cost of management, operation, and maintenance in a year was computed as shown in Table 4.7. The volume of irrigation water delivered to water users over the season of one year was calculated as shown in Table 4.1.

The outcome of the total cost of management, operation, and maintenance per unit crop production was calculated as 6.588 Ksh/kg as shown in Appendix 1, Table A1.2, indicator 18. The result was found by dividing the total cost of management, operation, and maintenance by the mass of crop production harvested in a year in kilograms. The value of the total cost of management, operation, and maintenance used in the calculation was drawn from Table 4.7. The total annual crop production harvested in a year was drawn from Table 4.8.

The outcome of the energy costs per unit crop production was calculated as 3.604 Ksh/kg as illustrated in Appendix 1, Table A1.2, indicator 19. The result was realized by dividing the energy costs by the mass of crop produced in a year in kilograms. The

energy cost in form of electricity bill used in the calculation was found by summing the monthly electricity costs to get the annual expense as shown in Table 4.7. The total mass of crop production produced in a year in kilograms was drawn from Table 4.8.

The proportion of the total annual energy cost to the total cost of management, operation, and maintenance was calculated as 54.7% as indicated in Appendix 1, Table A1.2, indicator 20. The result was computed by dividing the energy cost by the total management, operation, and maintenance cost. The energy cost used in the calculation was drawn from Table 4.7. The total cost of management, operation, and maintenance used in the computation was drawn from Table 4.7.

4.2.2 Discussion of results for financial indicators

The cost recovery ratio of 0.222 indicates that the gross revenue collected from farmers was way too low compared to the total management, operation, and maintenance expenses incurred in offering irrigation and drainage services, see Table 4.7. The gross revenue collected only covered 22.2% of the total cost of management, operation, and maintenance incurred, see Figure 4.5 and Appendix 1, Table A1.2, indicator 10. The maintenance cost to revenue ratio of 0.071 indicates that during the research period the maintenance cost incurred was 7.1% of the total revenue collected, see Appendix 1, Table A1.2, indicator 11.

From these statistics (indicator 10 and indicator 11), employing the use of economic analysis diagnostic tool which evaluates the benefits and costs clearly shows that the scheme is not financially sufficient because the revenue collected could not adequately

meet the expenses incurred (Edomah, 2018). The operation and maintenance revenue was little because the revenue was last reviewed in the year 2008.

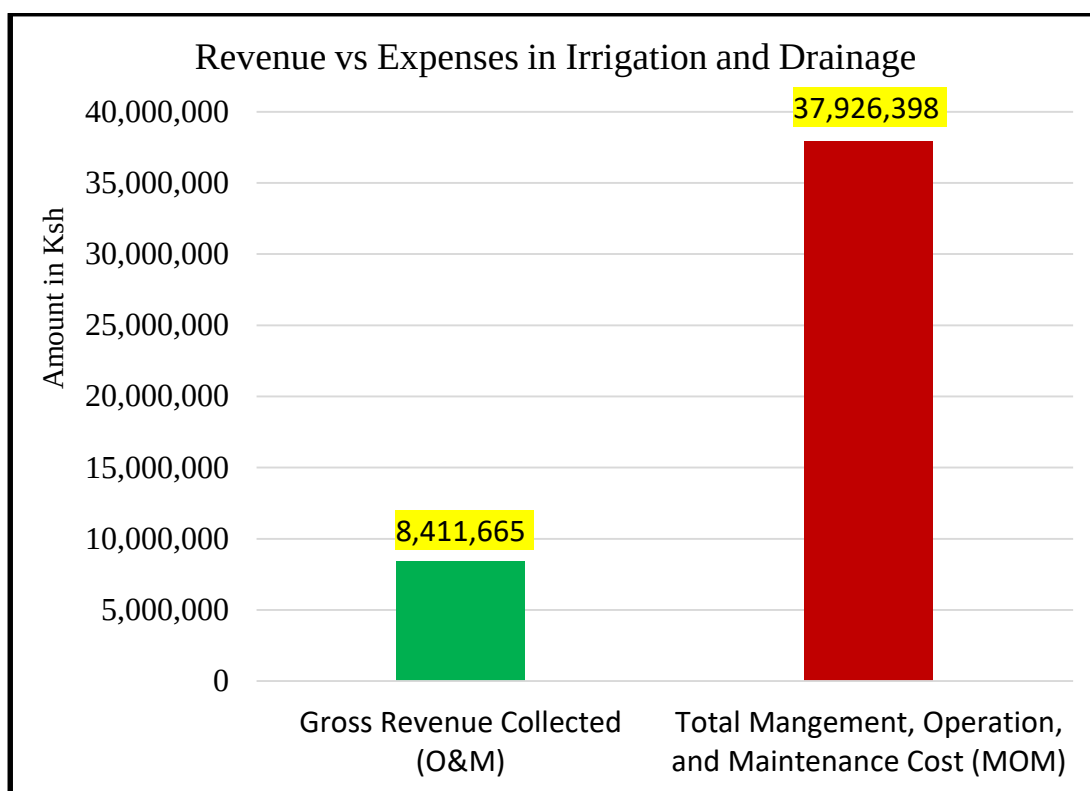


Figure 4.5: Revenue vs. expenses in irrigation and drainage

The benefit cost ratio which is a profitability indicator shows that the scheme did not get any financial gain during the research period. The benefit cost ratio for the scheme was calculated as 0.222 a value that is lower than a threshold value of 1. Values of benefit cost ratio greater than 1 indicates schemes are performing well financially. (Razzaq *et al.*, 2018). To improve the performance the scheme should find ways to reduce unnecessary costs and ways to increase the revenue generation. The operation and maintenance revenue collected from water users should be reviewed.

The total cost of management, operation, and maintenance incurred in offering irrigation and drainage services per unit cropped area that received irrigation water was calculated and found as 28,363.52 Ksh/ha, see Appendix 1, Table A1.2, indicator 12. The value of 28,363.52 Ksh/ha is equivalent to 236.363 US dollar per hectare (Using

currency exchange rate of 1 US dollar being equal to 120 Kenyan Shillings). Irrigation schemes in China have outcome in the range of (190 – 4) US dollar per hectare (Cornish, 2005). This illustrates that Ahero Irrigation Scheme in Kenya spent more on the cost of management, operation, and maintenance per unit irrigated area compared to the irrigation schemes in China.

The per capita cost incurred in offering irrigation and drainage services was calculated and found to be 321,133.33 Ksh/person annually, see Appendix 1, Table A1.2, indicator 13. The value of 321,133.33 Ksh/person is equivalent to 2676.18 US dollar per person (Using currency exchange rate of 1 US dollar being equal to 120 Kenyan Shillings). Irrigation schemes in China have outcome in the range of (1745 - 600) US dollar per person (Cornish, 2005). This illustrates that Ahero Irrigation Scheme in Kenya spent more on staff cost compared to irrigation schemes in China.

The performance of revenue collection from farmers was calculated and found to be 1.257, see Appendix 1, Table A1.2, indicator 14. The value of 1.257 shows that the collected operation and maintenance fee paid by IWUA members exceeded anticipated amount to be collected during the research period. The scheme collected 25.7% more revenue from the operation and maintenance fee than the amount anticipated. This is because during the research period the scheme had enforced collection of outstanding unpaid arrears from water users from the previous cropping season. This is an indication that the water users do not pay the revenue on time which is a salient characteristic of a scheme that is performing poorly financially (Qamar, et al., 2018).

The performance of revenue collection from farmers in Ahero Irrigation Scheme was poor in comparison to the financial performance of irrigation projects in Shandong Province China where the use of the ‘Integrated Circuit Card Automated Irrigation Charge Collection System’ was employed (Easter & Liu, 2005). The system employed

in Shandong province China was efficient because it ensured 100% fee collection from water users as opposed to a system employed in Ahero Irrigation Scheme that could not collect 25.7% of operation and maintenance fee from water users in the previous cropping season.

The ‘Integrated Circuit Card Automated Irrigation Charge Collection System’ employed in irrigation projects in Shandong Province China had the following advantages; i) the methods ensured 100% collection of fees from water users, ii) the method had reduced the administration cost related to; collection of fees, closing gates, indirect payments, and transaction charges, iii) reduced conflicts with water user as the system was transparent because water delivered was correctly recorded, iv) farmers had full control on how, when, and how much water they use, and v) the use of volumetric criteria to charge water which had reduced wastage of the scarce water resource (Yao *et al.*, 2017; Wang & Lu, 1999).

The irrigated area managed per person employed in offering irrigation and drainage services was computed as 98.235 ha/person, see Appendix 1, Table A1.2, indicator 15. Irrigation schemes in China had outcome in the range of (2,304 - 27) ha/person (Cornish, 2005). This illustrates that Ahero Irrigation Scheme in Kenya and irrigation schemes in China employed similar number of persons to manage the irrigated area of the scheme.

The IWUA members paid a sum of 0.727 Ksh for every 1m³ of water delivered to their farms through the operation and maintenance fee collected as revenue, see Appendix 1, Table A1.2, indicator 16. The total cost of management, operation, and maintenance incurred by the irrigation scheme’s management to deliver 1m³ of water to farmers was calculated as 3.277 Ksh, see Appendix 1, Table A1.2, indicator 17. The difference in these figures illustrates the government’s input as assistance towards meeting the irrigation and drainage costs in form of subsidies. These figures indicates that the

government settled 77.81% of the cost incurred while the farmers contributed the remaining 22.19%.

One of the most contentious questions is that of ‘Who should pay for the irrigation and drainage costs, the farmers or the government? Easter and Liu (2005) argued that the cost should be borne by both parties. The government and the farmers. They proposed components of irrigation and drainage costs for example; the bulk water cost, staff cost, energy cost (e.g., electricity, diesel, solar used in operating pumps and equipment etc.), maintenance cost (e.g., pumps, canals etc.), and overhead costs (e.g., administrative expenses, insurance, taxes, etc.) should be first identified and then a decision of who pays for what should be made later.

The total cost of management, operation, and maintenance incurred in production of 1 kg of paddy rice was 6.588 Ksh, see Appendix 1, Table A1.2, indicator 18. The energy cost in terms of electricity bill associated with production of 1 kilogram of paddy rice was computed as 3.604 Ksh, see Appendix 1, Table A1.2, indicator 19. Of all the cost incurred in offering irrigation and drainage services, the energy cost in form of electricity bill was the biggest which accounted for 54.704% of the total expenditure, see Figure 4.6. Also see Appendix 1, Table A1.2, indicator 20.

One of the reasons for high energy cost was the poor systems performance (Daudin *et al.*, 2022). Ahero Irrigation Scheme had four electric pumps with low performance efficiencies. The pumps of low performance efficiencies required more energy in their operations hence increased energy costs.

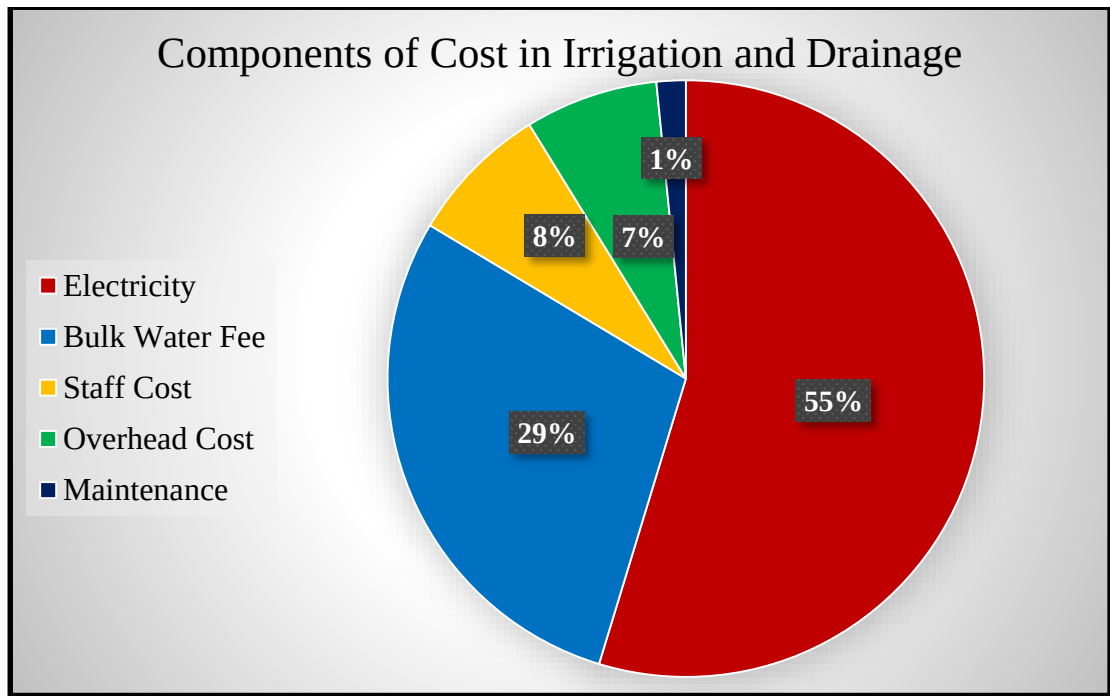


Figure 4.6: Components of cost in irrigation and drainage

The scheme's water conveyance system (canals) lost more water with increasing distance. The canals lost water through; seepage losses from their bed, transpiration losses from the opportunistic aquatic weeds in the canals, and evaporation losses of canal's water into the atmosphere. This necessitated more pumping to recover the amount of irrigation water lost in the conveyance system in order to meet the required levels of irrigation water demand in the fields. More pumping translates to more energy used and increased energy costs.

The water abstracted from River Nyando was variable according to the rainfall pattern of the catchment. During dry spells when water levels were too low, the electric pumps used more energy to abstract the water (Daudin *et al.*, 2022). This increased the energy cost.

The scheme should find alternative sources of electric energy to run the pumps to reduce the enormous electricity bill from KPLC. Solar energy is preferred. Solar energy

is clean and cheaper (Maka & Alabid, 2022). Solar energy can be stored in batteries for future consumption. This will reduce the irrigation cost associated to energy.

The scheme will benefit if the irrigation of water is supplied via gravity from Soin-koru dam upstream of Ahero Irrigation Scheme. The government should hasten completion of the dam. The supply of irrigation water via gravity will reduce the energy cost by reducing the amount of pumped irrigation water. The reduced pumping will lessen the energy used hence lowering the energy cost.

4.3 Crop Productivity Indicators

4.3.1 Results for crop productivity indicators

The description and results for the 9 indicators used in evaluating the crop productivity performance of the irrigation scheme is presented in Appendix 1, Table A1.3.

The result for the total annual crop production for the scheme was found to be 5,756.96 tonnes and can be referred in Appendix 1, Table A1.3, indicator 21. The yield received by farmers in a month was found by summing the produce from various irrigable blocks in the scheme. The annual crop production was computed by summing the produce received in 12 months as shown in Table 4.8.

The result for the total annual value of crop production was found to be 282,084,024 Ksh as indicated in Appendix 1, Table A1.3, indicator 22. The outcome was realized by multiplying the produce received by farmers in every month by the prevailing market prices of the produce as shown in Table 4.8.

The outcome for the output per unit command area was calculated and found to be 319,058.07 Ksh/ha as shown in Appendix 1, Table A1.3, indicator 23. The result was realised by dividing the monetary value of crop production in a year by the area in the design nominal provided with irrigation infrastructure. The area served by the irrigation infrastructure was found from the cropping calendar in Table 3.2 as 2,183 acres an equivalent of 884.115 hectares. The monetary value of crop production in a year used in the computation was drawn from Table 4.8.

The outcome for the output per unit irrigated area was computed and found to be 319,058.07 Ksh/ha as shown in Appendix 1, Table A1.3, indicator 24. The result was realized by dividing the annual monetary value of crop yield by the cropped area that received irrigation water. The annual monetary value of the crop production used in the calculation was drawn from Table 4.8. The cropped area that received irrigation water was 884.115 hectares.

Table 4.8: Total annual value of crop production

Total Annual Value of Agricultural Production					
No	Months	Production (Tonnes)	Production (Kg)	Cost (Ksh)	Monthly value of production (Ksh)
1.	Apr 2022	1,167.878	1,167,878	32	37,372,396
2.	May 2022	516.878	516,878	36	18,607,608
3.	Jun 2022	0	0	39	0
4.	Jul 2022	179.2	179,200	41	7,347,200
5.	Aug 2022	328.2	328,200	45	14,769,000
6.	Sep 2022	226.8	226,800	50	11,340,000
7.	Oct 2022	1,397.6	1,397,600	53	74,072,800
8.	Nov 2022	322	322,000	55	17,710,000
9.	Dec 2022	0	0	57	0
10.	Jan 2023	867.37	867,370	60	52,042,200
11.	Feb 2023	561.73	561,730	64	35,950,720
12.	Mar 2023	189.3	189,300	68	12,872,400
Total		5,756.96	5,756,956		282,084,024

The result for output per unit irrigation water delivered was calculated and found to be 24.376 Ksh/m³ as presented in Appendix 1, Table A1.3, indicator 25. The outcome was realised by dividing the monetary value of the crop yield in a year by the total volume of irrigation water delivered to farmers over a period of one year measured at the branch canals. The annual monetary value of the crop yield used in the computation was drawn from Table 4.8. The delivered irrigation water used in the calculation was drawn from Table 4.1.

The result for output per unit irrigation water supplied was calculated and found to be 20.282 Ksh/m³ as presented in Appendix 1, Table A1.3, indicator 26. The outcome was realised by dividing the monetary value of the crop yield in a year by the total volume of irrigation water supplied through pumping diverted at the pumping station from River Nyando. The annual monetary value of the crop yield used in the computation was drawn from Table 4.8. The supplied irrigation water used in the calculation was drawn from Table 4.2.

The outcome for the output per unit water supplied was computed and found to be 16.689 Ksh/m³ as presented in Appendix 1, Table A1.3, indicator 27. The result was realized by dividing the annual monetary value of produce received by farmers in one year by the summed volume of irrigation water supplied through pumping diverted into the scheme from River Nyando at the pump station and the volume of water received as effective rainfall. The annual monetary value of the produce received by farmers in one year used in the computation was drawn from Table 4.8. The value of volume of water supplied to the scheme used in the computation was drawn from Table 4.3.

The outcome for the output per unit crop water demand was calculated and found to be 12.243 Ksh/m³ as illustrated in Appendix 1, Table A1.3, indicator 28. The result was

realized by dividing the monetary value of the crop yield received in a year by the volume of water required to meet the crop's evapotranspiration needs in a period of one year. The monetary value of the crop yield received in a year used in the computation was drawn from Table 4.8. The value of the volume of water required to meet the crop's evapotranspiration needs for a period of one year used in the computation was drawn from Table 4.4.

The result for the total annual volume of water supply per unit crop production was calculated and found to be 2,936 litres/kg as shown in Appendix 1, Table A1.3, indicator 29. The outcome was realized by dividing the sum of the annual volume of irrigation water supplied through pumping diverted into the scheme from River Nyando at the pumping station and the volume of effective rainfall received in a year divided by the mass of crop yield received by farmers in a period of one year. The value of water supplied to the scheme used in the calculation was drawn from Table 4.3. The value of the mass of crop yield received by farmers in a period of one year was drawn from Table 4.8.

4.3.2 Discussion of results for crop productivity indicators

The total amount of paddy rice harvested for the year was summed and found to be 5,756.96 tonnes, see Appendix 1, Table A1.3, indicator 21. The yields from various irrigated blocks were summed to get the aggregate amount of harvest the farmers received in the year.

The monetary value of harvested paddy rice was calculated as 282,084,024 Ksh based on the prevailing market prices, see Appendix 1, Table A1.3, indicator 22. During the research period of one year the prices of paddy fluctuated from a minimum of Ksh 32 per kilogram to a maximum of Ksh 68 per kilogram, see Table 4.8. The market prices

were mainly influenced by the prevailing forces of demand and supply. Instances when paddy rice was surplus in the market the farmers competed against themselves to sell their produce hence lowering their prices. Other farmers stored their produce until the market prices had increased in order to sell their produce at a higher cost to gain more profit. The variations of supplying products to the market affected the demand leading to prices instability (Kumare et al., 2022). A platform should be set up that gives room for farmers to sell their produce jointly rather than individually. The farmers can sell their produce through well-managed cooperative societies. This will give power to the farmers to effectively negotiate for better prices for their produce and will mitigate the negative effects of fluctuating market prices.

The values of the output per unit command area and the output per unit irrigated area were found to be the equal as 319,058.07 Ksh/ha, see Appendix 1, Table A1.3, indicator 23 and indicator 24. This indicates that the area of land resource intended to grow the rice crop for the scheme was fully utilised (100%) throughout the research period. Full utilisation of available land resource indicates that scheme upheld best land management practices and the established irrigation and drainage infrastructure was capable to serving the whole scheme without deficiency.

By comparing the monetary values of 24.376 Ksh/m³ of delivering water to the fields through the canals' transport system to the value of 20.282 Ksh/m³ of diverting water into the scheme for irrigation at the pumping station from River Nyando illustrates that the scheme lost 4.092 Ksh for every 1m³ of water as conveyance losses, see Appendix 1, Table A1.3, indicator 25 and indicator 26. The lining of earthen canals with impervious layers reduces the irrigation costs (Hrozencik et al., 2022; Zou et al., 2013).

By comparing the monetary values of 24.376 Ksh/m³ of water delivered to the fields through the canals' transport system to the value of 16.689 Ksh/m³ of water supplied for irrigation which takes into account the effective rainfall illustrates that the effective rainfall reduced irrigation cost by 7.687 Ksh for every 1m³ of water supplied, see Appendix 1, Table A1.3, indicator 25 and indicator 27. Rainfall was important in crop production because it minimised the irrigation costs (Inocencio, et al., 2007).

By comparing the monetary values of 24.376 Ksh/m³ of water delivered to the fields through the canals' transport system to the value of 12.243 Ksh /m³ of water required by the crops to transpire illustrates that the scheme loses 12.133 Ksh for every 1m³ of water due to field water application losses, see Appendix 1, Table A1.3, indicator 25 and indicator 28.

The water application efficiency was a ratio that related the amount of water that was directly available to the crop at the root zone in comparison to the amount of water the rice irrigation basin received from its inlet. The low water application efficiency was attributed to; evaporation of irrigation water from the soil, surface runoff, wind drift, and percolation beyond the root zone (Howell, 2015; Irmak et al., 2011). To improve the field water application efficiencies the scheme should; i) uphold better water management practices that produce more crops with little water such as intermittent irrigation as opposed to full supply /continuous irrigation method (Abdelhalim et al., 2017), and ii) train farmers on techniques of managing water effectively at the field level such as; levelling irrigation basins, construction of basin bunds, and determining the correct amount and irrigation water application frequencies etc.

The measure of rice crop water productivity was found to be; 1kg of paddy rice was grown with 2,936 litres of supplied water (equivalent of 0.3406kg/m³), see Appendix 1, Table A1.3, indicator 29. This crop water productivity indicator was poor because

on average the crop water requirement for rice to meet evapotranspiration needs is 1,432 litres to produce 1kg of paddy rice (equivalent of 0.6983kg/m³) (Bouman, 2009). The scheme uses more water than required because of; i) high conveyance losses along the earthen canals, ii) poor irrigation technologies used, and iii) low water application efficiencies at the field level.

The poor irrigation technology used wasted away irrigation water intended to be used by the crop to transpire. Ahero Irrigation Scheme used surface irrigation as a method of applying water to the crop. The rice crop was grown in irrigation basins which were flooded continuously with irrigation water. The indicative field application efficiencies of various irrigation methods are as follows; i) surface irrigation – 60%, ii) sprinkler irrigation – 75%, and iii) drip irrigation – 90% (FAO, 2024). The scheme should embrace the intermittent method of irrigation. The intermittent method of irrigation is one in which the irrigated basin is wetted in cycles during crop development stages. Unlike full supply irrigation method or continuous flooding method, the intermittent irrigation method saves already scarce water resource (Abdelhalim et al., 2017).

The ratio of the amount of water directly available to the crop at the root zone to the amount of water that the irrigation basin received from its inlet was the water application efficiency. The water application efficiency of the scheme was low because; i) some of the irrigation basins were not well levelled, see Figure 4.7, and ii) some of the irrigation basins had broken bunds, see Figure 4.9.

Unlevelled irrigation basins caused poor distribution of water in them because they had high points and low points. The high points remained dry while the low points were wet. A lot of water was required to flood the unlevelled irrigation basins compared to well levelled irrigation basins. Figure 4.8 is a picture of a well levelled irrigation basin. The crops in unlevelled irrigation basins experienced water shortages and stress

hindering their growth and final production (Rogers, et al., 1997; Sadras, et al., 2016; Vorasoot, et al., 2003). The well levelled irrigation basins had good distribution efficiencies because the irrigation water application depth was uniform throughout the basin (Maroufpoor et al., 2010; Kara et al., 2008). Trainings should be provided to farmers by the scheme's management to educate them on the importance and techniques of undertaking levelling activities in the irrigation basins.



Figure 4.7: Poorly levelled irrigation basin.



Figure 4.8: Well levelled irrigation basin

Some of the irrigation basins in the scheme had poorly constructed or broken basin bunds. Figure 4.9 is a picture showing a broken basin bund in the irrigation scheme. The poorly constructed or broken basin bunds wasted away already scarce irrigation water resource. The poorly constructed basin bunds were thin and susceptible to collapse. The well-maintained basin bunds were thick and capable of retaining and conserving the precious irrigation water. Figure 4.10 is a picture showing a well-maintained basin bund in the irrigation scheme.

This scheme's management should organize for trainings to educate farmers how to construct and maintain basin bunds that will not fail when they are being flooded with irrigation water. When determining the height of the bunds the farmers should consider the irrigation depth and the freeboard. The freeboard is the height above the irrigation water depth provided to make sure that the applied irrigation water will not overtop the

bund (FAO, 2024). The bunds are also useful because they retain the rainwater after rainfall events which enhance utilisation of the water by the crop as effective rainfall.



Figure 4.9: Broken basin bunds



Figure 4.10: Well-maintained basin bunds

Ahero Irrigation Scheme used poor method of imposing irrigation water charges to the farmers. This impacted negatively water management at the field level by the water users. The scheme used the area-based pricing method as opposed to volumetric pricing method. The area-based pricing method used by the scheme required the farmers to pay a sum of Ksh 3,100 for every acre they irrigated. This method was poor because farmers did not have limits of irrigation water they used hence mismanaging the water resource by leaving broken bunds unattended and over application of irrigation water in unlevelled basins.

The volumetric pricing method charges the water users based on the volume of irrigation water they consumed. This method encourages efficient water use at the field level. The water charges imposed to the water users serves to; i) cover the operation and maintenance charges, and ii) encourage farmers to use less irrigation water resource in crop production (Easter & Liu, 2005).

It was a challenge for the scheme's management to allocate irrigation water to various users in the scheme. This impacted negatively the water resource management. It was difficult to allocate the volume of irrigation water equitably to all users because the scheme had limited discharge measurement infrastructure. There was disparity of irrigation water allocation between farmers located in the upstream of the main canal and the farmers located downstream of the main canal. The farmers located upstream of the main canal received more water than the farmers located downstream of the main canal.

The scheme needs to embrace the volumetric pricing method to impose charges on the irrigation water consumed by farmers. This method will require the scheme to set up reliable discharge measurement infrastructure to quantify irrigation water allocated to farmers and then charging them according to the volume of irrigation water they

received. Acquisition of dischargement infrastructure will also promote equitable water resource allocation between farmers located upstream and downstream of the canal. The scheme should consider acquiring current meters and well graduated staff gauges that will assist in measuring volume of discharge in canals.

4.4 Results and discussion from the comparative reference study

Section 4.4 presents the results and discussion from the research study that used BPCA evaluation technique to assess performance of Ahero Irrigation scheme.

4.4.1 Results from the comparative reference study

4.4.1.1 Results for water supply category

The average annual volume of irrigation water supplied was measured as 4,989,382 m³. The command area for the irrigation scheme and the average annual irrigated area were measured as 900 ha and 810 ha respectively. The average relative water supply was calculated as 1.42 and the average relative irrigation water supply was calculated as 1.17. The average annual water delivered per unit irrigated area was calculated as 6,124 m³/ha and the average water delivered per unit command area was calculated as 5,544 m³/ha.

4.4.1.2 Results for financial performance category

The gross revenue collected was averaged as 52,398.80 (US\$) while the gross revenue invoiced was averaged as 62,062.00 (US\$). The average revenue collection performance for the scheme was calculated as 85 percent. The average revenue per unit irrigation water supplied was calculated as 1.08 (US dollar cents /m³).

4.4.1.3 Results for agricultural productivity category

The average annual agricultural production was measured as 4,287 tonnes. The average annual value of agricultural production was calculated as 1,649,204 (US\$). The average

output per unit irrigated area was estimated as 1,832 (US\$/ha) while the output per unit command area was calculated as 2,047 (US\$/ha). The average output per unit irrigation water supplied and the average output per unit water supplied were calculated as 0.34 (US\$/m³) and 0.20 (US\$/m³) respectively. The average output per unit crop water demand was calculated as 0.27 (US\$/m³).

4.4.2 Discussion of results from the comparative reference study

4.4.2.1 Discussion of results for water supply category

During research period the scheme diverted water from river Nyando an estimation of 4,989,382 m³. The water abstracted was highly variable because of the occasional power outages experienced in the region. The variable rainfall received in the catchment affected the amount of water abstracted from the river. The cropped area also influenced the amount of water abstracted for supply.

The irrigation scheme did not manage to irrigate the whole land intended to grow the rice crop (command area) an estimation of 900 ha. Only 90% of the command area was irrigated (810 ha) because of the inability for farmers to acquire agricultural farming inputs.

The average relative irrigation supply (RIS) was calculated as 1.17 and the average relative water supply (RWS) was calculated as 1.42. When the values of RIS and RWS are below the value of 2 indicates there is water shortage supplied to the scheme (Molden *et al.*, 1998). Water shortage in the scheme was influenced by; low rainfall received in the catchment, faulty unusable pumps incapable of abstracting water, and occasional power outages in the region.

The amount of water supplied per unit area was influenced by the; availability of water in the river, cropping pattern, soil type, climate of the region, and the irrigation systems conditions. The average annual water delivered per unit irrigated area was calculated

as 6,124 m³/ha a value that is lower compared to the amount of water delivered per unit irrigated area of 22,029.43 m³/ha in MARIIS irrigation scheme located in Cagayan River Basin in Philippines (Balderama & Bareng, 2014). The average annual water delivered per unit command area was calculated as 5,544 m³/ha which is little compared to the average amount of water delivered per unit command area ranging from a value of 1,878 m³/ha to 10,484 m³/ha in the Susurluk River Basin, Turkey (Kusçu, 2012).

4.4.2.2 Discussion of results for financial performance category

The revenue collection performance from water users was poor. The collected operation and maintenance fee paid by water users was little (52,398.80 US\$) compared to the amount invoiced (62,062.00 US\$). This is an indication that the scheme's management failed to collect 15% of water revenue from the farmers during the research period. The desirable percentage for revenue collection is 100% (Yao *et al.*, 2017; Wang & Lu, 1999).

The operation and maintenance fee paid by water users is undercharged and cannot meet the costs incurred in offering irrigation and drainage services. The average revenue collected per unit irrigation water supplied was calculated as 1.08 US dollar cents /m³ which is little compared to the economic value of irrigation water estimated as 7.54 US dollar cents /m³ (Omondi, 2014).

4.4.2.3 Discussion of results for agricultural productivity category

The agricultural productivity indicators relate the inputs in crop production to the outputs. These indicators relate the yield to the resources applied in crop production. Examples of these resources include; the land used, the income generated, and the quantity of water used in irrigation.

The land productivity indicators describe the measure of cropping intensity for the irrigation scheme. Higher values of land productivity indicators show intensive irrigation. The value of average output per unit irrigated area of 1,832 (US\$/ha) shows that the production of rice in Ahero Irrigation Scheme was higher compared to the irrigation scheme in Thailand whose output per unit irrigated area was calculated as 1,300 (US\$/ha) in rainy season and 1,310 (US\$/ha) in dry season (Bumbudsanpharoke & Prajamwong, 2015). The average value of output per unit command area was calculated as 2,047 (US\$/ha) in Ahero Irrigation Scheme which was higher compared to the values of 1,921(US\$/ha) and 1,671 (US\$/ha) for West Kano and Bunyala irrigation schemes in Kenya.

By comparing the value of the output per unit irrigation water supplied (OIS) to the value of the output per unit water supplied (OWS) depicts the contribution of effective rainfall towards growing the crop. OIS was calculated as 0.34 (US\$/m³) and OWS was calculated as 0.20 (US\$/m³). The irrigation scheme saved 0.14 US\$ for every cubic meter of water required for irrigation because of rainfall. If the value of output per unit crop water demand (OCWD) is greater than the OIS, indicates that the irrigation water supplied was not fully utilised hence unproductive. By comparing the value of OCWD calculated as 0.27 (US\$/m³) to the value of OIS calculated as 0.34 (US\$/m³) indicates Ahero Irrigation Scheme was efficient in water management.

4.4.3 Comparison of findings from the two research studies

This section makes comparisons of findings from my research study and the findings from the research study made by Muema and others (2018). The similarities, differences, and gaps are discussed.

A. Similarities

The similarities in hydraulic performance include;

- i. The irrigation water abstracted from River Nyando was variable because of the changing rainfall pattern in the catchment.
- ii. The occasional power outages in the region influenced availability of irrigation water abstracted for supply. The scheme occasionally failed to supply required quantities of irrigation water because of frequent power outages.
- iii. There was scarce water resource to meet the crop water needs.

The similarities in financial performance include;

- i. The scheme's management failed to collect the operation and maintenance fee from water users effectively.
- ii. The operation and maintenance fee collected from water users was undercharged and therefore could not meet the expenses incurred in offering irrigation and drainage services.
- iii. The price of paddy rice was variable as per the market forces of demand and supply.

The similarities in crop water productivity performance include;

- i. The scheme had poor water management practices hence low water use efficiencies. The farmers in the irrigation scheme did not have limits of quantity of irrigation water to use proportional to the fees they were charged. This contributed to mismanagement of the irrigation water resource.

B. Differences

The two research studies did not have significant differences in the findings under hydraulic, financial, and crop water productivity performance evaluation.

C. Gaps filled (New findings)

The gaps filled in hydraulic performance include;

- i. The measured conveyance efficiency of the earthen main canal was measured as 83.2%.
- ii. The conveyance losses along the earthen main canal were caused by; percolation of irrigation water from the canal's bed, evaporation of the canal's irrigation water into the atmosphere, transpiration losses by the aquatic weeds in the canal, and vandalised water control structures that could not effectively control canal water.
- iii. The pumps had low performance efficiencies and could not pump required irrigation water as initially manufactured. The pumps were not able to meet the peak irrigation water consumptive demand for the scheme.

The gaps filled in financial performance include;

- i. The energy cost (electricity bill) was the biggest expense incurred by the scheme while offering irrigation and drainage services accounting for 54.7% of the total cost of management, operation, and maintenance.

The gaps filled in crop water productivity performance include;

- i. The crop water productivity performance for the scheme was poor as it required 2,936 litres of water to produce 1 kilogram of paddy rice (equivalent of 0.3406kg/m^3) compared to the crop water requirement of 1,432 litres (equivalent of 0.6983kg/m^3).
- ii. The mismanagement of irrigation water resource at the field level was due to poor land preparation techniques and broken basin bunds.

- iii. The scheme lacked adequate discharge measurement equipment that made it difficult to allocate appropriate quantities of water to irrigable lands in the scheme effectively.

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

- i.** The scheme's earthen main canal had low irrigation water conveyance efficiency and was invaded by the opportunistic aquatic weeds.
- ii.** The some of the water control structures along the earthen main canal had failed and could not control irrigation water in the canal effectively.
- iii.** The electric pumps serving the scheme had low performance efficiencies.
- iv.** The scheme only relied on KPLC grid lines to get its electric energy to run the pumps. The scheme lacked alternative sources of energy to run the pumps.
- v.** The scheme experienced water shortages during dry spells incapable of meeting the high crop water demands.
- vi.** The subsidized operation and maintenance fee paid by farmers was last reviewed in the year 2008. The same amount of fee was paid by farmers in the year 2023 and was found to be very little to meet the scheme's irrigation and drainage expenses.
- vii.** The scheme faced a challenge of settling high energy costs used to operate the pumps.
- viii.** The variable price of paddy rice was influenced by the market forces of demand and supply. The variable prices affected farmers negatively by lowering their value of produce.
- ix.** The scheme had low rice crop-water productivity.
- x.** The unlevelled irrigation basins used more irrigation water during flooding. The crops in unlevelled irrigation basins experienced water shortages and stress.

- xi.** The broken and poorly constructed basin bunds were found to be thin and susceptible to collapse during flooding.
- xii.** The scheme had limited discharge measurement infrastructure useful in irrigation water resource management.

5.2 Recommendations

- i.** The scheme will benefit if its earthen main canal is lined with impermeable lining to improve conveyance efficiency of irrigation water and to limit the growth of aquatic weeds. The preferable lining is concrete. The geometric design of the proposed lined canal should have a trapezoidal cross-section for efficient water conveyance. The existing earthen main canal should be properly maintained to improve the conveyance efficiency and to limit the growth of aquatic weeds as a cheaper alternative before lining the earthen main canal.
- ii.** The failing water control structures such as sluice gates and division boxes should be rehabilitated occasionally.
- iii.** The pumps' performance will be improved if the old pumps (that are at the end of their utility life) are replaced with new ones that can deliver more irrigation water with little energy from the abstraction point. The scheme's management should do regular maintenance of the pumps to ensure their performance is improved as a cheaper alternative before replacing the old pumps with new ones.
- iv.** The scheme should invest in developing alternative sources of energy to run the pumps in case of power outage. Solar energy is preferred.

- v. The scheme should utilise well the available scarce irrigation water resource by embracing efficient irrigation technologies that use less irrigation water such as intermittent method of irrigation to meet the high crop water requirements.
- vi. The operation and maintenance fees paid by water users for using irrigation and drainage services should be reviewed to meet the costs incurred.
- vii. The scheme should aim to improve the performance of the electric pumps to reduce the enormous electricity bills from KPLC. Alternative sources of energy that are cheaper should be considered such as solar to replace or supplement the existing electrical energy. The government should also hasten completion of Soin-Koru Dam upstream of Ahero Irrigation Scheme that will supply irrigation water via gravity to supplement the irrigation water abstracted by the electric pumps to lower the energy cost.
- viii. A platform should be set up that gives room for farmers to sell their produce jointly rather than individually to enable them negotiate for better prices for their produce. The farmers should sell their produce through well-managed cooperative societies.
- ix. Better water management practices should be adopted to enable production of more crop with little water. The earthen main canals should be lined with impervious layer to prevent loss of irrigation water conveyed. Trainings should be offered to farmers on techniques of managing water effectively at the field level to improve application efficiencies. Better irrigation technologies should be adopted that use less irrigation water resource such as intermittent method of irrigation.
- x. The NIA together with the IWUA should conduct trainings to educate farmers on the importance and techniques of undertaking levelling activities in the irrigation basins.

- xi.** The IWUA and the NIA should undertake trainings to educate farmers on how to construct and maintain basin bunds that will not fail when the irrigated fields are being flooded.
- xii.** The scheme should set up discharge measurement infrastructure and maintain the existing ones.

5.3 Contribution to new knowledge

The contributions of my research work to new knowledge under hydraulic performance evaluation were; i) the measured conveyance efficiency of the earthen main canal, ii) causes of conveyance losses along the earthen main canal, and iii) performance of electric pumps serving the scheme. The new knowledge added under financial performance evaluation was that of electricity being the biggest component of cost in irrigation and drainage. The contributions of new knowledge in crop water productivity performance evaluation were; i) the measure of rice crop water productivity for the scheme, ii) the state of irrigation water application efficiency in the irrigated fields, and iii) the state of discharge measurement infrastructure used in water resource management in the scheme.

5.4 Further research work

Sediments carried by pumped irrigation water had abrasive effect on parts of pumps. Further research studies should be carried out to investigate the amount and effects of sediments carried by pumped irrigation water from River Nyando on the performance of the electric pumps used in the abstraction.

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Appendix 1 – IPTRID Assessment Indicators

Table A1.1 Hydraulic indicators

Hydraulic Indicators			
1	Total annual volume of irrigation water delivered in m³.	Definition	Total volume of water delivered to water users over the season/ year. Measured daily at the interface between the irrigation authority and water users - Measured at the branch canals. Refer to Figure 3.3 , the points along the main canal where discharge measurement was conducted.
		Methodology	Multiplying the discharge rate drawn from the rating curve at a specific gauge reading with the duration in which water was delivered to the irrigated blocks.
		Results	11,572,188.36 m ³
		Reference	Table 4.1
2	Total annual volume of irrigation water supplied in m³.	Definition	Total annual volume of water diverted or pumped for irrigation. Obtained by summing the daily volume of water pumped for the crop growing season in a year. The daily volume of water pumped was obtained as the product of pumping hours and the pump's discharge rates.

		Methodology	Summing product of daily pumping hours and measured pump's operating discharge rates.
		Results	13,908,173.84 m ³
		Reference	Table 4.2
3	Total annual volume of water supplied in m³.	Definition	Total volume of water pumped for irrigation plus total volume of effective rainfall. Obtained by summing the total volume of water pumped for irrigation and the total volume of effective rainfall for the crop growing season in a year. The effective rainfall was computed using the USDA-Soil Conservation Method in-built in CROPWAT 8. The effective rainfall in terms of depth was converted into volume by multiplying by the total annual cropped area.
		Methodology	Summation of the daily volume of water pumped (Pumping hours * Measured pump operating discharge rate) + Daily effective rainfall (mm) * Cropped area
		Results	16,902,351.94 m ³
		Reference	Table 4.3

4	Annual irrigation water supplied per unit command area (m ³ /ha)	Definition	$\frac{\text{Total annual volume of irrigation water supplied}}{\text{Total command area of the system}}$ Total annual volume of irrigation water supplied: Total annual volume of water pumped for irrigation diverted at the pump station from River Nyando. Total command area of the system: The area in the nominal design provided with irrigation infrastructure. The net area serviced by the scheme less the right of way for canals, drains, roads and villages. NB: 2183 acres converted to hectares is 884.115 Ha
		Methodology	Summation of the daily volume of water pumped (Pumping hours * Measured pump's operating discharge rate) + Daily effective rainfall (mm)) * Cropped area divided by total area serviced by irrigation infrastructure of the scheme
		Results	$\frac{13,908,173.84}{884.115} = 15,731.18 \text{ m}^3/\text{ha}$
		Reference	Table 4.2 and Table 3.2

5	Annual irrigation water supplied per unit irrigated cropped area (m³/ha)	Definition	$\frac{\text{Total annual volume of irrigation water supplied}}{\text{Total annual irrigated cropped area}}$ Total annual volume of irrigation water supplied: Total annual volume of water diverted or pumped for irrigation. Total annual irrigated cropped area: The total area of land in a year on which irrigated crops were grown. - The cropped area was 2183 acres. NB: 2183 acres converted to hectares is 884.115
		Methodology	Summation of the daily volume of water pumped (Pumping hours * Measured pump operating discharge rate) + Daily effective rainfall (mm)) * Cropped area divided by total area cropped in a year
		Results	$\frac{13,908,173.84}{884.115} = 15,731.18 \text{ m}^3/\text{ha}$
		Reference	Table 4.2 and Table 3.2

6	Main system water delivery efficiency (%)	Definition	$\frac{\text{Total annual volume of irrigation water delivered}}{\text{Total annual volume of irrigation water supplied}} * 100$ Total annual volume of irrigation water delivered: Total volume of water delivered to the water users over the year measured in branch canals, the interface between NIA and the water users Total annual volume of irrigation supplied: Total annual volume of water diverted or pumped for irrigation
		Methodology	Total volume of water delivered to the water users over the year divided by Summation of product of; daily pumping hours * measured pump operating discharge rates
		Results	$\frac{11,572,188.36}{13,908,173.84} * 100 = 83.2\%$
		Reference	Table 4.1 and Table 4.2
7		Definition	$\frac{\text{Total annual volume of water supplied}}{\text{Total annual volume of crop water demand}}$

	Annual relative water supply		Total annual volume of water supplied: Total volume of water diverted into the scheme for irrigation through pumping plus total volume of effective rainfall. Total annual volume of crop water demand: Total annual volume of water used by the crop to meet evapotranspiration demands. Crop evapotranspiration was be calculated at a predetermined frequency using the FAO CROPWAT 8 model for the net area cropped. Computed as; $V.ET_c = ET_c \times A.$ $V.ET_c$ = Total volume of crop water demand (m³) ET_c = Crop evapotranspiration from planting to harvesting (m³); A = Cropped area. For the rice crop, the average percolation rate will be multiplied by the cropped area and the growing period to obtain the total percolation volume.
		Methodology	Summation of the daily volume of water pumped (Pumping hours * Measured pump's operating discharge rate) + Daily effective rainfall (mm)* Cropped area divided by total annual crop water demand.

		Results	$\frac{16,902,351.94}{23,040,704} = 0.734$
		Reference	Table 4.3 and Table 4.4
8	Annual relative irrigation water supply	Definition	$\frac{\text{Total annual volume of irrigation water supplied}}{\text{Total annual volume of crop irrigation demand}}$ Total annual volume of irrigation water supplied: Total annual volume of water diverted or pumped for irrigation. Total annual volume of crop irrigation demand: Total annual volume of crop water demand less volume of effective rainfall. The effective rainfall will be computed using the USDA-Soil Conservation Method in-built in CROPWAT 8 application. The effective rainfall in terms of depth is converted into volume by multiplying by the total annual cropped area. For the rice crops, the average percolation rate will be multiplied by the crop area and growth period to obtain the total percolation volume.
		Methodology	Summation of product of; daily pumping hours * measured pump operating discharge rates divided by Total annual volume of crop irrigation demand

		Results	$\frac{13,908,173.84}{17,100,616} = 0.813$
		Reference	Table 4.2 and Table 4.5
9	Water delivery capacity	Definition	$\frac{\text{Pump capacity to deliver water at system head}}{\text{Peak irrigation water consumptive demand}}$ Pumps' capacity to deliver water at system head: The pumps' capacity to deliver water at the system head was calculated by summing the pumps' discharge rates (l/s). Peak irrigation water consumptive demand: The peak irrigation water consumptive demand was expressed in flow rate (l/s) as the highest amount of water in a month required to meet the crop water requirements.
		Methodology	Pump capacity to deliver water at system head divided by Peak irrigation water consumptive demand *Pump 3 was grounded during the research period. The pumps' capacity to deliver water at the system head was calculated by adding discharge rates for pumps 1, 2, and 4. The pumps' discharge rates were as follows; Pump 1 (349 l/s), Pump 2 (528 l/s), and Pump 4 (291 l/s). *From Table 4.4, September had the highest water consumptive demand, 3,493,199m³ converted to a discharge rate of 1,347.685 l/s per day.

		Results	$\frac{1,168.90}{1,347.685} = 0.8673$
		Reference	Table 4.4

Table A1.2: Financial indicators

Financial Indicators			
10	Cost recovery ratio	Definition	$\frac{\text{Gross revenue collected}}{\text{Total management, operation, and maintenance cost}}$ Gross revenue collected: Total revenue collected from payment of operation and maintenance (O&M) fee by water users. Total cost of management, operation, and maintenance (MOM): The cost of providing irrigation and drainage services excluding capital expenditure. These costs include; • Bulk water cost • Staff cost • Energy cost (e.g., electricity used in operating pumps and equipment) • Maintenance cost

			Overhead costs (include administrative expenses, insurance, taxes, etc.)
		Methodology	Gross revenue collected divided by Total cost of management, operation, and maintenance (MOM)
		Results	$\frac{8,411,665}{37,926,398} = 0.222$
		Reference	Table 4.7
11	Maintenance cost to revenue ratio	Definition	$\frac{\text{Maintenance cost}}{\text{Gross revenue collected}}$ Maintenance cost: Total expenditure on system maintenance. Includes all the costs associated with maintenance of the irrigation and drainage infrastructure excluding major repairs or rehabilitation work. Gross revenue collected: Total revenue collected from payment of operation and maintenance fee services by water users.
		Methodology	Maintenance cost divided by Gross revenue collected

		Results	$\frac{600,000}{8,411,665} = 0.071$
		Reference	Table 4.7
12	Total management, operation, and maintenance cost per unit irrigated area (Ksh/ha)	Definition	$\frac{\text{Total management, operation, and maintenance cost}}{\text{Total annual irrigated area serviced by the system}}$ Total management, operation, and maintenance cost (MOM): Total management, operation and maintenance cost of providing the irrigation and drainage service excluding capital expenditure. Total annual irrigated area serviced by the system: Total actual irrigated area during the year.
		Methodology	Total cost management operation, and maintenance (MOM) divided by the Total annual irrigated area serviced by the system
		Results	$\frac{37,926,398}{884.115} = 28,363.52 \text{ Ksh/ha}$

		Reference	Table 4.7 and Table 3.2
13	Total personnel cost per person employed on water delivery (Ksh/person)	Definition	$\frac{\text{Total cost of personnel engaged in I\&D service}}{\text{Total number of personnel engaged in I\&D service}}$ Total cost of personnel engaged in I&D service: Total cost of personnel employed in the provision of irrigation and drainage (I&D) services. Total number of personnel engaged in I&D service: Total number of personnel employed in the irrigation and drainage service. Includes the cost of all personnel employed by the organization including contractors and contract employees engaged in the administration, management and operation of irrigation and drainage (I&D) services.
		Methodology	Total cost of personnel engaged in I&D service divided by Total number of personnel engaged in I&D service.
		Results	$\frac{2,890,200}{9} = 321,133.33 \text{ Ksh/person (yearly)}$
		Reference	Table 4.7

14	Revenue collection performance	Definition	$\frac{\text{Gross revenue collected}}{\text{Gross revenue invoiced}}$ Gross revenue collected: Total revenue collected from payment of operation and maintenance (O&M) fee by water users. Gross revenue invoiced: Total revenue due for collection from water users for provision of irrigation and drainage services.
		Methodology	Gross revenue collected divided by Gross revenue invoiced. NB. Gross revenue invoiced is the total amount of money ought to be collected from farmers in a year as operation and maintenance fee. - The scheme charged Ksh 3,100 per acre - The area irrigated was 2158 acres. - The gross revenue was calculated as $(2158 * 3100 = 6,689,800)$
		Results	$\frac{8,411,665}{6,689,800} = 1.257$

		Reference	Table 4.7
15	Total irrigated area managed per person (ha/Persons)	Definition	$\frac{\text{Total annual area serviced by the irrigation system}}{\text{Total number of personnel engaged in I\&D service}}$ Total annual area serviced by the irrigation system: The total actual area cropped during the year. Total number of personnel engaged in I&D service: Total number of personnel employed in offering irrigation and drainage services.
		Methodology	Total annual area serviced by the irrigation system divided by Total number of personnel engaged in I&D service. *2183 acres converted to hectares is 884.115 *9 Persons are employed in the I&D services
		Results	$\frac{884.115}{9} = 98.235 \text{ ha/person}$
		Reference	Table 3.2

16	Average revenue per cubic meter of irrigation water delivered (Ksh/m ³)	Definition	$\frac{\text{Gross revenue collected}}{\text{Total annual volume of irrigation water delivered}}$ Gross revenue collected: Total revenue collected from payment of operation and maintenance (O&M) fee by water users. Total annual volume of irrigation water delivered: Total volume of water delivered to the water users over the year measured in branch canals which is the interface between the NIA and the water users.
		Methodology	Gross revenue collected divided by the Total annual volume of irrigation water delivered.
		Results	$\frac{8,411,665}{11,572,188.36} = 0.727 \text{ Ksh/m}^3$
		Reference	Table 4.7 and Table 4.1
17	Total management, operation, and maintenance cost per	Definition	$\frac{\text{Total management, operation, and maintenance cost}}{\text{Total annual volume of irrigation water delivered}}$ Total cost of management, operation, and maintenance (MOM): The cost of providing the irrigation and drainage service excluding capital expenditure.

	unit volume of water delivered (Ksh/m³)		Total annual volume of irrigation water delivered: Total volume of water delivered to the water users over the year.
		Methodology	Total management, operation, and maintenance cost divided by Total annual volume of irrigation water delivered
		Results	$\frac{37,926,398}{11,572,188.36} = 3.277 \text{ Ksh/m}^3$
		Reference	Table 4.7 and Table 4.1
18	Total management, operation, and maintenance cost per unit crop production (Ksh/kg)	Definition	$\frac{\text{Total management, operation, and maintenance cost}}{\text{Total annual crop production}}$ Total cost of management, operation, and maintenance (MOM): The cost of providing the irrigation and drainage service excluding capital expenditure. Total annual crop production: Total annual crop production in Kg.
		Methodology	Total management, operation, and maintenance cost divided by Total annual crop production
		Results	$\frac{37,926,398}{5,756,960} = 6.588 \text{ Ksh/kg}$

		Reference	Table 4.7 and Table 4.8
19	Total annual energy cost per unit crop production (Ksh/kg)	Definition	$\frac{\text{Total annual energy cost}}{\text{Total annual crop production}}$ Total annual energy cost: Electricity cost incurred in operation of pumps and equipment. Total annual crop production: Total annual crop production in Kg.
		Methodology	Total annual energy cost divided by Total annual crop production in Kg.
		Results	$\frac{20,747,075}{5,756,960} = 3.604 \text{ Ksh/kg}$
		Reference	Table 4.7 and Table 4.8
20	Percentage of total annual energy cost to the total management operation, and maintenance cost (%)	Definition	$\frac{\text{Total annual energy cost}}{\text{Total management, operation, and maintenance cost}} * 100$ Total annual energy cost: Electricity cost incurred in operation of pumps and equipment. Total cost of management, operation, and maintenance (MOM): The cost of providing the irrigation and drainage service excluding capital expenditure.
		Methodology	Total annual energy cost divided by Total cost of management, operation, and maintenance.

		Results	$\frac{20,747,075}{37,926,398} * 100 = 54.704 \%$
		Reference	Table 4.7

Table A1.3: Crop productivity indicators

Crop Productivity Indicators			
21	Total annual crop production (tons)	Definition	Total annual tonnage of crop production.
		Methodology	Sum the crop production of various blocks in the year.
		Results	5,756.96 tonnes
		Reference	Table 4.8
22		Definition	Total annual value of crop production received by producers.

	Total annual value of crop production (Ksh)		The total value of crop production was determined by using existing market prices. The total value of crop production was be computed into a gross value of production as; $GVP = \sum [Y * P]$ GVP - Gross Value of Production Y - The yield of the crop P – The local price of the crop
		Methodology	The yield of the crop multiplied by the local price of the crop.
		Results	282,084,024 Ksh
		Reference	Table 4.8

23	Output per unit command area (Ksh/ha)	Definition	$\frac{\text{Total annual value of crop production}}{\text{Total command area of the system}}$ Total annual value of crop production: Total annual value of crop yield. Total command area of the system: This is the area in the design nominal provided with irrigation infrastructure less the area covered by the canals, drains, roads, and villages.
		Methodology	Total annual value of crop production divided by Total command area of the system. NB: 2183 acres converted to hectares is 884.115
		Results	$\frac{282,084,024}{884.115} = 319,058.07 \text{ Ksh/ha}$
		Reference	Table 4.8 and Table 3.2

24	Output per unit irrigated area (Ksh/ha)	Definition	$\frac{\text{Total annual value of crop production}}{\text{Total annual irrigated area}}$ Total annual value of crop production: Total annual value of crop yield received by producers Total annual irrigated area: The total actual irrigated area during the year
		Methodology	Total annual value of crop production divided by Total annual irrigated area NB: 2183 acres converted to hectares is 884.115
		Results	$\frac{282,084,024}{884.115} = 319,058.07 \text{ Ksh/ha}$
		Reference	Table 4.8 and Table 3.2
25	Output per unit irrigation water delivered (Ksh/ m ³)	Definition	$\frac{\text{Total annual value of crop production}}{\text{Total annual volume of irrigation water delivered}}$ Total annual value of crop production: Total annual value of crop yield received by producers

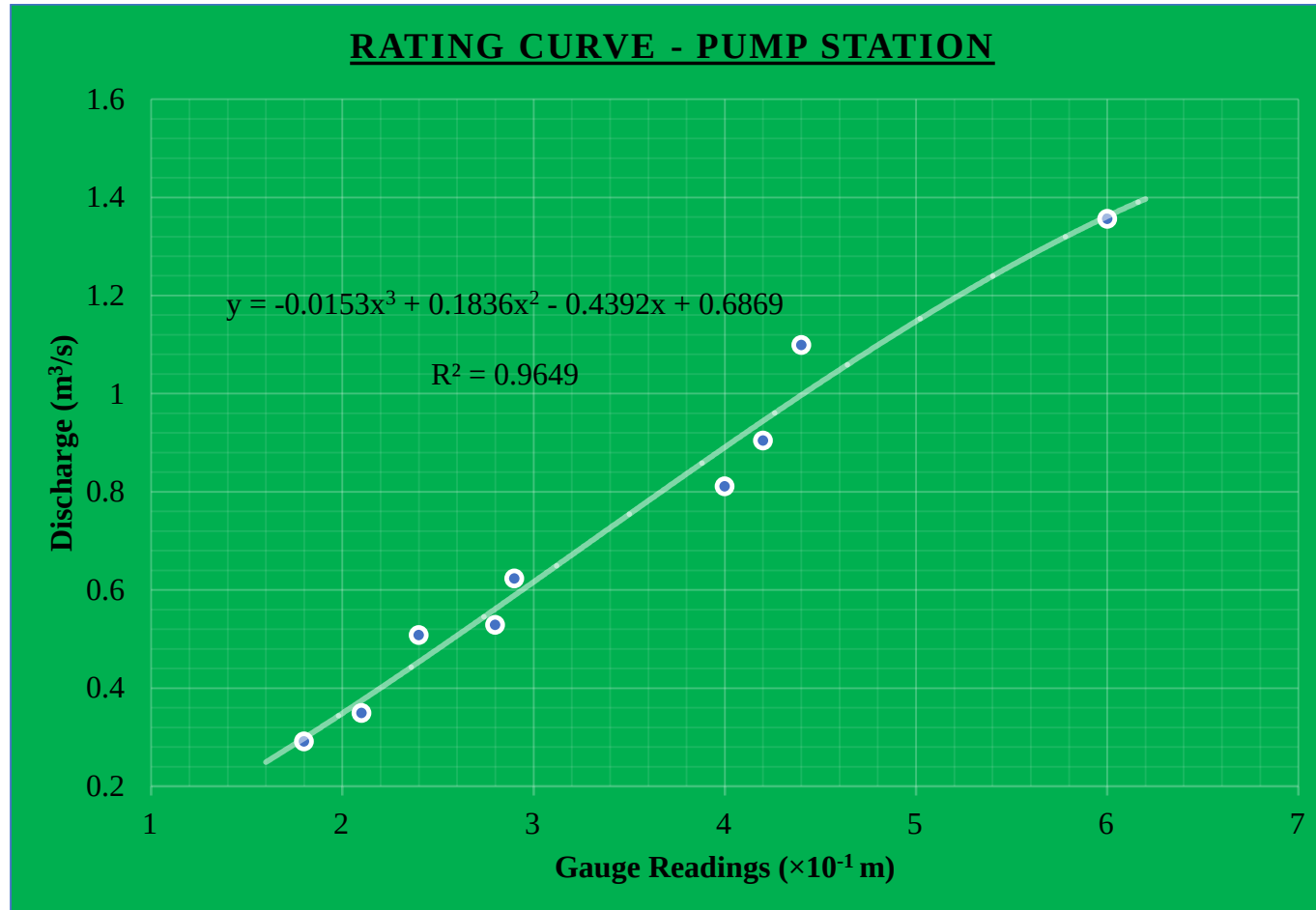
			Total annual volume of irrigation water delivered: Total volume of water delivered to water users over the year measured at the interface between the NIA and the water users in branch canals.
		Methodology	Total annual value of crop production divided by Total annual volume of irrigation water delivered
		Results	$\frac{282,084,024}{11,572,188.36} = 24.376 \text{ Ksh/m}^3$
		Reference	Table 4.8 and Table 4.1
26	Output per unit irrigation water supplied (Ksh/m³)	Definition	$\frac{\text{Total annual value of crop production}}{\text{Total annual volume of irrigation water supplied}}$ Total annual value of crop production: Total annual value of crop yield received by producers. Total annual volume of irrigation water supplied: Total annual volume of water diverted or pumped for irrigation.

		Methodology	Total annual value of crop production divided by Total annual volume of irrigation water supplied
		Results	$\frac{282,084,024}{13,908,173.84} = 20.282 \text{ Ksh}/m^3$
		Reference	Table 4.8 and Table 4.2
27	Output per unit water supplied (Ksh/m ³)	Definition	$\frac{\text{Total annual value of crop production}}{\text{Total annual volume of water supplied}}$ Total annual value of crop production: Total annual value of crop yield received by producers. Total annual volume of water supplied: Total annual volume of water diverted or pumped for irrigation plus total volume of effective rainfall.
		Methodology	Total annual value of crop production divided by Total annual volume of water supplied
		Results	$\frac{282,084,024}{16,902,351.94} = 16.689 \text{ Ksh}/m^3$

		Reference	Table 4.8 and Table 4.3
28	Output per unit crop water demand (Ksh/m³)	Definition	$\frac{\text{Total annual value of crop production}}{\text{Total annual volume of crop water demand}}$ Total annual value of crop production: Total annual value of crop yield received by farmers. Total annual volume of crop water demand: The total annual volume of water used by the crop to meet evapotranspiration needs.
		Methodology	Total annual volume of water supplied divided by Total annual crop production
		Results	$\frac{282,084,024}{23,040,704} = 12.243 \text{ Ksh/m}^3$
		Reference	Table 4.8 and Table 4.4

29	Total annual volume of water supplied per unit crop production (litres/kg)	Definition	$\frac{\text{Total annual volume of water supplied}}{\text{Total annual crop production}}$ Total annual volume of water supplied: Total annual volume of water diverted or pumped for irrigation plus total volume of effective rainfall. Total annual crop production: Total annual crop yield received by the farmers in kilograms.
		Methodology	Total management, operation, and maintenance cost divided by Total annual crop production
		Results	$\frac{16,902,351,940}{5,756,960} = 2,936 \text{ litres/kg (Equivalent of 0.3406kg/m}^3\text{)}$
		Reference	Table 4.3 and Table 4.8

Appendix 2 – Discharge Measurement Calculations

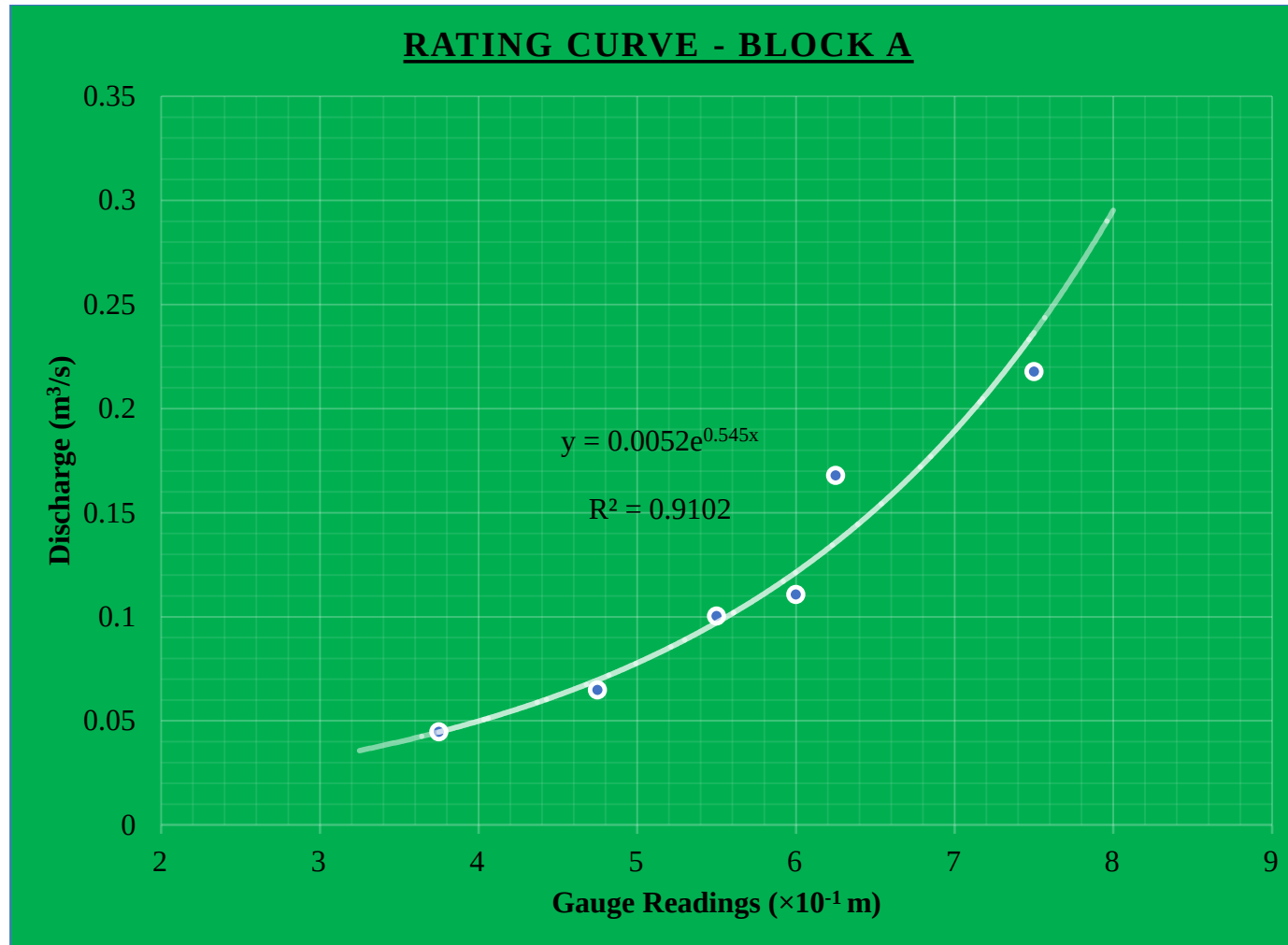


Raw data collected used in rating curve preparation

Reference: Appendix 2, Table A2.1 to Table A2.9

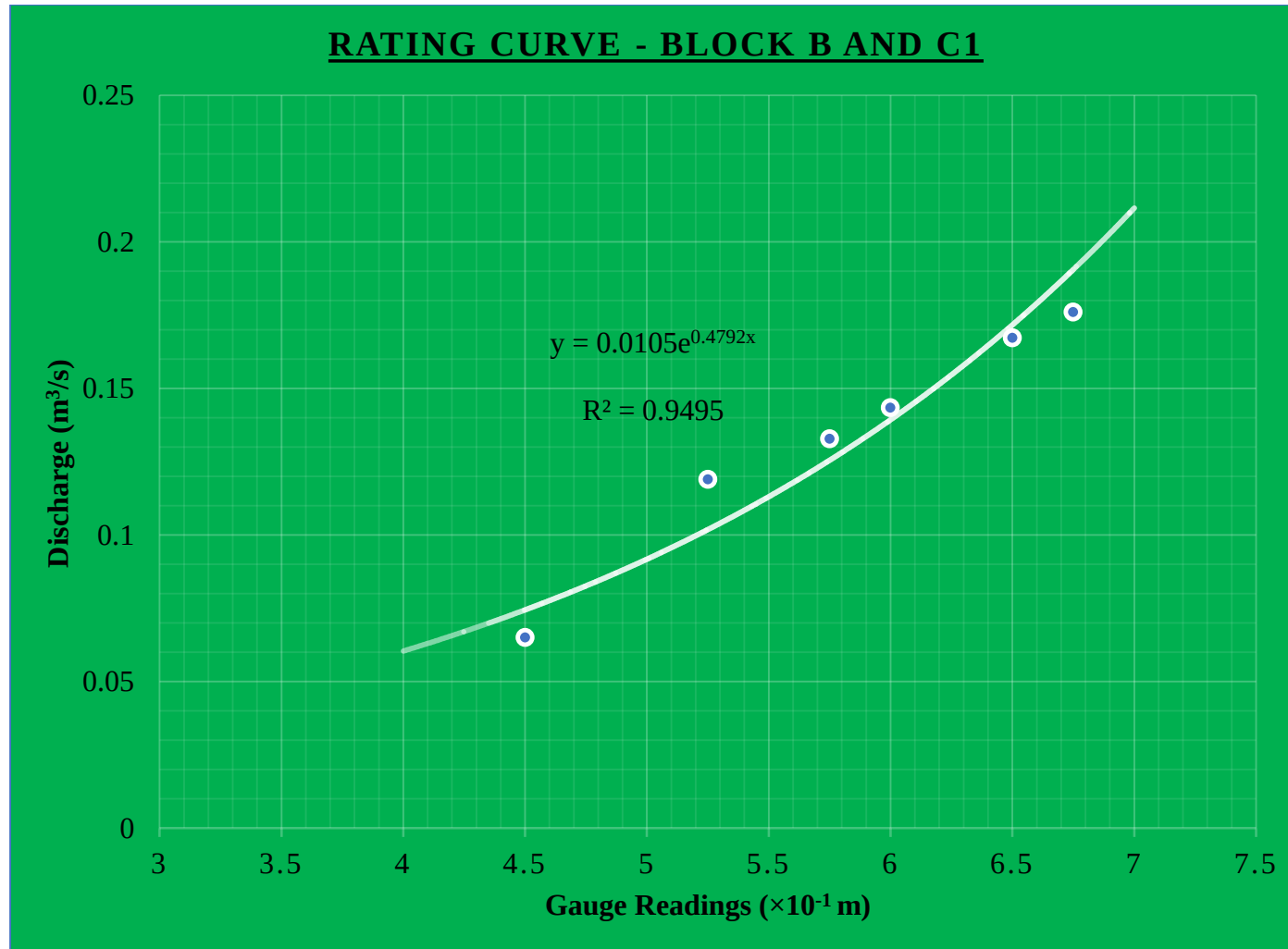
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
2.4	0.5075
2.8	0.5287
4	0.8112
2.1	0.3492
2.9	0.6234
4.2	0.9039
4.4	1.0991
1.8	0.2910
6	1.35579

Figure A2.1 The rating curve – Pump Station



Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.10 to Table A2.15	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
3.75	0.045498
4.75	0.064746
5.5	0.100153
6	0.110715
6.25	0.167742
7.5	0.217727

Figure A2.2 The rating curve – Block A

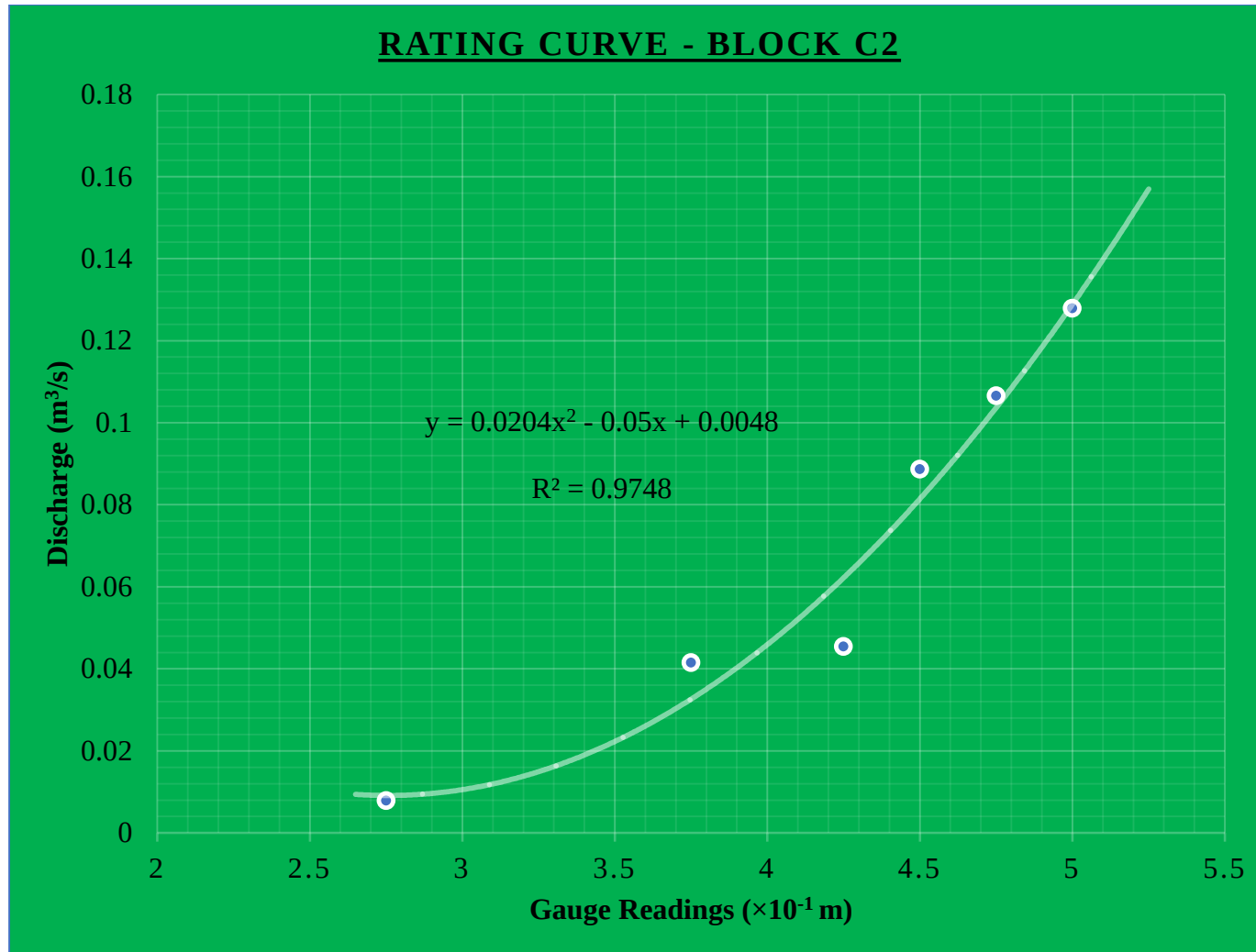


Raw data collected used in rating curve preparation

Reference: Appendix 2,
Table A2.16 to Table A2.21

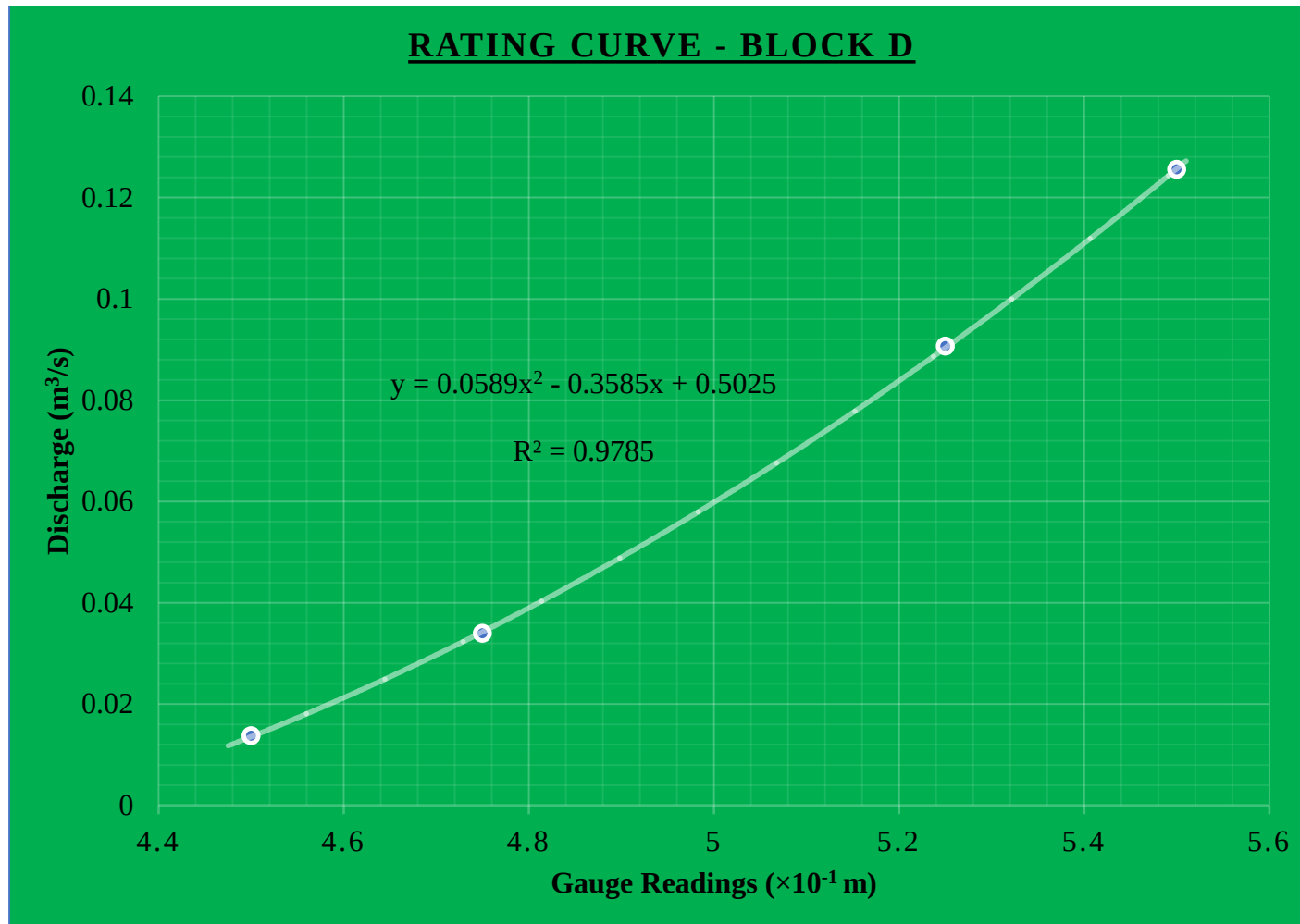
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
4.5	0.0650275
5.25	0.1189846
5.75	0.1328520
6	0.1433696
6.5	0.1672708
6.75	0.1760367

Figure A2.3 The rating curve – Block B and C1



Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.22 to Table A2.27	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
2.75	0.0078750
3.75	0.0414675
4.25	0.0454575
4.5	0.0886652
4.75	0.1065485
5	0.1278600

Figure A2.4 The rating curve – Block C2

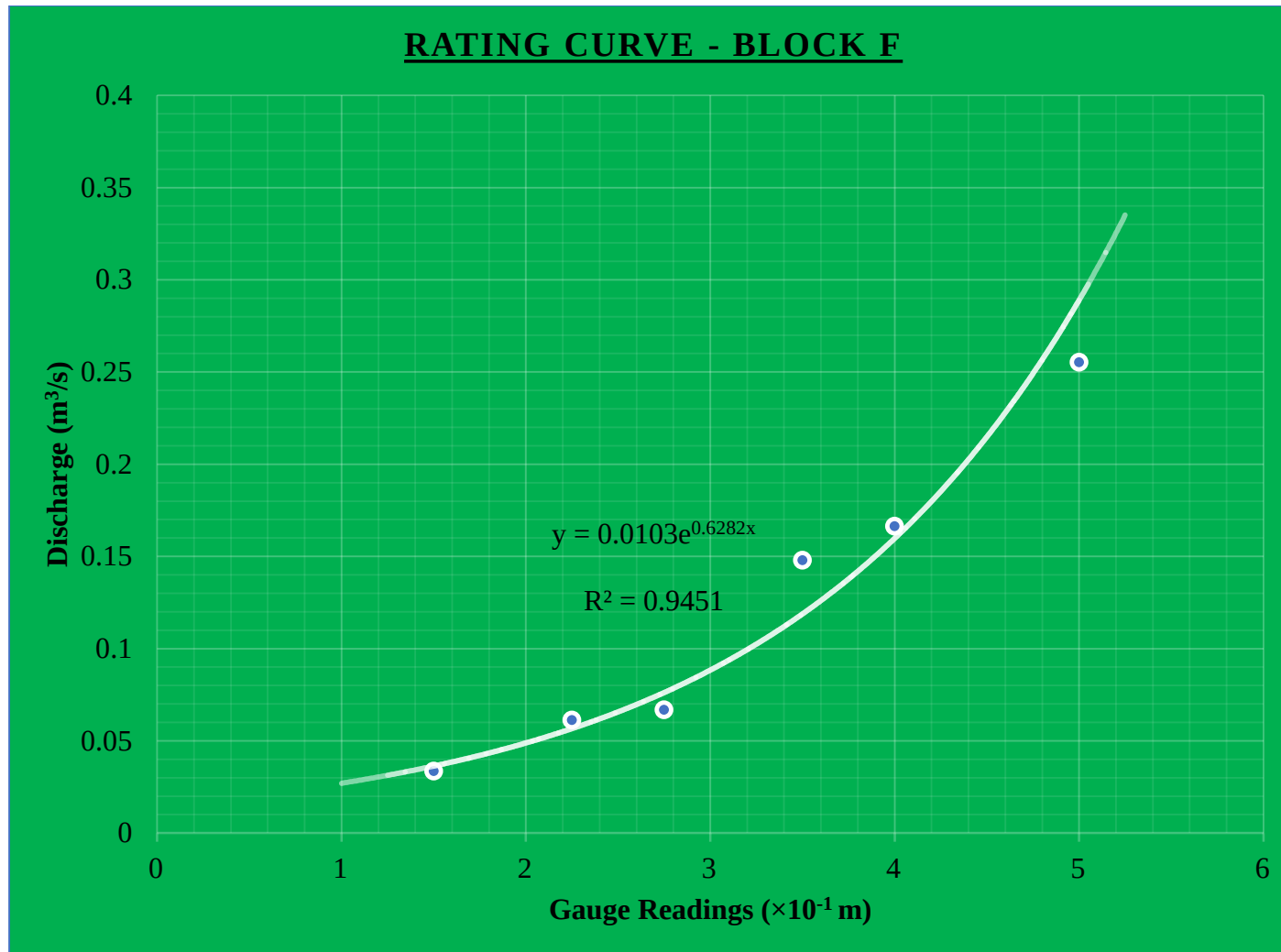


Raw data collected used in rating curve preparation

Reference: Appendix 2,
Table A2.28 to Table A2.31

Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
4.5	0.0137185
4.75	0.0339485
5.25	0.0906260
5.5	0.1255443

Figure A2.5 The rating curve – Block D



Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.32 to Table A2.37	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
1.5	0.0334565
2.75	0.0667933
2.25	0.0612567
3.5	0.1478718
4	0.1664037
5	0.2552712

Figure A2.6 The rating curve – Block F

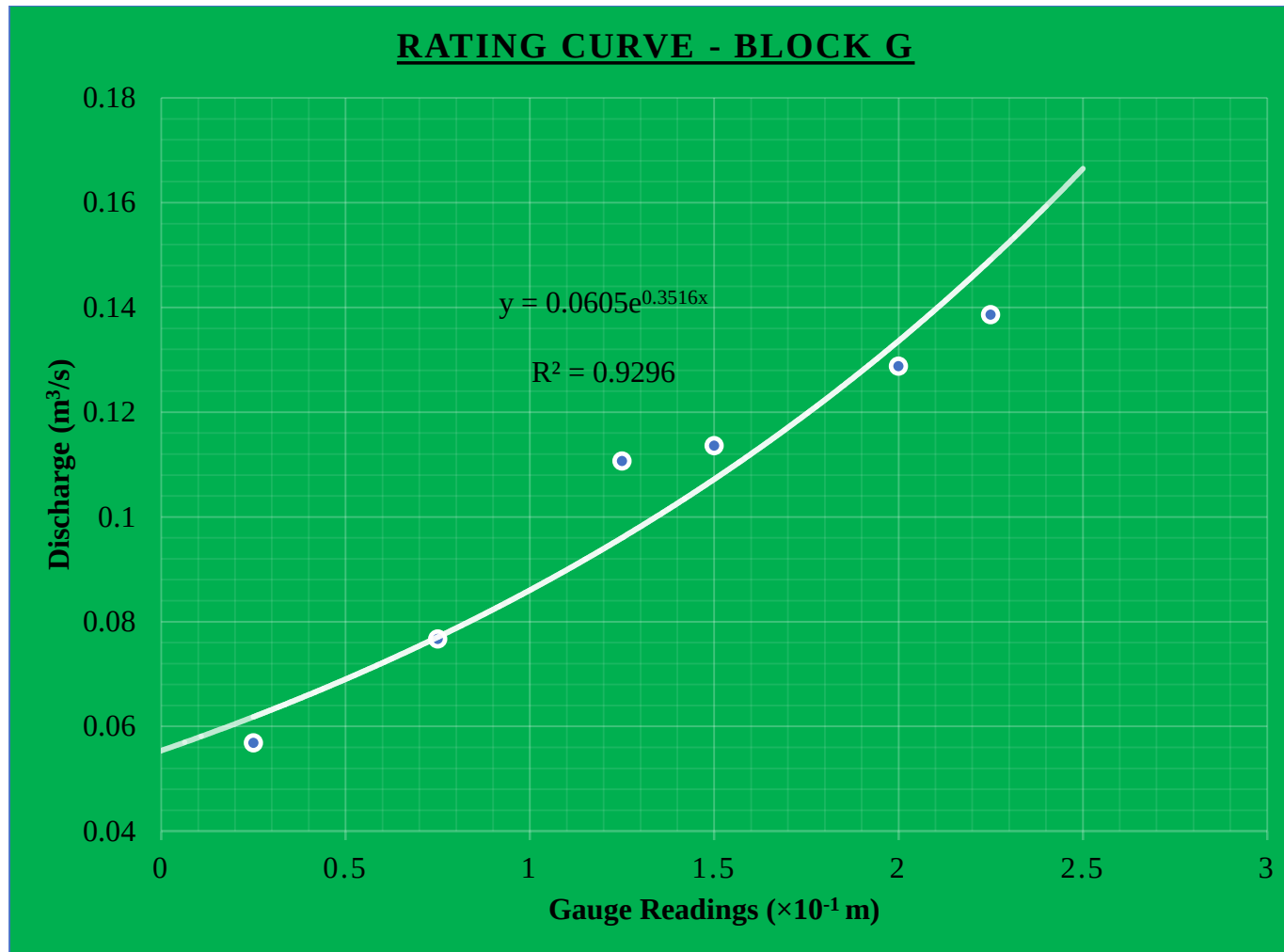
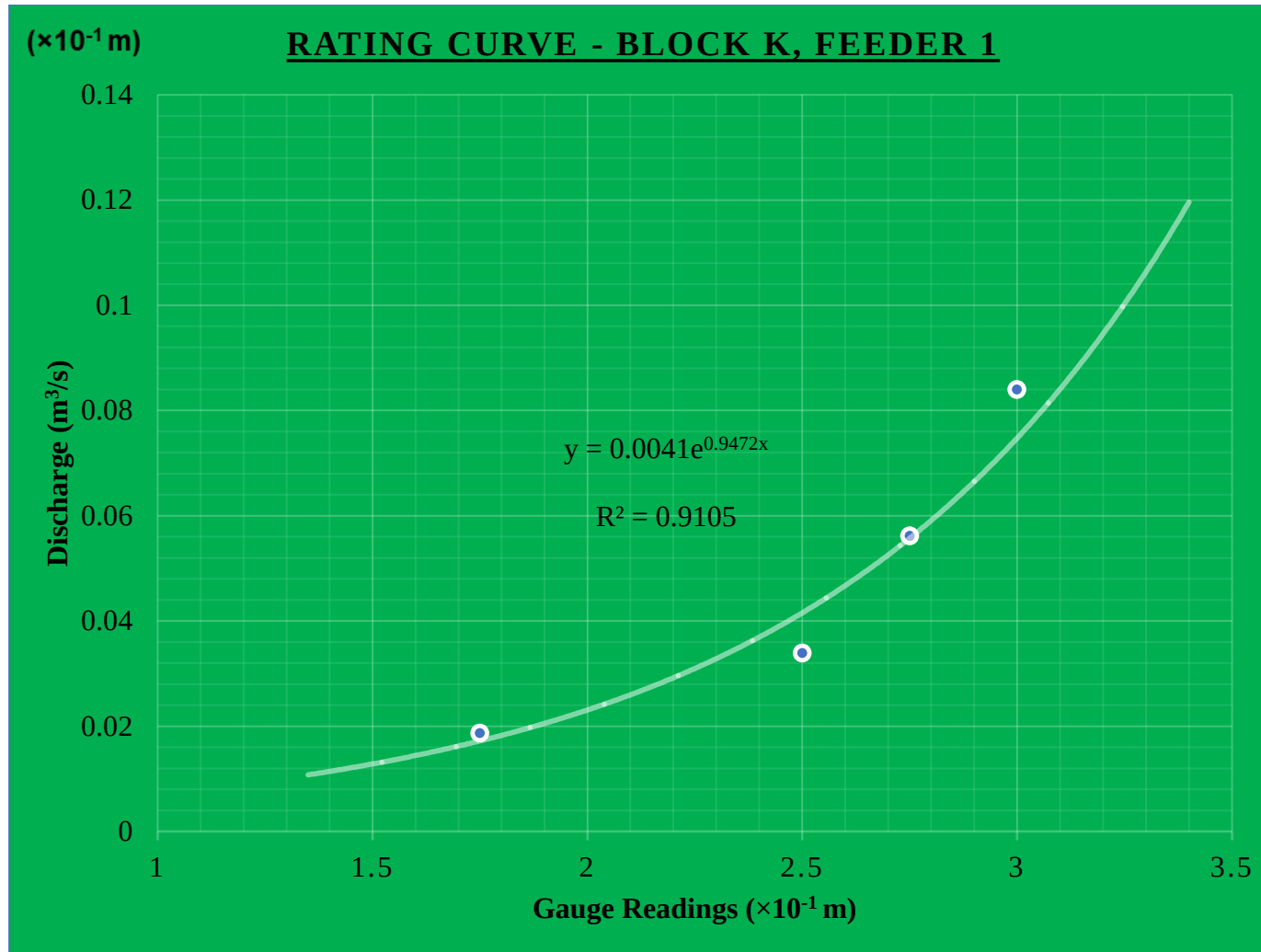


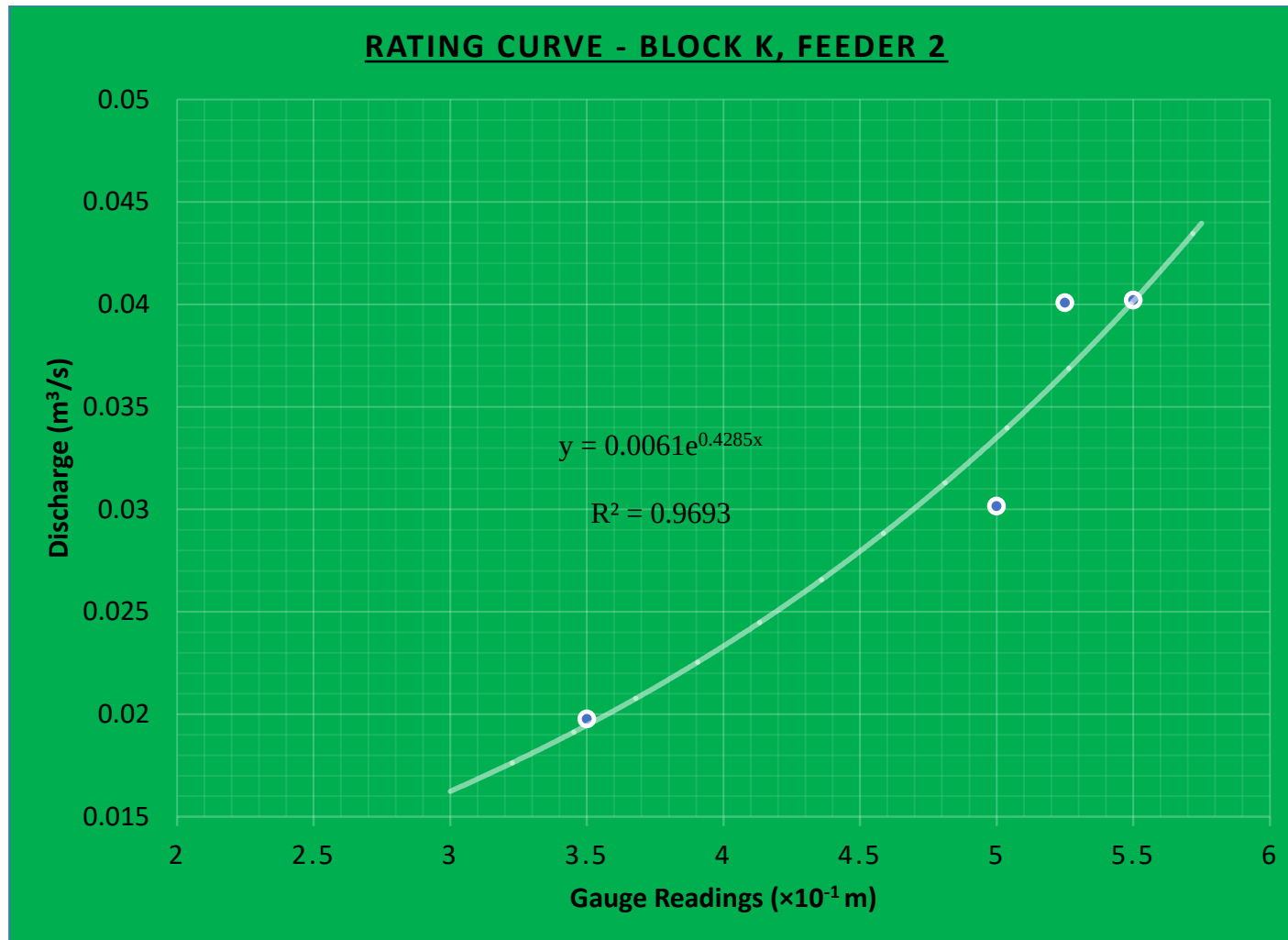
Figure A2.7 The rating curve – Block G

Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.38 to Table A2.43	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
0.25	0.0568508
0.75	0.0766608
1.25	0.1106500
1.5	0.1135597
2	0.1287312
2.25	0.1386130



Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.44 to Table A2.47	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
3	0.083978
2.75	0.056157
2.5	0.033859
1.75	0.018646

Figure A2.8 The rating curve – Block K, Feeder 1

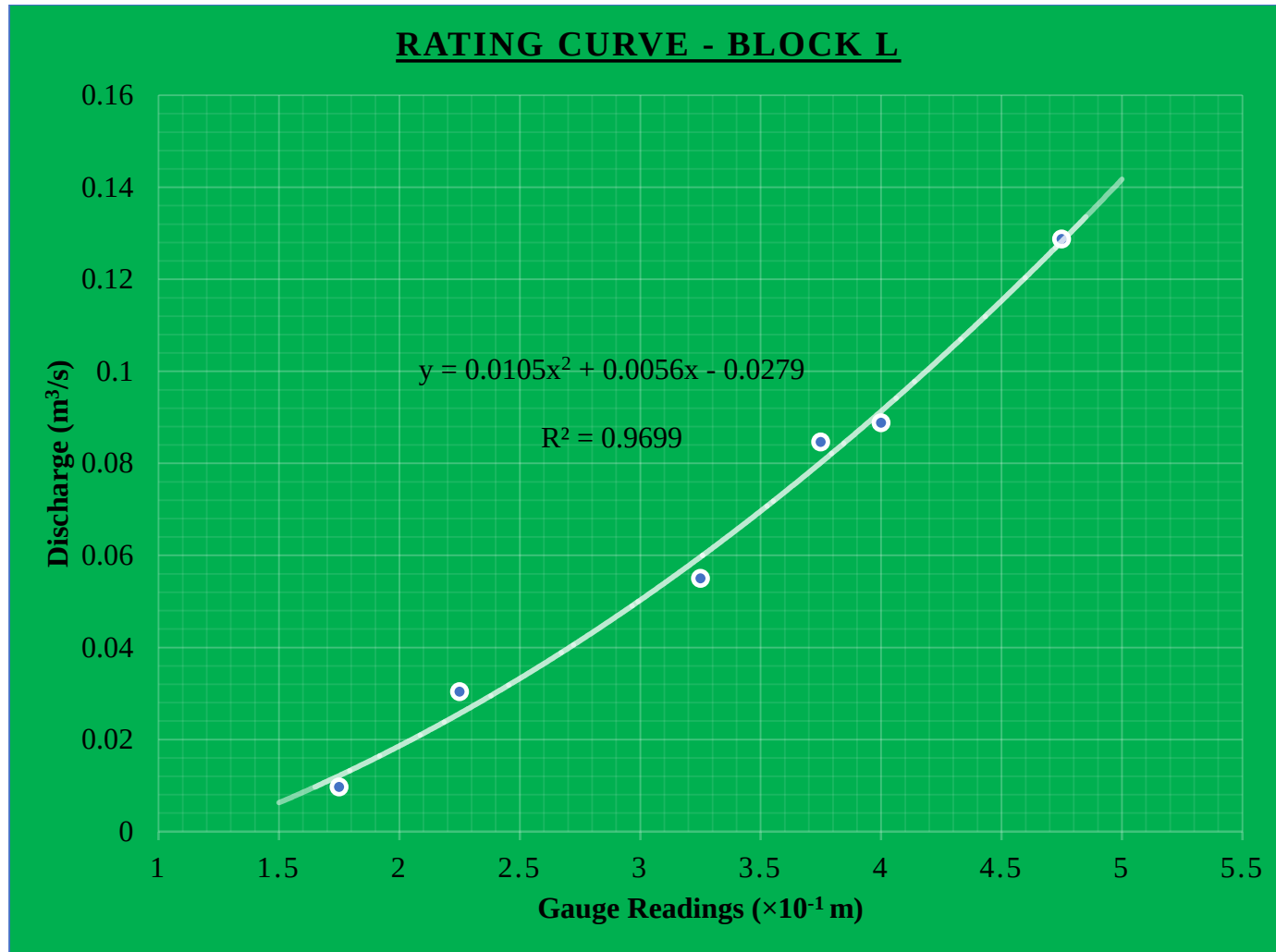


Raw data collected used in rating curve preparation

Reference: Appendix 2,
Table A2.48 to Table A2.51

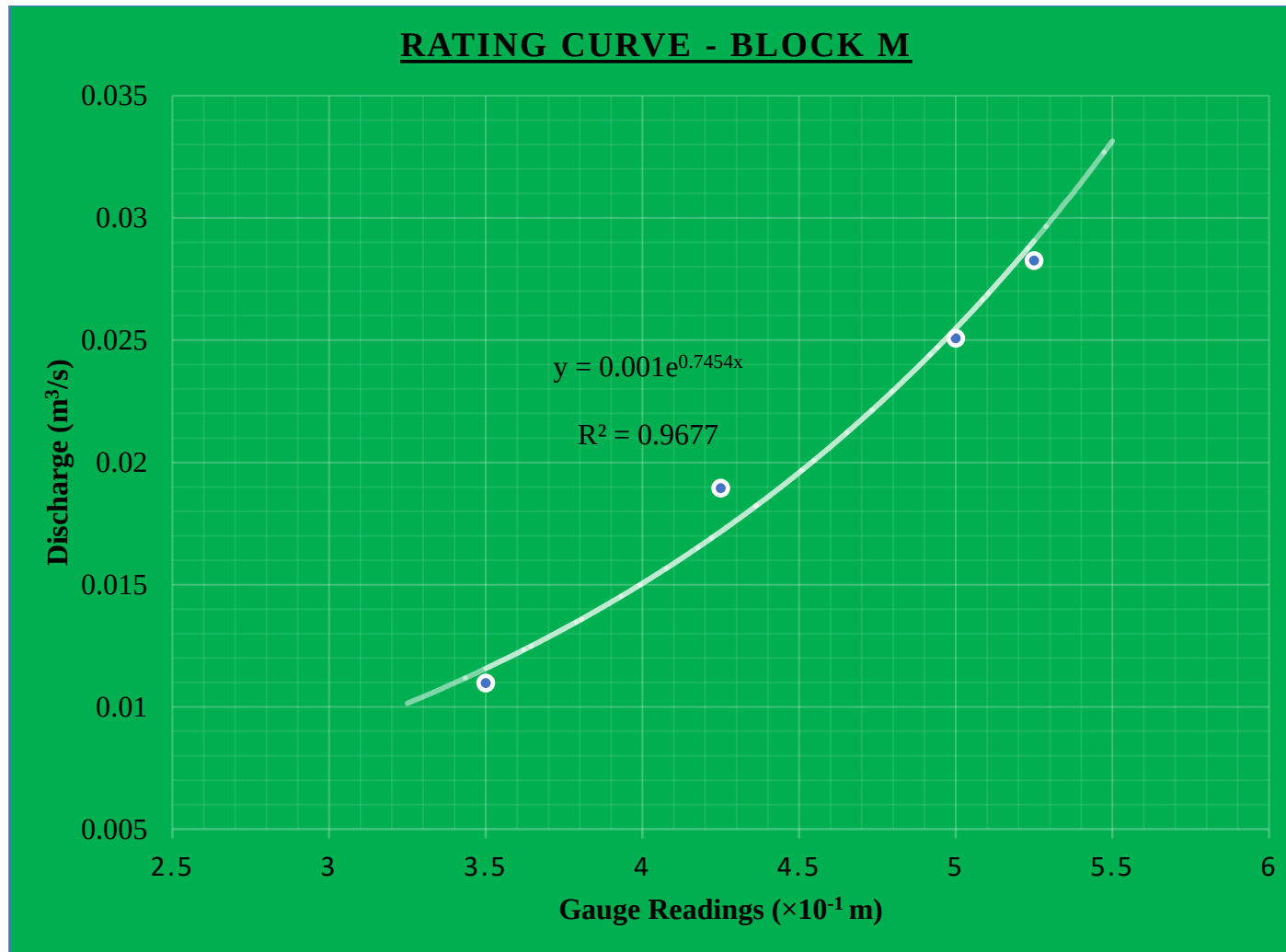
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
3.5	0.0197613
5	0.0301533
5.25	0.0400800
5.5	0.0402120

Figure A2.9 The rating curve – Block K, Feeder 2



Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.52 to Table A2.57	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
4.75	0.1287387
4	0.0887787
3.75	0.0846473
3.25	0.0549900
2.25	0.0303560
1.75	0.0096860

Figure A2.10 The rating curve – Block L

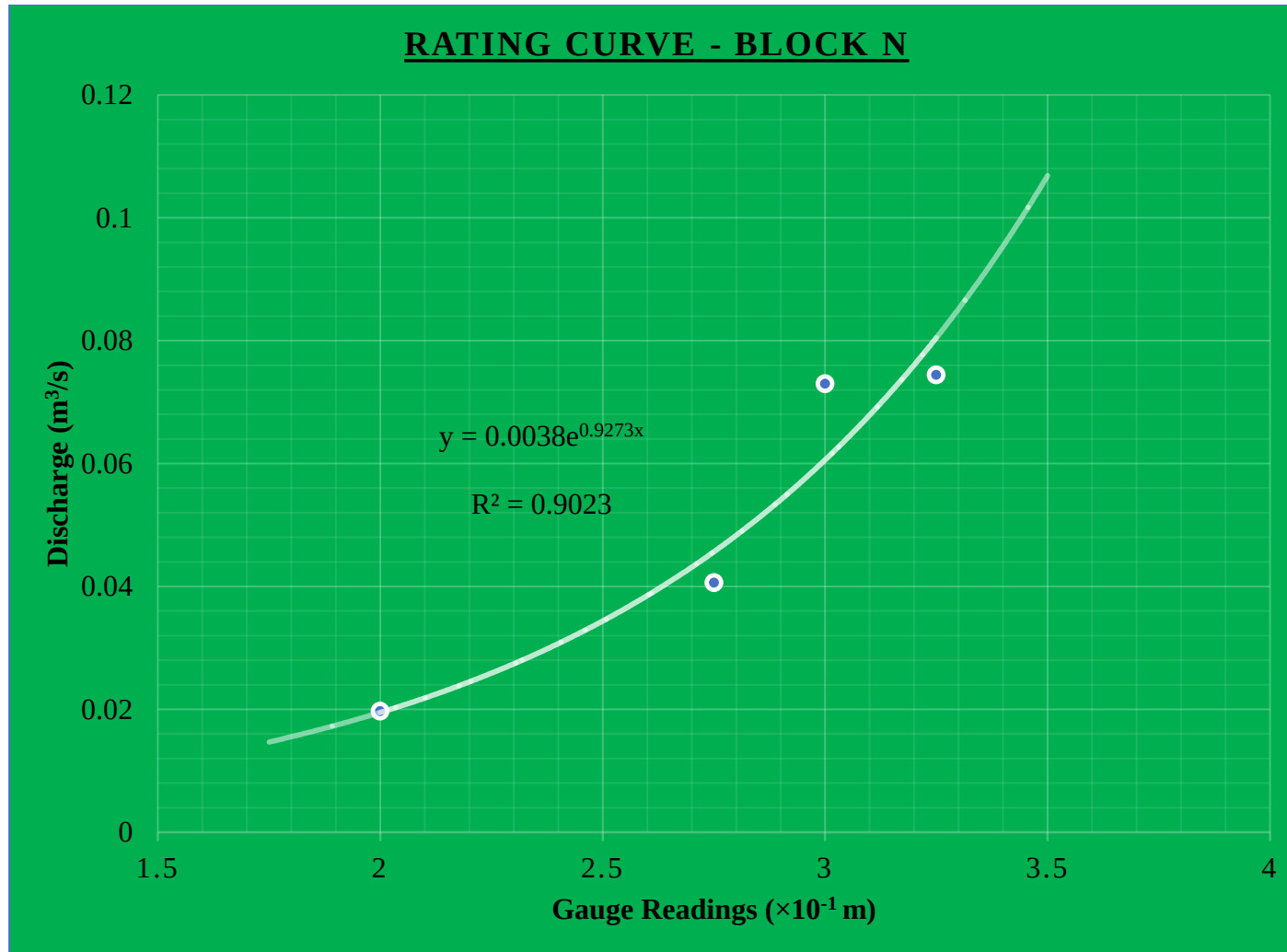


Raw data collected used in rating curve preparation

Reference: Appendix 2,
Table A2.58 to Table A2.61

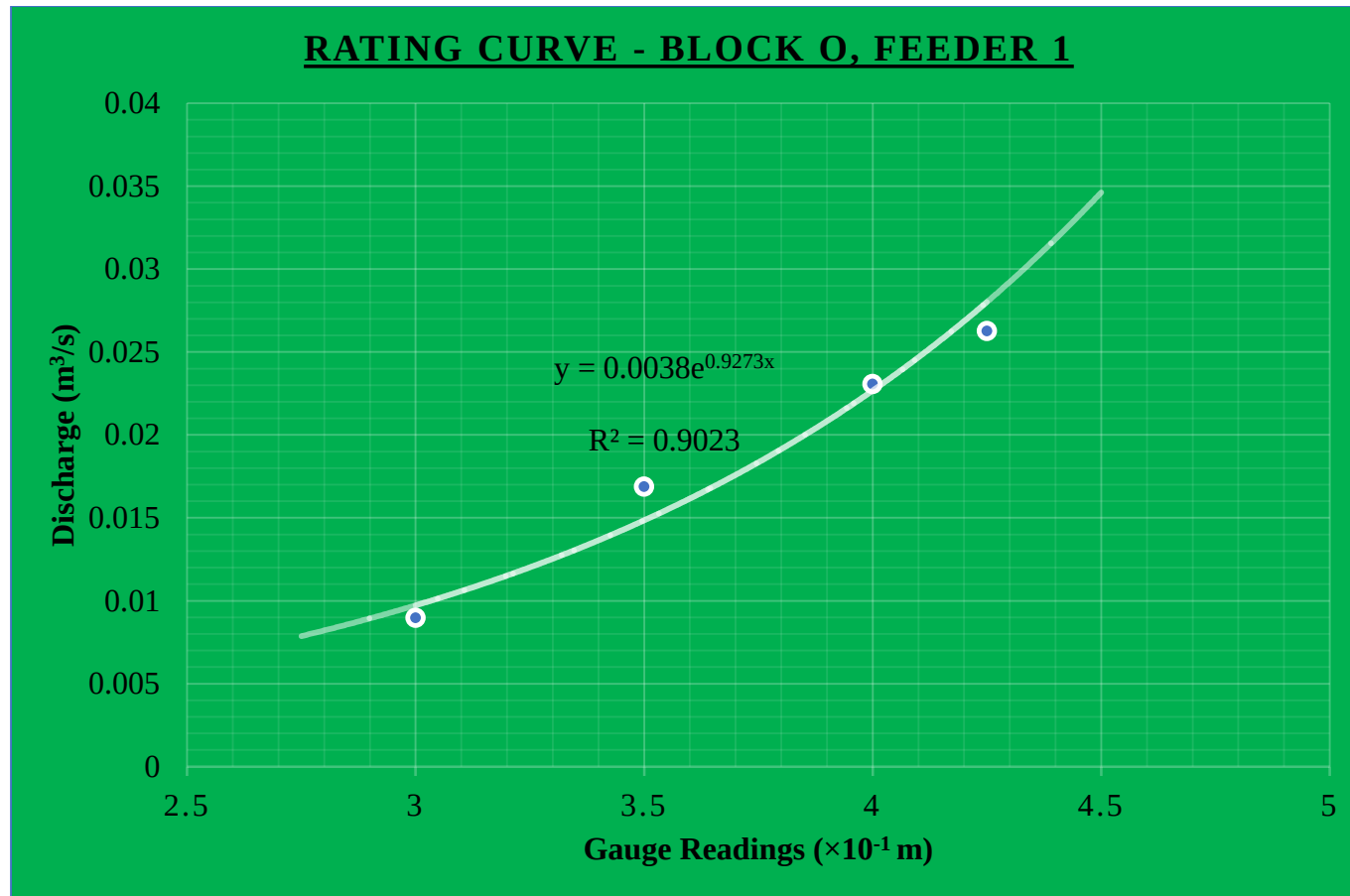
Gauge Readings ($\times 10^{-1}$ m)	Discharge (m^3/s)
5.25	0.0282522
5	0.0250752
4.25	0.0189400
3.5	0.0109650

Figure A2.11 The rating curve – Block M



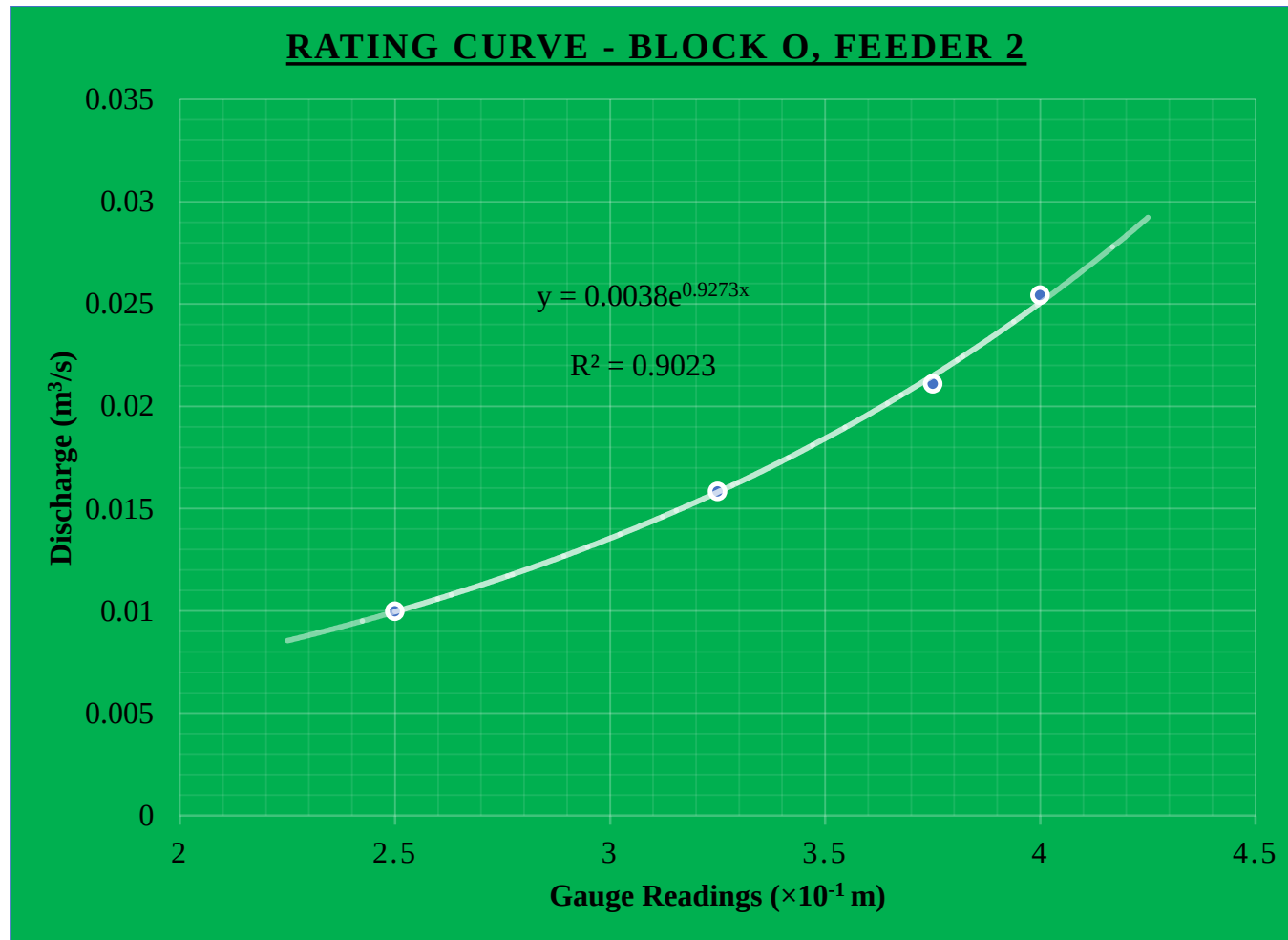
Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.62 to Table A2.65	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
2	0.0196913
2.75	0.0406100
3	0.0729627
3.25	0.0744213

Figure A2.12 The rating curve – Block N



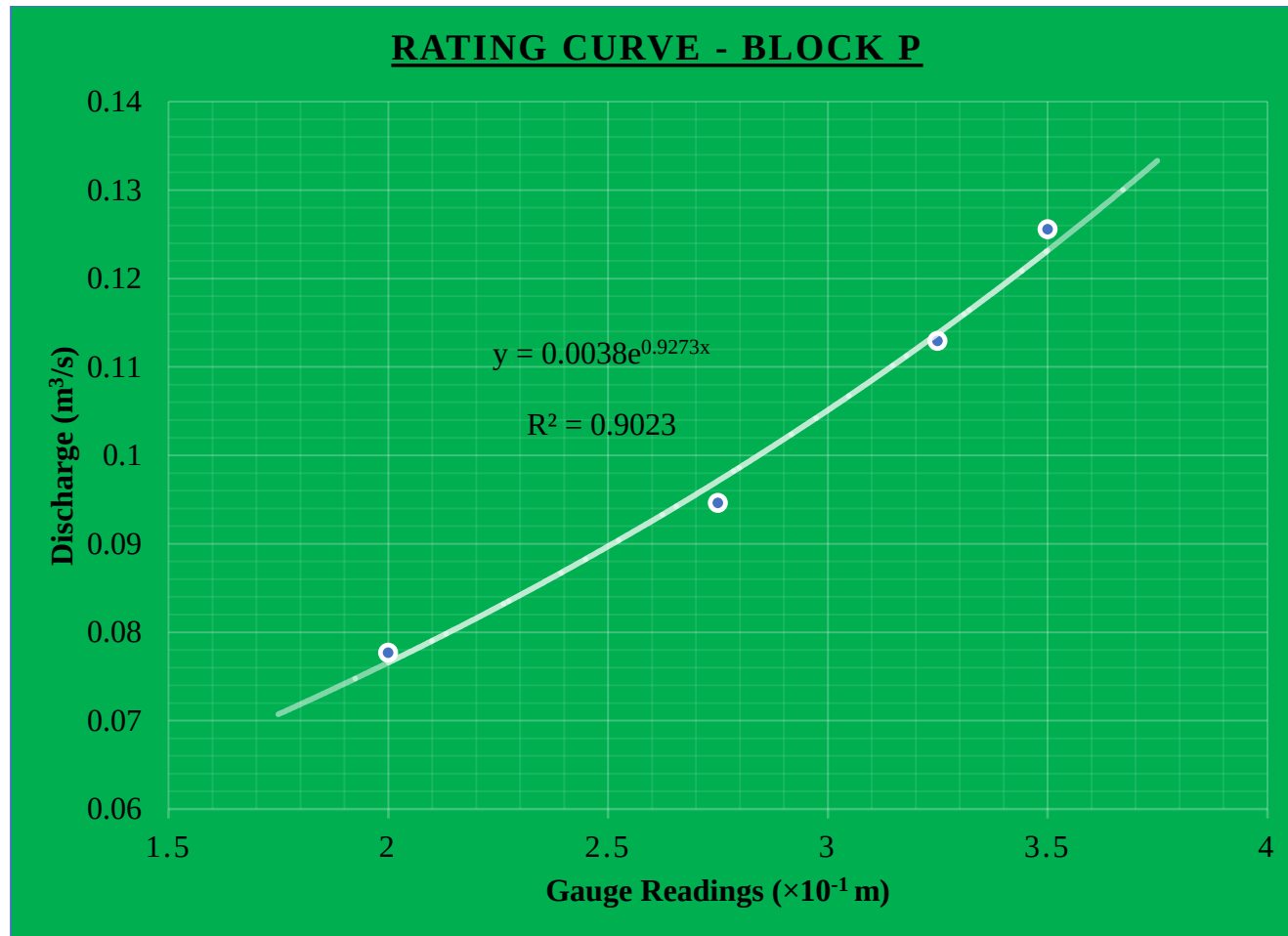
Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.70 to Table A2.73	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
4	0.0254260
3.75	0.0210890
3.25	0.0158400
2.5	0.0099808

Figure A2.13 The rating curve – Block O, Feeder 1



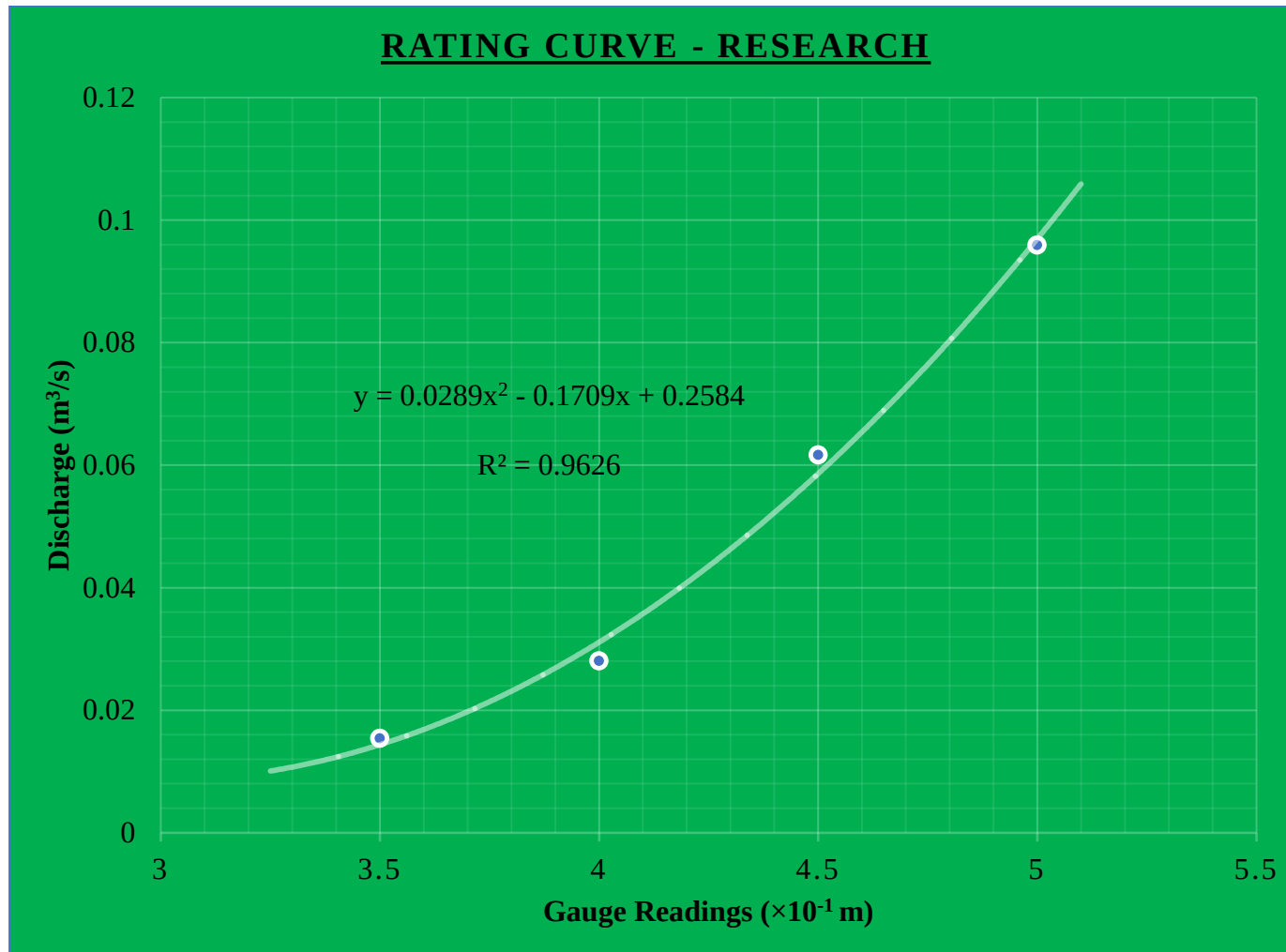
Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.78 to Table A2.81	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
3.5	0.0153918
4	0.0280573
4.5	0.0616508
5	0.0959392

Figure A2.14 The rating curve – Block O, Feeder 2



Raw data collected used in rating curve preparation	
Reference: Appendix 2, Table A2.66 to Table A2.69	
Gauge Readings ($\times 10^{-1} \text{ m}$)	Discharge (m^3/s)
4.25	0.0262657
4.0	0.0230587
3.5	0.0168780
3.0	0.0089758

Figure A2.15 The rating curve – Block P



**Raw data collected used in
rating curve preparation**

**Reference: Appendix 2,
Table A2.74 to Table A2.77**

Gauge Readings ($\times 10^{-1}$ m)	Discharge (m^3/s)
2.0	0.077667
2.75	0.094602
3.25	0.112944
3.5	0.125547

Figure A2.16 The rating curve – Research



Ahero Irrigation Research Station

Discharge Data Collection and Calculation Template

Table A2.1: Pump station - Discharge measurement 1

Day:			Day 1								
Date:			April 2022								
Location:			Pump Station								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2.4								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	40	20	8	1.25	0.011	0.018	0.017	0.015333	0.25	0.0038333
R1	40	40	40	16	1	0.220	0.225	0.214	0.219667	0.40	0.0878667
R2	40	46	43	17.2	1	0.213	0.211	0.243	0.222333	0.43	0.0956033
R3	46	48	47	18.8	1	0.207	0.206	0.211	0.208000	0.47	0.0977600
R4	48	42	45	18	1	0.238	0.219	0.222	0.226333	0.45	0.1018500
R5	42	38	40	16	1	0.199	0.230	0.220	0.216333	0.40	0.0865333
TR	38	20	29	11.6	1.25	0.091	0.085	0.106	0.094000	0.3625	0.0340750
Total Q										0.5075217	



Ahero Irrigation Research Station

Discharge Data Collection and Calculation Template

Table A2.2: Pump station - Discharge measurement 2

Day:			Day 1								
Date:			April 2022								
Location:			Pump Station – Pump 2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2.8								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	37	18.5	7.4	1.25	0.115	0.095	0.1	0.103333	0.23125	0.023895
R1	37	40	38.5	15.4	1	0.223	0.227	0.219	0.223000	0.38500	0.085855
R2	40	44	42	16.8	1	0.239	0.244	0.255	0.246000	0.42000	0.103320
R3	44	45	44.5	17.8	1	0.262	0.272	0.276	0.270000	0.44500	0.120150
R4	45	38	41.5	16.6	1	0.262	0.249	0.2	0.237000	0.41500	0.098355
R5	38	36	37	14.8	1	0.211	0.219	0.201	0.210333	0.37000	0.077823
TR	36	15	25.5	10.2	1.25	0.064	0.049	0.069	0.060667	0.31875	0.019337
										Total Q	0.528704

Table A2.3: Pump station - Discharge measurement 3

Day:			Day 1								
Date:			April 2022								
Location:			Pump Station								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			4.0								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	0	48	24	9.6	1.5	0.058	0.035	0.011	0.034667	0.360	0.0124800
R1	48	50	49	19.6	1	0.336	0.258	0.269	0.287667	0.490	0.1409567
R2	50	55	52.5	21	1	0.235	0.226	0.230	0.230333	0.525	0.1209250
R3	55	58	56.5	22.6	1	0.296	0.304	0.319	0.306333	0.565	0.1730783
R4	58	55	56.5	22.6	1	0.311	0.317	0.325	0.317667	0.565	0.1794817
R5	55	48	51.5	20.6	1	0.240	0.267	0.259	0.255333	0.515	0.1314967
TR	48	19	33.5	13.4	1.5	0.091	0.115	0.109	0.105000	0.5025	0.0527625
Total Q											0.8111808



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Discharge Data Collection and Calculation Template

Table A2.4: Pump station - Discharge measurement 4

			Day 1								
Date:			April 2022								
Location:			Pump Station – Pump 1								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading (×10 ⁻¹ m)			2.1								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	0	31	15.5	6.2	1	0.118	0.109	0.101	0.109333	0.1550	0.016947
R1	31	31	31	12.4	1	0.188	0.200	0.207	0.198333	0.3100	0.061483
R2	31	35.5	33.25	13.3	1	0.192	0.181	0.177	0.183333	0.3325	0.060953
R3	35.5	37	36.25	14.5	1	0.209	0.197	0.211	0.205667	0.3625	0.074554
R4	37	30.5	33.75	13.5	1	0.193	0.186	0.174	0.184333	0.3375	0.062212
R5	30.5	30	30.25	12.1	1	0.191	0.196	0.176	0.187667	0.3025	0.056769
TR	30	0	15	6	1	0.098	0.113	0.115	0.108667	0.1500	0.016300
Total Q											0.349224

Table A2. 6: Pump station - Discharge measurement 6

			Day 1								
Date:			April 2022								
Location:			Pump Station								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			4.2								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	0	76	38	15.2	2.15	0.001	0.001	0.001	0.001000	0.81700	0.0008170
R1	76	69	72.5	29	1	0.197	0.167	0.192	0.185333	0.72500	0.1343667
R2	69	72.5	70.75	28.3	1	0.241	0.284	0.270	0.265000	0.70750	0.1874875
R3	72.5	76.5	74.5	29.8	1	0.240	0.244	0.236	0.240000	0.74500	0.1788000
R4	76.5	72.5	74.5	29.8	1	0.231	0.211	0.192	0.211333	0.74500	0.1574433
R5	72.5	69	70.75	28.3	1	0.273	0.299	0.257	0.276333	0.70750	0.1955058
TR	69	0	34.5	13.8	2.15	0.066	0.046	0.088	0.066667	0.74175	0.0494500
Total Q											0.9038703



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Discharge Data Collection and Calculation Template

Table A2.7: Pump station - Discharge measurement 7

		Day 1									
Date:		April 2022									
Location:		Pump Station									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		4.4									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	40	20	8	1.3	0.045	0.044	0.025	0.038000	0.2600	0.0098800
R1	40	58	49	19.6	2	0.324	0.324	0.337	0.328333	0.9800	0.3217667
R2	58	64	61	24.4	2	0.281	0.292	0.305	0.292667	1.2200	0.3570533
R3	64	57	60.5	24.2	2	0.323	0.324	0.253	0.300000	1.2100	0.3630000
R4	57	0	28.5	11.4	1.3	0.162	0.085	0.137	0.128000	0.3705	0.0474240
R5											
TR											
										Total Q	1.099124

Table A2.8: Pump station - Discharge measurement 8

			Day 1								
Date:			April 2022								
Location:			Pump Station – Pump 4								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading (×10 ⁻¹ m)			1.8								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m²)	Discharge Q = A*V Q (m³/s)
	Left	Right									
TL	0	45	22.5	9	1.1	0.001	0.006	0.006	0.004333	0.2475	0.001072500
R1	45	47.5	46.25	18.5	1	0.109	0.121	0.117	0.115667	0.4625	0.053495833
R2	47.5	47	47.25	18.9	1	0.109	0.119	0.111	0.113000	0.4725	0.053392500
R3	47	47	47	18.8	1	0.156	0.157	0.148	0.153667	0.4700	0.072223333
R4	47	42	44.5	17.8	1	0.116	0.119	0.108	0.114333	0.4450	0.050878333
R5	42	38.5	40.25	16.1	1	0.114	0.105	0.101	0.106667	0.4025	0.042933333
TR	38.5	0	19.25	7.7	1.1	0.09	0.068	0.083	0.080333	0.21175	0.017010583
Total Q										0.291006417	



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Table A2.9: Pump station - Discharge measurement 9

		Day 1									
Date:		April 2022									
Location:		Pump Station									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		6									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	84.5	42.25	16.9	2.35	0.056	0.038	0.069	0.054333	0.99288	0.0539462
R1	84.5	95	89.75	35.9	1	0.220	0.202	0.216	0.212667	0.89750	0.1908683
R2	95	95	95	38	1	0.283	0.29	0.285	0.286000	0.95000	0.2717000
R3	95	94	94.5	37.8	1	0.285	0.309	0.303	0.299000	0.94500	0.2825550
R4	94	92	93	37.2	1	0.288	0.308	0.288	0.294667	0.93000	0.2740400
R5	92	87.5	89.75	35.9	1	0.244	0.282	0.286	0.270667	0.89750	0.2429233
TR	87.5	0	43.75	17.5	2.35	0.012	0.042	0.062	0.038667	1.02813	0.0397542
										Total Q	1.3557870



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Table A2.10: Block A - Discharge measurement 1

		Day 2									
Date:		April 2022									
Location:		Block A									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		3.75									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	26	13	5.2	0.5	0.052	0.028	0.040	0.040000	0.065	0.0026000
R1	26	30	28	11.2	0.5	0.214	0.222	0.217	0.217667	0.140	0.0304733
R2	30	0	15	6	0.5	0.189	0.143	0.165	0.165667	0.075	0.0124250
R3											
R4											
R5											
TR											
										Total Q	0.0454983



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Table A2.11: Block A - Discharge measurement 2

		Day 2									
Date:		April 2022									
Location:		Block A									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		4.75									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	30	15	6	0.5	0.131	0.103	0.093	0.109	0.075	0.0081750
R1	30	32	31	12.4	0.8	0.207	0.198	0.189	0.198	0.248	0.0491040
R2	32	0	16	6.4	0.5	0.104	0.078	0.098	0.093	0.080	0.0074667
R3											
R4											
R5											
TR											
										Total Q	0.0647457



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Table A2.12: Block A - Discharge measurement 3

		Day 2									
Date:		April 2022									
Location:		Block A									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		5.5									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	38	19	7.6	0.5	0.107	0.167	0.156	0.143333	0.0950	0.0136167
R1	38	35	36.5	14.6	1	0.223	0.232	0.204	0.219667	0.3650	0.0801783
R2	35	0	17.5	7	0.5	0.083	0.066	0.069	0.072667	0.0875	0.0063583
R3											
R4											
R5											
TR											
										Total Q	0.1001533



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Table A2.14: Block A - Discharge measurement 5

		Day 2									
Date:		April 2022									
Location:		Block A									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		6.25									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	51	25.5	10.2	0.6	0.144	0.156	0.177	0.159000	0.153	0.0243270
R1	51	41	46	18.4	1	0.238	0.264	0.244	0.248667	0.460	0.1143867
R2	41	0	20.5	8.2	0.6	0.232	0.220	0.256	0.236000	0.123	0.0290280
R3											
R4											
R5											
TR											
										Total Q	0.1677417



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Table A2.16: Block B and C1 - Discharge measurement 1

		Day 3									
Date:		April 2022									
Location:		Block B and C1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		4.5									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	37	18.5	7.4	0.75	0.006	0.002	0.004	0.004	0.13875	0.0005550
R1	37	37	37	14.8	1	0.118	0.135	0.137	0.130	0.37000	0.0481000
R2	37	0	18.5	7.4	0.75	0.115	0.118	0.121	0.118	0.13875	0.0163725
R3											
R4											
R5											
TR											
										Total Q	0.0650275



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Table A2.17: Block B and C1 - Discharge measurement 2

		Day 3									
Date:		April 2022									
Location:		Block B and C1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		5.25									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	43	21.5	8.6	0.75	0.020	0.023	0.034	0.025667	0.16125	0.0041388
R1	43	43	43	17.2	1	0.218	0.189	0.194	0.200333	0.43000	0.0861433
R2	43	0	21.5	8.6	0.75	0.176	0.180	0.178	0.178000	0.16125	0.0287025
R3											
R4											
R5											
TR											
										Total Q	0.1189846



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Table A2.18: Block B and C1 - Discharge measurement 3

		Day 3									
Date:		April 2022									
Location:		Block B and C1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		5.75									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	55	27.5	11	0.8	0.122	0.096	0.089	0.102333	0.220	0.0225133
R1	55	51	53	21.2	1	0.149	0.168	0.179	0.165333	0.530	0.0876267
R2	51	0	25.5	10.2	0.8	0.106	0.109	0.119	0.111333	0.204	0.0227120
R3											
R4											
R5											
TR											
										Total Q	0.132852



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Table A2.19: Block B and C1 - Discharge measurement 4

		Day 3									
Date:		April 2022									
Location:		Block B and C1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		6									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	47	23.5	9.4	0.75	0.039	0.050	0.032	0.040333	0.17625	0.0071088
R1	47	47	47	18.8	1	0.229	0.222	0.196	0.215667	0.47000	0.1013633
R2	47	0	23.5	9.4	0.75	0.231	0.180	0.183	0.198000	0.17625	0.0348975
R3											
R4											
R5											
TR											
										Total Q	0.1433696



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Discharge Data Collection and Calculation Template

Table A2.20: Block B and C1 - Discharge measurement 5

			Day 3								
Date:			April 2022								
Location:			Block B and C1								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			6.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	50	25	10	0.75	0.095	0.098	0.116	0.103000	0.1875	0.0193125
R1	50	50	50	20	1	0.219	0.213	0.200	0.210667	0.5000	0.1053333
R2	50	0	25	10	0.75	0.234	0.220	0.228	0.227333	0.1875	0.0426250
R3											
R4											
R5											
TR											
										Total Q	0.1672708

Table A2.21: Block B and C1 - Discharge measurement 6

			Day 3								
Date:			April 2022								
Location:			Block B and C1								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			6.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	53	26.5	10.6	0.75	0.064	0.081	0.079	0.074667	0.19875	0.0148400
R1	53	51	52	20.8	1	0.189	0.244	0.241	0.224667	0.52000	0.1168267
R2	51	0	25.5	10.2	0.75	0.223	0.233	0.240	0.232000	0.19125	0.0443700
R3											
R4											
R5											
TR											
Total Q										0.1760367	



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Discharge Data Collection and Calculation Template

Table A2.22: Block C2 - Discharge measurement 1

			Day 4								
Date:			April 2022								
Location:			Block C2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	25	12.5	5	0.75	0.014	0.019	0.050	0.027667	0.09375	0.0025938
R1	25	0	12.5	5	0.75	0.055	0.052	0.062	0.056333	0.09375	0.0052813
R2											
R3											
R4											
R5											
TR											
Total Q											0.007875



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Discharge Data Collection and Calculation Template

Table A2.23: Block C2 - Discharge measurement 2

		Day 4									
Date:		April 2022									
Location:		Block C2									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		3.75									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	27	13.5	5.4	0.5	0.042	0.042	0.041	0.041667	0.0675	0.0028125
R1	27	27	27	10.8	1	0.121	0.120	0.117	0.119333	0.2700	0.0322200
R2	27	0	13.5	5.4	0.5	0.098	0.099	0.089	0.095333	0.0675	0.0064350
R3											
R4											
R5											
TR											
										Total Q	0.0414675



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Discharge Data Collection and Calculation Template

Table A2.24: Block C2 - Discharge measurement 3

		Day 4									
Date:		April 2022									
Location:		Block C2									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		4.25									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	29	14.5	5.8	0.5	0.041	0.04	0.036	0.039000	0.0725	0.0028275
R1	29	31	30	12	1	0.146	0.109	0.100	0.118333	0.3000	0.0355000
R2	31	0	15.5	6.2	0.5	0.087	0.09	0.099	0.092000	0.0775	0.0071300
R3											
R4											
R5											
TR											
										Total Q	0.0454575



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Discharge Data Collection and Calculation Template

Table A2.25: Block C2 - Discharge measurement 4

		Day 4									
Date:		April 2022									
Location:		Block C2									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		4.5									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	33	16.5	6.6	0.65	0.037	0.039	0.041	0.039000	0.10725	0.0041828
R1	33	29	31	12.4	1	0.282	0.252	0.248	0.260667	0.31000	0.0808067
R2	29	0	14.5	5.8	0.65	0.036	0.041	0.04	0.039000	0.09425	0.0036758
R3											
R4											
R5											
TR											
										Total Q	0.0886652



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Discharge Data Collection and Calculation Template

Table A2.26: Block C2 - Discharge measurement 5

		Day 4									
Date:		April 2022									
Location:		Block C2									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		4.75									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	37	18.5	7.4	0.65	0.041	0.044	0.047	0.044	0.12025	0.0052910
R1	37	35	36	14.4	1	0.282	0.257	0.265	0.268	0.36000	0.0964800
R2	35	0	17.5	7	0.65	0.042	0.044	0.04	0.042	0.11375	0.0047775
R3											
R4											
R5											
TR											
										Total Q	0.1065485



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Discharge Data Collection and Calculation Template

Table A2.27: Block C2 - Discharge measurement 6

			Day 4								
Date:			April 2022								
Location:			Block C2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	35	17.5	7	0.65	0.045	0.039	0.044	0.042667	0.11375	0.0048533
R1	35	36	35.5	14.2	1	0.344	0.324	0.327	0.331667	0.35500	0.1177417
R2	36	0	18	7.2	0.65	0.046	0.047	0.042	0.045000	0.11700	0.0052650
R3											
R4											
R5											
TR											
										Total Q	0.127860



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Discharge Data Collection and Calculation Template

Table A2.28: Block D - Discharge measurement 1

			Day 5								
Date:			April 2022								
Location:			Block D								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			4.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	44	22	8.8	0.7	0.024	0.032	0.032	0.029333	0.1540	0.0045173
R1	44	37	40.5	16.2	1	0.025	0.024	0.015	0.021333	0.4050	0.0086400
R2	37	0	18.5	7.4	0.7	0.002	0.008	0.003	0.004333	0.1295	0.0005612
R3											
R4											
R5											
TR											
										Total Q	0.0137185



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Discharge Data Collection and Calculation Template

Table A2.29: Block D - Discharge measurement 2

			Day 5								
Date:			April 2022								
Location:			Block D								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			4.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	43	21.5	8.6	0.7	0.071	0.072	0.058	0.067	0.1505	0.0100835
R1	43	43	43	17.2	1	0.037	0.054	0.044	0.045	0.4300	0.0193500
R2	43	0	21.5	8.6	0.7	0.029	0.022	0.039	0.030	0.1505	0.0045150
R3											
R4											
R5											
TR											
										Total Q	0.0339485



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Discharge Data Collection and Calculation Template

Table A2.30: Block D - Discharge measurement 3

			Day 5								
Date:			April 2022								
Location:			Block D								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			5.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	44	22	8.8	0.8	0.201	0.193	0.161	0.185000	0.176	0.032560
R1	44	42	43	17.2	1	0.153	0.122	0.118	0.131000	0.430	0.056330
R2	42	0	21	8.4	0.8	0.017	0.011	0.003	0.010333	0.168	0.001736
R3											
R4											
R5											
TR											
										Total Q	0.090626



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Discharge Data Collection and Calculation Template

Table A2.31: Block D - Discharge measurement 4

		Day 5									
Date:		April 2022									
Location:		Block D									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		5.5									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	42	21	8.4	0.8	0.219	0.208	0.209	0.212000	0.168	0.0356160
R1	42	41	41.5	16.6	1	0.186	0.183	0.206	0.191667	0.415	0.0795417
R2	41	0	20.5	8.2	0.8	0.095	0.078	0.017	0.063333	0.164	0.0103867
R3											
R4											
R5											
TR											
										Total Q	0.1255443



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Discharge Data Collection and Calculation Template

Table A2.32: Block F - Discharge measurement 1

			Day 6								
Date:			April 2022								
Location:			Block F								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			1.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	33	16.5	6.6	0.7	0.203	0.193	0.191	0.195667	0.1155	0.0225995
R1	33	0	16.5	6.6	0.7	0.104	0.091	0.087	0.094000	0.1155	0.010857
R2											
R3											
R4											
R5											
TR											
										Total Q	0.0334565



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Discharge Data Collection and Calculation Template

Table A2.33: Block F - Discharge measurement 2

			Day 6								
Date:			April 2022								
Location:			Block F								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	47	23.5	9.4	0.85	0.200	0.166	0.163	0.176333	0.19975	0.0352226
R1	47	0	23.5	9.4	0.85	0.137	0.141	0.113	0.130333	0.19975	0.0260341
R2											
R3											
R4											
R5											
TR											
										Total Q	0.0612567



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Discharge Data Collection and Calculation Template

Table A2.34: Block F - Discharge measurement 3

		Day 6									
Date:		April 2022									
Location:		Block F									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		2.75									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	43	21.5	8.6	0.8	0.216	0.241	0.194	0.217000	0.172	0.0373240
R1	43	0	21.5	8.6	0.8	0.183	0.165	0.166	0.171333	0.172	0.0294693
R2											
R3											
R4											
R5											
TR											
										Total Q	0.0667933



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Discharge Data Collection and Calculation Template

Table A2.36: Block F - Discharge measurement 5

			Day 6								
Date:			April 2022								
Location:			Block F								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			4								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	31	15.5	6.2	0.6	0.167	0.152	0.178	0.165667	0.0930	0.0154070
R1	31	43	37	14.8	0.75	0.288	0.279	0.269	0.278667	0.2775	0.0773300
R2	43	35	39	15.6	0.75	0.195	0.198	0.207	0.200000	0.2925	0.0585000
R3	35	0	17.5	7	0.5	0.182	0.176	0.162	0.173333	0.0875	0.0151667
R4											
R5											
TR											
										Total Q	0.1664037



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Discharge Data Collection and Calculation Template

Table A2.37: Block F - Discharge measurement 6

			Day 6								
Date:			April 2022								
Location:			Block F								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	37	18.5	7.4	1.1	0.146	0.154	0.141	0.147000	0.2035	0.0299145
R1	37	54	45.5	18.2	0.7	0.330	0.362	0.296	0.329333	0.3185	0.1048927
R2	54	41	47.5	19	0.7	0.291	0.306	0.309	0.302000	0.3325	0.1004150
R3	41	0	20.5	8.2	0.6	0.165	0.182	0.142	0.163000	0.1230	0.0200490
R4											
R5											
TR											
										Total Q	0.2552712



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Discharge Data Collection and Calculation Template

Table A2.39: Block G - Discharge measurement 2

			Day 7								
Date:			April 2022								
Location:			Block G								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			0.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	34	17	6.8	0.55	0.115	0.137	0.131	0.127667	0.0935	0.0119368
R1	34	32	33	13.2	1	0.173	0.203	0.182	0.186000	0.3300	0.0613800
R2	32	0	16	6.4	0.55	0.046	0.014	0.054	0.038000	0.0880	0.0033440
R3											
R4											
R5											
TR											
										Total Q	0.0766608



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Discharge Data Collection and Calculation Template

Table A2.40: Block G - Discharge measurement 3

			Day 7								
Date:			April 2022								
Location:			Block G								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			1.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	40	20	8	0.6	0.095	0.071	0.089	0.085000	0.120	0.01020
R1	40	38	39	15.6	1	0.204	0.242	0.220	0.222000	0.390	0.08658
R2	38	0	19	7.6	0.6	0.104	0.142	0.119	0.121667	0.114	0.01387
R3											
R4											
R5											
TR											
										Total Q	0.11065

Table A2.41: Block G - Discharge measurement 4

			Day 7								
Date:			April 2022								
Location:			Block G								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			1.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	43	21.5	8.6	0.6	0.165	0.120	0.126	0.137000	0.129	0.0176730
R1	43	42	42.5	17	1	0.182	0.218	0.222	0.207333	0.425	0.0881167
R2	42	0	21	8.4	0.6	0.068	0.079	0.038	0.061667	0.126	0.0077700
R3											
R4											
R5											
TR											
										Total Q	0.1135597



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Discharge Data Collection and Calculation Template

Table A2.42: Block G - Discharge measurement 5

		Day 7									
Date:		April 2022									
Location:		Block G									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		2									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	49	24.5	9.8	0.65	0.067	0.086	0.037	0.063333	0.15925	0.0100858
R1	49	49	49	19.6	1	0.205	0.214	0.219	0.212667	0.49000	0.1042067
R2	49	0	24.5	9.8	0.65	0.081	0.110	0.081	0.090667	0.15925	0.0144387
R3											
R4											
R5											
TR											
										Total Q	0.1287312



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Discharge Data Collection and Calculation Template

Table A2.43: Block G - Discharge measurement 6

		Day 7									
Date:		April 2022									
Location:		Block G									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		2.25									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	48	24	9.6	0.65	0.080	0.092	0.087	0.086333	0.15600	0.013468
R1	48	45	46.5	18.6	1	0.224	0.268	0.216	0.236000	0.46500	0.109740
R2	45	0	22.5	9	0.65	0.126	0.078	0.112	0.105333	0.14625	0.015405
R3											
R4											
R5											
TR											
										Total Q	0.138613



Ahero Irrigation Research Station
Discharge Data Collection and Calculation Template

Table A2.44: Block K, Feeder 1 - Discharge measurement 1

		Day 8									
Date:		April 2022									
Location:		Block K, Feeder 1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		3									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	25	12.5	5	0.4	0.079	0.081	0.089	0.083	0.050	0.004150
R1	25	42	33.5	13.4	0.4	0.513	0.599	0.568	0.560	0.134	0.075040
R2	42	0	21	8.4	0.4	0.072	0.050	0.049	0.057	0.084	0.004788
R3											
R4											
R5											
TR											
										Total Q	0.083978



Ahero Irrigation Research Station
Discharge Data Collection and Calculation Template

Table A2.45: Block K, Feeder 1 - Discharge measurement 2

		Day 8									
Date:		April 2022									
Location:		Block K, Feeder 1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		2.75									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	24	12	4.8	0.4	0.053	0.049	0.051	0.051000	0.048	0.0024480
R1	24	37	30.5	12.2	0.4	0.415	0.407	0.415	0.412333	0.122	0.0503047
R2	37	0	18.5	7.4	0.4	0.023	0.062	0.053	0.046000	0.074	0.0034040
R3											
R4											
R5											
TR											
										Total Q	0.0561567



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Discharge Data Collection and Calculation Template

Table A2.46: Block K, Feeder 1 - Discharge measurement 3

			Day 8								
Date:			April 2022								
Location:			Block K, Feeder 1								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	29	14.5	5.8	0.3	0.033	0.033	0.029	0.031667	0.0435	0.0013775
R1	27	33	30	12	0.3	0.351	0.339	0.319	0.336333	0.0900	0.0302700
R2	33	0	16.5	6.6	0.3	0.055	0.044	0.035	0.044667	0.0495	0.0022110
R3											
R4											
R5											
TR											
										Total Q	0.0338585

Table A2.47: Block K, Feeder 1 - Discharge measurement 4

			Day 8								
Date:			April 2022								
Location:			Block K, Feeder 1								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			1.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	23	11.5	4.6	0.25	0.019	0.011	0.013	0.014333	0.02875	0.0004121
R1	23	26	24.5	9.8	0.3	0.231	0.233	0.240	0.234667	0.07350	0.0172480
R2	26	0	13	5.2	0.25	0.022	0.041	0.028	0.030333	0.03250	0.0009858
R3											
R4											
R5											
TR											
										Total Q	0.0186459



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Discharge Data Collection and Calculation Template

Table A2.48: Block K, Feeder 2 - Discharge measurement 1

			Day 8								
Date:			April 2022								
Location:			Block K, Feeder 2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			5.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	32	16	6.4	0.4	0.013	0.002	0.007	0.007333	0.064	0.0004693
R1	32	34	33	13.2	0.4	0.213	0.194	0.199	0.202000	0.132	0.0266640
R2	34	0	17	6.8	0.4	0.174	0.202	0.201	0.192333	0.068	0.0130787
R3											
R4											
R5											
TR											
										Total Q	0.040212



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Discharge Data Collection and Calculation Template

Table A2.49: Block K, Feeder 2 - Discharge measurement 2

			Day 8								
Date:			April 2022								
Location:			Block K, Feeder 2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			5.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	30	15	6	0.4	0.005	0.014	0.006	0.008333	0.060	0.0005000
R1	30	34	32	12.8	0.4	0.279	0.294	0.301	0.291333	0.128	0.0372907
R2	34	0	17	6.8	0.4	0.076	0.009	0.016	0.033667	0.068	0.0022893
R3											
R4											
R5											
TR											
										Total Q	0.040080



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Discharge Data Collection and Calculation Template

Table A2.50: Block K, Feeder 2 - Discharge measurement 3

			Day 8								
Date:			April 2022								
Location:			Block K, Feeder 2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	27	13.5	5.4	0.4	0.134	0.109	0.101	0.114667	0.054	0.006192
R1	27	32	29.5	11.8	0.4	0.169	0.175	0.186	0.176667	0.118	0.0208467
R2	32	0	16	6.4	0.4	0.050	0.029	0.067	0.048667	0.064	0.0031147
R3											
R4											
R5											
TR											
										Total Q	0.0301533



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Discharge Data Collection and Calculation Template

Table A2.51: Block K, Feeder 2 - Discharge measurement 4

			Day 8								
Date:			April 2022								
Location:			Block K, Feeder 2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			3.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	26	13	5.2	0.4	0.002	0.014	0.010	0.00867	0.052	0.000452
R1	26	30	28	11.2	0.4	0.151	0.161	0.164	0.15867	0.112	0.017771
R2	30	0	15	6	0.4	0.022	0.052	0.003	0.02667	0.060	0.001540
R3											
R4											
R5											
TR											
										Total Q	0.0197613

Discharge Data Collection and Calculation Template

			Day 9								
Date:			April 2022								
Location:			Block L								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			1.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	7	11	9	3.6	0.4	0.095	0.093	0.094	0.094	0.036	0.003384
R1	11	12	11.5	4.6	0.4	0.148	0.131	0.132	0.137	0.046	0.006302
R2											
R3											
R4											
R5											
TR											
										Total Q	0.009686

Discharge Data Collection and Calculation Template

			Day 9								
Date:			April 2022								
Location:			Block L								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	9	15	12	4.8	0.4	0.096	0.089	0.090	0.091667	0.048	0.004400
R1	15	13	14	5.6	0.4	0.337	0.345	0.344	0.342000	0.056	0.019152
R2	13	14	13.5	5.4	0.4	0.13	0.122	0.126	0.126000	0.054	0.006804
R3											
R4											
R5											
TR											
										Total Q	0.030356



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Discharge Data Collection and Calculation Template

Table A2.54: Block L - Discharge measurement 3

		Day 9									
Date:		April 2022									
Location:		Block L									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		3.25									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	15	20	17.5	7	0.4	0.149	0.148	0.151	0.149333	0.070	0.0104533
R1	20	21	20.5	8.2	0.4	0.412	0.351	0.367	0.376667	0.082	0.0308867
R2	21	18	19.5	7.8	0.4	0.195	0.204	0.126	0.175000	0.078	0.0136500
R3											
R4											
R5											
TR											
										Total Q	0.054990



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Discharge Data Collection and Calculation Template

Table A2.55: Block L - Discharge measurement 4

			Day 9								
Date:			April 2022								
Location:			Block L								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			3.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	20	26	23	9.2	0.4	0.193	0.196	0.181	0.190000	0.092	0.0174800
R1	26	26	26	10.4	0.4	0.491	0.467	0.496	0.484667	0.104	0.0504053
R2	26	25	25.5	10.2	0.4	0.150	0.173	0.170	0.164333	0.102	0.0167620
R3											
R4											
R5											
TR											
										Total Q	0.0846473



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Discharge Data Collection and Calculation Template

Table A2.56: Block L - Discharge measurement 5

			Day 9								
Date:			April 2022								
Location:			Block L								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			4								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	19	27	23	9.2	0.4	0.265	0.264	0.276	0.268333	0.092	0.0246867
R1	27	26	26.5	10.6	0.4	0.481	0.460	0.480	0.473667	0.106	0.0502087
R2	26	23	24.5	9.8	0.4	0.122	0.141	0.162	0.141667	0.098	0.0138833
R3											
R4											
R5											
TR											
Total Q											0.0887787



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Discharge Data Collection and Calculation Template

Table A2.57: Block L - Discharge measurement 6

			Day 9								
Date:			April 2022								
Location:			Block L								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading (×10 ⁻¹ m)			4.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	23	31	27	10.8	0.4	0.382	0.369	0.368	0.373000	0.108	0.0402840
R1	31	30	30.5	12.2	0.4	0.572	0.545	0.560	0.559000	0.122	0.0681980
R2	30	29	29.5	11.8	0.4	0.181	0.161	0.173	0.171667	0.118	0.0202567
R3											
R4											
R5											
TR											
Total Q											0.1287387



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Discharge Data Collection and Calculation Template

Table A2.58: Block M - Discharge measurement 1

			Day 10								
Date:			April 2022								
Location:			Block M								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			5.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	18	29	23.5	9.4	0.7	0.002	0.002	0.005	0.003000	0.1645	0.0004935
R1	29	35	32	12.8	1	0.051	0.065	0.071	0.062333	0.3200	0.0199467
R2	35	19	27	10.8	0.7	0.041	0.057	0.026	0.041333	0.1890	0.0078120
R3											
R4											
R5											
TR											
Total Q											0.0282522



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Discharge Data Collection and Calculation Template

Table A2.59: Block M - Discharge measurement 2

		Day 10									
Date:		April 2022									
Location:		Block M									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		5									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	16	28	22	8.8	0.7	0.010	0.010	0.012	0.010667	0.1540	0.0016427
R1	28	35	31.5	12.6	1	0.066	0.058	0.051	0.058333	0.3150	0.0183750
R2	35	16	25.5	10.2	0.7	0.029	0.031	0.025	0.028333	0.1785	0.0050575
R3											
R4											
R5											
TR											
										Total Q	0.0250752



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Discharge Data Collection and Calculation Template

Table A2.60: Block M - Discharge measurement 3

			Day 10								
Date:			April 2022								
Location:			Block M								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading (×10 ⁻¹ m)			4.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	15	27	21	8.4	0.5	0.005	0.007	0.004	0.005333	0.105	0.00056
R1	27	33	30	12	1	0.061	0.056	0.048	0.055000	0.300	0.01650
R2	33	15	24	9.6	0.5	0.019	0.015	0.013	0.015667	0.120	0.00188
R3											
R4											
R5											
TR											
										Total Q	0.01894

Table A2.61: Block M - Discharge measurement 4

			Day 10								
Date:			April 2022								
Location:			Block M								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			3.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	14	26	20	8	0.4	0.008	0.002	0.005	0.005000	0.080	0.000400
R1	26	31	28.5	11.4	1	0.029	0.039	0.035	0.034333	0.285	0.009785
R2	31	14	22.5	9	0.4	0.011	0.008	0.007	0.008667	0.090	0.000780
R3											
R4											
R5											
TR											
										Total Q	0.010965



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Discharge Data Collection and Calculation Template

Table A2.62: Block N - Discharge measurement 1

			Day 11								
Date:			April 2022								
Location:			Block N								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	19	26	22.5	9	0.4	0.088	0.090	0.099	0.092333	0.090	0.0083100
R1	26	31	28.5	11.4	0.4	0.059	0.040	0.027	0.042000	0.114	0.0047880
R2	31	15	23	9.2	0.4	0.078	0.076	0.061	0.071667	0.092	0.0065933
R3											
R4											
R5											
TR											
										Total Q	0.0196913



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Discharge Data Collection and Calculation Template

Table A2.63: Block N - Discharge measurement 2

		Day 11									
Date:		April 2022									
Location:		Block N									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		2.75									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	29	36	32.5	13	0.4	0.116	0.161	0.141	0.139333	0.13	0.0181133
R1	36	39	37.5	15	0.4	0.055	0.044	0.032	0.043667	0.15	0.0065500
R2	39	26	32.5	13	0.4	0.136	0.117	0.115	0.122667	0.13	0.0159467
R3											
R4											
R5											
TR											
										Total Q	0.040610



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Discharge Data Collection and Calculation Template

Table A2.64: Block N - Discharge measurement 3

		Day 11									
Date:		April 2022									
Location:		Block N									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		3									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	25	35	30	12	0.4	0.302	0.254	0.270	0.275333	0.120	0.0330400
R1	35	38	36.5	14.6	0.4	0.296	0.169	0.154	0.206333	0.146	0.0301247
R2	38	31	34.5	13.8	0.4	0.107	0.056	0.050	0.071000	0.138	0.0097980
R3											
R4											
R5											
TR											
										Total Q	0.0729627

Discharge Data Collection and Calculation Template

			Day 11								
Date:			April 2022								
Location:			Block N								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			3.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	23	30	26.5	10.6	0.4	0.215	0.189	0.204	0.202667	0.106	0.0214827
R1	30	35	32.5	13	0.4	0.222	0.190	0.162	0.191333	0.130	0.0248733
R2	35	27	31	12.4	0.4	0.207	0.249	0.223	0.226333	0.124	0.0280653
R3											
R4											
R5											
TR											
Total Q										0.0744213	



Ahero Irrigation Research Station
Discharge Data Collection and Calculation Template

Table A2.67: Block O, Feeder 1 - Discharge measurement 2

		Day 10									
Date:		April 2022									
Location:		Block O, Feeder 1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		4									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	17	27	22	8.8	0.6	0.009	0.011	0.022	0.014000	0.132	0.0018480
R1	27	34	30.5	12.2	1	0.064	0.056	0.052	0.057333	0.305	0.0174867
R2	34	15	24.5	9.8	0.6	0.031	0.024	0.021	0.025333	0.147	0.0037240
R3											
R4											
R5											
TR											
										Total Q	0.0230587



Ahero Irrigation Research Station
Discharge Data Collection and Calculation Template

Table A2.68: Block O, Feeder 1 - Discharge measurement 3

		Day 10									
Date:		April 2022									
Location:		Block O, Feeder 1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		3.5									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	14	26	20	8	0.4	0.003	0.004	0.007	0.004667	0.080	0.0003733
R1	26	32	29	11.6	1	0.055	0.062	0.042	0.053000	0.290	0.0153700
R2	32	14	23	9.2	0.4	0.016	0.012	0.009	0.012333	0.092	0.0011347
R3											
R4											
R5											
TR											
										Total Q	0.016878



Ahero Irrigation Research Station
Discharge Data Collection and Calculation Template

Table A2.69: Block O, Feeder 1 - Discharge measurement 4

		Day 10									
Date:		April 2022									
Location:		Block O, Feeder 1									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		3.25									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	13	25	19	7.6	0.3	0.011	0.002	0.004	0.005667	0.0570	0.0003230
R1	25	30	27.5	11	1	0.027	0.034	0.028	0.029667	0.2750	0.0081583
R2	30	13	21.5	8.6	0.3	0.008	0.009	0.006	0.007667	0.0645	0.0004945
R3											
R4											
R5											
TR											
										Total Q	0.0089758



Ahero Irrigation Research Station

Discharge Data Collection and Calculation Template

Table A2.70: Block O, Feeder 2 - Discharge measurement 1

			Day 10								
Date:			April 2022								
Location:			Block O, Feeder 2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			4								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	16	26	21	8.4	0.6	0.006	0.003	0.004	0.004333	0.126	0.000546
R1	26	34	30	12	1	0.057	0.058	0.069	0.061333	0.300	0.018400
R2	34	20	27	10.8	0.6	0.036	0.056	0.028	0.040000	0.162	0.006480
R3											
R4											
R5											
TR											
										Total Q	0.025426

Table A2.71: Block O, Feeder 2 - Discharge measurement 2

			Day 10								
Date:			April 2022								
Location:			Block O, Feeder 2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			3.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	16	25	20.5	8.2	0.6	0.008	0.011	0.002	0.007000	0.123	0.000861
R1	25	32	28.5	11.4	1	0.046	0.051	0.059	0.052000	0.285	0.014820
R2	32	20	26	10.4	0.6	0.030	0.043	0.031	0.034667	0.156	0.005408
R3											
R4											
R5											
TR											
										Total Q	0.021089



Ahero Irrigation Research Station

Discharge Data Collection and Calculation Template

Table A2.72: Block O, Feeder 2 - Discharge measurement 3

			Day 10								
Date:			April 2022								
Location:			Block O, Feeder 2								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading (×10 ⁻¹ m)			3.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	15	24	19.5	7.8	0.6	0.004	0.090	0.006	0.033333	0.117	0.00390
R1	24	30	27	10.8	1	0.034	0.027	0.037	0.032667	0.270	0.00882
R2	30	18	24	9.6	0.6	0.021	0.025	0.019	0.021667	0.144	0.00312
R3											
R4											
R5											
TR											
										Total Q	0.01584



Ahero Irrigation Research Station

Discharge Data Collection and Calculation Template

Table A2.74: Block P - Discharge measurement 1

			Day 13								
Date:			April 2022								
Location:			Block P								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	34	17	6.8	0.55	0.113	0.139	0.132	0.128	0.0935	0.011968
R1	34	32	33	13.2	1	0.171	0.205	0.185	0.187	0.3300	0.061710
R2	32	0	16	6.4	0.55	0.047	0.028	0.061	0.045	0.0880	0.003989
R3											
R4											
R5											
TR											
										Total Q	0.077667



Ahero Irrigation Research Station

Discharge Data Collection and Calculation Template

Table A2.75: Block P - Discharge measurement 2

			Day 13								
Date:			April 2022								
Location:			Block P								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			2.75								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	42	21	8.4	0.5	0.161	0.106	0.121	0.1293333	0.1050	0.01358
R1	42	41	41.5	16.6	1	0.145	0.195	0.201	0.1803333	0.4150	0.07483
R2	41	0	20.5	8.2	0.5	0.056	0.079	0.046	0.0603333	0.1025	0.00618
R3											
R4											
R5											
TR											
										Total Q	0.094602



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Discharge Data Collection and Calculation Template

Table A2.76: Block P - Discharge measurement 3

			Day 13								
Date:			April 2022								
Location:			Block P								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			3.25								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	0	43	21.5	8.6	0.6	0.164	0.111	0.124	0.133	0.129	0.017157
R1	43	42	42.5	17	1	0.181	0.217	0.223	0.207	0.425	0.087975
R2	42	0	21	8.4	0.6	0.069	0.078	0.039	0.062	0.126	0.007812
R3											
R4											
R5											
TR											
Total Q											0.112944



Ahero Irrigation Research Station
Discharge Data Collection and Calculation Template

Table A2.77: Block P - Discharge measurement 4

		Day 13									
Date:		April 2022									
Location:		Block P									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		3.5									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	48	24	9.6	0.5	0.162	0.129	0.148	0.146333	0.1200	0.017560
R1	48	49	48.5	19.4	1	0.161	0.201	0.236	0.199333	0.4850	0.096676
R2	49	0	24.5	9.8	0.5	0.101	0.098	0.078	0.092333	0.1225	0.011310
R3											
R4											
R5											
TR											
										Total Q	0.125547

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Discharge Data Collection and Calculation Template

Table A2.78: Research Fields- Discharge measurement 1

			Day 14								
Date:			April 2022								
Location:			Research								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading ($\times 10^{-1}$ m)			3.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	0	43	21.5	8.6	0.35	0.009	0.010	0.012	0.010333	0.07525	0.0007776
R1	43	45	44	17.6	0.3	0.083	0.071	0.063	0.072333	0.13200	0.0095480
R2	45	0	22.5	9	0.35	0.06	0.073	0.06	0.064333	0.07875	0.0050663
R3											
R4											
R5											
TR											
Total Q											0.0153918



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Discharge Data Collection and Calculation Template

Table A2.79: Research Fields - Discharge measurement 2

			Day 10								
Date:			April 2022								
Location:			Research								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading (×10 ⁻¹ m)			4								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m²)	Discharge Q = A*V Q (m³/s)
	Left	Right									
TL	0	50	25	10	0.35	0.09	0.011	0.005	0.035333	0.08750	0.0030917
R1	50	47	48.5	19.4	0.3	0.127	0.132	0.141	0.133333	0.14550	0.0194000
R2	47	0	23.5	9.4	0.35	0.074	0.067	0.062	0.067667	0.08225	0.0055656
R3											
R4											
R5											
TR											
Total Q											0.0280573



Ahero Irrigation Research Station Discharge Data Collection and Calculation Template

Table A2.80: Research Fields - Discharge measurement 3

			Day 14								
Date:			April 2022								
Location:			Research								
Current Meter Model:			Electromagnetic Current Meter - KENEK Model								
Gauge Reading (×10 ⁻¹ m)			4.5								
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right									
TL	35	54	44.5	17.8	0.5	0.13	0.139	0.156	0.141667	0.2225	0.0315208
R1	54	38	46	18.4	0.5	0.104	0.133	0.156	0.131000	0.2300	0.0301300
R2											
R3											
R4											
R5											
TR											
										Total Q	0.0616508



Ahero Irrigation Research Station
Discharge Data Collection and Calculation Template

Table A2.81: Research Fields - Discharge measurement 4

		Day 14									
Date:		April 2022									
Location:		Research									
Current Meter Model:		Electromagnetic Current Meter - KENEK Model									
Gauge Reading ($\times 10^{-1}$ m)		5									
	Depth d (cm)		Average Depth d (cm)	0.4d (cm)	Span s (m)	Velocity Reading (m/s)			Average Velocity V (m/s)	Area A = d*s (m ²)	Discharge Q = A*V Q (m ³ /s)
	Left	Right				Reading 1	Reading 2	Reading 3			
TL	39	58	48.5	19.4	0.5	0.137	0.213	0.231	0.193667	0.2425	0.0469642
R1	58	32	45	18	0.5	0.231	0.227	0.195	0.217667	0.2250	0.0489750
R2											
R3											
R4											
R5											
TR											
										Total Q	0.0959392

Appendix 3 - Plagiarism Report

SR665

ISO 9001:2019 Certified Institution

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