THE STATE OF IRRIGATION WATER LOSSES AND MEASURES TO IMPROVE WATER USE EFFICIENCY ON SELECTED IRRIGATION SCHEMES

Report to the
WATER RESEARCH COMMISSION
and the
DEPARTMENT OF AGRICULTURE, LAND REFORM AND RURAL DEVELOPMENT

by

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WRC Report No. 2970/1/23
ISBN 978-0-6392-0482-6

July 2023

Obtainable from
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EXECUTIVE SUMMARY

Background

Agriculture accounts for 70% of global freshwater withdrawals worldwide (FAO, 2017) with most of the water being used for crop production (Morison et al., 2008). Water scarcity has escalated into a global environmental challenge (Srinivasan et al., 2012) due to, among many factors, wastages in agriculture, growing demand from cities and industries, climate change and the need to leave enough to sustain ecosystems (Sharma et al., 2015). In South Africa, water scarcity has gained a spotlight position with a deficit of 17% predicted by 2030 (WWF, 2017). The country is drifting into a water-shedding mode as coping strategy. South Africa (SA) is a semi-arid water stressed country whose long-term annual precipitation averages 480 mm yr^{-1} (Dennis and Dennis, 2012), which is much lower than the global average of 860 mm yr^{-1}. The precipitation varies greatly across the country with 43% occurring on 13% of the total land area of the country. Moreover, only 9% of the precipitation turns into runoff (Dennis and Dennis, 2012) that feeds inland dams and rivers.

Irrigated agriculture in the country accounts for at least 62% of the national water demand (DWAF, 2004; SSA, 2010). Ironically, agriculture is the least water use efficient sector with reported wastages of up to 45% (DWA, 2013), which cannot be accepted (DWA, 2013) for a semi-arid country. With 10% of agricultural land in the country being irrigated and consuming 10 221 Mm^3 yr^{-1} by 2015 (Van Niekerk et al., 2018), 4 600 Mm^3 of the water were wasted. The country is striving to increase irrigated land by more than 50%, which can hardly be achievable without increasing water use efficiency (WUE) in the sector. The National Water Act (No 36 of 1998) lists increased WUE and sustainability as its key objectives. In addition, the National Development Plan (NDP) 2011 dedicated a support programme to deal with high agricultural water demand and wastages to respond to growing scarcity. Improved agricultural water security is important to meet rising demand for food, changing diet patterns of growing, wealthier and increasingly urbanized populations (Molden et al., 2010) and for environmental protection. Moreover, water security underpins the future economic growth of the country.

Agricultural water conservation and demand management remains behind that of domestic and wastewater systems (DWA, 2011) despite past studies and recommendations (Reinders et al., 2010; Denison and Manona, 2007a; 2007b). Upgrading of the irrigation infrastructure is very costly, and it is important to redirect funding to endeavours that yield more water saving benefits, e.g. information management in the sector, which has shown potential to improve sustainability and identifying opportunities for developing, rehabilitating, and modernizing irrigation systems. In line with this, the Department of Water and Sanitation requested a general framework for reporting on WUE in agriculture. The framework aims to generate information on the extent of agricultural water losses at irrigation schemes in the country. Therefore, the framework borrows cues from the successes of existing frameworks such as the Green-Drop, Blue-Drop and, more recently, the No-Drop Reports, for rating water use efficiencies in wastewater and municipal water management. In line with this, the requested framework dubbed Irri-Drop Report aims to provide a means for assessing and rating irrigation schemes in terms of water conveyance efficiency and their readiness to deal with water losses in a transparent manner, which is important as an incentive for water users to strive for excellence. The project entitled "*The state of irrigation water losses and measures to improve WUE on selected irrigation schemes*" was tasked with developing a general framework for the Irri-Drop Report based on available data from Vaalharts and Loskop Irrigation Schemes.

Aims

The following were the aims of the project:

1. To assess the state of water losses and water use efficiency (WUE) in conveyance systems of representative irrigation schemes in South Africa through quantifying major water losses in the conveyance systems

2. To develop a framework (Irri-Drop Report) for reporting the major water losses which the Department of Water and Sanitation (DWS) can use on all irrigation schemes in South Africa

3. To suggest and put in place measures for improving water use efficiency in the irrigation schemes

4. To build the capacity of irrigation scheme managers on compiling and evaluating monthly Water Use Efficiency Accounting Reports (WUEAR) and on identifying opportunities for improving irrigation water use efficiency

5. To publish the project outcomes in a prescribed format as specified by DWS.

Methodology

Aim 1: Assessing the state of water losses and water use efficiency in conveyance systems

The state of water losses and water conveyance efficiency in conveyance systems was assessed for Vaalharts and Loskop irrigation schemes using data available on the Water Administration System (WAS) platform. Therefore, the activity was desktop-based where WAS reports, specifically the Water Use Efficiency Accounting Reports (WUEAR), for the two irrigation schemes were accessed online. The WUEAR for each irrigation scheme reports on several things, but the Irri-Drop Report, through its Water Balance Report (WBR) component focusses on:

- volume of water released into the canal network
- volume of water delivered to water users on the canal network(defined on the WAS platform as: agricultural, industrial, municipality, household, downstream, tail end and other)
- water losses from the canal network.

The activity aimed to decipher the disaggregated canal water loss types (defined by the project as: seepage, leakage, evaporation, operational and others) for the different subareas of the canal network (main, secondary, tertiary canal, etc.).

Aim 2: Developing a framework for reporting major water losses

The activity used available literature on frameworks used for assessing the efficiency of water management in South Africa (Green-Drop, Blue-Drop and No-Drop Reports) and globally (numerous water balance frameworks) to understand the syntax of water balance frameworks for water resource management at different levels (e.g. process, municipality and irrigation scheme levels). The information gathered from the literature was used to develop a framework for reporting the major water losses (the Irri-Drop Report). The framework needed to conform to the reporting format prescribed by DWS, the end users of the framework. Stakeholders were consulted on the idea of the framework and its components. Officials from DWS were consulted during formal meetings, while the other stakeholders (mostly the water managers from Vaalharts and Loskop irrigation schemes and from their neighbouring irrigation schemes) were consulted during a training session and in informal meetings.

Aim 3: Suggesting and putting in place measures for improving WUE in irrigation schemes

The activity used information and knowledge gained from activities of Aims 1 & 2 to suggest best practices for the two study sites, namely: Vaalharts and Loskop Irrigation Scheme. The suggestions were shared with the water managers from the two and surrounding irrigation schemes during a training session geared at capacity development of the same (Aim 4). Further engagements with the idea of sharing knowledge on the best practices will be pursued during further trainings on the Water Balance Report component and when the Irri-Drop Report framework is ready for implementation.

Aim 4: Developing the capacity of irrigation scheme water managers

The activity was geared at improving the capacity of irrigation scheme water managers in terms their ability to master online systems for capturing and uploading user and water data from their irrigation schemes. The second objective of the activity was to improve the skills of the water managers with regard to understanding the online reports of the water delivery performance of their canal networks. That understanding was envisaged to offer opportunities for identifying factors and areas that require attention in order to improve the efficiencies of their systems. Any mode of training was acceptable as long the planned key goals of the training were achieved.

Aim 5: Publishing project outcomes in a format prescribed by DWS

The main objective of the activity was to disseminate information relating to the water delivery performance of the irrigation schemes, i.e. reporting on the water losses that occur in the water conveyance systems of the irrigation schemes. The report format prescribed by DWS was a water balance approach where stakeholders needed to be informed on the volume of water released into the canal network over a specific period (week, month and year), the volume of water delivered to specific users over the same period, and the corresponding losses. Therefore, the report could take any form but a summary table showing the same was a requirement to accompany the reports. The reports needed to be available online and open to all stakeholders.

Results and Discussion

1: The state of water losses and conveyance system efficiency (Chapter 4)

While the major water loss types from open channels, particularly irrigation scheme canals, can theoretically be identified and defined, current available technology does not enable their disaggregation and subsequent quantification as individuals under normal canal network operating condition. The WAS program, the source of data for the current analysis, can report water releases, deliveries and losses for an unlimited number of subareas in a canal network. However, it is limited by the actual number of measurement stations available on the canal network and also the equipment at the measurement stations. Offtake points of main and secondary canals at both Vaalharts and Loskop irrigation schemes are equipped with flumes. Flumes are now obsolete; hence, new less labour intensive technology is required to reduce drudgery and associated human errors. Moreover, some of the flume set-ups have missing gauging staves. Use of electronic data loggers can significantly reduce both human labour and the associated errors. Electronic data loggers are compatible with the WAS program which is used at both Vaalharts and Loskop irrigation schemes. Moreover, data stored in the electronic data loggers can be downloaded from a remote location. However, electronic data loggers are expensive and it is currently economically challenging to install them, for example, at every offtake point on the canal networks including the farm gates. The global (total) water losses and efficiency of entire canal networks at Vaalharts and Loskop irrigation scheme varied with month and year. The annual water losses incurred at Vaalharts were 19.4 and 18.7% for the 2019/2020 and 2020/2021 water year, respectively. On the other hand, Loskop incurred 25.2 and 25.1% for the same water years, respectively. However, it is important to put these losses in their proper contexts. For instance, the lower percentage losses at Vaalharts still constitute much greater volumetric losses (81.9 and 67.6 Mm^3 for 2019/2020 and 2020/2021, respectively) compared to Loskop (34.7 and 35.6 Mm^3 for 2019/2020 and 2020/2021, respectively) because it a much bigger irrigation scheme with greater annual water consumption.

2: Framework for reporting major water losses from canal networks (Chapter 6)

The limitations highlighted in the above result mean only global water losses could be computed for the two and other irrigation schemes in South Africa. Global water loss means the sum of all water loss types that occur on an entire canal network. Therefore, the framework that was developed by the project for reporting water losses and efficiency of conveyance systems can only report the global losses and efficiency. In fact, that framework known as the Irri-Drop Report, does not only account for the water losses from canal networks. The global water losses and conveyance system efficiency are handled by the Water Balance Report (*WBR*) component of the framework. The framework has six other components, namely: Water Management Plan (*WMP*), Maintenance Plan (*ManPlan*), Condition Assessment Report (ConAs), Technical Competency Report (*TechCom*), Budgeting Report (*BudgetA*), Credibility and Regulation Enforcement Report (*CredReg*). Out of these six components, only the ConAs involves the physical assessment of the physical water conveyance infrastructure. The other components assess the readiness of the irrigation schemes to deal with water losses from their canal networks. This readiness is evaluated in terms of the adequacy of water management and infrastructural maintenance plans in place, technical competency of the human resources personnel in the various positions that define the capacity of the irrigation scheme, credibility of the rules and regulations put in place and how these regulations are enforced toward reducing water losses, and the adequacy of the budget to implement these plans and measures. Each of these seven components can be implemented as independent criteria (with individual indices generated for each component) to assess the irrigation schemes; however, the Irri-Drop Report framework dictates that they all contribute to the overall Irri-Drop Index for the irrigation scheme for the period under review. Their contributions toward the Irri-Drop Index are weighted according to their relative influence on the state of the irrigation scheme with respect to water conveyance efficiency, condition of the infrastructure and readiness to deal with water losses. However, the minimum condition for the application of the Irri-Drop Report to an irrigation scheme is that the irrigation scheme needs a set of electronic loggers to at least be able to quantify the water releases into the canal network, quantify the water deliveries to the water users, and then be able to compute the water losses and conveyance efficiency. This minimum requirement is part of the reason the project devoted a lot of effort on developing the WBR framework, which mirrors the WUEAR of the WAS program. WBR is premised on accurate and timely measurements of water releases into the canal network and deliveries to the various users on the network.

3: Measures for improving the efficiency of canal networks (Chapter 2 & 3)

Water shortages for agriculture are due to limited availability of water and inefficient use of the available water. Human beings have better manipulation of water use efficiency than water availability. Higher levels of water conveyance efficiency are needed because agricultural water availability is already limited in the midst of declining water supplies and increasing competition for water from other sectors. The project considered the physical factors and canal characteristics with possible effects on water conveyance efficiency. One of the key findings from that exercise was confirmation that evaporation water loss from canals is negligible in comparison with the other losses; hence, its influence on the conveyance efficiency of canal networks can be ignored in the analysis of water losses from canals under normal operating conditions. The second key finding is that results on the efficiency of canal networks depend on the methods used to collect and analyse the data. The third finding is that the canal cross-sectional profile, together with derivative characteristics such as wetted perimeter and wetted area, has significant influence on water losses. The last very important finding is that good technical design of canals needs to be supported by equally good management and maintenance plans for better water conveyance performance. Several measures for improving conveyance efficiencies of canals are put forward including improvements in operations and maintenance of the infrastructure. Operational improvement is a requirement in terms of water distribution management, where the water bailiffs need to adhere strictly to the prescribed times for opening and closing sluice gates because delivering more water than scheduled constitute a loss to the canal network. Installation of automatic measuring devices would be of great help in this regard. Proper maintenance plans and sealing of gaps between the concrete slabs which make the canal walls and beds can significantly reduce leakages.

4: Capacity development of water managers (Chapter 7)

One training session was organised for the irrigation scheme water managers. Opportunities for physical meetings were restricted by the outbreak of the Covid-19 pandemic. Therefore, online interaction was the only safe option. However, online training sessions has their own challenges such as poor internet connectivity in some remote parts of the country, internet data is costly, and suitable gadgets are sometimes inaccessible to many people. The training that took place focused on handling data from numerous sources, including electronic data loggers, and uploading the Water Use Efficiency Accounting Report (WUEAR). WUEAR is a component of the computer-based WAS program. The training also covered how to interpret the WUEAR results on the online platform and how to identify potential opportunities for improving water conveyance efficiency in the canal networks. The training session was very interactive with a lot of examples being used. This training on WUEAR was important because the Water Balance Report (WBR) for the Irri-Drop Index is mirrors this. In fact, WBR only emphasizes on a part of the WUEAR, namely: water release, delivery and loss. Although seven components for the Irri-Drop Report framework have been identified, only one component (i.e. WBR) is usable at the moment. Hence, more trainings shall be done when the other six components are developed and ready for use. In addition to the Irri-Drop Report assessed-to-be (i.e. the water managers as representatives of the irrigation scheme), the assessors-to-be (the Department of Water and Sanitation officials) shall also be included in the trainings. Other stakeholders, such as the academics and researchers who have vested interests in the Irri-Drop Report as a tool for assessing and rating irrigation schemes shall also be included in the trainings.

5: Publishing project outcomes (Chapter 5)

The Water Balance Reports (WBRs), the most important component of the Irri-Drop Report, are hosted on the Water Administration System (WAS) through the Water Use Efficiency Accounting Report (WUEAR). The WBRs are not reporting the indices yet. The indices shall be generated when the other components are ready. The current focus of the WBRs is to account for the volume of water released into a canal network over a specified period, the volume of water delivered to the users over the same period, the water losses that occur along the canal network, and subsequently the conveyance efficiency of the canal network. The online platform developed is capable of handling an unlimited number of subareas of a canal network at an irrigation scheme provided adequate electronic data loggers are procured and installed at appropriate inflow and outflow positions on the canal network. However, it is not possible to report on the disaggregated water loss types due to lack of appropriate technology to separate the different water loss types during the normal operations of canals. Instead, global loss, which is the sum of the different water loss types that occur on the canal network, is reported for each irrigation scheme over a prescribed period. This platform provides the infrastructure for a dynamic and automated monthly reporting system. It allows individual irrigation schemes to upload their own data. It also allows new irrigation schemes to be added to the list automatically. The monthly reports are used to generate annual reports at the end of each water year. Like other computer-based programs, the quality of the reports published on the online platform depends on the quality of input data. Therefore, it is important to have a good working data collection system and competent personnel to handle the data collected.

Innovations and Products

The main innovation generated by the project is the roadmap conceptual framework for the Irri-Drop Report, which is described in chapter 6 of this report. The Irri-Drop Report consists of seven components, each with its own actors to be assessed during evaluation. Weighted outputs of the factor assessments generate component indices (based on relative contributions of the component factors). The relative contributions of the seven component indices are used to generate an Irri-Drop Report Index for an irrigation scheme for the assessment period. The tool shall be used by the Department of Water and Sanitation (DWS) to rate the water conveyance efficiency of canal networks at irrigation schemes in South Africa, and also to rate the preparedness levels of the irrigation schemes to deal with water losses from the canal networks. Therefore, the framework shall be used as a tool to assess the performance of irrigation schemes in terms of water conveyance efficiency and dealing with water losses over specific periods. The indices generated by the tool can be used as basis for comparing the performances of irrigation schemes over time. The major limitation of the framework is that it focusses on the water conveyance systems only, i.e. the network of canals connecting the main water reservoir to the farms. It does not include the reservoirs and the farms; Therefore, the indices generated will not reflect performance of farms and reservoirs in terms water losses.

Conclusions

It can be concluded from the project outputs that it is feasible to develop an incentive-based program (similar to the No Drop Report) for use by the Department of Water and Sanitation as a tool to encourage high water conveyance efficiency among irrigation schemes and to enhance their levels of preparedness to deal with recurrent and emergent water losses. The seven components identified for the Irri-Drop Report conceptual framework are geared at assessing water conveyance efficiency at the irrigation schemes and competency in managing a water scheme (i.e. staff compliments, technical skills, water management and maintenance plans, and enforcement of regulations, and budgeting). It can also be concluded that global water loss data generated by the WUEAR of the WAS program (www.wateradmin.co.za) are adequate to initiate an Irri-Drop Report at an irrigation scheme because the Water Balance Report is the minimum requirement. It is currently not practically feasible to disaggregate major canal network water loss types (seepage, leakage, evaporation and operational losses) under normal canal network operation. Nevertheless, the other components of the Irri-Drop Report framework still need to be implemented for comprehensive rating of irrigation schemes. The other conclusion is that two MSc students were part of the project capacity development program. In addition, water managers from neighbouring irrigation schemes to Vaalharts and Loskop irrigation schemes, which were the study sites, also attended a training facilitated by the project.

Recommendations

While the state of water losses and water conveyance efficiency was deciphered at the level of a canal network, it was not feasible to do the same at the subarea level of a network due to inadequate measurement stations and/or accurate measurement equipment. The most urgent recommendation to irrigation schemes is, therefore, to identify appropriate gauging stations on the canal networks which adequately define the desired subareas (e.g. main canal, secondary canal, tertiary canal, and community canal) and to equip these gauging stations with accurate measurement devices. Automatic data loggers would be more appropriate as they reduce labour requirements and the errors associated humans when they handle large data. If more gauging stations are equipped with automatic loggers, then it is recommended that the water balance component of the Irri-Drop Report be refined to include the subareas. Therefore, further work on development of the Irri-Drop Report framework is recommended until a stage when all its components can generate individual indices which can jointly be used to generate a single Irri-Drop index for an irrigation scheme. The other very important recommendation is to extend the Irri-Drop Report concept to at least cover on-farm water delivery networks in addition to the current focus on water conveyance networks between the main reservoir/s and farm gates. A more comprehensive irrigation scheme water balance should be consistent with the standard definition of an irrigation scheme which covers the reservoir/s, water conveyance network and the farm/s.

ACKNOWLEDGEMENTS

The research reported here formed part of project (K5/2970/4), funded and managed by the Water Research Commission (WRC) and implemented by the Agricultural Research Council-Natural Resources and Engineering division (ARC-NRE). The project team is sincerely grateful to the WRC for funding and management of the project. The project team also wishes to sincerely thank the following members of the Reference Group for their valuable contributions and guidance:

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Dr Samkelisiwe Hlophe-Ginindza	Water Research Commission (WRC)
Prof. Sylvester Mpandeli	Water Research Commission (WRC)
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°C	degrees Celsius
ha	hectares
$L\ s^{-1}$	litres per second
km	kilometres
l/s	litres per second
$L\ s^{-1}\ 100m^{-1}$	litres per second per 100 metres
l/s/100m	litres per second per 100 metres
m	metres
$m\ s^{-1}$	metres per second
masl	metres above sea level
mm	millimetres
$mm\ yr^{-1}$	millimetres per year
m^2	square metres
m^3/h	cubic metres per hour
m^3/ha	cubic metres per hectare
$m^3\ s^{-1}$	cubic metres per second
Mm^3	million cubic metres
$Mm^3\ yr^{-1}$	million cubic metres per year
mnth	month

ACRONYMS & ABBREVIATIONS

ARC	Agricultural Research Council
A_{WET}	Wetted area
A_{WL}	Water surface area
A_X	Cross-sectional area
B_W	Bottom width of channel
CV	Coefficient of Variation
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
f_c	frictional coefficient
GIS	Geographical Information System
ICID	International Commission on Irrigation and Drainage
K_{sat}	Saturated hydraulic conductivity
LIB	Loskop Irrigation Board
LIS	Loskop Irrigation Scheme
N	Number or sample size
NDP	National Development Plan
NWRS2	National Water Resources Strategy No. 2
P	Wetted perimeter
Q_t	Water flow discharge rate
R	Hydraulic radius
r_s	Spearman rank correlation coefficient
S	Channel slope
T_W	Water surface width
VIS	Vaalharts Irrigation Scheme
V_t	Water flow velocity
VW	Vaalharts Water
VWUA	Vaalharts Water Users' Association
W	Average width
WAS	Water Administration System
WCE	Water Conveyance Efficiency
WRC	Water Research Commission
WUA	Water Users' Association
WUE	Water Use Efficiency
WUEAR	Water Use Efficiency Accounting Report

CHAPTER 1: INTRODUCTION

1.1 Background

Agriculture consumes 70% of the freshwater withdrawals worldwide (FAO, 2017). Most of the agriculture water is used for crop production in irrigation schemes (Morison et al., 2008). Water scarcity has escalated into a global environmental challenge (Srinivasan et al., 2012) due to, among many factors, wastages in agriculture, growing demand from cities and industries, climate change and the need to leave enough to sustain ecosystems (Sharma et al., 2015). In South Africa, water scarcity has gained a spotlight position with a deficit of 17% predicted by 2030 (WWF, 2017). The country is currently drifting into a water-shedding mode as a coping strategy. South Africa (SA) is a semi-arid water stressed country whose long-term annual precipitation averages 480 mm yr^{-1} (Dennis and Dennis, 2012), which is much lower than the global average of 860 mm yr^{-1}. The precipitation varies greatly across the country with 43% occurring on 13% of the total land area of the country. Moreover, only 9% of the precipitation turns into runoff (Dennis and Dennis, 2012) that feeds inland dams and rivers.

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Agricultural water conservation and demand management remains behind that of domestic and wastewater systems (DWA, 2011) despite past studies and recommendations (Reinders et al., 2010; Denison and Manona, 2007a; 2007b). Upgrading of the irrigation infrastructure is very costly, and it is important to redirect funding to endeavours that yield more water saving benefits, e.g. information management in the sector, which has shown potential to improve sustainability and identifying opportunities for developing, rehabilitating, and modernizing irrigation systems. In line with this, the Department of Water and Sanitation (DWS) requested a general framework for reporting on WUE in agriculture. The framework aims to generate information on the extent of agricultural water losses at irrigation schemes in the country. Therefore, the framework borrows cues from the successes of existing frameworks such as the Green Drop, Blue-Drop and, more recently, the No-Drop Reports, for rating water use efficiencies in wastewater and municipal water management. In the same way, the requested framework (the Irri-Drop Report) aims to provide a means for assessing and rating irrigation schemes in terms of WUE and their readiness to deal with water losses in a transparent manner, which is important as an incentive for water users to strive for excellence. The project entitled "The state of irrigation water losses and measures to improve WUE on selected irrigation schemes" was tasked with developing a general framework for the Irri-Drop Report based on available data from Vaalharts and Loskop Irrigation Schemes.

1.2 Project aims

The aim of the project was to develop a general (Irri-Drop Report) framework for a tool that can be used to evaluate the capacity of irrigation schemes in terms of water use efficiency and in dealing with water losses in a transparent manner. This aim addresses the capacity building and skills development targets of the National Water Resources Strategy 2 (NWRS2) by enhancing nationwide knowledge on water uses and losses at irrigation schemes.

The specific objectives of the project were:

1. To assess the state of water losses and water use efficiency in conveyance systems of representative irrigation schemes in South Africa through quantifying major water losses in the conveyance systems
2. To develop a framework (the Irri-Drop report) for reporting the major water losses which the Department of Water and Sanitation can use on all irrigation schemes in South Africa
3. To suggest and put in place measures for improving water use efficiency in the irrigation schemes
4. To build the capacity of irrigation scheme managers on compiling and evaluating monthly Water Use Efficiency account reporting and on identifying opportunities for improving irrigation water use efficiency
5. To publish the project outcomes in a prescribed format as specified by the Department of Water and Sanitation

1.3 Scope and Limitations of the project

The project was tasked with developing a general framework for assessing the state of water losses and water use efficiency in conveyance systems of irrigation schemes. The aim was to be accomplished using water use and loss data published from Vaalharts and Loskop irrigation schemes, in South Africa, as published by the Water Administration System (www.wateradmin.co.za). Vaalharts and Loskop are the two biggest irrigation schemes in the country; hence they do not represent the whole spectrum of available irrigation schemes in the country. Medium, and small sized irrigation schemes are left out although their characteristics and how they are managed could significantly influence the layout of the framework, and the nature and quantity of its input data requirements.

Determining WUE for irrigation schemes normally involves detailed assessments of entire water delivery-application chain, capturing the essential data from the source of the water all the way to the last plant on the crop field. However, the current project was restricted to the conveyance systems linking the reservoirs to the irrigated lands. The Water Administration Systems uses water delivery and loss data from the conveyance systems to compute water use efficiencies for the irrigation schemes. This is, perhaps, the most significant limitation of the Irri-Drop framework developed because it does not consider the irrigators themselves, who are the ultimate water users in that space.

It is also important to note that while Green-Drop, Blue-Drop and No-Drop Reports deal with piped systems, water conveyance systems at major irrigation schemes in South Africa are dominated by canals, which are open channels where water flow is driven by the influence of gravitational force. The use of natural gravitational force makes canals a cheap means of conveying bulk irrigation water. Therefore, the water uses and losses data collection protocols for the Irri-Drop Report framework are different from that of the Green-Drop, Blue-Drop and No-Drop Reports, which are used for rating wastewater works and municipalities.

The Irri-Drop Report framework has seven components, namely: Water Balance Report, Water Management Plan, Maintenance Plan, Condition Assessment Report, Technical Competency Report, Budgeting Report, and Credibility and Regulation Enforcement Report. While each one of these components can be treated as a stand-alone assessment tool or used in preferred combinations, the project treats them as weighted inputs to the Irri-Drop Report. Amongst them, the project treats the Water Balance Report component as the cornerstone of the framework because it accounts for water deliveries and losses as physically assessed from the conveyance infrastructure at the irrigation schemes. Therefore, physical assessment of water deliveries and losses at the irrigation schemes are critical for implementation of the Irri-Drop Report as an assessment tool for rating the performance of irrigation schemes. Although WAS has existed for decades covering only 23 big irrigation schemes in the country, it does not include smallholder systems which constitute significant water consumption each year. Therefore, rolling out the Irri-Drop Report to all irrigation schemes will help to fill in the information gap on water deliveries to irrigation schemes and the losses.

The water conveyance infrastructure needs to be well equipped for accurate accounting of water delivery and loss. Ill-equipped irrigation schemes in the country are reported to release up to 50% more water than necessary to compensate for unknown transit losses Bonthuys (2017). Equipping the conveyance infrastructure at major irrigation schemes for the purpose of implementing WAS has helped some irrigation schemes to reduce water delivery losses from 40 to 20%, which is testimony that significant water losses still exist. These irrigation schemes are still grappling with challenges of inadequate and sometimes dysfunctional water control and measurement equipment.

The Irri-Drop Report aims to enhance WCE by encouraging more accurate accounting of water deliveries and losses, and general readiness to deal with conveyance water losses, which resonates well with NDP (2011) agenda of alleviating poverty and creating jobs through improved WUE in agriculture.

1.4 Study area

The current Irri-Drop Report framework was developed based on information from two irrigation schemes: namely Vaalharts Water User Association (VWUA) and Loskop Irrigation Board (LIB). Figure 1.1 shows the geographical locations of Vaalharts and Loskop irrigation schemes in South Africa.

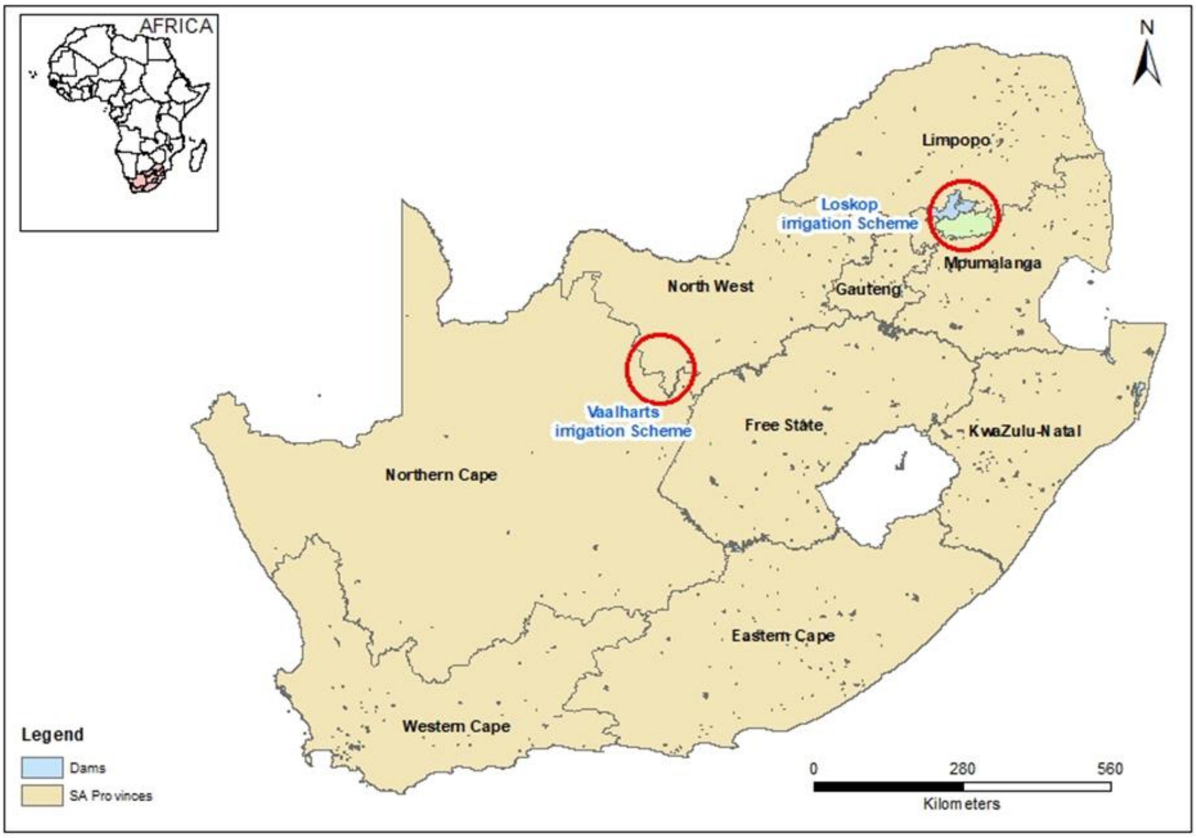


FIGURE 1.1 Location of Vaalharts and Loskop Irrigation Schemes in South Africa

1.4.1 Vaalharts Water User Association

Vaalharts Water Users' Association (VWUA), commonly known as Vaalharts Water (VW), is located at the boundary of Northwest and Northern Cape provinces. The main reservoir is located near the town of Warrenton at the confluence of Vaal and Harts. VW supplies water to irrigation schemes and municipalities through 1176-km long network of canals comprising about 100 km of main canals, 180 km secondary canals, 540 km tertiary canals and 320 km community canals. The rest are storm drains. The water is supplied to irrigation schemes, surrounding towns and industries through 1873 water abstraction points on the canal network. The main canal capacity was increased from the original 28 $m^3 s^{-1}$ to 48 $m^3 s^{-1}$.

The largest water using facility supplied by VW is the Vaalharts Irrigation Scheme (VIS), which has a land size of about 29 181 ha (Van Vuuren and Backeberg, 2015) making it the largest irrigation scheme in South Africa. Its development started around 1934. The irrigation scheme lies within an altitude of 1050-1150 masl. Its flat topographical gradient and typical soil profiles make natural drainage poor. The sedimentary strata making up most of the geology is of similar age to that of the Karoo, but basement rocks are Precambrian igneous formations (Ellington et al., 2004). The landscape is an open Savannah type characterised by diverse wildlife and vegetation; but the vegetation is dominated by camelthorn trees. The climate is arid to semi-arid, with long-term average annual precipitation in the range of 200-500 mm and mean annual evaporation of about 2800 mm.

Water is delivered to VIS through an 812-km long network of concrete lined canals. Figure 1.2 shows the areal extent of VIS, revealing the farm blocks and canal network. Water supplied to VIS is primarily for irrigation of crops throughout the year. The main method of applying water to the crops is the centre-pivot irrigation system. However, traditional methods such as overhead sprinklers and flooding systems are still in use but on very limited scale. Flooding irrigation systems are used for irrigating tree crops; however, their use is declining and being replaced by micro-sprayer and drip systems. Water use for livestock production is negligible in comparison to irrigation water use. There are also a few small-scale industries located on some farms.

The main canal supplying to VIS transmits about 272.6 $Mm^3\ yr^{-1}$ of water. The main canal also supplies 54.4 $Mm^3\ yr^{-1}$ of water to Taung Irrigation Scheme (6424 ha), located further downstream. There are 16 pressure regulating sluice gates on the main canal at VIS. The water flow measurements used to be done by means of chart recorders, which had to be read off and captured manually. However, they have since been replaced by electronic loggers. There are flumes at outlets to secondary and tertiary canals for flow measurements and manual recording. Electronic loggers have now been installed at all 15 secondary canal inlets at VIS. The number of tertiary canals abstracting water from the secondary canals vary greatly. The number of inlets supplying water from tertiary canals to farms also vary. There are also balancing dams of varying sizes dotted across VIS.

The major crops produced at VIS are lucerne, groundnuts, pecan nuts, potatoes, cotton, olives, citrus, apricots, grapes, peaches, watermelons, grains, and vegetables, (Van Vuuren and Backeberg, 2015). The high valued food crops are produced for South Africa as well as for export to neighbouring countries.

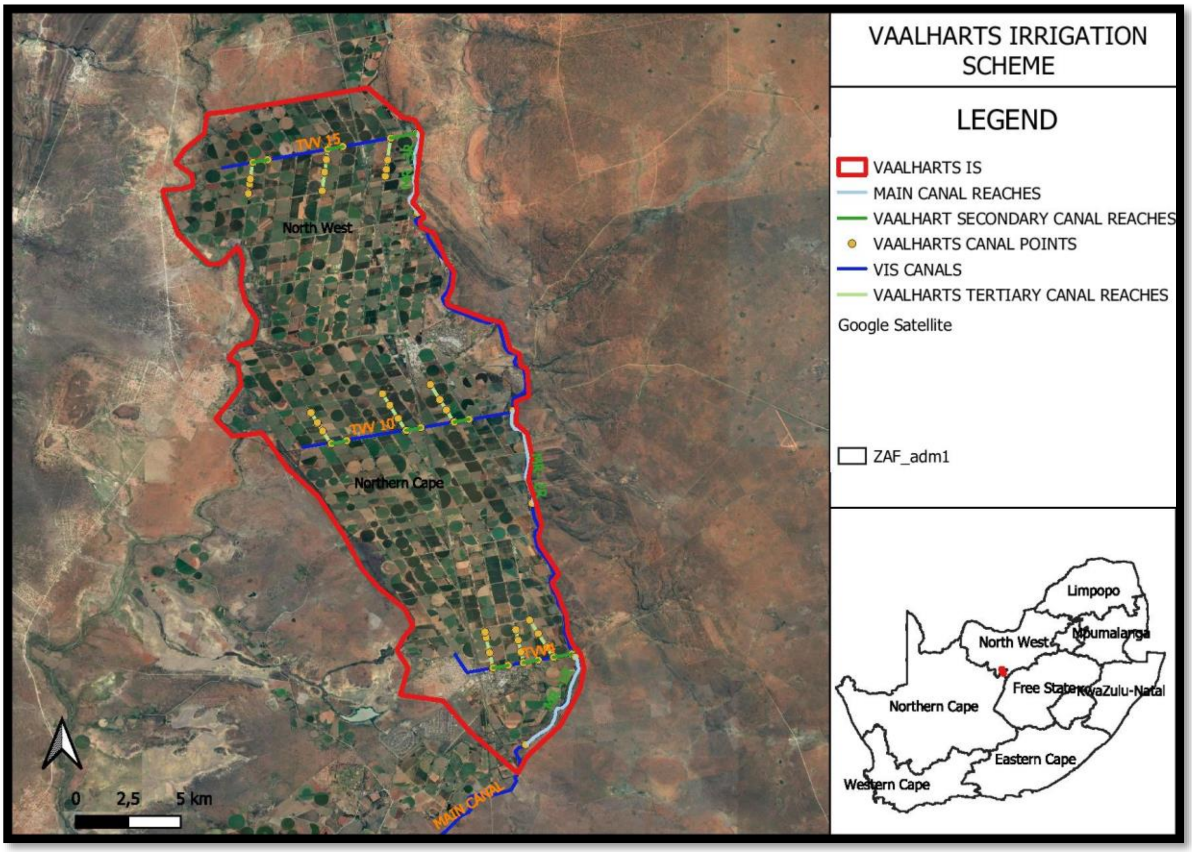


FIGURE 1.2 Network of canals at Vaalharts Irrigation Scheme

1.4.2 Loskop Irrigation Board

The irrigation scheme is located at the boundary of Limpopo and Mpumalanga provinces. The main reservoir is Loskop Dam; a combined gravity and arch type dam constructed on a solid rock base across a gorge on the Olifants River, 32-km south of Groblersdal town. This massive concrete structure is 506 m long, 54 m high and 24 m wide at the base. The storage capacity of the reservoir is 348 $Mm^3 yr^{-1}$ and caters for surrounding irrigation schemes, towns, municipalities, and other non-agricultural uses. The amount of water committed to non-agricultural uses is 4.4 $Mm^3 yr^{-1}$. Water is delivered through two main canals, a left bank canal of 96-km long and right bank canal of 60 km long, and about 330 km of secondary and tertiary canals. In addition, there is a network of 250 km drains for draining and returning excess water from the farms to the river. There are seven balancing dams on the irrigation scheme: four of them on the left and three on the right bank of the Olifants River.

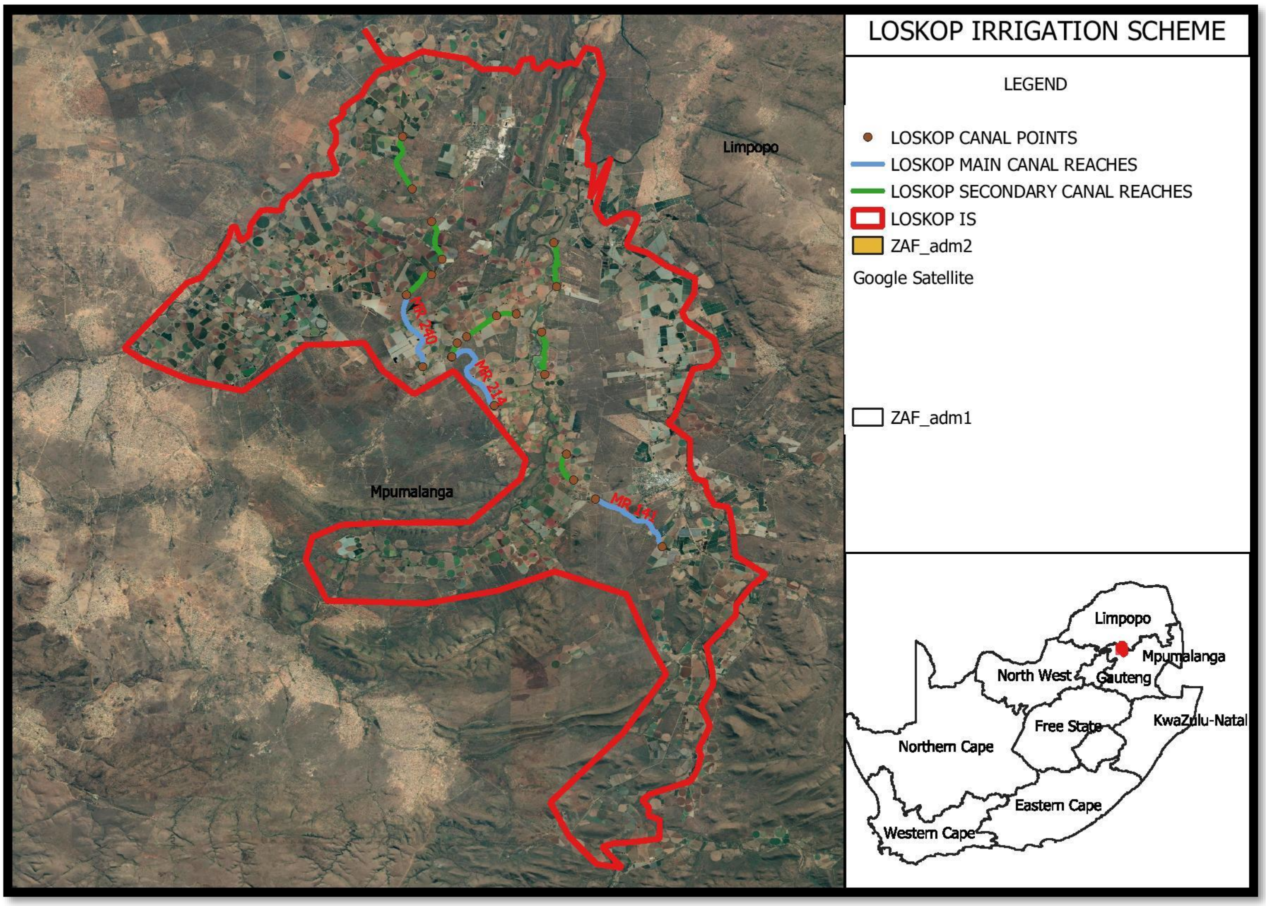


FIGURE 1.3 Network of canals at Loskop Irrigation Scheme

The largest water consuming facility on the irrigation scheme is the Loskop Irrigation Scheme (LIS), which stretches about 64 km to the north of Groblersdal town. Its irrigated land size of about 19000 hectares makes it the second biggest irrigation system in South Africa. One-third or 124 $Mm^3 yr^{-1}$ of Loskop Dam storage capacity is devoted to the irrigation scheme. The irrigation scheme is located on a mountainous bushveld to undulating terrain with average altitude of 916 masl. LIS gets water supply through a 495-km long network of concrete-lined canals. There are 667 properties on the irrigation scheme drawing water from the canal network using 794 abstraction points. Main canal flow measurement also used to be by means of chart recorders, but electronic loggers are now in place. Inlets to secondary and tertiary canals are equipped with flumes installed at the time of construction. The irrigation scheme is divided into eight wards. Figure 1.3 shows the areal extent of LIS, revealing the canal network.

The most prominent rock types occurring in the area are mud rocks, quarzitic sandstones, ironstones, quartzites and feldspars. The area falls within the savannah biome of South Africa (Barrett et al, 2010) dominated by thorn trees. The mean annual temperature is 20°C, while the mean annual rainfall is 552 mm. The subtropical climate can support the production of many different crops but summer tobacco and cotton, and winter wheat are the mainstays. The other major crops cultivated on the irrigation scheme are soybeans, groundnuts, peas, maize, citrus and table grapes. Most of the farmers use sprinkler systems for irrigating their crops, but the use of centre-pivots is increasing. The use of micro irrigation systems such as micro-sprayers and drip systems is also increasing with production of permanent crops such as citrus and table grapes.

1.4.3 Water management at the two irrigation schemes

Both irrigation schemes are headed by a Chief Executive Officer who is assisted by a Head of Water Control Officer. Water bailiffs, maintenance staff and office workers make the rest of the staff compliment. The irrigation schemes use the available political boundaries (called wards) to manage the water affairs and each water bailiff is assigned to at least one ward. Water delivery management at the two irrigation schemes is intensive with high losses inevitable.

Both irrigation schemes have transitioned from the old manual system to the WAS, which is computer based. The old system had several limitations leading to excessive water losses. The limitations included:

- large number of people involved in water calculations leading to calculation errors
- measuring station data were processed manually and quantifying released water volumes from chart recorders was inaccurate resulting in inaccurate release calculations and reporting figures
- system was slow and inefficient when recalculating water distribution sheets in the event of changes in demand for water
- compiling water conveyance efficiency reports was always time consuming and not very accurate
- information and experience were always lost with change in personnel, which affected water distribution management negatively
- water loss factors were largely unknown and had to be estimated most of the time

The new water management system at the two irrigation schemes is based on the Water Administration System (www.admin.co.za), a computer-based program introduced to address the above problems in the following ways:

- water orders are captured directly into the computer by water control officers
- calculation errors are now eliminated because computers do the calculations
- water balances are now updated daily basis
- electronic loggers, which are fast and accurate, and volumes are now quantified more frequently
- water distribution sheets can now quickly be recalculated in cases of water order changes because the sheets are linked to variable water loss percentage per canal
- Water conveyance efficiency reports are now generated automatically; all that is required is that water orders are captured, and that measuring station data captured by electronic loggers is imported into the computers
- all water control officers are computer literate due to the user friendliness of the WAS

The other advantages of implementing the WAS program at the irrigation schemes are:

- reduced paperwork because all water reports are now generated electronically
- human error induced water shortages are now limited
- fixed water losses enhance the ease of monitoring canal leakages and breakages
- the attitude of water control officers is now more positive due to reduced administration work and they can spend more time outside on the scheme
- the water control officers have more time for inspections, minor repairs, and time for clients
- productivity has vastly improved, and water reports are more reliable
- the water control office now gets more good service delivery complements, which make officers positive and proud to work
- overall water losses on the irrigation schemes have decreased significantly (e.g. by 5% from 32% to 26.7% yr^{-1} at Vaalharts), which offer opportunities for expanding irrigated lands and water supplies to other sectors

CHAPTER 2: REVIEW OF FACTORS AFFECTING CANAL WATER LOSSES BASED ON A META-ANALYSIS OF WORLDWIDE DATA

2.1 Introduction

Water has significant economic importance for many countries, especially those that are dependent on agricultural production. Its availability in correct quantity, quality and at the right time determines the success of agriculture, which enhances food security, employment creation and poverty reduction. Canals remain a major means of conveying water for agriculture (Eshetu and Alamirew, 2018) because they are a cheap means of transporting large quantities of water. However, canals have low water conveyance efficiency (Sultan et al., 2014) because water losses during transportation are often very high. For example, Backeberg et al. (1996) reported that water losses from irrigation canals in South Africa account for about 30% of the water released. The water losses from irrigation canals are a growing concern (Ahuchaogu et al., 2015) due to increasing water scarcity amid rising demand and dwindling freshwater resources (Falkenmark, 1990; Roudi-Fahimi et al., 2002).

Canal water losses refer to those that occur between the canal headworks and farm offtakes (Akkuzu et al., 2007; Fairweather et al., 2003; Schulze & Maharaj, 2007). The main types of canal water loss are seepage and leakage. Seepage refers to water movement out of the canals, through pores in the bed and walls (Worstell, 1976; Sarki et al., 2008). It is the most significant type of water loss from canal networks (Badenhorst et al., 2002; Wang et al., 2002). Seepage losses are generally higher from unlined than lined canals (Eshetu & Alamirew, 2018). It is logical that canal sections that experience high seepage losses are prioritized for lining. However, when the lining materials break down, the resultant water losses from these sections become comparatively higher than in those that have always been unlined. Therefore, while proper design and construction are essential to minimize seepage from canals, proper management and maintenance are also critical. Many factors, including texture of the canal bed and side soils, siltation conditions, water flow velocity, bank storage changes and groundwater table fluctuations, influence seepage losses from canals (Worstell, 1976). On the other hand, leakage refers to water escaping through cracks and holes in the canal due to physical damage (Mohammadi et al., 2019) and through inefficient gates. However, it is impractical to separate leakage from seepage when canals are in full operation and is reason for the two being often estimated jointly. There are various methods for estimating seepage and leakage losses such as the use of analytical and empirical formulae, and direct measurement techniques such as the use of seepage meters, ponding, and inflow-outflow tests (Alam and Bhutta, 2004).

Other important water losses from canals, which are minor in comparison with seepage and leakage, are due to evaporation, transpiration, and absorption (Patel et al., 2016). Evaporation is the loss through a free water surface, while transpiration is the loss through plants. These two water loss types can be significant in hot and dry weather conditions. In addition to high temperatures, winds and low humidity, transpiration losses are also generally high in heavily vegetated canals. Absorption is another relatively minor loss which is similar to seepage in that water seeps into the canal bed and sides; however, absorption water does not transmit to the surrounding soils.

Water loss and types vary across and within sites such as from one canal to another. However, their variability and the major factors of influence are still not clear, especially at a global scale. Such understanding would be very important for water scientists, engineers and role players involved in allocating resources to operate and maintain water conveyance infrastructure. Therefore, the current analysis aims at identifying and performing quantitative comparisons of the common water loss types from canals and elucidating the main factors of control.

2.2 Methodology

2.2.1 Study set-up

Publicly available literature on water losses from canals was obtained from electronic archives and search engines such as Google Search, Web of Science and Scopus. Key terms such as ‘canal water losses’, ‘open channel water losses’, ‘canal seepage’, ‘canal leakage’, ‘transit water loss’ and ‘conveyance water losses’ were used to facilitate the search for literature from the electronic archives and search engines. In order to be accepted, the literature material had to report on at least one water loss measurement using a clearly defined method. The type of water loss and its quantitative value needed to be reported. The other information targeted from the materials were experimental site and canal characteristics such as length, width, depth of flow, longitudinal slope, and channel treatment (i.e. whether the channel was unlined, compacted or lined). Reference lists of accepted materials were also consulted for other potential sources of information. While hundreds of potential journal articles and other materials were found online, retrieving the sources and the data contained by third parties proved difficult in many cases. As a result, only 48 published articles met the acceptance criteria; however, they were eventually reduced to 45 (Table 2.1) during the normalization of units of water losses from various units to litres per second per 100 m length of channel (L s^{-1} 100 m^{-1}), because it was not possible to convert the reported water losses from three articles into the preferred units of L s^{-1} 100 m^{-1}.

TABLE 2.1 Summary database

No	Author & year	Country	L	W	Y	P	R	A_X	A_{WL}	A_{WET}	Loss
			m					m^2			l/s/100 m
1	Ahuchaogu et al 2015	Nigeria	2.45	0.95	0.08	1.11	0.06	0.07	2.33	2.72	1.90
2	Akkuzu et al 2007	Turkey	263	3.85	0.82	4.37	0.72	4.49	2661	2977	12.90
3	Arshad et al 2009	Pakistan	282	0.56	0.23	1.02	0.12	0.12	156	289	0.99
4	Birajdar et al 2016	India	34960								258
5	Birara and Halefom 2017	Ethiopia	100	0.53	0.34	1.21	0.15	0.19	52.80	121	0.68
6	Bosman 1993	South Africa	72.19	7.76	2.33	12.67	1.43	18.09	813	914	0.06
7	Burt et al 2008	USA	1271	8.90					15679		0.63
8	Eshetu and Alamirew 2018	Ethiopia	359	1.83	0.46	2.23	0.38	1.03	1123	996	5.30
9	Iqbal et al 2002	Canada	358511								0.04
10	Kadu et al 2017	India	7000								19.27
11	Kahlown and Temper 2004	Pakistan	515	0.51	0.76	2.03	0.19	0.39	261	1046	2.69
12	Karad et al 2013	India	753		0.81	8.92	0.59	6.65		7542	55.54
13	Kasali et al 2018	Nigeria	2.50	6.68	0.40	2.14	0.22	0.46	32,50	5.35	20.94
14	Kedir 2015	Ethiopia	652	2.39	0.87	4.01	0.50	2.10	1688	2742	10.50
15	Khair et al 1984	Bangladesh	1.50	0.90	0.30	1.45	0.19	0.27	1.80	2.17	13.62
16	Khan et al 2019	Pakistan	138			17.92	0.31	5.63		2462	0.01
17	Kilic and Tuylu 2011	Turkey	461			4.23				3155	273
18	Kinzli et al 2010	USA	5150	6.60	0.84	7.47	5.51	45.78	35548	40171	2.01
19	Koradiya and Khasiya 2014	India	44584	21.05	2.70	30.77	2.19	67.93	890813	1318811	2.07
20	Kumar 2017	India	8356	30.59	3.18	37.20	2.60	97.09	296167	311447	8.74
21	Leigh and Fipps	USA		5.89	1.52	8.94	0.96	10.50			1.49
22	Leigh and Fipps 2002	USA	285	6.02	1.17	7.80	0.81	6.43	1990	1468	0.34
23	Leigh and Fipps 2003	USA	458	12.04	1.37	14.78	1.12	16.48	5511	6764	2.19
24	Meng et al 2015	China	14500	2.30	1.50	5.04	0.68	3.45	55100	73118,29	1.78
25	Moghazi and Ismail 1997	Saud Arabia	20.00	0.60	0.10	0.81	0.07	0.06	15.00	16.21	1.24
26	Mohammadi et al 2019	Iran	1021			2.11				2360	2.53
27	Mohsen and Mohammed 2016	Iraq	620		1.38	6.47				4106	38.23
28	Momenzadeh et al 2017	Iran	100	0.72	0.62	1.95	0.23	0.47	71.67	195	0.32
29	Mowafy 2001	Egypt	11182	39.90	4.30	48.49	3.48	179	474673	572125	7.07
30	Naidhu and Ghiridar 2013	India	11988								0.25
31	Nofziger et al 1979	USA		5.39		5.90					1.38
32	Patel et al 2016	India	614	67.50	7.30	90.10	6.65	599	41445	55321	166
33	Pognant et al 2013	Italy	500	3.00	0.20	3.40	0.24	0.81	1500	1700	8.00
34	Saeed and Khan 2014	Pakistan	2605	0.64	0.26	1.98	0.09	0.17	1714	5111	36.59
35	Sarki et al 2008	Pakistan	75.00	1.31	0.21	1.73	0.16	0.27	98.53	130	21.28
36	Sathe et al 2018	India	30000								2.48
37	Sen et al 2018	Bangladesh	15.24	0.24	0.15						19.31
38	Shumye and Singh 2018	Ethiopia	223	1.21	0.35	2.11	0.20	0.43			254
39	Sitender et al 2015	India	60.98	0.58	0.18	0.93	0.11	0.10	35.06	56.68	91.64
40	Skoperboe et al 1999	Pakistan	13247							77988	2.18
41	Solangi et al 2018	Pakistan	851								3.73
42	Soothar et al 2015	Pakistan	9.14	0.56	0.28	1.34	0.17	0.22	5.08	12.21	7.45
43	Sunjoto 2010	Indonesia	653	8.29	0.64	9.54	0.54	5.84	6354,22	6808	9.58
44	Zeb et al 2000	Pakistan	757								2.53
45	Zhang et al 2016	China	30.00	3.65	0.80	5.20	0.54	6.55	200	156	0.64
		Mean	12866	7.90	1.14	10.21	1.01	34.85	65490	75761	30.48
		SEM	8364	2.49	0.26	2.96	0.28	19.96	36239	43416	10.26
		CV%	426	178	131	172	157	319	293	329	226

Notes: canal characteristics
L: reach
W: width
Y: water depth
P: wetted perimeter
R: hydraulic radius
A_X: cross-sectional area
A_{WL}: area exposed to atmosphere
A_{WET}: wetted area
and water losses (L s^{-1} 100 m^{-1})

2.2.2 Description of factors that control canal water losses

The main factors that influence canal water losses are canal linings, cross-sectional profile and water level, soil hydraulic properties and their spatial variations, groundwater table location, and amount of sediment inside the canal (Yao et al., 2012). There are so many attributes associated with these factors such that it is difficult for a single study to cover all of them. This study initially considered many potential factors, but some were dropped due to limited information from the source articles. Canal characteristics consist of length of studied reach (L, m) and its longitudinal slope (S, %), frictional coefficient (f_c, no units), side slope (h: y, fraction), top width (T_W, m), bottom width (B_W, m) and average width (W, m). A reach is a length of a canal usually suggesting a straight, level, uninterrupted stretch. Note that T_W is the width at the water surface level and not the nominal top width of the canal. Water flow parameters captured from accepted articles and used in the current analyses were water flow depth (Y, m), wetted perimeter (P, m), and hydraulic radius (R, m). Relevant information present in the articles was used to compute missing parameters whenever possible. Hence, cross-sectional area of flow (A_X, m^2), free surface area (A_{WL}, m^2) and wetted area (A_{WET}, m^2) had to be calculated in many instances. The other flow characteristics captured were water flow velocity (V_t, m s^{-1}), discharge (Q_t, m^3 s^{-1}) and volume in the reach (Q, m^3). Two factors relating to surrounding soil characteristics (Clay %: soil clay content and K_{sat}: saturated hydraulic conductivity) were also used in the analyses. Data on W, Y and Clay % were used to develop three classes each (Table 2.2). No strict rules guided the categorization into classes; however, the main aim was to generate approximately equal sample sizes without upsetting generic knowledge. The three Clay % classes were based on Dotto et al. (2016).

TABLE 2.2 Channel and soil class definitions

Parameter	Class
Width (m)	<1.50
	1.50–3.00
	>3.00
Depth (m)	<1.00
	1.00–1.50
	>1.50
Clay content (%)	<15
	15-35
	>35

2.2.3 Description of methods used for determining water losses

Conveyance, seepage, leakage, and evaporation dominate the water loss types encountered during the literature search. The difference between conveyance, seepage and leakage losses was not clear in many cases. In some instances, they were estimated using similar methods. The current study uses the method of determination to discriminate the water loss types. In that regard, all water losses determined by the inflow-outflow approach are classified as transit losses, while those determined by ponding are seepage losses. This approach eliminates leakage losses from the current analysis. The inflow-outflow method relied on the difference in discharge between two points on a canal reach. The discharges were determined by means of flow velocities and areas, and/or flumes. On the other hand, the rate at which the ponded water depth receded was also used to determine seepage loss. Several formulae were also used to determine both transit and seepage losses. In addition, geographic information system (GIS) approaches were also used. Evaporation losses from canals were determined by use of open pans; weather data in conjunction with some formulae were used in some cases.

2.2.4 Data analyses

The current study did not calculate canal water losses *per se*; the data were reported in the articles. The water losses reported in other units were normalized to litres per second per 100 m of canal reach length (L s^{-1} 100 m^{-1}). This was followed by simple statistical analyses to determine the minimum, maximum, mean, median, standard error of mean (SEM) and coefficient of variation (CV, %). These general statistics were used to compare water losses between factors and factor classes. Box plots (generated using StatiStica 7 software) were used to elucidate trends from one factor level to another. Outliers are not shown in all the box plots; however, they were part of the other analyses. T-tests were performed to determine the significance of differences ($p<0.05$). Finally, Spearman rank correlations (r_s) were used to quantify the bivariate relationships between factors and water losses because the data sets were not normally distributed.

2.3 Results

2.3.1 Variability of factors and water losses across the world

The literature search yielded 45 scientific papers from around the world (Table 2.1). India and Pakistan contributed nine papers each. Other papers from the same region came from Bangladesh, China, and Iran with two papers each, and Indonesia, Iraq, and Saudi Arabia with one paper each. Europe contributed three papers from Turkey (with two papers) and Italy. Canada (with one paper) and USA (with six papers) contributed seven papers from North America. Ethiopia dominated the African contribution with four papers, followed by Nigeria with two, and lastly Egypt and South Africa with one paper each. The 45 papers reported water losses from 1388 canal reaches. The average length was 12 866 ± 3364 m with a coefficient of variation (CV) of 426%. The other canal and flow characteristics showed lower CVs, ranging from 131 to 329% for flow depth and A_{WET}, respectively.

The most reported water loss type was transit (1157), followed by seepage (205) and lastly evaporation (26). The transit losses averaged 31.98 ± 2.83 L s^{-1} 100 m^{-1}. Seepage losses averaged 2.59 ± 0.35 L s^{-1} 100 m^{-1}, while evaporation averaged 0.06 ± 0.01 L s^{-1} 100 m^{-1}. Transit losses exhibited the highest variability (with a CV of 303%), followed by seepage (191%) and lastly evaporation (78%).

The factor categories used in the analyses are defined in Table 2.2. The T_W categories <1.50, 1.50-3.00 and >3.00 m are typical of tertiary, secondary and main canals, respectively. Likewise, the flow depth classes <1.00, 1.00-1.50 and >1.50 m are also typical of tertiary, secondary and main canals, respectively. The soil clay content classes of <15, 15-35 and >35% are typical of sandy, loamy, and clayey soils, respectively.

2.3.2 Comparison of the different water loss types

Figure 2.1 compares the different major water loss types from the canal reaches reported in the 45 data sources used in the current analysis. The results show that evaporation is negligibly lower than both seepage and transit losses. On the basis of mean values, the figure suggests that evaporation is 43 and 533 times lower than seepage and transit losses, respectively. On the other hand, transit losses are only 12 times higher than seepage losses. Therefore, evaporation loss should only be considered when other losses are also small (Sonnichsen, 1993).

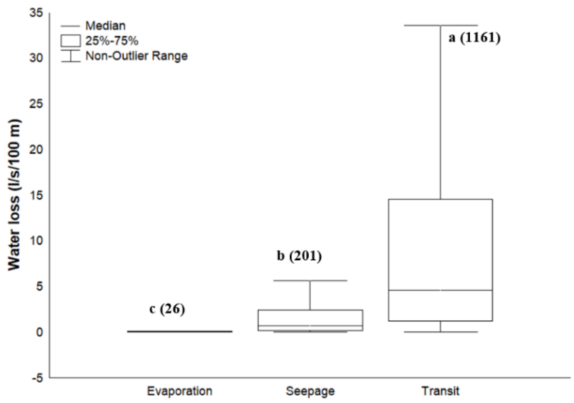


FIGURE 2.1 A comparison of canal water loss types
Note that boxplots accompanied by similar letters were not significantly different (p<0.05), while numbers between brackets (N) represent sample sizes.

2.3.3 Potential effects of measurement methods on water losses

The study results show that method of water loss determination has significant effects on water losses (Figure 2.2). The results in Figure 2.2A suggest that ponding tends to give lower seepage loss values than seepage meters and formulae. However, ponding values do not differ significantly with seepage meter (S meter) values. The formulae values tend to vary more than those obtained by ponding and seepage meters. Figure 2.2B also shows a tendency of transit water losses to depend on estimation method. The GIS method exhibits significantly lower values, while the inflow-outflow method shows the highest values. Coincidentally, inflow-outflow values are also the most varied (CV = 204%). The formulae, which was the most popular method (N = 708), gives transit loss values that are intermediate but still significantly greater than those that the GIS method generates.

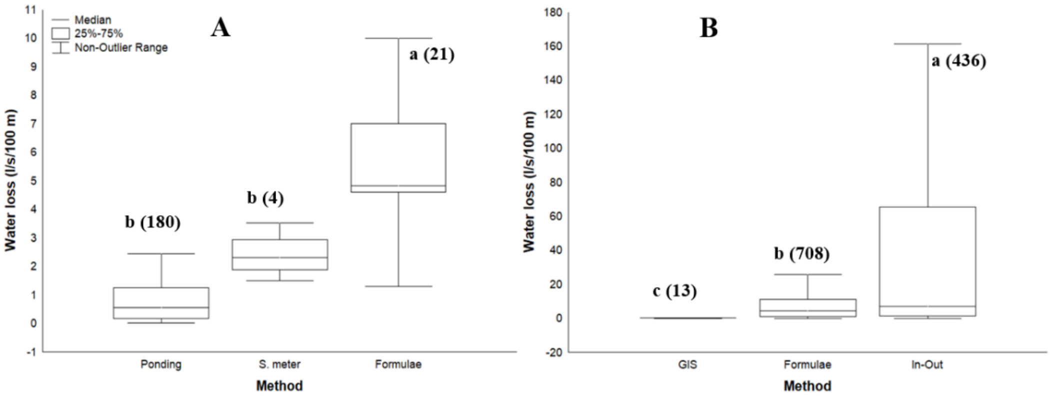


FIGURE 2.2 Comparisons of different methods used to estimate (A) seepage and (B) transit water losses
Note that boxplots accompanied by similar letters were not significantly different (p<0.05), while numbers between brackets (N) represent sample sizes.

2.3.4 Potential effects of canal and flow characteristics on water losses

2.3.4.1 Canal shape

Canal shape shows significant effects on water losses (Figure 2.3). Trapezoidal canals tend to give significantly higher and most varied (CV = 163%) seepage losses than other canal shapes (Figure 2.3A). Ironically, the trapezoidal shape was the most popular shape in the canal networks (N = 96). The parabolic shape exhibits the lowest seepage losses; however, this is not significantly different from the U-shape. Nevertheless, median values suggest that seepage losses from trapezoidal, rectangular, and U-shaped canals might not differ greatly after all. The ellipse shape exhibits the most significant transit losses (Figure 2.3B). Despite showing a very low median value, rectangular-shaped canals show significantly higher transit losses than trapezoidal and irregularly shaped canals. Surprisingly, irregularly shaped canals, which were often unlined, have the lowest transit water losses. Overall, canal shape has a significant effect on both seepage and transit water losses. However, other factors such as channel treatment and/or soil type may also contribute to these results.

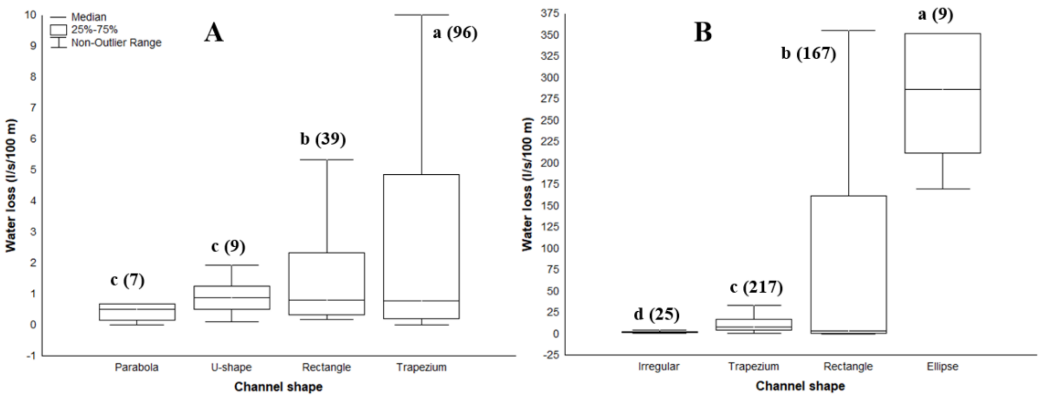


FIGURE 2.3 Comparisons of (A) seepage and (B) transit water losses from different shaped open canals
Note that boxplots accompanied by similar letters were not significantly different (p<0.05), while numbers between brackets (N) represent sample sizes.

2.3.4.2 Canal treatment

The results in Figure 2.4, which show significantly higher water losses from lined canals than both unlined and compacted canals, were a big surprise. Figure 2.4A shows the most significant seepage losses from lined canals, followed by unlined and lastly compacted canals. Variability follows the same order with respective CVs of 164, 140 and 123%. However, median values suggest the seepage losses amongst the three treatments could be of the same order of magnitude at 0.77, 0.67 and 0.70 L s^{-1} 100 m^{-1} for lined, unlined and compacted canals, respectively. Lined canals also exhibit the most significant transit water losses, followed by compacted and lastly unlined canals (Figure 2.4B). Median values (16.50, 10.57 and 3.66 L s^{-1} 100 m^{-1} for lined, compacted and unlined canals, respectively) also follow the same order. However, there is no significant difference between transit losses from compacted and unlined canals.

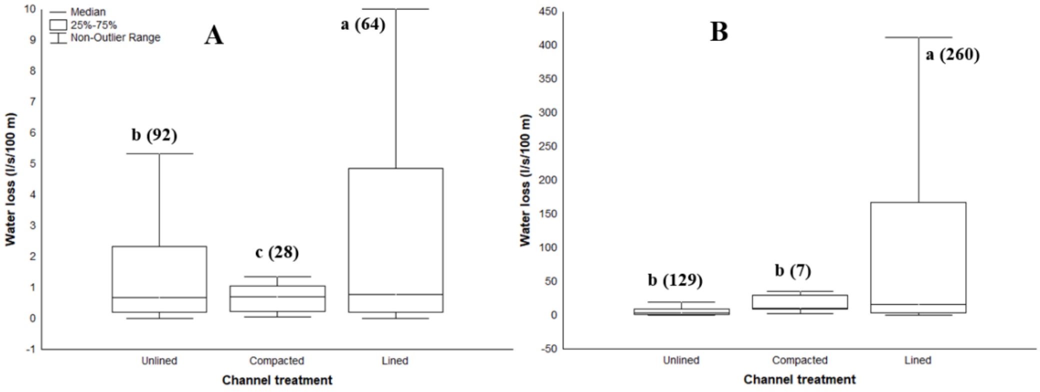


FIGURE 2.4 Comparisons of (A) seepage and (B) transit water losses from different canal treatments
Note that boxplots accompanied by similar letters were not significantly different (p<0.05), while numbers between brackets (N) represent sample sizes.

2.3.4.3 Canal width

Figure 2.5 shows that canal width has significant effect on seepage (Figure 2.5A) and transit water losses (Figure 2.5B). The results suggest lowest water losses from secondary canals. Main canals (wider than 3.00 m) exhibit the highest seepage losses, which are significantly higher than from the other two categories (Figure 2.5A). Seepage losses from tertiary (<1.50 m wide) and secondary canals (1.50-3.00 m wide) are not significantly different; however, losses from secondary canals tend to be lower. Median values confirmed the trend with values of 0.80, 0.36 and 0.65 L s^{-1} 100 m^{-1} for tertiary, main and secondary canals, respectively. In contrast, tertiary canals have the highest transit losses, but secondary canals exhibit the lowest transit losses. However, secondary canal transit losses are not significantly different from those of main canals. The median values are of the same order of magnitude (5.07, 4.31 and 4.12 L s^{-1} 100 m^{-1} for tertiary, secondary and main canals, respectively).

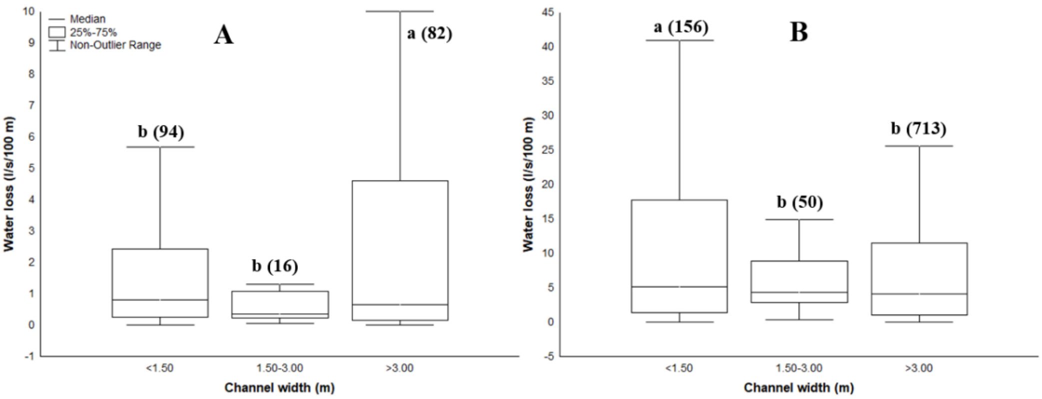


FIGURE 2.5 A comparison of the effect of channel width on (A) seepage and (B) transit water losses
Note that boxplots accompanied by similar letters were not significantly different (p<0.05), while numbers between brackets (N) represent sample sizes.

2.3.4.4 Flow depth

While seepage losses are lowest in the secondary canals (1.00-1.50 m flow depth) (Figure 2.6A), transit losses show a tendency to decrease with increasing flow depth (Figure 2.6B). Seepage losses are significantly lower in secondary canals than both tertiary (<1.00 m flow depth) and main canals (>1.50 m flow depth) (Figure 2.6A). Median values confirm the same trend. However, it is important to note that the secondary canal category is based on a much smaller sample size in comparison to the tertiary and main canal categories. Transit losses tend to decrease with increasing flow depth and the differences between canal categories are all significant (Figure 2.6B). Median and CV values also exhibit a general decrease as flow depth increases. Similar to the case with seepage losses (Figure 2.6A), transit losses for the secondary canal category are also based on a much smaller sample size when compared with tertiary and main canal categories.

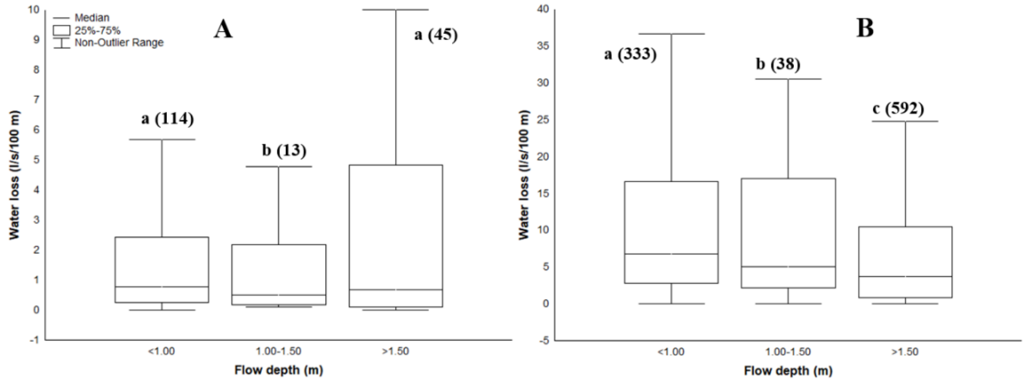


FIGURE 2.6 A comparison of the effect of flow depth on (A) seepage and (B) transit water losses

Note that boxplots accompanied by similar letters were not significantly different ($p<0.05$), while numbers between brackets (N) represent sample sizes.

2.3.4.5 Soil clay content

Figure 2.7 shows that seepage water losses from canals tend to decrease with increasing soil clay content. Variability of seepage losses also tends to decrease in the same direction. Canals on sandy soils (<15% clay content) exhibit significantly higher seepage losses than on loamy soils (15-35% clay content) (Figure 2.7A). However, lack of significant difference with canals on clayey soils (>35% clay content) is surprising. The lack of a significant seepage difference between canals on loamy and clayey soils is also surprising. Transit losses from canals also exhibit the characteristic decrease with soil clay content (Figure 2.7B). However, there is no significant difference between canals on sandy and loamy soils, which is also a surprising result. Indeed, canals on clayey soils exhibit significantly lower transit losses.

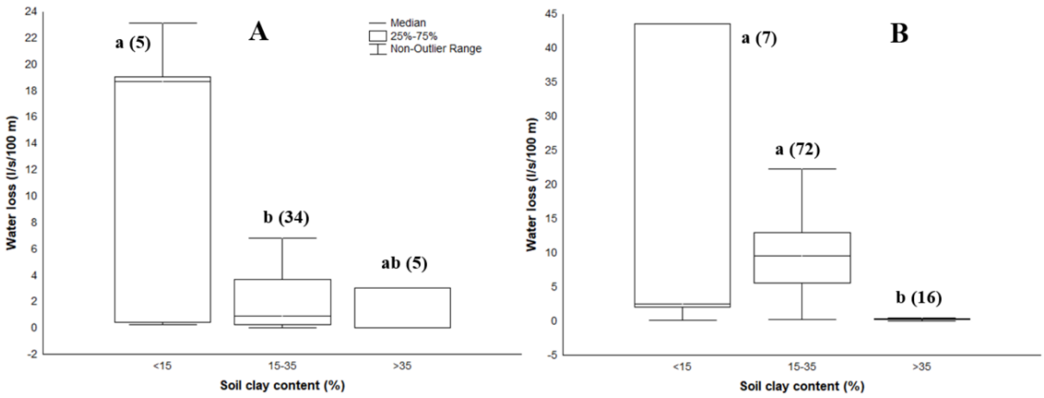


FIGURE 2.7 A comparison of the effect of soil clay content on (A) seepage and (B) transit water losses

Note that boxplots accompanied by similar letters were not significantly different ($p<0.05$), while numbers between brackets (N) represent sample sizes.

2.3.4.6 Bivariate relationships

The overall one-on-one relationships between water losses and controlling factors are elucidated by means of Spearman rank correlations analysis (r_s) because a complementary investigation showed that the data sets are not normally distributed. The results of the correlation analysis are presented in Table 2.3. The results show that evaporation losses correlate strongly and positively with canal reach length (L, m), side slope (h: y, fraction) and frictional coefficient (f_c, no units). The respective r_s values are 0.61, 0.62 and 0.50. Seepage losses correlate strongly with f_c and longitudinal slope (S). However, the correlation with f_c is positive (r_s =

0.63), while that with S is negative (r_s = -0.73). On the other hand, transit losses correlate significantly with L, bottom width of canal (BW), canal side slope (h:y) and S. Nevertheless, the correlations are generally weak, except with h: y (r_s = 0.77). Similar to seepage, the correlation between transit losses and S is also negative (r_s = -0.27). Evaporation and seepage losses correlate strongly with some flow characteristics, while transit losses correlate weakly with the same characteristics. It is interesting to note that all three water loss types correlate significantly with average discharge (Q_t) and velocity (V_t); however, Q_t correlated positively while V_t correlated negatively. Another exciting observation is the weaker correlation with transit losses than the other two water loss types. It is surprising that only transit losses show significant correlations with soil properties. The correlations are quite strong at -0.59 and 0.64 for soil clay content (Clay) and saturated hydraulic conductivity (K_{sat}), respectively.

TABLE 2.3 Spearman Rank correlation analysis results

Factor class	Factor	Evaporation	Seepage	Transit
Canal characteristics	L (m)	0.61*	0.14	0.24*
	T_W (m)	0.01	0.08	0.02
	B_W (m)	0.01	-0.04	0.13*
	W (m)	0.01	0.03	0.03
	h: y (fraction)	0.62*	0.10	0.77*
	f_c (no units)	0.50*	0.63*	-0.08
	S (%)	-	-0.73*	-0.27*
Flow characteristics	Y (m)	0.01	0.03	-0.10*
	P (m)	0.01	0.07	0.07*
	R (m)	0.01	0.03	0.02
	A_{WL} (m^2)	0.61*	-	-
	A_X (m^2)	-	0.03	-0.02
	A_{WET} (m^2)	-	0.09	0.13*
	Q_t (m^3 s^{-1})	0.50*	0.62*	0.11*
	V_t (m s^{-1})	-0.50*	-0.53*	-0.36*
	Q (m^3)	0.61*	-0,19	-0,06
Surrounding soil characteristics	Clay (%)	-	-0.05	-0.59*
	K_{sat} (cm h^{-1})	-	0.14	0.64*

Note: values in the table which are accompanied by * were significant at $p<0.05$

2.4 Discussion

An adequate water supply is a basic requirement for successful agriculture (Abidi, 2013). Water shortages for agriculture are due to the limited availability and inefficient use of available water (Laghari et al., 2008). High levels of water conveyance efficiency are needed because agricultural water availability is already limited in many regions of the world. The first step in any intervention strategy should be a diagnosis of the present situation (FAO, 2002). Reliable information on the nature and extent of water losses, which are affected by multiple factors which act collectively (Alam and Bhutta, 2004), is very important. The current study confirms, without considering potential inherent errors in the data sets used, that evaporation losses from canals are negligibly small in comparison with seepage and transit losses. Evaporation is 43 and 533 times lower than seepage and transit losses, respectively, while seepage is only 12 times lower than transit losses. This result agrees with assertions by other researchers such as Lancaster (1952), who advised ignoring it in general discussion.

Seepage and transit losses are estimated by use of direct methods such as seepage meters, ponding and inflow-outflow approaches, and indirect methods such as the use of formulae (Alam and Bhutta, 2004). The ponding method gives the lowest values, which are not significantly different from seepage meter values. In contrast, the inflow-outflow technique gives the highest and most varied values. These results are consistent with the findings of Alam and Bhutta (2004) whose study results point to 2.1 times higher values by inflow-outflow than the ponding method. The high variability of water loss values obtained by the inflow-outflow technique also agrees with the findings of Dukker et al. (1994). The formulae approach is the most popular technique in terms of the number of cases where it was used to estimate water losses in the literature consulted to generate data for the current analysis. The water loss values obtained by formulae are significantly lower than for the inflow-outflow method, but significantly greater than those obtained through the GIS approach.

The high water losses estimated by the inflow-outflow method can be explained by the fact that the technique is generally applied to long canals and in situations where water loss rates are high (Alam and Bhutta, 2004). Hence, it gives high values due to the large volumes of water handled. Another explanation, related to the first, is that estimated losses are often small differences between relatively large quantities such that small percentage errors in flow measurements can become big errors in calculated water losses. Low water losses for the ponding method can be explained in terms of suspended materials that settle on the wetted perimeter of the canals and, subsequently, reduce water losses through seepage (Alam and Bhutta, 2004).

The trapezium, which is the most popular canal shape, in terms of the number of canal sections that bear the shape amongst the canals used to generate data for the current analysis, gives the most significant water losses. This result is in contrast with the findings of Swamee et al. (2002) who computed potential seepage losses during the design of canals of different cross-sectional shapes. Swamee et al. (2002) concluded that the trapezoidal section would lose the least water and would also be less sensitive to increase in canal bed width. However, it is important to note that Swamee et al. (2002) obtained their results from design computations, while the current study data are based on field measurements. On the other hand, the ellipse shape has the most significant transit losses. Rectangular-shaped canals exhibit the most varied transit losses but with a median value lower than that of the trapezoidal shape. It is surprising that irregularly shaped canals, which are often not lined, have the lowest transit water losses. In fact, the current analysis shows significantly higher water losses from lined than both unlined and compacted canals, which contrasts with results from many studies (e.g. Siddique et al., 1993; Garg, 1999; Khan et al., 2001; Sultan et al., 2014), which reported 32 and 90% lower seepage losses from lined than unlined canals. However, the current analysis result agrees somewhat with the finding of Yao et al. (2012), who reported that clay lining plus compaction provides better anti-seepage performance than concrete lining.

While there could be some other underlying factors explaining higher water losses from lined than unlined canals, damage to lining materials can explain this result. In practice, canal sections that experience high seepage losses are prioritized for lining. If cracks at joints and holes (created by rodents and people poaching water) propagate to dilapidation levels due to lack of repairs, water losses become high; obviously to levels higher than in sections that are not lined. Maintenance and repair work of water infrastructure in irrigations schemes are sometimes hampered by a lack of clarity over ownership and responsibility between water users and irrigation authorities. In addition, water users generally lack the skills and resources to maintain and repair lined canals; hence, they depend on the authorities who are also often financially limited (Abidi, 2013). In addition to a lack of skills and resources, water users also lack the collective ability and willingness to perform the tasks needed (Hassan et al., 1999) because, partly, maintenance requires closing the canals for long enough (Memon et al., 2013), which interrupts production and subsequently farmers' livelihoods. This is one reason why farmers are generally reluctant to support rehabilitation works in the absence of subsidies.

The cross-sectional shape and area of a canal affect the wetted perimeter (Sonnichsen, 1993), which in turn has a bearing on the wetted area available for seepage and leakage losses. Therefore, it would be prudent to compare water losses from canals of equivalent cross-sectional areas, which is not done by the current analysis. The result showing the highest seepage losses from the widest canals (which are typically main canals) somewhat confirms the notion of financial constraints on the part of irrigation authorities because main canals are normally their responsibility. The narrowest canals (which are typically tertiary canals and in most cases under the control of water users) exhibit the highest transit water losses to further confirm the potential lack of collective remedial efforts by water users. Tertiary canals are in parts of the irrigation schemes inundated by vehicular and human traffic. Hence, they are more prone to damage and require more frequent repair work to keep them in good functional order than both secondary and main canals. It is also prudent to compare water losses between canals supplying water to individual farmers and those that supply groups of farmers, which is not done by the current analysis.

Intermediate canals (which are typically secondary canals) have the lowest seepage and transit water losses for unclear reasons. But one might speculate that since these canals are mostly under the care of irrigation authorities and are located close to water users, the authorities focus their meagre resources there for visibility by water users who are often levied for water use. The water losses and variability of the data sets used tend to decrease with increasing soil clay content, which agree with laboratory findings by Zhang et al. (2020). Zhang et al. (2020) demonstrated that the internal stability of soils changes from piping to the transitional type as soil clay content increases. Their results effectively mean that the drainage capability of a soil decreases with increasing soil clay content because clay soil particles are very small and low in hydraulic conductivity. The tortuosity of flow increases with soil clay content, which ultimately contributes to a reduction in the drainage capability of soils.

2.5 Conclusions

A number of key insights emerged from the study. The first is confirmation that evaporation water loss from open canals is negligible in comparison with seepage and transit losses. Therefore, evaporation can still be ignored in the analysis of major water losses from canals at a global scale. The second is that the inflow-outflow technique gives highly varied values, making it highly uncertain as well. On the other hand, the results of the ponding technique are also uncertain due to the effects of sediment settling on the canal bed and walls, which reduces seepage losses. The third insight is that canal cross-sectional profile, together with derivative characteristics such as wetted perimeter and wetted area, have a significant influence on water losses. The fourth insight is that lining of canals, often done in canal sections experiencing high seepage losses, might not be cost effective if not accompanied by proper and sustained maintenance and repair schedules because the same sections will experience very high water losses when the lining breaks down. Therefore, good technical design of canals needs to be supported by equally good management and maintenance plans for better performance of the canals in terms of water conveyance. It is recommended that future studies consider investigating the physical mechanisms of water losses and the different water loss types involved. It is also recommended that future investigations include the effects of factors such as canal embankment height and depth of freeboard on, especially, evaporation losses.

CHAPTER 3: ASSESSMENT OF WATER MEASUREMENT DEVICES AND CONVEYANCE SYSTEMS OF VAALHARTS & LOSKOP IRRIGATION SCHEMES

3.1 Introduction

Water conveyance infrastructure deteriorate over time, which might have a significant effect on its performance in terms of transmitting water. One of the most likely outcomes of conveyance infrastructure deterioration is increased water losses through leakage. However, water conveyance at the irrigation schemes in South Africa is not only about canals, concrete lined or not. There are many control and measurement devices on the canal networks whose condition might have a significant bearing on, for example, the accuracy of water flow quantification. The water measurement devices on the canal network enable the quantification of water input volumes and delivery to the different users; hence, major water losses can be computed at least for the timescale of the measurements. It is important to note that the current project placed a lot of emphasis on conveyance infrastructure efficiency in terms of transmitting water because the Water Balance Report is the main pillar of the Irri-Drop Report framework. The project envisages that the minimum requirement for the Irri-Drop Report at any irrigation scheme is the Water Balance Report.

It is also important to reiterate that the current project aimed at assessing the state of irrigation water losses at selected irrigation schemes and the possible measures to improve water use efficiency. The assessment was to be done using data collected and published by the Water administration System (Benadé, 2011; Benadé et al., 1997), which is publishing irrigation water usage and loss data for 23 irrigation schemes in South Africa. This, therefore, made the project a desktop study. However, it was still important to understand the condition state of the infrastructure at the irrigation schemes and the major drivers of the water losses being incurred. This was achieved through consulting available reports about the infrastructure and visits to the sites to perform visual checks on the infrastructure. A literature review of the major canal water loss types and their main drivers was also performed and constitute Chapter 2 of the current report. The current chapter is based on the assessment of the water measurement devices and conveyance systems at Vaalharts and Loskop irrigation schemes.

Most big irrigation schemes in South Africa use canal networks to transmit irrigation water from sources (such as dams) to the farms. The canal networks differ in configuration and shape depending on many factors that include relative location of scheduled blocks and their sizes, soil types and their drainage properties, available resources and skills for constructing the canals. However, three main components of the canal networks can commonly be observed: namely the main, secondary and tertiary canals. The cross-sectional properties of the canals generally change from the main to secondary canal and from secondary to tertiary canal, and so forth. In particular, the cross-sectional area of the canals change with discharge from main to tertiary level. While the Water Administration System, which is reporting on the water usage and losses at 23 big irrigation schemes in the country, can handle the complexities that come with variability in cross-sectional properties, it is very difficult if not impossible for human beings to do the same. Moreover, it would be arduous to cover entire the canal networks, which run into hundreds of kilometres in length at some irrigation schemes. Therefore, the current project had to select representative canal sections for the purpose of the assessment exercise.

3.2 Methodology

Data on the state of water measurement devices and conveyance systems at Vaalharts and Loskop irrigation schemes was obtained in two ways; (i) available reports and publications, and (ii) physical assessments at the irrigation schemes. The physical assessment involved visiting the two sites and meeting with the managers before proceeding to do checks on the infrastructure. The visits took place on 13th and 20th February 2020 for Vaalharts and Loskop irrigation scheme, respectively. Meetings were held with the water managers at the irrigation schemes to discuss:

- The general overview of the irrigation schemes paying particular attention to the water infrastructure in place and canal system layout (presented in Chapter 1 of the current report)

- The proposed Irri-Drop conceptual framework focusing on the target water loss types and how they can possibly be measured (reported in Chapters 4 and 6 of the current report)
- Selection of representative canals whose state was to be assessed

Note that it was not possible to visit the entire canal network due to time constraints, hence, the need to select the representative canals. The selection of the canals to tour were made jointly with the water managers. Visits to the irrigation schemes and tours of the canals offered opportunities for the project team to familiarize with the irrigation schemes. It is important to highlight that visits coincided with the peak irrigation season and physical observations could not be done with canals in full flow. The tours were rescheduled to May and June 2020, when the canals had dry windows due to scheduled maintenance and rehabilitation activities. Few water managers accompanied the project team on the tours during that period. The information collected from literature and during the tours included the following:

- Length of conveyance systems (reported in Chapter 1 of the current report)
- Number of irrigators (reported in Chapter 1 of the current report)
- Water delivery points (reported in Chapter 1 of the current report)
- Scheduled area (reported in Chapters 1 and 6 of the current report)
- Water allocation (reported in Chapter 1 of the current report)

The condition state of the infrastructure was qualitative and subjective. The participants on the tour had to indicate whether thought the infrastructure was in ***very good*, *good*, *acceptable*, *bad*** or ***very bad*** condition. ***Very good*** condition meant that the infrastructure was in perfect functional state, while ***very bad*** meant immediate rehabilitation was needed because its condition had deteriorated to a dysfunctional state. When differences in opinion occurred, consensus was sought. The decision on condition state of the infrastructure was guided by the prevalence of the following:

- Holes, cracks and collapsing of the canal walls
- Wear of the canal walls and bed
- Wear of sluice gates and existence of leakages
- Wear of flumes and water depth measuring devices
- Gaping at joints of blocks used to construct the canals
- Silt, trash, and stones on the canal bed
- Trees and grass in or on edges of canals

According to Akkuzu et al. (2007), selection of canals should consider the following guides:

- flow should be the normal operating condition of the canal
- preferred measurement method should not cause change in water level
- no disruption/ change of cross-sectional geometry occurs during measurement and flow depth should be sufficient for measurement

The following were discussed with the water managers at the irrigation schemes to guide selection of the canals.

- Characteristics of the main, secondary, tertiary and other canal levels selected in terms of:
    - total length
    - cross-sectional properties
    - longitudinal slope
    - number of abstraction points
    - control and measurement devices installed
    - lining and lining materials used
    - main soil types along the canals
    - age and level of deterioration and/or damage
    - vegetation growth and sedimentation in canals
- Zones of the canal levels
    - since discharge decreases in downstream direction, canals are divided into upper (nearest to water source), middle and low (furthest from water source) sections
- Selecting canals
    - if irrigation system consists of more than one main canal, the main canal supplying the main block or group of farmers is selected
    - at least three secondary canals are selected from the main canal: one from the upper, middle and lower zone
    - at least three tertiary canals are selected from each selected secondary canal, i.e. one in the upper, middle and lower zone

- equal numbers of canals are selected for the zones at each network level
- selected canals should be good representatives of the network in terms of variability in:
  - shapes and cross-sectional geometry
  - age and condition
  - flow control and flow measurement devices
  - canal reaches lengths (lengths of the same order are preferred)
  - number of abstraction points spanned by sections (keep number of abstraction points to a minimum)
- canals to be selected should be in current use by the WAS program and with historical data available, i.e. flow measurement devices need to be in place
- canals to be selected should exhibit potential for the existence of many water loss types

3.3 Results

3.3.1 Selected canals

The selected canal sections are highlighted in the figures presented in Chapter 1 of the current report. They are described in the current section.

3.3.1.1 Vaalharts Irrigation Scheme

Main canal
The selected main canal is on the right bank. This is the same main canal that supplies water to Taung Irrigation Scheme. It is important to point that the zoning adopted in the current project apply within Vaalharts Irrigation Scheme only and was done to facilitate selection of secondary canals.

Secondary canals
One secondary canal was selected from each of the three main canal zones (upper, middle and lower). Flow into the secondary canals is controlled by manually operated sluice gates and all the secondary canals are equipped with flumes at the inlet point. The inlets of the secondary canals are permanently equipped with flumes. The selected secondary canals (known as feeder canals at the irrigation scheme) are:

- TVV4 (upper)
- TVV10 (middle)
- TVV15 (lower)

Tertiary canals
Three tertiary canals were selected on each secondary canal (upper, middle and lower). Flow into these tertiary canals is controlled by means of manually operated sluice gates. The inlets of these canals are also permanently equipped with flumes. These tertiary canals are known as community canals at irrigation scheme level. The selected tertiary canals are:

- TVV4:
  - TVV4C (upper)
  - TVV4E (middle)
  - TVV4G (lower)
- TVV10:
  - TVV10E (upper)
  - TVV10H (middle)
  - TVV10N (lower)
- TVV15:
  - TVV15D (upper)
  - TVV15H (middle)
  - TVV15P (lower)

3.3.1.2 Loskop Irrigation Scheme

Main canal
The selected main canal is on the left bank.

Secondary canals
Flow into the secondary canals is controlled by manually operated sluice gates and all the secondary canals are permanently equipped with flumes at the inlet points. However, electronic loggers are now in use to collect flow data. The three secondary canals, also known as feeder canals at irrigation scheme level, are:

- TK141 (upper)
- TK214 (middle)
- TK240 (lower)

Tertiary canals
The tertiary canals are also known as community canals at the irrigation scheme. However, it is point to highlight that the tertiary canal level at Loskop is not as clear as at Vaalharts Irrigation, where all farms get water through community canals. Some farms at Loskop Irrigation get their water supply directly from what is referred as secondary canals in the current report. Nevertheless, flow into these tertiary canals is also controlled by means of manually operated sluice gates. The selected tertiary canals are:

- TK141: there are no tertiary canals present on this secondary canal; hence, three reaches were selected as follows:
    - F6-F10 (upper)
    - F14-F16 (middle)
    - F22-F23 (lower)
- TK214: there are also no tertiary canals present on this secondary canal; hence, the three selected reaches are defined by names of the adjacent farms as follows:
    - E9-E11 (upper)
    - E26-E28 (middle)
    - E31-E33 (lower)
- TK240:
    - TK240A (upper)
      The tertiary canal is branched and the selected branches were identified by names of adjacent farms as follows:
        - H59-H60 (upper)
        - H63-H65 (middle)
        - H66-H68 (lower)
    - TK240D (middle)
      The tertiary canal is also branched and the two selected branches were identified by adjacent farm names as follows:
        - H45-H46,
        - section to Marble Hall
- TK240G (lower):
    - H75 (upper)
    - H8-H9 (middle)
    - H14 (lower)

The table below presents the primary properties of the selected canal sections as observed during the field tours. It is important to indicate that all the canal sections assessed were concrete lined. Note that the abbreviations used here are not standard and may not be accepted in some quarters. They are only meant for the current report and they are described as follows:

- L = reach length (measured in m)
- T_W = top width of canal section (measured in m)
- B_W = bottom width of canal section (measured in m)
- D = depth of canal section (measured in m)
- S_L = length of sloping canal side wall (m)
- P = wetted perimeter when canal is 100% full (measured in m)

TABLE 3.1 Dimensions of the selected canal sections at Loskop and Vaalharts Irrigation Schemes

Irrigation Scheme	Canal type	Name	Reach	Shape	L	T_W	B_W	D	S_L	P
						------------------	------------------	M	------------------	------------------
Vaalharts	Main		Upper	Trapezium	5050	10.30	5.80	3.00	4.40	14.60
	Secondary	TVV4	Upper	Parabola	950	1.65		1.05		2.65
	Tertiary	TVV4C	Upper	Parabola	540	1.08		0.35		1.43
	Tertiary	TVV4C	Middle	Parabola	880	0.93		0.28		1.18
	Tertiary	TVV4C	Lowe	Parabola	840	0.90		0.23		1.10
	Secondary	TVV4	Middle	Parabola	700	1.48		0.95		2.50
	Tertiary	TVV4E	Upper	Parabola	600	1.10		0.40		1.50
	Tertiary	TVV4E	Middle	Parabola	610	1.08		0.35		1.45
	Tertiary	TVV4E	Lower	Parabola	580	1.08		0.35		1.45
	Secondary	TVV4	Lower	Parabola	730	1.65		0.95		2.80
	Tertiary	TVV4G	Upper	Parabola	830	1.15		0.45		1.65
	Tertiary	TVV4G	Middle	Parabola	810	1.03		0.35		1.35
	Tertiary	TVV4G	Lower	Parabola	560	0.83		0.33		1.15
	Main		Middle	Trapezium	5000	8.98	4.00	2.60	4.00	12.00
	Secondary	TVV10	Upper	Parabola	2100	1.60		0.85	.	2.60
	Tertiary	TVV10E	Upper	Parabola	720	1.10		0.38		1.50
	Tertiary	TVV10E	Middle	Parabola	630	1.15		0.45		1.55
	Tertiary	TVV10E	Lower	Parabola	950	1.08		0.43		1.43
	Secondary	TVV10	Middle	Parabola	720	1.65		1.05		2.80
	Tertiary	TVV10H	Upper	U-shape	710	1.10		0.40		1.50
	Tertiary	TVV10H	Middle	U-shape	780	1.10		0.40		1.40
	Tertiary	TVV10H	Lower	U-shape	770	0.93		0.35		1.15
	Secondary	TVV10	Lower	Parabola	710	1.83		1.25		3.35
	Tertiary	TVV10N	Upper	U-shape	760	1.08		0.45		1.45
	Tertiary	TVV10N	Middle	U-shape	550	1.00		0.35		1.25
	Tertiary	TVV10N	Lower	U-shape	550	1.00		0.35		1.30
	Main		Lower	Trapezium	4600	6.80	3.30	2.20	3.10	9.50
	Secondary	TVV15	Upper	Parabola	1290	1.65		1.05		2.70
	Tertiary	TVV15D	Upper	U-shape	1170	1.13		0.43		1.55
	Tertiary	TVV15D	Middle	U-shape	520	1.00		0.38		1.30
	Tertiary	TVV15D	Lower	U-shape	550	0.90		0.33		1.10
	Secondary	TVV15	Middle	Parabola	700	1.65		1.10		2.85
	Tertiary	TVV15H	Upper	U-shape	530	1.15		0.53		1.60
	Tertiary	TVV15H	Middle	U-shape	700	1.10		0.50		1.53
	Tertiary	TVV15H	Lower	U-shape	1030	1.00		0.40		1.33
	Secondary	TVV15	Lower	Parabola	670	1.73		1.05		2.95
	Tertiary	TVV15P	Upper	U-shape	910	1.25		0.55		1.75
	Tertiary	TVV15P	Middle	U-shape	270	1.30		0.63		1.85
	Tertiary	TVV15P	Lower	U-shape	540	1.10		0.48		1.45
Loskop	Main		Upper	Trapezium	5000	7.20	4.20	2.10	2.40	9.00
	Secondary	TK141	Upper	Trapezium	4100	1.30	0.40	0.65	0.73	1.85
	Secondary	TK141	Middle	Trapezium	3000	1.35	0.55	0.60	0.75	2.05
	Secondary	TK141	Lower	Trapezium	3200	1.40	0.48	0.60	0.78	2.03
	Main		Middle	Trapezium	5000	6.10	3.45	1.90	2.30	8.05
	Secondary	TK214	Upper	Trapezium	930	1.60	0.55	0.73	0.85	2.25
	Secondary	TK214	Middle	Trapezium	2370	1.65	0.63	0.68	0.88	2.38
	Secondary	TK214	Lower	Trapezium	980	0.80	0.20	0.40	0.45	1.10
	Main		Lower	Trapezium	5000	3.10	2.85	1.60	1.90	6.65
	Secondary	TK240	Upper	Trapezium	2110	2.30	0.80	1.13	1.45	3.70
	Secondary	TK240	Middle	Trapezium	2840	2.00	0.68	0.85	1.10	2.88
	Secondary	TK240	Lower	Trapezium	3690	1.85	0.63	0.85	1.00	2.63

TABLE 3.2 Condition of the selected canal sections at Loskop and Vaalharts Irrigation Schemes

Irrigation Scheme	Canal type	Name	Reach	Shape	Condition state
Vaalharts	Main		Upper	Trapezium	*Acceptable*
	Secondary	TVV4	Upper	Parabola	*Good*
	Tertiary	TVV4C	Upper	Parabola	*Bad*
	Tertiary	TVV4C	Middle	Parabola	*Bad*
	Tertiary	TVV4C	Lowe	Parabola	*Bad*
	Secondary	TVV4	Middle	Parabola	*Good*
	Tertiary	TVV4E	Upper	Parabola	*Good*
	Tertiary	TVV4E	Middle	Parabola	*Bad*
	Tertiary	TVV4E	Lower	Parabola	*Very bad*
	Secondary	TVV4	Lower	Parabola	*Good*
	Tertiary	TVV4G	Upper	Parabola	*Bad*
	Tertiary	TVV4G	Middle	Parabola	*Bad*
	Tertiary	TVV4G	Lower	Parabola	*Very bad*
	Main		Middle	Trapezium	*Bad*
	Secondary	TVV10	Upper	Parabola	*Good*
	Tertiary	TVV10E	Upper	Parabola	*Good*
	Tertiary	TVV10E	Middle	Parabola	Good
	Tertiary	TVV10E	Lower	Parabola	*Bad*
	Secondary	TVV10	Middle	Parabola	*Good*
	Tertiary	TVV10H	Upper	U-shape	*Bad*
	Tertiary	TVV10H	Middle	U-shape	*Bad*
	Tertiary	TVV10H	Lower	U-shape	*Very bad*
	Secondary	TVV10	Lower	Parabola	*Acceptable*
	Tertiary	TVV10N	Upper	U-shape	*Bad*
	Tertiary	TVV10N	Middle	U-shape	*Bad*
	Tertiary	TVV10N	Lower	U-shape	*Bad*
	Main		Lower	Trapezium	*Bad*
	Secondary	TVV15	Upper	Parabola	*Good*
	Tertiary	TVV15D	Upper	U-shape	*Good*
	Tertiary	TVV15D	Middle	U-shape	*Bad*
	Tertiary	TVV15D	Lower	U-shape	*Bad*
	Secondary	TVV15	Middle	Parabola	*Good*
	Tertiary	TVV15H	Upper	U-shape	*Good*
	Tertiary	TVV15H	Middle	U-shape	*Good*
	Tertiary	TVV15H	Lower	U-shape	*Bad*
	Secondary	TVV15	Lower	Parabola	*Good*
	Tertiary	TVV15P	Upper	U-shape	*Bad*
	Tertiary	TVV15P	Middle	U-shape	*Very bad*
	Tertiary	TVV15P	Lower	U-shape	*Very bad*
Loskop	Main		Upper	Trapezium	*Good*
	Secondary	TK141	Upper	Trapezium	*Good*
	Secondary	TK141	Middle	Trapezium	*Good*
	Secondary	TK141	Lower	Trapezium	*Bad*
	Main		Middle	Trapezium	*Good*
	Secondary	TK214	Upper	Trapezium	*Good*
	Secondary	TK214	Middle	Trapezium	*Good*
	Secondary	TK214	Lower	Trapezium	*Good*
	Main		Lower	Trapezium	*Good*
	Secondary	TK240	Upper	Trapezium	*Good*
	Secondary	TK240	Middle	Trapezium	*Good*
	Secondary	TK240	Lower	Trapezium	*Bad*

3.4 Discussion

The table on dimensional properties of the canal sections observed show a very wide variability in size within the same canal type an across the different canal types. However, there was a general decrease of size in downstream direction (Table 3.1). For instance, the main canal at Vaalharts Irrigation Scheme showed a general decrease in cross-sectional area in the downstream direction. The top width (T_W) decreased from 10.30 m in the upper reach to 8.98 m in the mid reach and finally to 6.80 m in the lower reach, while the bottom width (B_W), decreased from 5.80 to 4.00 and 3.30 m, respectively. Depth followed a similar trend with values of 3.00, 2.60 and 2.20 m, respectively. All the other canals at the irrigation scheme followed a similar trend; however, the bottom widths and length of sloping canal side walls (S_L) could not be established at some of the canals, especially those with parabolic or U-shapes. The same trend of a decrease in canal size in the downstream direction was also observed at Loskop Irrigation Scheme, where the main canal top width decreased from 7.20 m in the upper reach to 6.10 m in the mid reach and 3.10 m in the lower reach. However, the other canal types at this irrigation scheme did not follow the same pattern with some canals showing greater sizes around the mind reach while others exhibited greater sizes in the lower reaches.

The general decrease in canal sizes was anticipated because the amount of water to be transmitted generally decrease with the area commanded. It follows that less and less water needs to be transmitted as the tail end of a canal is approached. However, other factors may influence a deviation from this rule. For example, a change in the gradient of canal bed may change the flow velocity as a result steeper gradients may economically require smaller canal sections where those areas where flow is sluggish may require bigger sizes. This may explain the observations made at Loskop Irrigation Scheme. However, it is important to indicate that the project did not assess the slope gradients of the canal beds.

Although consensus on the condition state of the canals and associated infrastructure was always sought among the participating, it was not possible to consistently keep the same people doing the exercise at an irrigation scheme and across irrigation schemes. Therefore, inconsistencies could not be avoided. However, the results showed a general tendency for the condition to deteriorate in a downstream direction (Table 3.2), especially at Vaalharts Irrigation Scheme. The main canal deteriorated from an acceptable condition in the upper reach to a bad condition in the mid and lower reaches. The secondary and tertiary canals showed a similar trend at the same irrigation scheme. It was interesting to note the very bad conditions in the lower reaches of some tertiary canals. Loskop Irrigation Scheme did not show much variability in terms of conveyance infrastructure condition. The condition of the infrastructure was generally rated good. The lower parts of two secondary canals were rated bad.

A close look at the condition assessment criteria used by the project suggests the condition state is closely linked to the general maintenance of the infrastructure. While the Irri-Drop Report framework is intended for those parts of the conveyance infrastructure which are managed by the irrigation scheme (water user association, irrigation board or government water scheme), the current exercise overlapped onto tertiary canals which managed by the water users (irrigators) themselves. The level of management and amount of resources put into the care and maintenance of the infrastructure differ significantly between the farmers and the irrigators. The situation at Vaalharts Irrigation Scheme suggests poorer farmer management of the infrastructure than the irrigation scheme management. However, it is still important to indicate that the main canal condition at Vaalharts Irrigation Scheme was not in a good condition despite its management falling under the auspices of the irrigation scheme.

3.5 Conclusions

The insights gained from the review of available literature about Vaalharts and Loskop irrigation schemes and visits to the same were important to the development of the Irri-Drop Report framework. The Irri-Drop Report framework developed by the project had to take cognisance of the insight gained that irrigation schemes are unique and are operated differently. Another conclusion is the need for a non-subjective and unambiguous means of collecting and analysing data on the condition state of irrigation infrastructure for consistency. Seeking consensus all the time can be arduous and costly in certain circumstances.

CHAPTER 4: COMPONENTS OF WATER LOSSES FROM CANALS AT VAALHARTS & LOSKOP IRRIGATION SCHEMES

4.1 Introduction

The efficiency of a water delivery system is determined through the water losses that occur during its operation. The losses are a result of environmental and operational factors, and structural weaknesses of the canal. A water delivery network will always incur water. Therefore, the objective of an efficient water delivery system for an irrigation scheme is to deliver the correct volume of water to the right place and at the right time with minimum losses within the constraints of the system. The total water loss is calculated as the difference between water released and delivered after accounting for the water abstracted between the inlet and outlet points. At most irrigation schemes in South Africa, water released into canal networks is accurately measured using electronic data loggers. Non-agricultural abstractions on the canal network (e.g. for municipal, household, mine, and school uses) are through metered facilities, hence, the flow measurements are generally accurate. However, the same cannot be said of the farm gates, where the flumes have worn out over time and the flow depth measuring devices missing in some cases. In the absence of reliable measurement devices at the farm gates, water delivery is simply equated to the amount of water ordered by the farmers. This assumption favours the farmers because they always push to receive at least the amount of water they ordered and not less. There are also discords in recording water abstractions from the canal networks because farmers order their water on weekly bases, while the non-agricultural users are billed on a monthly basis.

Three water loss types are known to occur from open channels, namely: seepage, leakage and evaporation. Additional losses occur from human managed channels operational losses. Although all canals at major South African irrigation schemes are concrete lined, seepage loss through the lining is inevitable and it varies with quality, density and thickness of the lining, age of the concrete, and water pressure (which a function of water depth). Seepage loss from canals is quantified using the inflow-outflow, ponding, seepage meter, and unsteady flow simulation methods. However, these methods are only applicable in laboratory experiments or isolated control volumes in a canal network. The inflow-outflow method is a water balance approach where the difference between water flowing into and out of a section of a canal is treated as seepage loss after accounting for abstractions, leakages and evaporation. Abstractions can be accounted for through accurate measurements at the offtake points. Leakage occurs at various points throughout a canal network, e.g. joints between concrete slabs of canal lining, slabs that have shifted, cracks in the canal lining materials, and sluices. There is no practical way of determining leakage only from a canal network in normal operation using this method, hence seepage and leakage are considered jointly.

On the other hand, the ponding method of determining seepage involves sealing off at the inflow and outflow sides to isolate a canal section from the entire canal network. The water level of the isolated section is then monitored over time to determine the volume that is lost from the control volume. An evaporation pan is used to quantify the evaporation volume over the same period. A simple mass balance calculation is then used to calculate the seepage loss through the wetted area of the section. It is worth mentioning that this method will also include the leakage loss that occurs through any joints in the selected section if any. Therefore, seepage and leakage losses can also not be separated from each other. The only advantage of this method is that it will indicate the water loss in the section, but this cannot be applied throughout an entire canal network due to variability of canal lining and other factors. The seepage meter is used to quantify local seepage loss through a canal lining. The meter consists of a cylindrical cup attached to a bag filled with water by means of a plastic tube. The cup is attached to the canal wall or bed and the bag is left floating. The change in floating bag water volume is measured over a certain period to determine the seepage loss for that specific area. It is obvious this method cannot practically be applied to the entire canal network. In short, it is impossible to differentiate leakage from seepage on a canal network scale and for that reason the two are considered jointly.

Evaporation loss is water lost through the free surface of the canal water. It is theoretically possible to estimate evaporation losses from the free water surfaces using evaporation pan data. However, unlike in evaporation pans, canal water surface area is a function of water depth, which varies with flow rate in the canal. Factors such as temperature, humidity, rainfall, and wind need also to be considered. There is also the issue of changing microclimates across a canal network, which calls for a weather station for each microclimate. All these factors make it economically impractical to quantify evaporation losses accurately for a canal network. The best alternative is, perhaps, to use a calibrated unsteady flow simulation model (described in Methodology section of the current chapter).

Operational water losses are attributed to how the canal network is managed. During distribution of water through a canal network, for example, there are various sluice gates that need to be opened, adjusted, or closed at certain times for water released to reach its intended destination on time. These sluices are operated manually in South Africa. A water bailiff uses a distribution sheet, which indicates when and which sluice to open by how much. If these sluices are adjusted too early or too late, water is potentially lost. It is accepted that water bailiffs cannot operate the same sluice continuously and the water bailiffs cannot adjust all sluices in the system every minute or even every hour. This is how operational water losses occur. Theoretically, the more frequently the sluices are adjusted, the lower the operational losses will be, which is demonstrated through the use of a Water Release module in the Water Administration System program (described in Methodology section of the current chapter). Operational losses also include any loss due to mistakes on the administrative side of the irrigation scheme. It is theoretically possible to quantify the operational losses of a canal system due to incorrect sluice settings. The opening and closing times of the abstractions and the flow rates will need to be recorded. This will require loggers to be installed at every abstraction point in the canal network, which is not economically feasible in the current circumstances. The current chapter aimed at separating the major water loss types from canal water loss data published by the Water Administration System. The relevance of this is to be able to determine how much each component contributes to the total loss.

4.2 Methodology

The major canal water loss components have been identified as: seepage, leakage, evaporation, and operational. However, most of these water loss components are either impractical or impossible to quantify as individuals or at canal network level. The Water Administration System (WAS), therefore, does not separate them and reports them as a global loss for the canal network. WAS uses the Water Use Efficiency Accounting Report (WUEAR) to determine the canal network efficiency. The current chapter obtained data for Vaalharts and Loskop irrigation schemes from WAS and used it to generate WUEAR for the periods 2019/2020 and 2020/2021 to show either an improvement or decline in the efficiency of the systems.

4.2.1 Water release module

As already alluded to, the only way to come close to quantifying the water losses (except operational loss) is to use a calibrated unsteady flow simulation model for the canal network because water flow in most irrigation canals is naturally unsteady and non-uniform. The WAS has a water release module, which can simulate the evaporation and seepage losses. The basis for this module is to divide the canal network into sections or reaches as seen in Figure 4.1. A reach is section of a canal network between one outflow point and the next. These reaches are then defined and modelled.

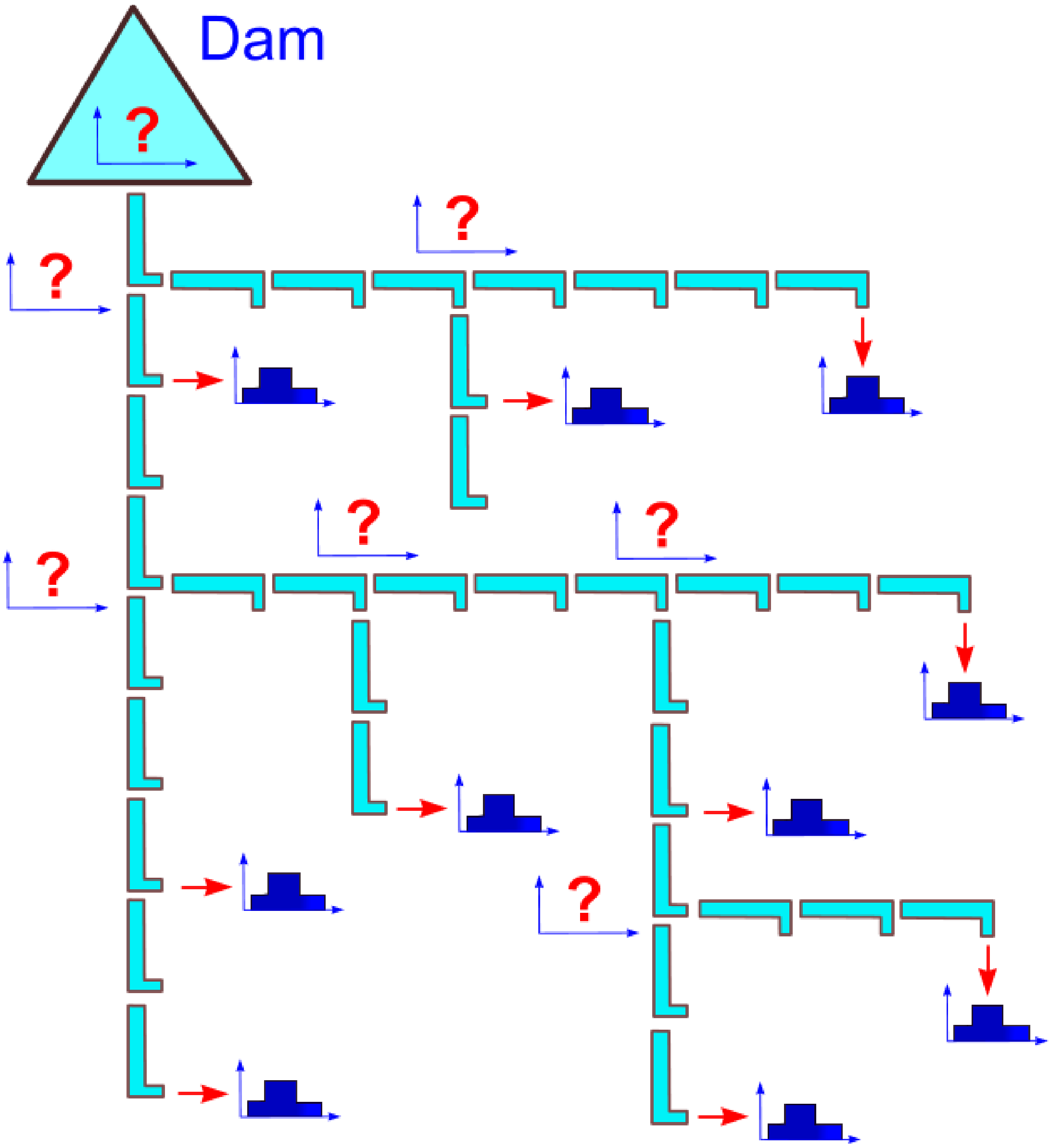
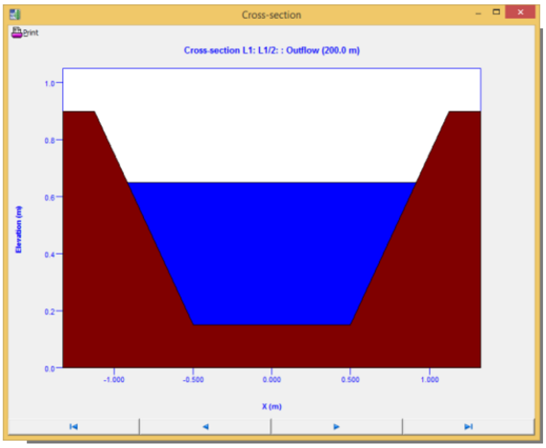


FIGURE 4.1 Water Release Module conceptual diagram

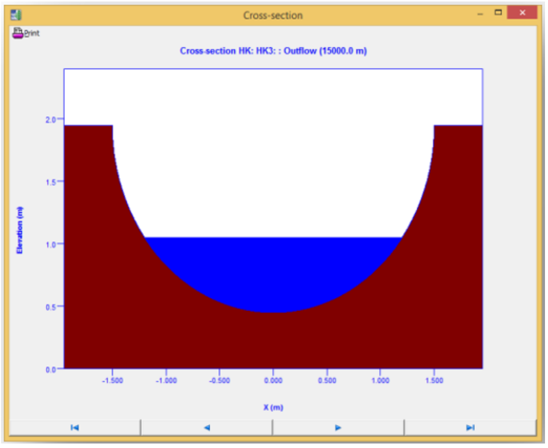
The water release module can be used to:

- Minimize distribution losses on canal networks and in river systems.
- Calculate water releases for the main canal and all its branches allowing for lag times and water losses such as seepage and evaporation.

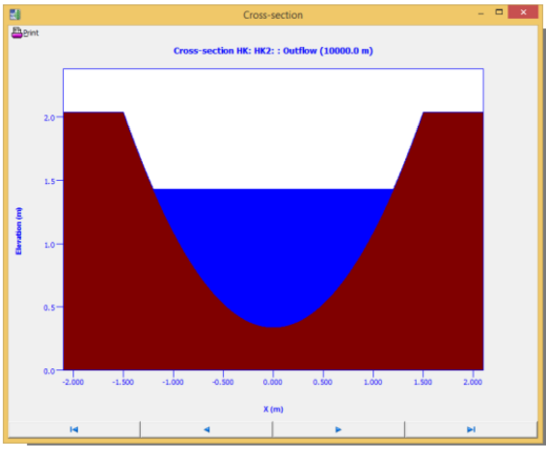
A schematic layout of the total canal network is captured with details such as the cross-sectional properties (Figure 4.2), position of sluices or pumps, canal slope, measuring structures and canal capacities. Every reach can be analysed and calibrated on its own with a built-in properties' calculator. Global changes to the canal are simplified by means of a built-in tool.

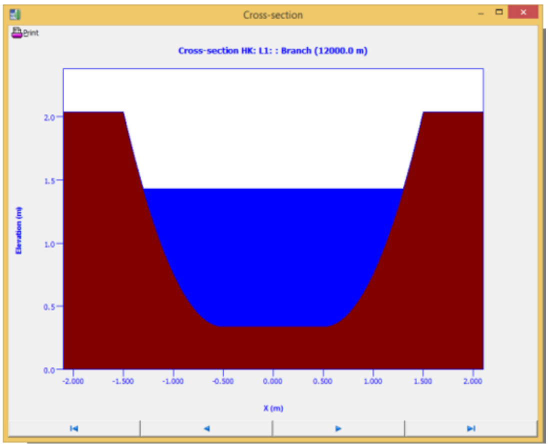


Trapezoidal

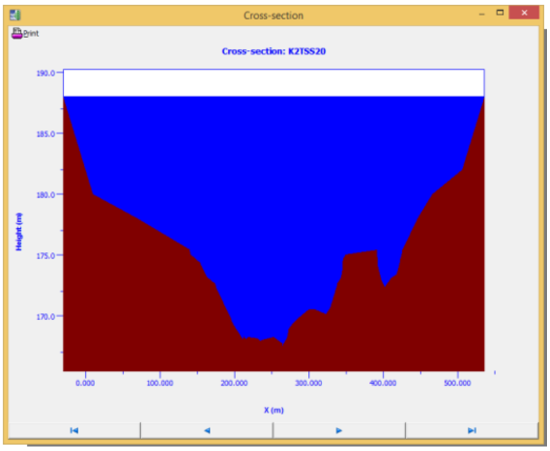


Circular





Parabolic & flat bottom



User defined

FIGURE 4.2 Types of canal cross-sections

Discharges are converted to the corresponding measuring plate readings where needed. Water release graphs, calculated with different settings, can be superimposed for comparison purposes. The seepage losses are calculated using the following equation:

$$\boldsymbol{Seepage} = \boldsymbol{Seepage\ rate}\left(\frac{l}{s}\boldsymbol{per\ 1000m^2}\right) \times \boldsymbol{Reach\ length}(\boldsymbol{m}) \times \boldsymbol{Wetted\ perimeter}(\boldsymbol{m}) \qquad \textbf{Equation 1}$$

Where *l/s per 1000 m²* are litres per second per 1000 m^2 of the wetted area of the canal in contact with the water

The seepage rate of concrete lined canal has been estimated to be 0.35 to 1.9 l/s per 1000 m^2 (Reid, et al., 1986). In addition to length, a section of a canal is also defined by its cross-sectional parameters, as shown in Figure 4.3. For example, the wetted perimeter is the perimeter of the cross-section that is in contact with the water in the canal.

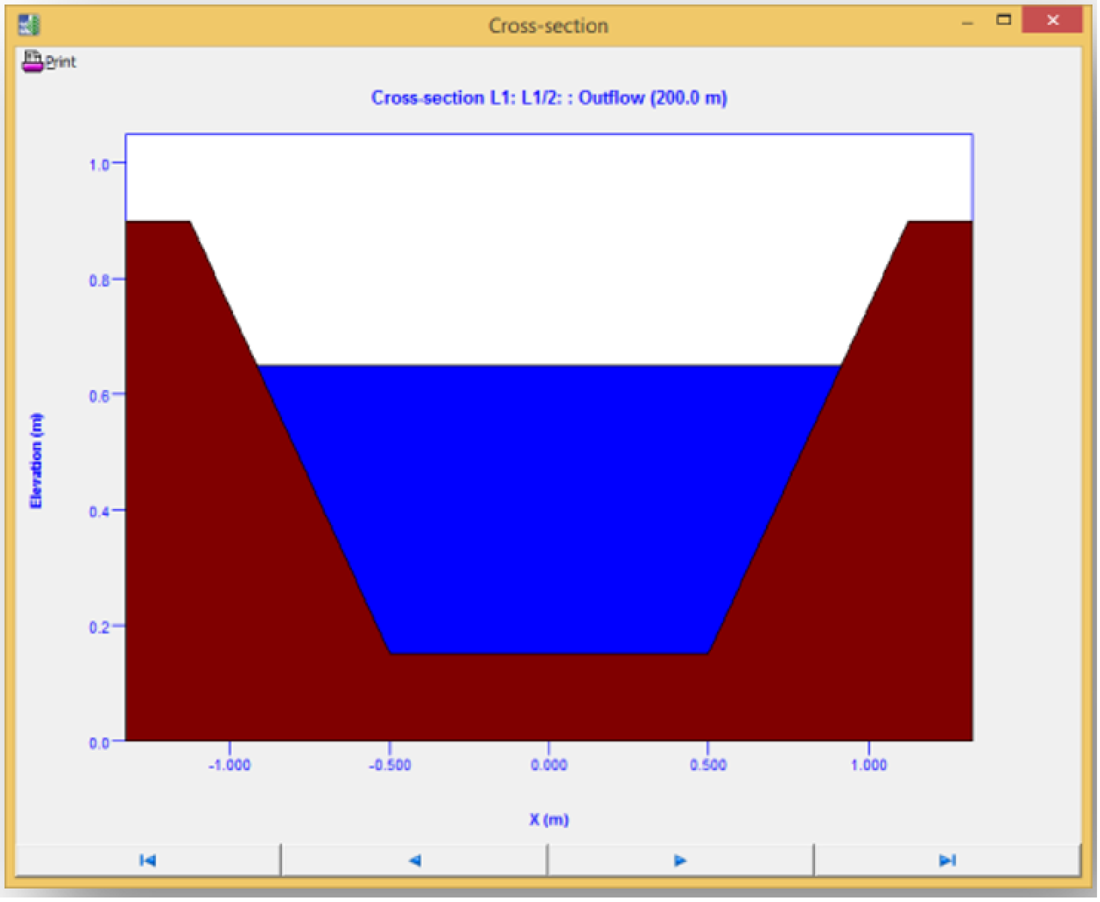


FIGURE 4.3 Canal cross-section diagram

The evaporation losses are calculated using the following equation:

$$Evaporation = Evap\ rate\ \left(\frac{l}{s} per\ 1000m^2\right) \times Reach\ length(m) \times Water\ surface\ width\ (m) \quad \textbf{Equation 2}$$

Where *Evap rate* is the evaporation rate, and *l/s per 1000 m^2* are litres per second per 1000 m^2 of the free water surface.

According to Reid et al. (1986), the evaporation loss is close to 0.3% of the total flowrate. This percentage is independent of the exposed surface area of the water and can, therefore, not be applied to the entire network. The simulation can only estimate the evaporation losses based on a generalized evaporation rate. The basic idea behind the simulation module is to solve the problem for a single reach. Starting at the end of each branch of the network each reach is simulated and added to the next one until the simulation reaches the dam. This is illustrated in Figure 4.4.

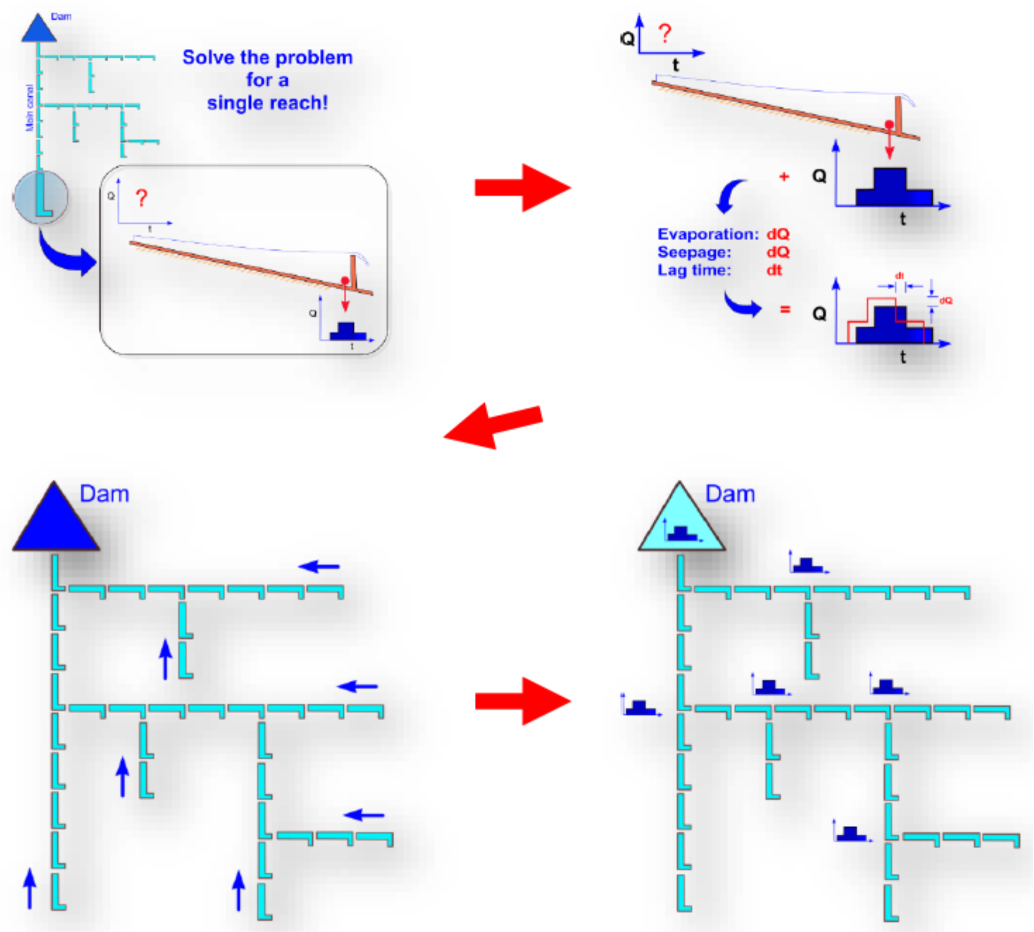


FIGURE 4.4 Water release simulation module

The results are then displayed in the form of hydrographs for each outlet in the network. An example of the total results can be seen in the hydrograph in Figure 4.5.

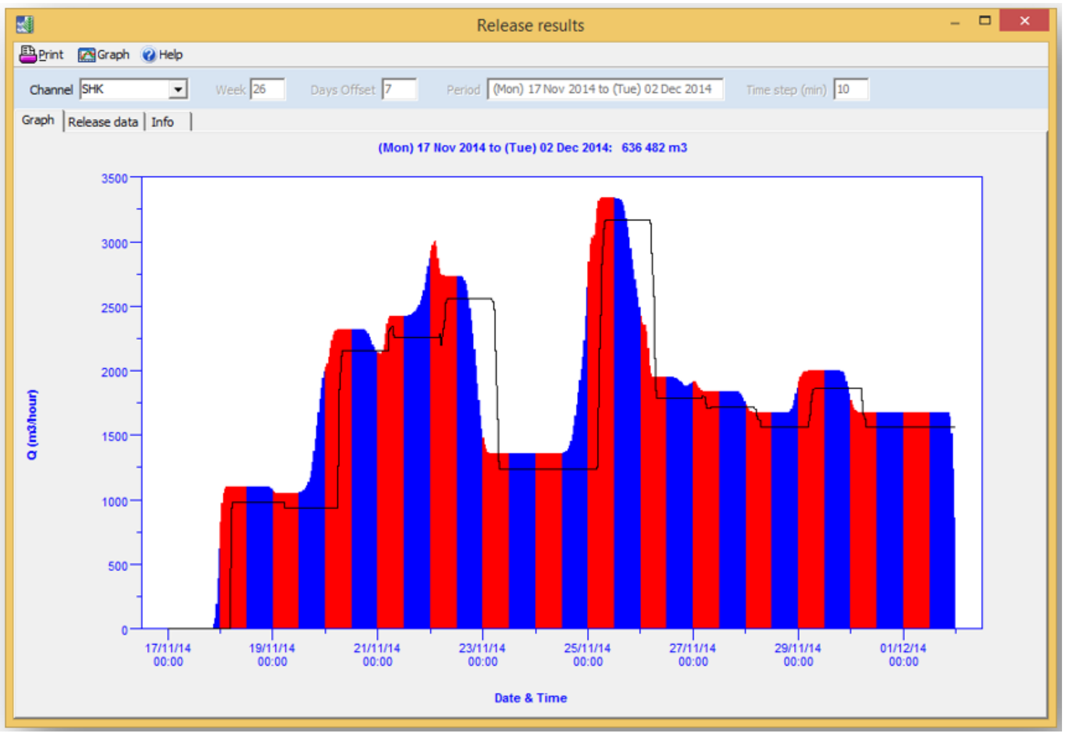


FIGURE 4.5 Hydrograph – Simulation results

The hydrograph shows a filled in multi-coloured graph and a simple line graph over that. The line represents the summation of the water orders in the system and the times at which they are supposed to arrive at the farmers' sluices. The multi-coloured graph represents the same graph as the single line, but with travel times and losses added to it. This means that the difference in volume between the two graphs is the evaporation and seepage losses. Figure 4.5 represents a very unrealistic water release for the network because it is impossible to control the sluice settings to this level of accuracy. As discussed in operational losses, the water distribution settings are adjusted to match a more practical distribution schedule with larger intervals, as seen in Figure 4.6.

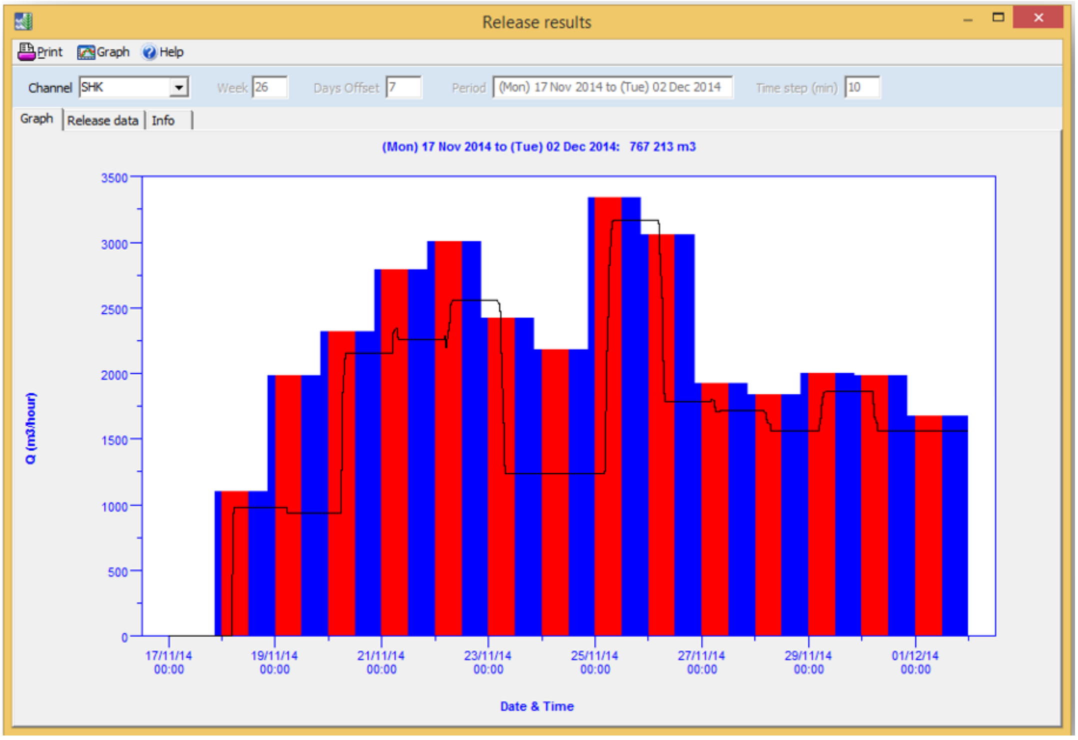


FIGURE 4.6 Hydrograph – Refined simulation results

The added difference between the two graphs represents the necessary operational losses that need to be added for enough water to arrive at the farmers' sluices on time. This does not include human errors made during operation, which would also add to operational losses.

The water release module requires a lot of data to setup the network model and initialize the simulation. This method is also overly complicated for most irrigation schemes and requires qualified input and calibration to function properly. This data and expertise are unavailable for Loskop and Vaalharts irrigation schemes and outside the scope of the present project.

4.2.2 Mass Water Balance Method

The best and most practical method to quantify the total water loss on a canal network is the mass water balance method. This requires inflow data and the total water volume used by the scheme. The difference is the total water loss, which represents evaporation, seepage and leakage, and operational water losses.

This is all that is needed (excluding canal maintenance) to manage and reduce the total water loss in a canal system. Water loss due to evaporation is outside the control of an irrigation scheme. If a canal system is maintained properly then there is also little a scheme can do to reduce seepage and leakage losses. Operational losses are the only other loss that a scheme can try and reduce. Setting an initial benchmark and tracking the total water loss on a monthly basis is an excellent tool to measure whether a scheme is successful in reducing or maintaining their water losses. The WAS uses the WUEAR that has been specified by the Department of Water and Sanitation (DWS) to calculate and report the water usage and total loss of an irrigation scheme monthly. All the necessary data is readily available in the WAS database to generate a report for the Loskop and Vaalharts irrigation schemes.

4.2.3 Water Use Efficiency Accounting Report (WUEAR)

The WUEAR for Loskop and Vaalharts irrigation schemes for the current chapter were generated using the data collected for the water year of 2019/2020. It is important to note that a water year is different from a calendar year. The water years for Vaalharts and Loskop start in April and May respectively. The data was collected using a Cello data logger connected to an electronic probe that is installed in a stilling basin next to the measuring structure. The probe measures the flow depth which is converted to a flow rate using a corresponding discharge table. The data logger used for Loskop can be seen in Figure 4.7.

FIGURE 4.7 Cello data logger at left bank inflow for Loskop irrigation scheme

The data is recorded every 12 and 15 minutes for Loskop and Vaalharts, respectively. The data is then transmitted to the Zednet platform, where WAS is then able to download and import this data into its database.

WAS uses the measuring structure's discharge table to convert the flow depth (mm) to a flow rate (m^3/h), which can then be used to calculate the volume (m^3) of water that is released into the canal. The water used is captured using the water order module. This includes water order forms and meter readings. This is used to generate the WUEAR, and graphs as seen in in the respective sections for each irrigation scheme. The total water loss is shown as non-revenue water in the WUEAR tables.

4.2.4 Selected canals

The selected canals are shown on Figures 1.2 and 1.3 presented in Chapter 1 and described in Chapter 3 of the current report. However, canal details are presented again for the benefit of the readers. The canals selected at Vaalharts Irrigation Scheme are:

- Main canal
- Secondary canal TVV4
    - Tertiary canal C
    - Tertiary canal E
    - Tertiary canal G
- Secondary canal TVV10
    - Tertiary canal E
    - Tertiary canal H
    - Tertiary canal N
- Secondary canal TVV15
    - Tertiary canal D
    - Tertiary canal H

- Tertiary canal P

The canals selected at Loskop Irrigation Scheme are:

- Main canal
- Secondary canal TK141
    - Tertiary canal F6-F10
    - Tertiary canal F14-F16
    - Tertiary canal F22-F23
- Secondary canal TK214
    - Tertiary canal E9-E11
    - Tertiary canal E26-E28
    - Tertiary canal E31-E33
- Secondary canal TK240A
    - Tertiary canal H59-H60
    - Tertiary canal H63-H65
    - Tertiary canal H66-H68
- Secondary Canal 240D
    - Tertiary canal H45-H46
    - section to Marble Hall
- Secondary canal 240G
    - Tertiary canal H75
    - Tertiary canal H8-9
    - Tertiary canal H14

At the time of the project, these canals did not have data loggers. It is important to reiterate that the Water Administration System is a computer-based program that makes use of data collected by electronic loggers. However, the program can also accept water order data, which is generated by farmers through water bailiffs. Only the main canals were equipped with electronic data loggers (Figure 4.8) and is the main reason why global water losses at irrigation schemes are computed as the difference between water released and water ordered after accounting for non-agricultural water abstractions.

FIGURE 4.8 Vaalharts main inflow and measuring point

4.3 Results

4.3.1 Water Use Efficiency Accounting Report (WUEAR)

The WUEAR for Loskop and Vaalharts irrigation schemes was generated using the data collected for the water year 2020/2021. The water year is different from a calendar year in that the water years for Vaalharts and Loskop start in April and May, respectively. The input data was collected using a Cello data logger connected to an electronic probe that is installed in a stilling basin next to the measuring structure (Figure 4.7). The probe measures the flow depth which is converted to a flow rate using a corresponding discharge table. The data is recorded every 12 and 15 minutes for Loskop and Vaalharts, respectively. The data is then transmitted to the Zednet platform, where WAS is then able to download and import this data into its database. WAS uses the measuring structure's discharge table to convert the flow depth (mm) to a flow rate (m^3/h), which can then be used to calculate the volume (m^3) of water that is released into the canal.

The water used is captured using the water order module, which includes water order forms and meter readings. Remember that it is assumed that what farmers ordered is what was delivered. Under the prevailing circumstances during the time of the project, it was impractical to manually measure water abstraction from the canal network by each farmer individually. There are pressure regulated sluices at each of the extraction points and there are flumes at some of them, typically a 1FT Parshall. The sluices are calibrated so that they deliver water at certain flowrates based on the settings of the sluices. The flumes can be used to verify this but not necessarily to measure the volume delivered.

The WUEAR generated using information for the water years 2019/2020 and 2020/2021 are presented in the next sections for Vaalharts and Loskop irrigation schemes.

4.3.1.1 Vaalharts WUA

The water year starts in April. Water input data was collected at the measuring station equipped with an electronic logger on the main canal inflow (C9H018). The discharge curve used for processing the data collected for the crump weir is shown in Figure 4.9.

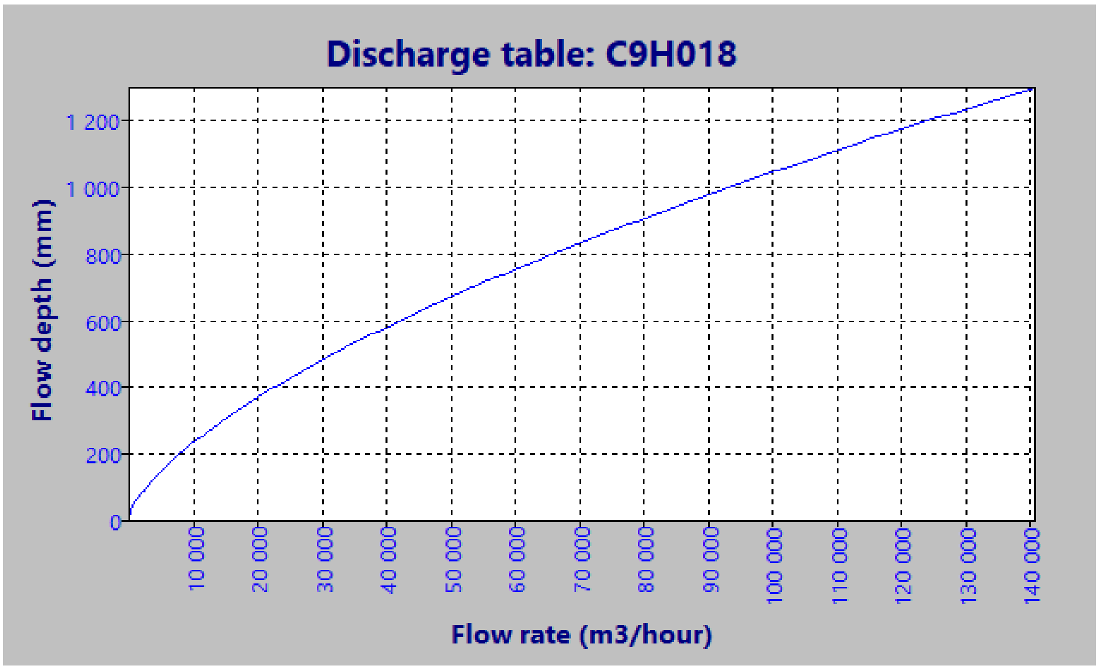


FIGURE 4.9 Vaalharts WUA – main inflow discharge curve C9H018

The summary WUEAR for Vaalharts Irrigation scheme during the water year 2019/2020 is shown in Table 4.1.

TABLE 4.1 Vaalharts – WUEAR 2019/2020

		(x1000m³)											%		
Year	Mnth	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Alloc used	Alloc avail	Non-revenue water	Used	Avail
2019	Apr	1542	10	1182	36	5181	1431	9383	17731	8348	2742	281518	47.08	1.0	99.0
2019	May	5263	6	1685	45	4078	7657	18733	21182	2449	9712	274548	11.56	3.4	96.6
2019	Jun	11177	13	966	36	5156	41	17389	21544	4155	21910	262350	19.29	7.7	92.3
2019	Jul	7357	10	1221	36	6432	22	15078	19251	4173	30520	253740	21.68	10.7	89.3
2019	Aug	21223	12	1317	45	8981	47	31624	39791	8167	53118	231142	20.52	18.7	81.3
2019	Sep	25507	22	1221	36	9931	43	36760	43899	7138	79912	204348	16.26	28.1	71.9
2019	Oct	41458	22	1603	45	15661	65	58853	71970	13116	123060	161200	18.23	43.3	56.7
2019	Nov	22764	44	1518	36	8470	43	32874	38649	5774	147429	136831	14.94	51.9	48.1
2019	Dec	26832	40	1017	36	9521	104	37549	45336	7786	175421	108839	17.18	61.7	38.3
2020	Jan	24068	49	1297	45	9430	40	34928	44141	9213	200875	83385	20.87	70.7	29.3
2020	Feb	11610	19	1393	36	10109	25	23191	24654	1463	213921	70339	5.93	75.3	24.7
2020	Mar	17334	25	1096	36	5042	99	23632	33737	10105	232475	51785	29.95	81.8	18.2
Totals		**216135**	**272**	**15516**	**468**	**97992**	**9617**	**339994**	**421885**	**81887**	**1291095**	**2120025**	**19.41**	**81.8**	**18.2**

Figure 4.10 shows the monthly water volumes released (red) compared against corresponding the water volumes delivered (blue).

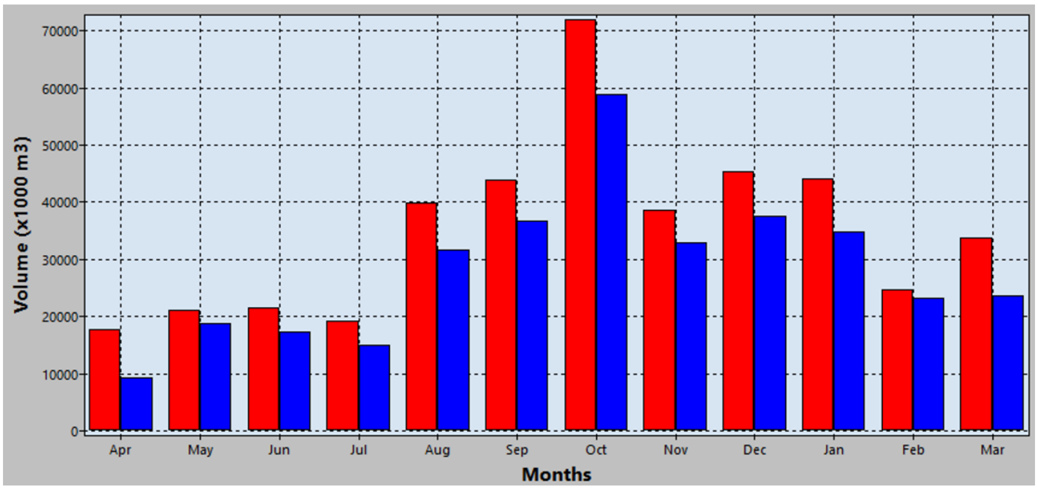


FIGURE 4.10 Vaalharts – Water released & delivered 2019/2020

Figure 4.11 shows the volumetric monthly water losses only for the water year 2019/2020.

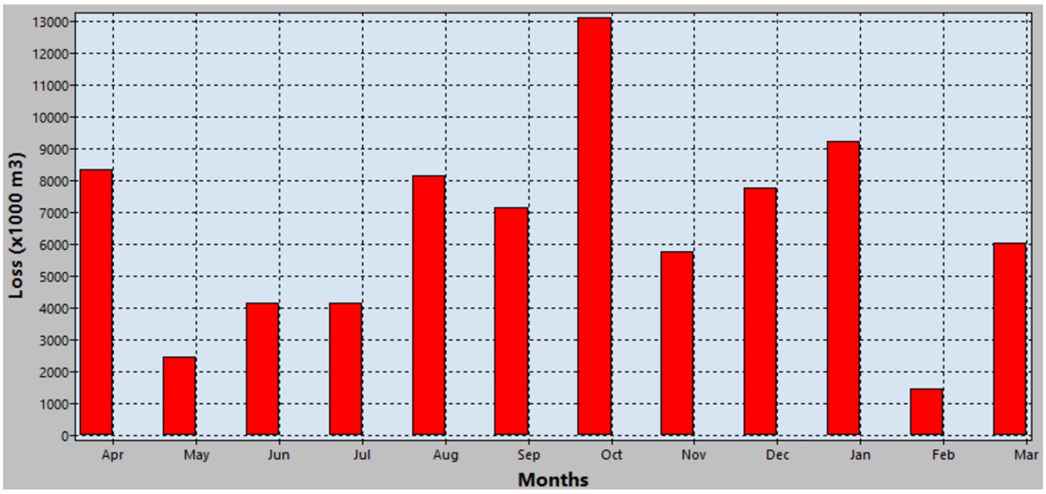


FIGURE 4.11 Vaalharts – Monthly loss (m³) 2019/2020

Figure 4.12 shows the monthly water loss percentages for the water year 2019/2020.

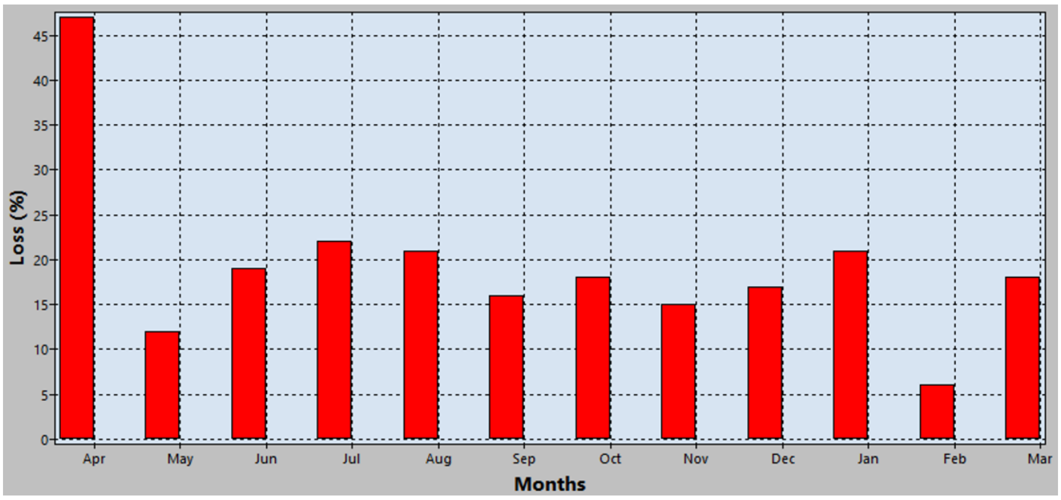


FIGURE 4.12 Vaalharts – Monthly loss (%) 2019/2020

Table 4.2 is the WUEAR for Vaalharts WUA during the water year 2020/2021.

TABLE 4.2 Vaalharts – WUEAR 2020/2021

		(x1000m³)											%		
Year	Mnth	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Alloc used	Alloc avail	Non-revenue water	Used	Avail
2020	Apr	2544	8	1230	45	7334	13	11174	16067	4893	3795	280370	30.45	1.3	98.7
2020	May	3676	6	1033	36	3400	43	8194	10896	2702	8553	275612	24.8	3.0	97.0
2020	Jun	10371	213	899	36	11829	79	23427	26112	2685	20116	264049	10.28	7.1	92.9
2020	Jul	10765	-189	891	45	12290	79	23881	27239	3358	31663	252502	12.33	11.1	88.9
2020	Aug	14875	5	1197	36	9921	101	26135	32332	6197	47841	236324	19.17	16.8	83.2
2020	Sep	22356	7	1116	36	10135	112	33762	47818	14056	71432	212733	29.39	25.1	74.9
2020	Oct	38165	25	991	45	17931	180	57337	71429	14092	110793	173372	19.73	39.0	61.0
2020	Nov	13798	37	1157	36	10052	76	25155	28031	2875	125861	158304	10.26	44.3	55.7
2020	Dec	18376	37	927	45	12314	95	31794	37605	5811	145297	138868	15.45	51.1	48.9
2021	Jan	4696	13	953	36	5569	22	11289	11782	494	150981	133184	4.18	53.1	46.9
2021	Feb	8752	7	946	36	7618	94	17452	21593	4141	160779	123386	19.18	56.6	43.4
2021	Mar	15917	7	1080	36	7642	112	24794	31127	6334	177895	106270	20.35	62.6	37.4
Totals		**164291**	**176**	**12420**	**468**	**116035**	**1006**	**294394**	**362031**	**67638**	**1055006**	**2354974**	**18.68**	**62.6**	**37.4**

The graph in Figure 4.13 shows the monthly water volumes released (red) compared against the corresponding water volumes delivered (blue). Looking at this graph shows that the demand for water starts low in April and rises to a peak in October. After that it drops and varies until March. Comparing the released against the delivered, the relative difference each month is kept almost the same. The only exception being the months of September and October, which is also the months with the highest demand.

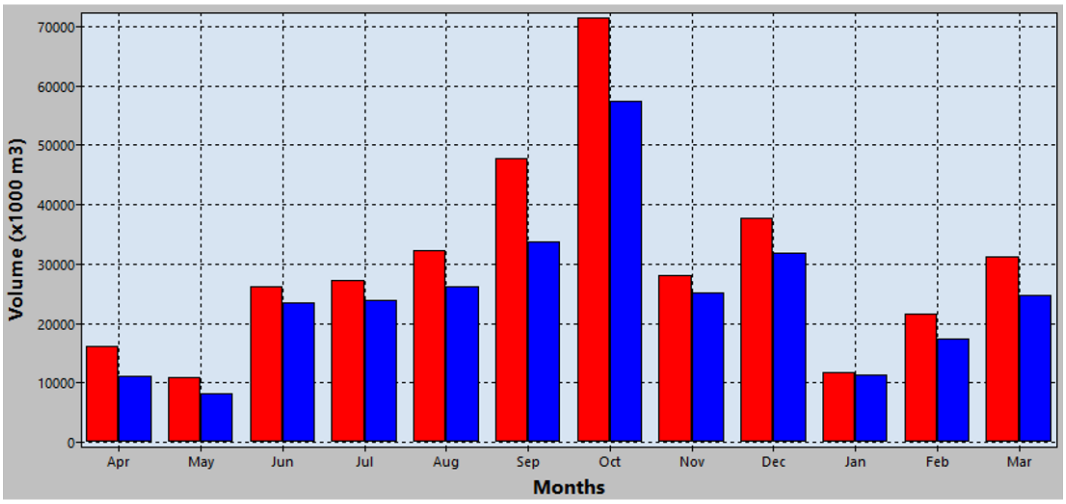


FIGURE 4.13 Vaalharts – Water released & delivered 2020/2021

Figure 4.14 shows the volumetric monthly water losses only for the water year 2020/2021.

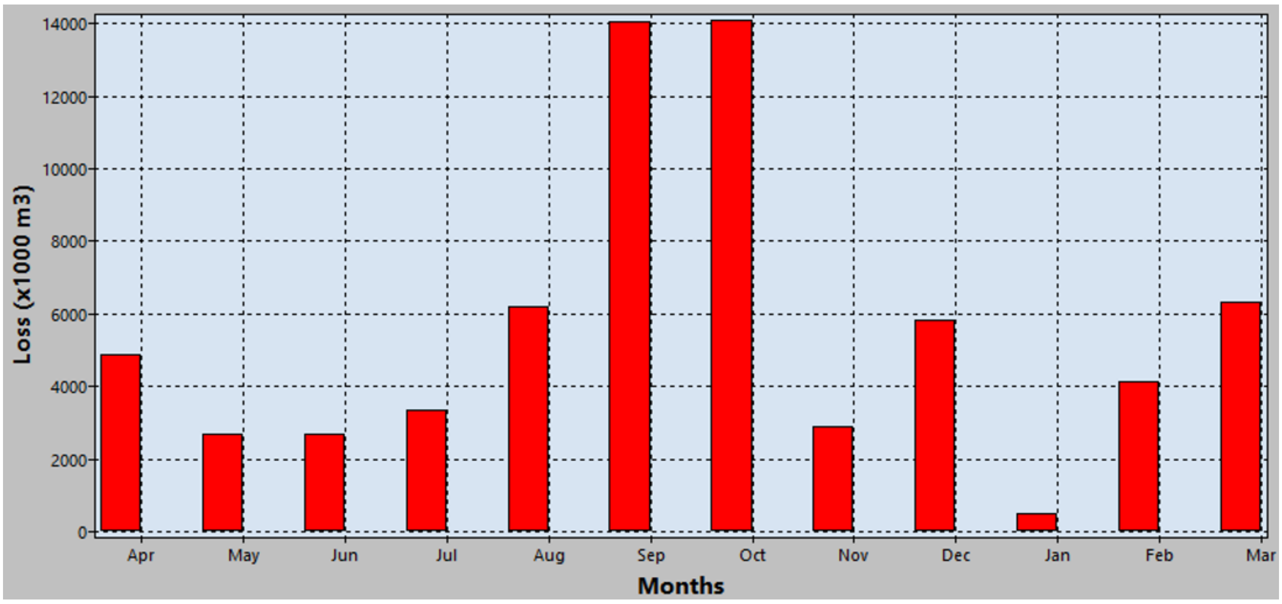


FIGURE 4.14 Vaalharts – Monthly loss (m^3) 2020/2021

Looking at the loss percentages for each month in Figure 4.15, the lowest efficiency was in April. This is also one of the months with the lowest demand for water, but the actual water volume lost is not that high relative to the other months. The totals for the water year show that Vaalharts WUA achieved a very good system efficiency of 81.3%.

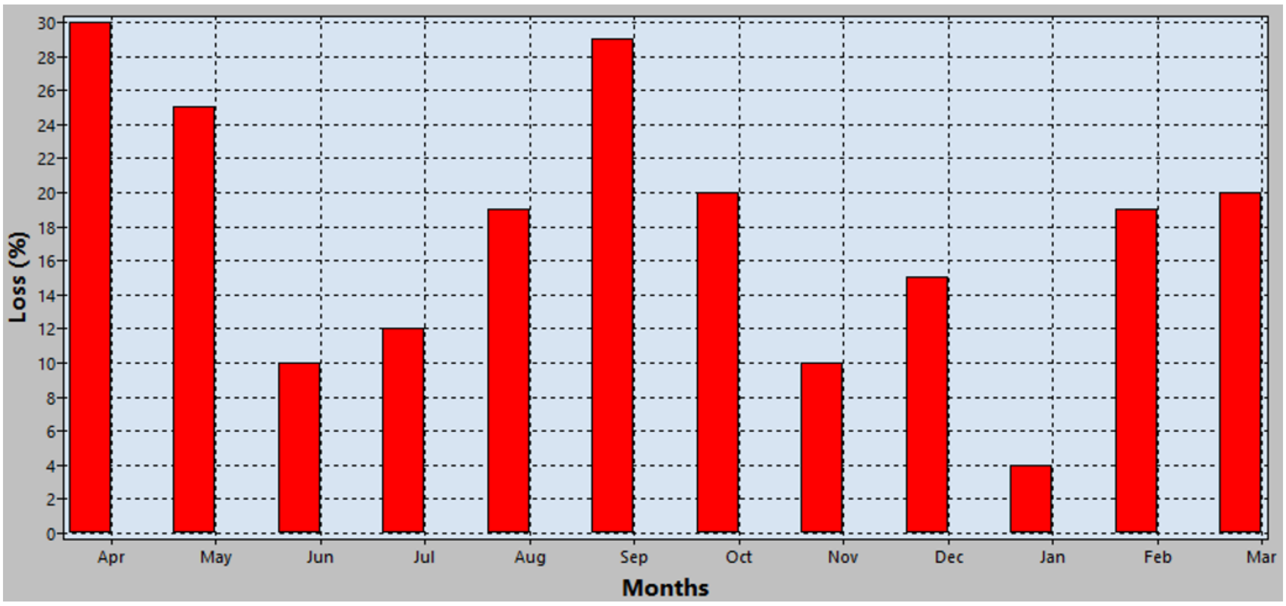


FIGURE 4.15 Vaalharts – Monthly loss (%) 2020/2021

4.3.1.2 Loskop IB

At the time of compiling this report the canals had measuring structures with no flowrate measuring equipment, such as electronic loggers. Input data was collected from a 12 feet Parshall flume at the inflow of the left bank main canal (Figure 4.16).

FIGURE 4.16 Left bank main canal inflow

The water year starts in May. The input data was collected from the left bank main canal inflow as shown in Figure 4.16. The discharge curve in Figure 4.17 was used to process the data.

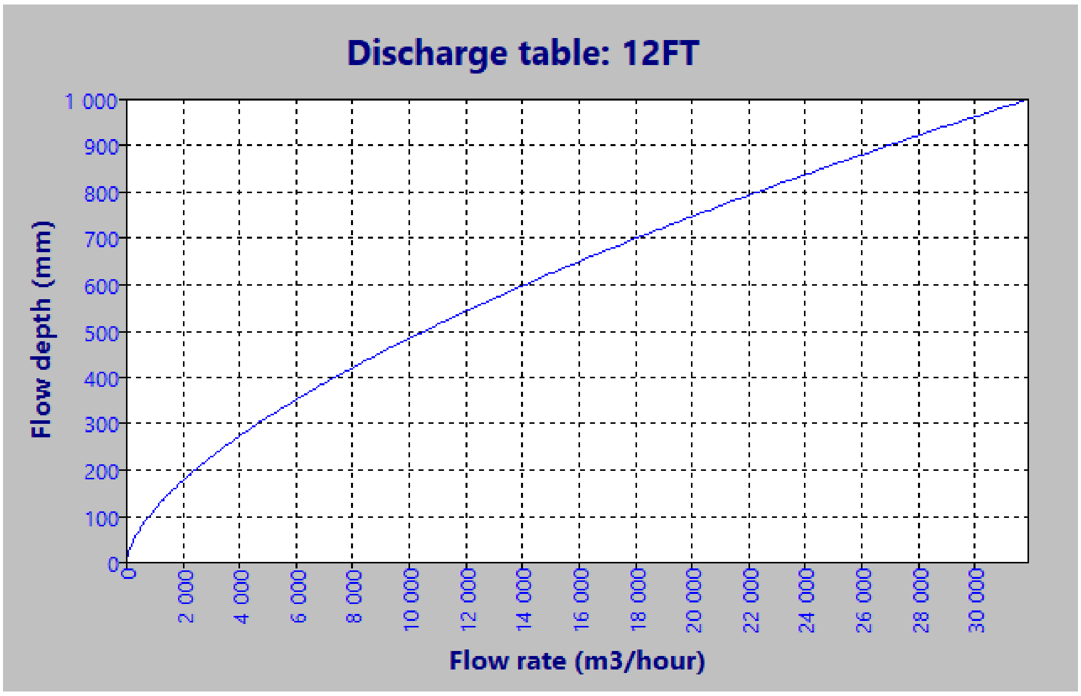


FIGURE 4.17 Loskop – Left bank inflow discharge table 12 FT Parshall

The summary WUEAR for Loskop Irrigation scheme during the water year 2019/2020 is shown in Table 4.3.

TABLE 4.3 Loskop – Left bank WUEAR 2019/2020

		(x1000m³)											%		
Year	Mnth	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Alloc used	Alloc avail	Non-revenue water	Used	Avail
2019	May	4993	98	0	15	0	0	5106	7291	2185	5091	124618	29.97	3.9	96.1
2019	Jun	4715	67	0	12	0	0	4794	5771	976	9873	119836	16.93	7.6	92.4
2019	Jul	6868	93	0	12	0	0	6973	9386	2413	16834	112875	25.71	13.0	87.0
2019	Aug	11857	131	0	15	0	0	12003	15831	3827	28822	100887	24.18	22.2	77.8
2019	Sep	12784	93	0	12	0	0	12890	16925	4036	41699	88010	23.84	32.1	67.9
2019	Oct	14520	118	0	15	0	0	14653	19657	5004	56337	73372	25.46	43.4	56.6
2019	Nov	7449	70	0	12	0	0	7531	10089	2557	63856	65853	25.35	49.2	50.8
2019	Dec	6571	86	0	12	0	0	6670	9473	2803	70514	59196	29.59	54.4	45.6
2020	Jan	6764	100	0	15	0	0	6880	9232	2352	77378	52331	25.48	59.7	40.3
2020	Feb	7676	88	0	12	0	0	7776	10714	2938	85142	44567	27.42	65.6	34.4
2020	Mar	10066	96	0	12	0	0	10174	13590	3416	95304	34405	25.14	73.5	26.5
2020	Apr	7428	86	0	12	0	0	7526	9678	2152	102819	26891	22.24	79.3	20.7
Totals		**101691**	**1126**	**0**	**156**	**0**	**0**	**102976**	**137637**	**34659**	**653669**	**902841**	**25.18**	**79.3**	**20.7**

Figure 4.18 shows the monthly water volumes released (red) compared against corresponding the water volumes delivered (blue).

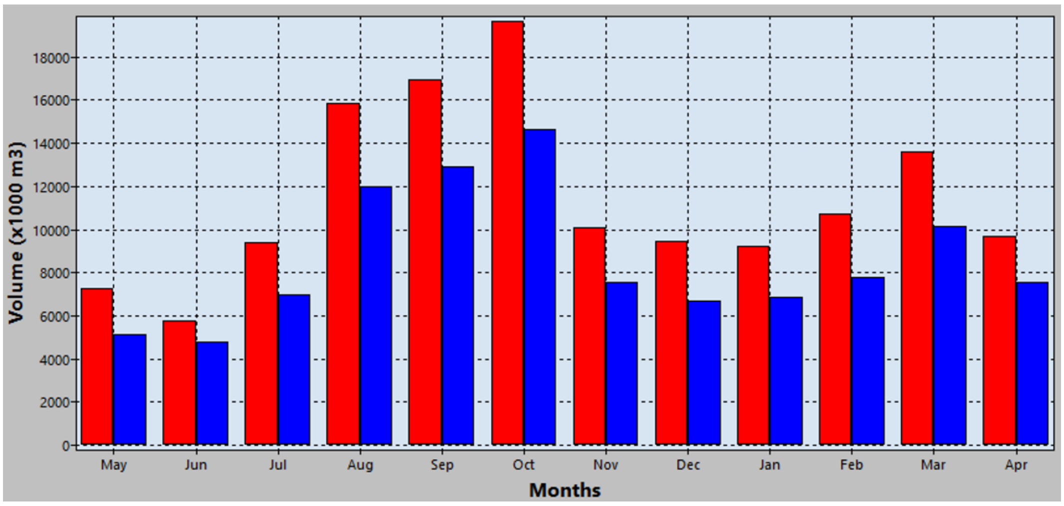


FIGURE 4.18 Loskop – Water released & delivered 2019/2020

Figure 4.19 shows the volumetric monthly water losses only for the water year 2019/2020.

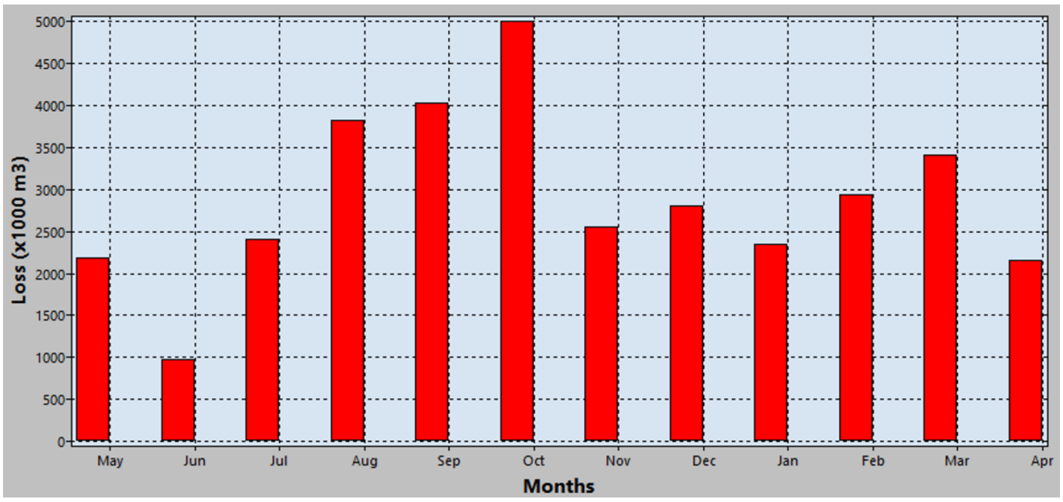


FIGURE 4.19 Loskop – Monthly loss (m³) 2019/2020

Figure 4.20 shows the monthly water loss percentages for the water year 2019/2020.

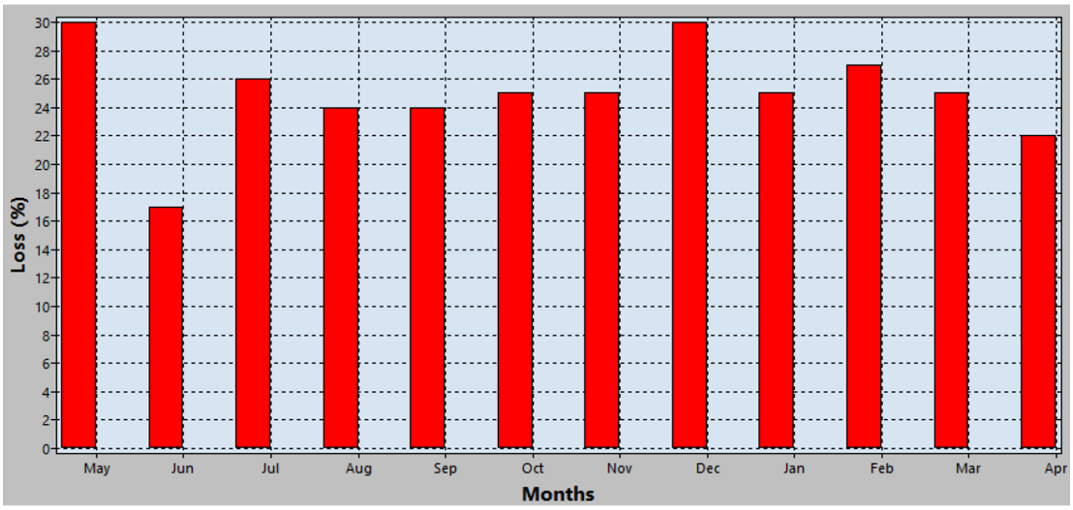


FIGURE 4.20 Loskop – Monthly loss (%) 2019/2020

Table 4.4 is the WUEAR for Loskop IB during the water year 2020/2021.

TABLE 4.4 Loskop – Left bank WUEAR 2020/2021

		(x1000m³)											%		
Year	Mnth	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Alloc used	Alloc avail	Non-revenue water	Used	Avail
2020	May	4390	98	0	12	0	0	4500	6914	2414	4488	108378	34.91	4.0	96.0
2020	Jun	4571	99	0	12	0	0	4682	5942	1260	9158	103708	21.2	8.1	91.9
2020	Jul	7205	95	0	15	0	0	7316	10119	2803	16459	96407	27.7	14.6	85.4
2020	Aug	8922	86	0	12	0	0	9020	11426	2406	25466	87399	21.06	22.6	77.4
2020	Sep	11537	92	0	12	0	0	11641	15602	3962	37095	75771	25.39	32.9	67.1
2020	Oct	10514	97	0	15	0	0	10626	14674	4048	47705	65160	27.59	42.3	57.7
2020	Nov	7604	83	0	12	0	0	7700	9975	2276	55392	57473	22.81	49.1	50.9
2020	Dec	12818	106	0	15	0	0	12940	17084	4144	68317	44548	24.26	60.5	39.5
2021	Jan	10048	87	0	12	0	0	10147	13697	3550	78452	34413	25.92	69.5	30.5
2021	Feb	5983	37	0	12	0	0	6032	8517	2485	84472	28393	29.18	74.8	25.2
2021	Mar	8869	86	0	12	0	0	8967	11986	3019	93427	19438	25.19	82.8	17.2
2021	Apr	12285	122	0	15	0	0	12422	15645	3222	105834	7031	20.6	93.8	6.2
Totals		**104746**	**1088**	**0**	**156**	**0**	**0**	**105993**	**141581**	**35589**	**626265**	**728119**	**25.14**	**93.8**	**6.2**

Figure 4.21 shows the monthly water volumes released (red) compared against the water volumes delivered (blue). This shows three peaks in water demand. September, December, and April. However, the comparison later in the report will show that this is not the case every water year.

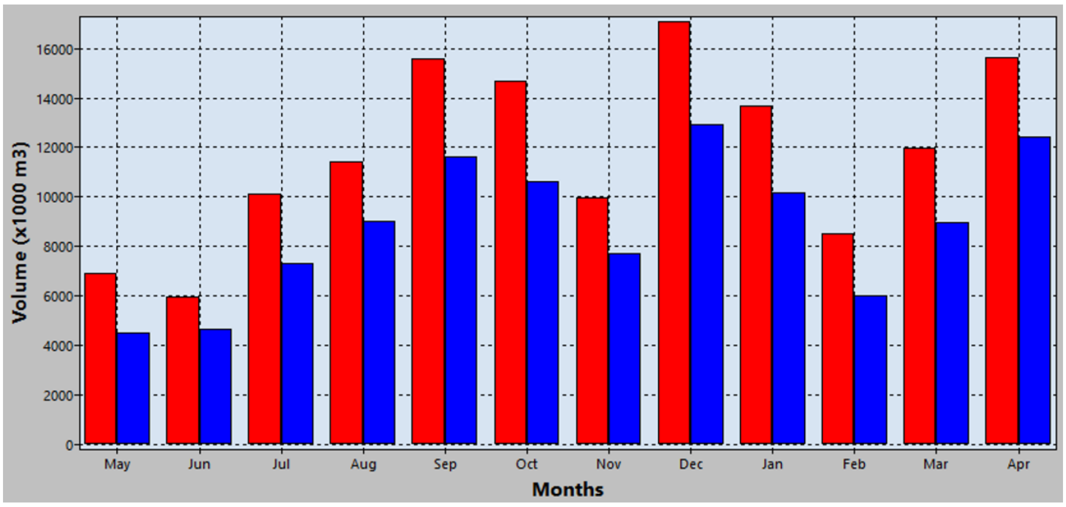


FIGURE 4.21 Loskop – Water released & delivered 2020/2021

That can also be seen in Figure 4.22 which shows the volumetric monthly water losses for the water year.

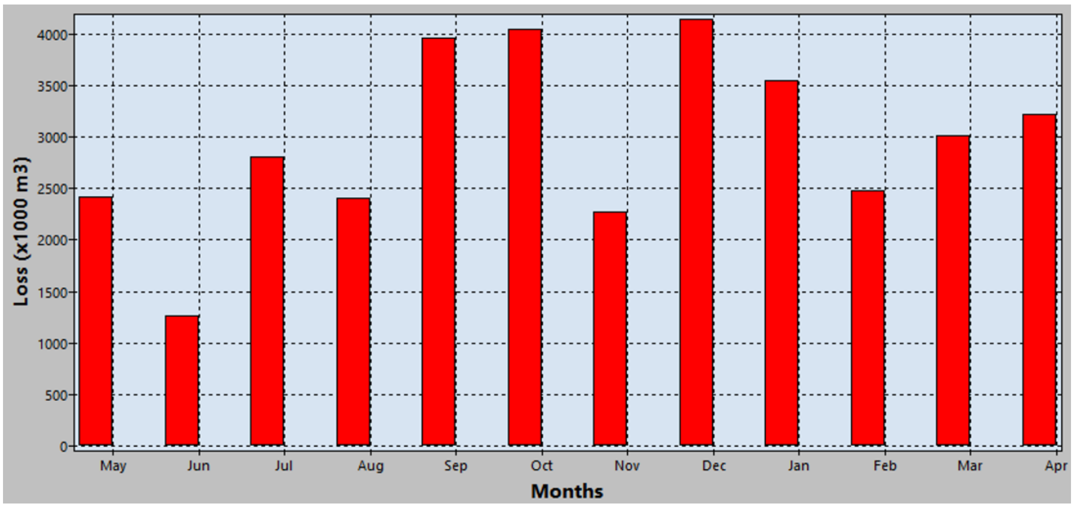


FIGURE 4.22 Loskop – Monthly loss (m³) 2020/2021

Figure 4.23 shows the monthly water losses in terms of percent. The monthly percentage loss graph shows that Loskop keeps the efficiency of their system relatively constant between 70a and 80%; however, the month of May appears to be an outlier with water losses of about 35%. The average for Loskop IB during that year was a good system efficiency of 74.86%.

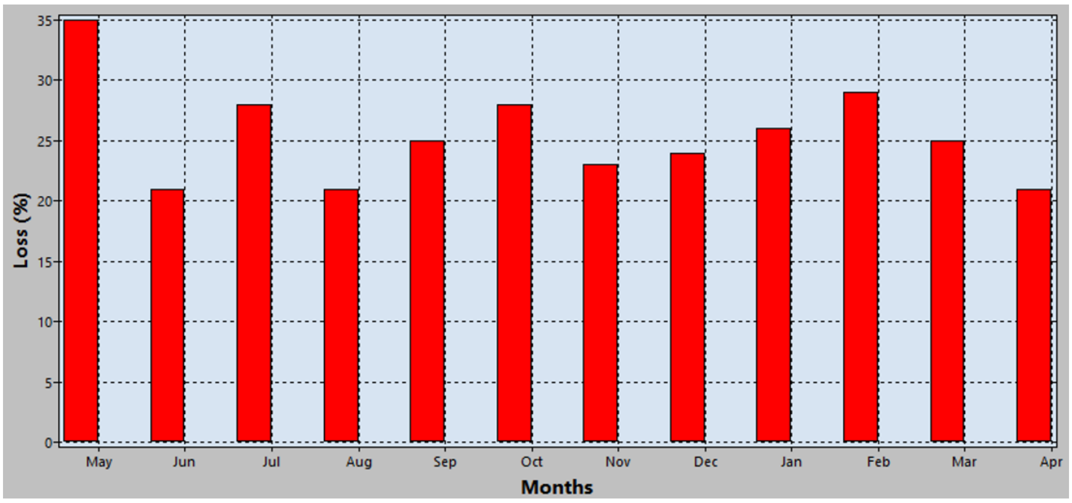


FIGURE 4.23 Loskop – Monthly loss (%) 2020/2021

4.3.1.3 Comparisons

Vaalharts WUA

A comparison of the water releases at Vaalharts WUA for the water years 2019/2020 and 2020/2021 is made in Figure 4.24.

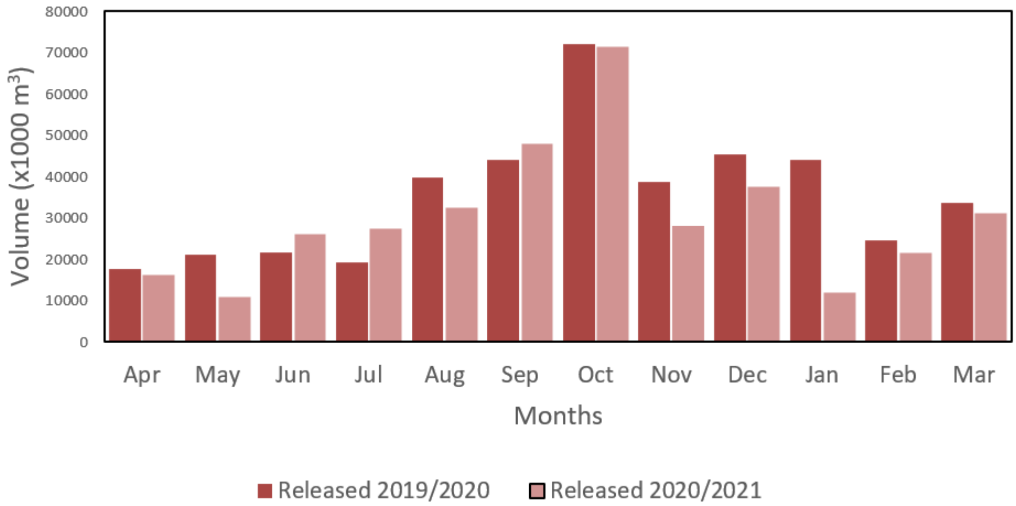


FIGURE 4.24 Vaalharts released comparison

The first thing to notice is that the general pattern of water released into the system remained the same between the two water years. The demand for water rises from April until the peak in October. Then it lowers again until the start of the next water year. The biggest differences in water releases between the two water years are in May and in January. In both months the water released into the system dropped a lot in the water year 2020/2021.

A comparison of the water delivered at Vaalharts WUA for the water years 2019/2020 and 2020/2021 is made in Figure 4.25.

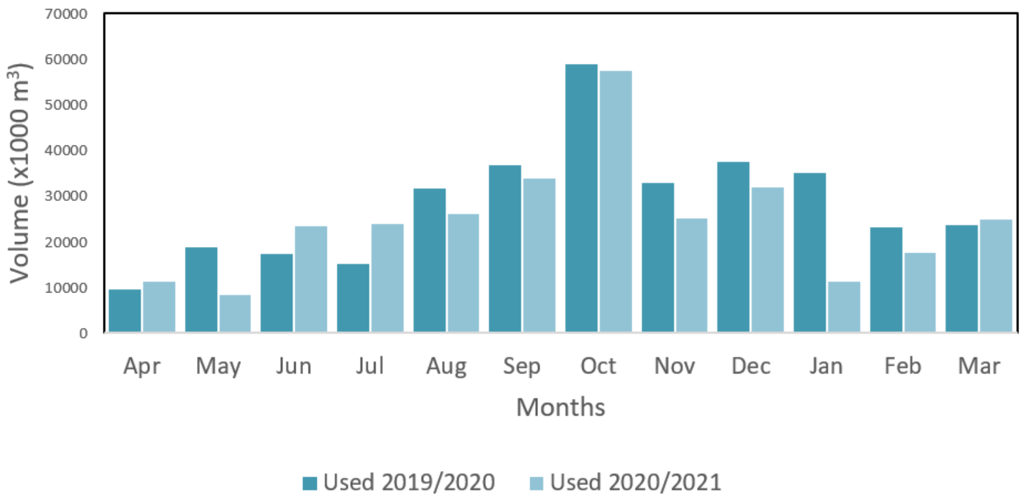


FIGURE 4.25 Vaalharts delivered comparison

Figure 4.25 shows that the pattern of monthly water delivered between the two water years is also very similar. The big differences are also in the months of May and January. The water losses are compared in Figure 4.26.

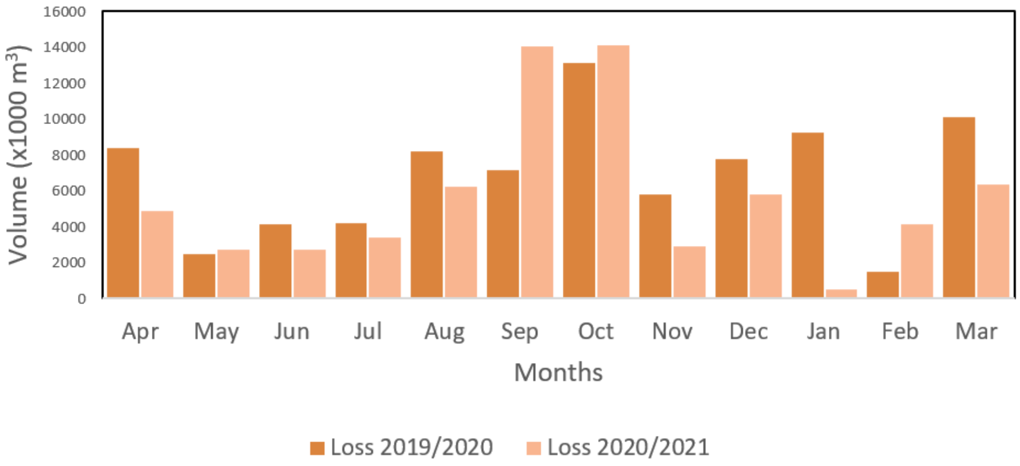


FIGURE 4.26 Vaalharts loss comparison

A comparison of the water losses shows that there is no discernible pattern between the two water years. The highest losses do not always occur in the months of highest demand.

The total water released and losses over the two water years are compared in Table 4.5. The totals of 2020/2021 are lower than the previous year. The percentage loss is lower, but the total water demand was lower as well. In terms of efficiency, there was an improvement of 0.7%.

TABLE 4.5 Vaalharts total results comparison

Totals	2019/2020	2020/2021
Released (m^3)	421 885 000	362 031 000
Delivered (m^3)	339 994 000	294 394 000
Loss (m^3)	81 887 000	67 638 000
Loss (%)	19.4	18.7

Loskop IB

Figure 4.27 compares the water release at Loskop Irrigation Board during the water years 2019/2020 and 2020/2021.

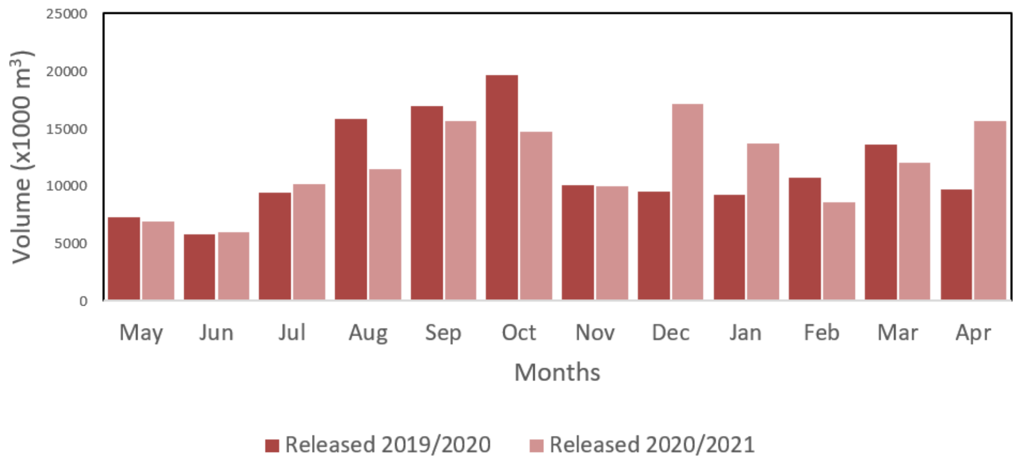


FIGURE 4.27 Loskop released comparison

The pattern of water released into the system for the water years of 2019/2020 and 2020/2021 is generally the same. The biggest differences were in December and April, where the released water volume for 2020/2021 is a lot higher than the previous year. The water deliveries for the water years 2019/2020 and 2020/2021 are compared in Figure 4.28. The figure shows that the water delivered over the two water years closely follow the same pattern.

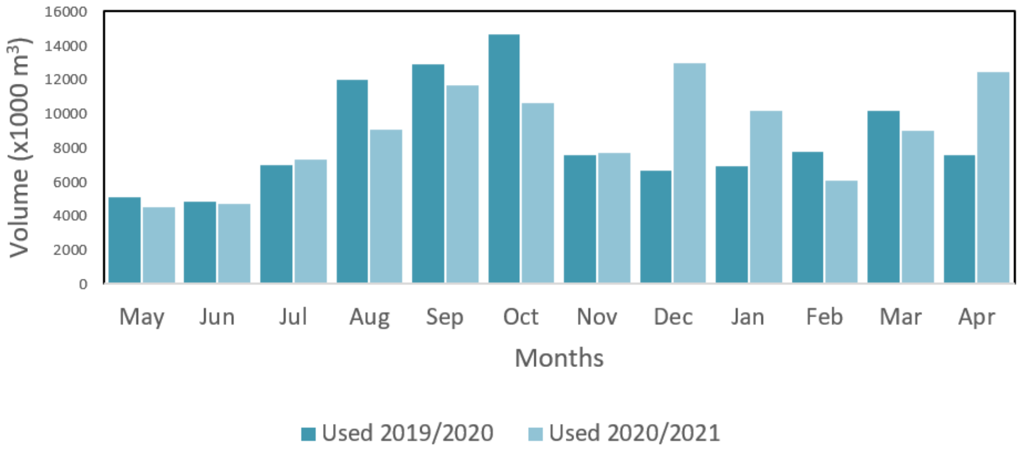


FIGURE 4.28 Loskop delivered comparison

The water losses are compared in Figure 4.29. The figure shows a steadier water loss pattern between the two water years than at Vaalharts WUA. In this case the losses also closely follow the pattern of both the released and used water volumes.

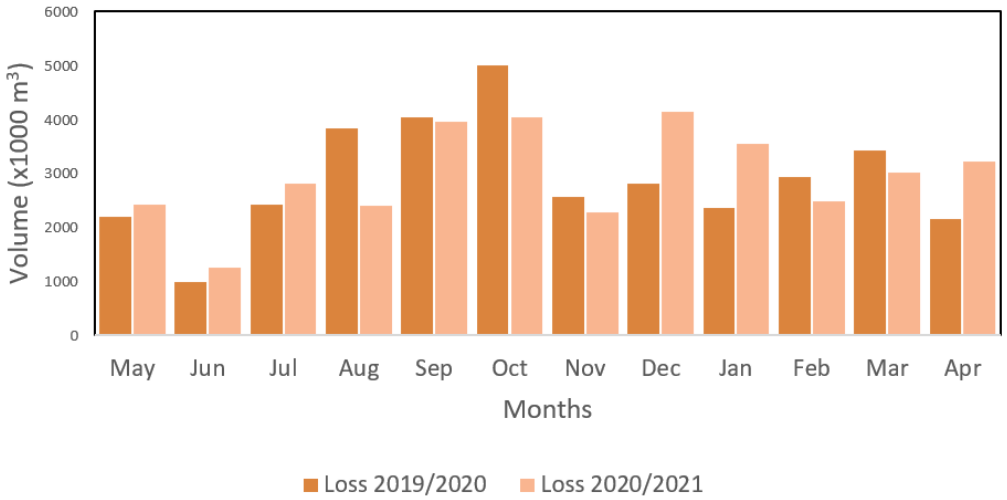


FIGURE 4.29 Loskop loss comparison

The total water released and losses over the two water years are compared in Table 4.6. The totals of 2020/2021 are higher than the previous year. The percentage loss is lower, but the total water demand was lower as well. In terms of efficiency, there was an improvement of 0.1%.

TABLE 4.6 Loskop total results comparison

Totals	2019/2020	2020/2021
Released (m^3)	137 637 000	141 581 000
Delivered (m^3)	102 976 000	105 993 000
Loss (m^3)	34 659 000	35 589 000
Loss %	25.2	25.1

4.4 Discussion

While the major canal water loss types are known in theory, it is very difficult to disaggregate them when it comes to actual measurements in the field under normal canal operations. Therefore, the only practical way to report water losses from a canal section is to account for the total water losses as a whole without trying to separate them, especially seepage and leakage. It is also not economically easy to account for water losses from different subareas of a canal network because all abstraction points would need to be equipped with measurement devices. The only practical method for now is to use a mass water balance approach to quantify global (total) water loss on an irrigation scheme. This has a number of advantages that include the fact that it is simple and practical to implement on canal network or any subarea of the network, and it is also economically feasible. However, accurate measurements or estimation of water inflow into and outflow from the canal network or section of the network cannot be negotiated. Setting an initial benchmark for an irrigation and tracking the total water loss is an excellent tool to measure whether a scheme is successful in reducing or maintaining their water losses.

Computerised technology dictates that electronic loggers be installed at all inlet and abstraction positions to accurately quantify the water flow there. The costs of such a campaign are prohibitive. Therefore, the best way is to account for a global water loss for an irrigation. This global loss is a simple total of all the water loss types for the entire canal network. The global water loss can be estimated more accurately with accurate measurements of water deliveries at the farm gates. The flumes at the farm gates are currently not used because many of them have deteriorated and measurements not accurate, which is precisely the reason the current project has to rely on water orders for water deliveries.

While the Irri-Drop Report will compare the water delivery performance of different irrigation schemes, it is important to always remember that these irrigation schemes are different in many ways. Therefore, the implications of the observations will always differ. For example, a comparison of the water loss results shows that the percentage losses are close to each other between the Vaalharts and Loskop irrigation schemes, but the volumetric water losses are hugely different. The 2019/2020 annual water loss of 81 887 000 m^3 is almost three times that of Loskop (34 659 000 m^3) over the same period. This makes sense, because Vaalharts is a much larger irrigation scheme tan Loskop. The capacity, length and age of canals also differ between irrigation schemes, which is also good reason why caution is needed in comparing irrigation schemes. In addition, water is managed differently at different irrigation schemes. For example, water bailiffs at Vaalharts only control the sluices up to the community sluice, beyond that it is the responsibility of the representative farmers. On the other hand, water bailiffs at Loskop are responsible for operating all the sluices in the system. Sluice settings are typically done once a day at Loskop compared to multiple settings for major sluices at Vaalharts. This has an impact on the operational losses.

4.5 Conclusions

Based on currently available knowledge and technology, it is not feasible to quantitively disaggregate the different water loss types occurring on canal networks in South Africa when the canals are in normal operation. Therefore, seepage, leakage, evaporation and other loss types are estimated together and the resultant total loss is referred to as the global water loss. It is also currently not economically practical to establish global water losses for different canal network subareas due to limited numbers of gauging stations at the irrigation schemes. Hence, the current approach is to estimate global losses for entre canal networks because there is always a reliable measuring device at the headwork of the main canal and what the water users order is assumed to be what is delivered to them. There is an urgent need to address this information gap for better accounting of water deliveries to farmers. Nevertheless, establishment of more gauging stations at strategic positions of the canal networks is still important because the best and less financially stressing way to minimize water losses from canal networks is to identify problem areas and take remedial actions, which is only possible with a dense network of gauging stations.

CHAPTER 5: ONLINE PLATFORM FOR REPORTING CONVEYANCE EFFICIENCIES OF CANAL SYSTEMS AT VAALHARTS & LOSKOP IRRIGATION SCHEMES

5.1 Introduction

One of the requirements of the Department of Water and Sanitation (DWS) on the Irri-Drop Report is that it needs to be published regularly online in line with technological developments in the country and the world over. Primarily, the Irri-Drop Report is expected to publish water release and delivery data from irrigation schemes, and ultimately the delivery efficiencies. Naturally, the online platform is expected to be more interactive than the Water Administration Systems (www.wateradmin.co.za) whose data was utilized in the development of the Irri-Drop Report framework. It is also expected to store and display a summary of monthly reports for various irrigation schemes using the Water Administration System (WAS).

The Irri-Drop Report framework has seven components (Chapter 6 of the current report). Therefore, assessment of a fully Irri-Drop Report ready irrigation scheme expects seven indices to be generated in addition to the overall Irri-Drop Index for that irrigation scheme. Therefore, the online platform for reporting conveyance efficiencies of canal systems needs to have the capacity to handle a big amount of data. It is important to indicate that the project managed to develop the Water Balance Report (see Chapter 6 of the current report) only out of the seven components of the Irri-Drop Report framework. Note that the water use and loss reporting format requested by DWS is a water balance showing the input water amounts and the deliveries made over a specified period for each irrigation. Therefore, the online platform was developed to handle the Water Balance Report component; however, additional space shall be created as the other components get ready for implementation.

The aim of the exercise reported in this chapter was to develop an online platform for reporting conveyance efficiencies of canal systems at Vaalharts and Loskop irrigation schemes. Note that Vaalharts and Loskop irrigation schemes are only test sites; the platform is intended for use to report for all the irrigation schemes in South Africa. The current chapter elaborates on the main features of the online platform; however, Chapter 7 of the current report give a step by step guide on how to navigate through the platform. They guidelines were used as training material for the water managers who attended the capacity development training hosted by the project team.

5.2 Methodology

Development of the platform was an iterative process where changes were appended each time new insights and requirements emerged. This is anticipated to continue as long as the Irri-Drop Report framework remains in developmental process because there will be need to incorporate the other components in addition to the one under current focus (reporting water release, delivery, and losses). The current platform was created by upgrading the existing Water Administration System. The upgrading was necessary due to a need to include new variables consistent with the expectations of Irri-Drop Report framework (see Chapter 6 of the current report) as well as new developments in technology. There were consultations with water managers from Vaalharts and Loskop irrigation scheme water managers, and those from their neighbouring irrigations, on their capacity requirements with regard to handling data for uploading onto online systems as well as on their expert input on some variables of interest to the development of the online platform.

5.3 Results

A platform for reporting water releases, deliveries and losses at Vaalharts and Loskop irrigation schemes was developed by integrating the Water Administration System, which has been reporting on water releases and uses for a while. The fact that water losses are also reported means the canal efficiencies are also generated. The key attributes of the platform are described in reasonable detail in the following sections.

5.3.1 Website map

Perhaps one of the most important to know right from start is the kind of reports the platform is capable of generating. As shown in Figure 5.1, monthly and annual water delivery and loss reports at the level of an irrigation scheme. This cascades to summary tables of water releases, deliveries and losses at national level. Corresponding graphs are also generated to make analysis easier. There is a list of participating irrigation schemes on the platform and the water release and delivery data is uploaded against a specific irrigation scheme. Details of each irrigation scheme are captured at the beginning.

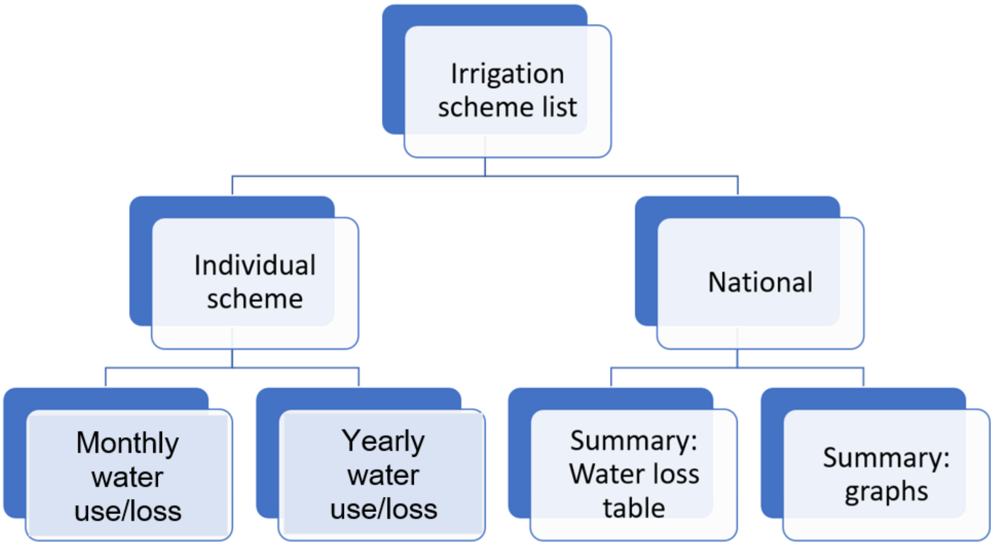


FIGURE 5.1 Web-Site map

5.3.2 Information flow

Figure 5.2 displays how information is transferred from the possible different sources. All the information uploaded is processed and made accessible through the monthly report. The water delivery and loss reports are uploaded to the Internet as well as to the *iScheme* database, which generates the WUEAR History table for each scheme and the summary table and graphs. All these are then uploaded to the Internet. After the data has been uploaded, it is automatically made available on the monthly report.

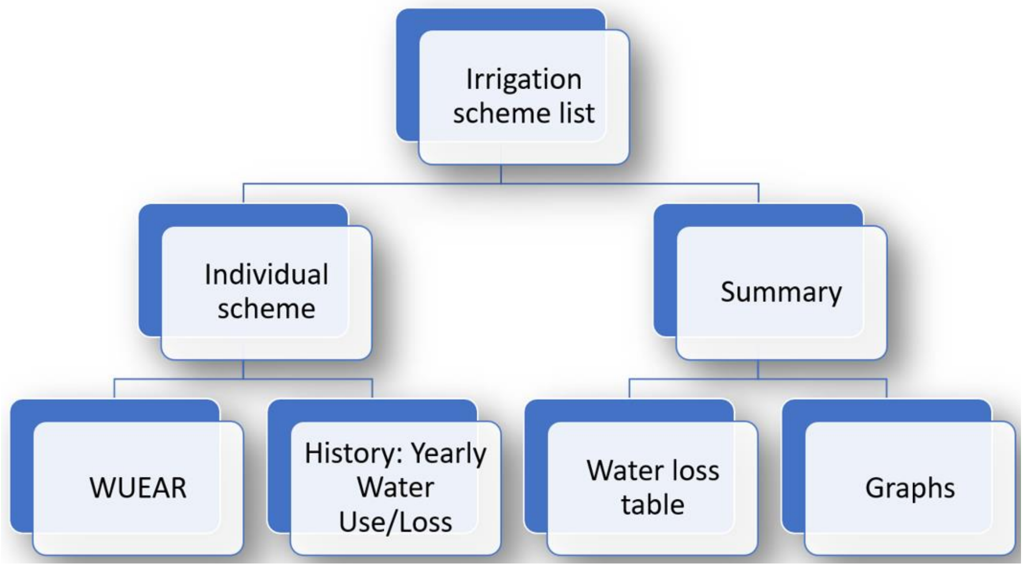


FIGURE 5.2 Information flow chart

5.3.3 Irrigation scheme list

This is the main landing page of the monthly report online platform (Figure 5.3). It shows a list of all the participating irrigation schemes. The list is automatically updated based on the data that is available on the online platform. This means that whenever an irrigation scheme uploads their reports for the first time, they are added to the list.

FIGURE 5.3 Irrigation scheme list

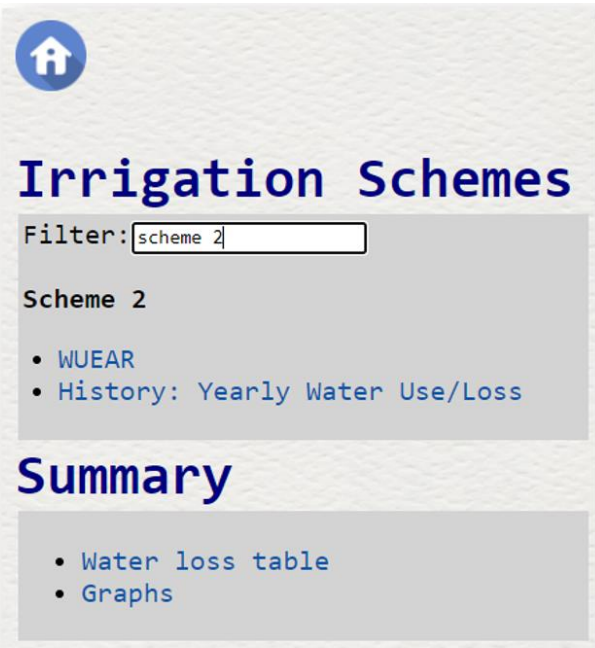


FIGURE 5.4 Irrigation scheme list – filtered

5.3.3.1 Features

- **Home:** Returns the user to the irrigation scheme list
- **Filter:** Allows the user to filter the list to show scheme names that contain the specified text. An example of this can be seen in Figure 5.4.
- **WUEAR:** Link to corresponding scheme's WUEAR report page.
- **History: Yearly water delivery/loss:** Link to a summary of all the uploaded WUEAR reports of the corresponding schemes
- **Water loss table:** Link to a summary table of all schemes as uploaded using *iScheme*
- **Graphs:** Link to summary graphs comparing certain aspects of all the schemes as uploaded using *iScheme*

5.3.4 WUEAR

The WUEAR (Table 5.1) shows an overview of the water delivery, loss and balance of an irrigation scheme on a monthly basis. This web page displays these reports according to the scheme specific reports selected and the water year. The available options are updated dynamically based on what the irrigation scheme uploads. Note that the Water Balance Report (WBR) elaborated in Chapter 6 of the current report is very much the same as WUEAR.

5.3.4.1 Features

- **Home:** Returns the user to the irrigation scheme list
- **Report:** Select the different reports uploaded by the irrigation scheme.
- **Water year:** Select the water year of the report to display

TABLE 5.1 WUEAR

Scheme 1 WUEAR

Report: Main

Water year: 2/3

		(x1000m^3)											%		
Year	Mnth	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Alloc used	Alloc avail	Non-revenue water	Used	Avail
2	Jun	4189	73	0	31	0	0	4293	6105	1811	9040	120670	29.68	7.0	93.0
2	Jul	5646	73	0	31	0	0	5750	7805	2055	14777	114932	26.33	11.4	88.6
2	Aug	10774	106	0	46	0	0	10925	15059	4134	25687	104022	27.45	19.8	80.2
2	Sep	12136	107	0	37	0	0	12280	16225	3945	37955	91754	24.31	29.3	70.7
2	Oct	11657	107	0	46	0	0	11810	15973	4163	49750	79960	26.06	38.4	61.6
2	Nov	10089	96	0	34	0	0	10219	13550	3331	59956	69753	24.58	46.2	53.8
2	Dec	9843	110	0	28	0	0	9981	13503	3522	69925	59784	26.08	53.9	46.1
3	Jan	7565	97	0	40	0	0	7702	10655	2953	77612	52097	27.71	59.8	40.2
3	Feb	7661	100	0	37	0	0	7798	10465	2667	85398	44312	25.48	65.8	34.2
3	Mar	10273	74	0	37	0	0	10384	13720	3337	95769	33940	24.31	73.8	26.2
3	Apr	5090	82	0	35	0	0	5207	6791	1583	100964	28745	23.32	77.8	22.2
3	May	0	0	0	0	0	0	0	0	0	100964	28745	0.0	77.8	22.2
Totals		94923	1025	0	402	0	0	727797	129851	33501	727797	828714	12.12	77.8	22.2

5.3.4.2 Fields

- **Year:** The actual year within the specific water year. This is automatically generated using the weekly timetable.
- **Month:** The corresponding month within the actual year. This is automatically generated using the weekly timetable.
- **Revenue water: Agriculture:** Water used for agriculture for the specific month
- **Billed metered: Industrial:** Industrial water used for the specific month

- **Billed metered: Municipality:** Water used by municipalities for the specific month
- **Billed unmetered: Household**: Household water used for the specific month. Household pipes with a corresponding pipe diameter are captured for each water user. A fixed delivery volume in m^3/year is captured for each pipe diameter. This volume is converted to an average monthly volume, which is used to generate the WUEA report. The total household volume for a given water year is divided by 52 to convert it to a weekly volume, which is then translated to a monthly volume.
- **Downstream**: Water volume that is released for a specific user downstream of the scheme
- **Other**: Other water use for the specific month that does not belong to any of the previous water usage types
- **Total water delivered**: Total water used per month which is the sum of all the different water usage types
- **System input volume**: The total water released per month into the system The recommended method of data capture for water released is electronic loggers that upload the data to the Internet
- **Non-revenue water**: This is calculated by subtracting the total water used from the total water released per month
- **Alloc used**: Total water allocation used for the specific month
- **Alloc avail**: Water allocation available for the specific month
- **% Non-revenue water** : The % loss per month is calculated automatically using the following equation:

$$= 100 \times \frac{Water\ released - Water\ delivered}{Water\ released} \qquad \textbf{Equation 3}$$

- **% Used**: Water allocation used calculated as a percentage
- **% Avail**: Water allocation available calculated as a percentage

Using the report ID and setup, the information in the report uploaded to the online platform can be divided into subarea reports. The canal network can be divided into as many subareas as required; however, loggers need to be installed to collect data on these sections, which can be expensive.

5.3.5 History: Annual water delivery/loss

This page summarizes all the WUEAR reports that have been uploaded by an irrigation scheme according to a calendar year. This report is generated and uploaded through *iScheme*. It displays both a table and a graph overview of the historical information.

TABLE 5.2 WUEAR history

WUEAR History

Report: Main

	(x1000m³)									%
Year	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Non-revenue water
0	77668	874	0	245	0	0	78786	102359	23573	23.03
1	77235	1161	0	437	0	0	78829	132857	54028	40.67
2	91667	1160	0	474	0	0	93297	125156	31859	25.46
Totals	**246570**	**3195**	**0**	**1156**	**0**	**0**	**250912**	**360372**	**109460**	**25.78**

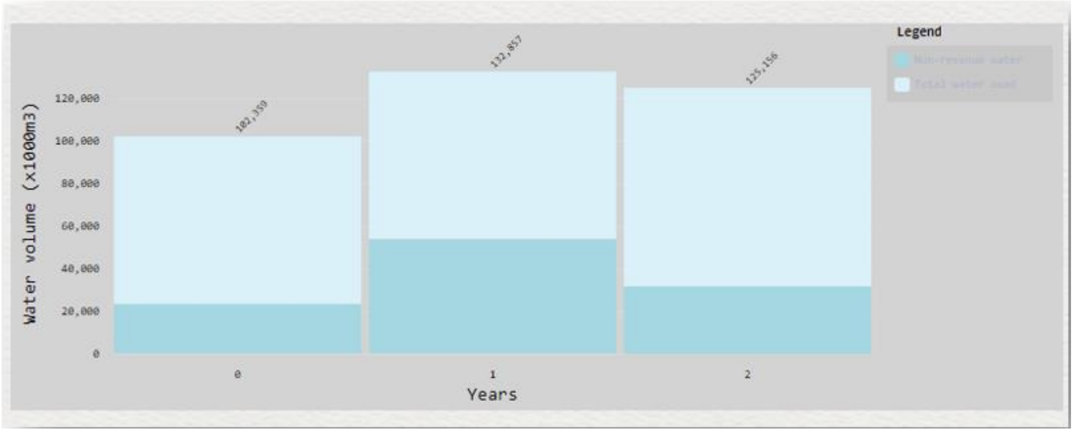


FIGURE 5.5 WUEAR history graph

5.3.5.1 Features

- **Home:** Returns the user to the irrigation scheme list.
- **Report:** Select the different reports available to the specific scheme.
- **Graph:** The graph (e.g. Figure 5.5) shows a comparison of different years of data that has been uploaded. Each bar represents the release (*System input volume)* for that year. The bars themselves are comprised of *non-revenue water* and *total water delivered*.

5.3.5.2 Fields

- **Year:** The calendar year within which the information is summarized
- **Revenue water: Agriculture:** Water used for agriculture for the specific year
- **Billed metered: Industrial:** Industrial water used for the specific year
- **Billed metered: Municipality:** Water used by municipalities for the specific year
- **Billed unmetered: Household**: Household water used for the specific year
- **Downstream**: Water volume that is released for a specific user downstream of the scheme
- **Other**: Other water use for the specific year that does not belong to any of the previous water usage types
- **Total water delivered**: Total water used for the specific year, which is the sum of all the different water usage types
- **System input volume**: The total water released into the system for the specific year
- **Non-revenue water**: This is calculated by subtracting the total water used from the total water released for the specific year
- **% Non-revenue water**: The % loss for the specific year is calculated using the following equation:

$$= \mathbf{100} \times \frac{\boldsymbol{Water\ released - Water\ delivered}}{\boldsymbol{Water\ released}} \qquad \textbf{Equation 4}$$

5.3.6 Water loss summary table

This page displays a table that summarizes information for different irrigation schemes with different reports per calendar year (in a format similar to Table 5.3).

TABLE 5.3 Water loss table

Scheme: Water loss summary

Year: 2

Irrigation scheme	Region	Scheduled area (ha)	Allocation (m^3/ha)	Full quota (m^3)	Avg loss(%)	Loss per mnth	No of irrigators
Scheme 1	Mpumalanga	14,398	7,700	110,864,600	30	5,000	586
Scheme 2	North-West	7,083	6,200	43,914,600	20	4,000	867

5.3.6.1 Features

- **Home:** Returns the user to the irrigation scheme list
- **Year:** Filter the report according to a calendar year
- **Column titles:** Clicking on the titles of each column sorts the table in a descending order according to the column selected

5.3.6.2 Fields

- **Irrigation scheme:** Name of irrigation scheme
- **Region:** Name of province in South Africa where the irrigation scheme is located
- **Scheduled area (ha):** Irrigation scheme scheduled area in hectares
- **Allocation (m^3/ha):** Irrigation scheme quota allocation m^3 per hectare
- **Full quota (m^3):** Irrigation scheme maximum quota in m^3
- **Avg loss %:** Average water loss for the irrigation scheme as a percentage (calculated by *iScheme* for the specified calendar year)
- **Loss per month (m^3):** Average water loss per month for the specified calendar year
- **No of irrigators:** Number of irrigators for the irrigation scheme

5.3.7 Graphs

This page displays summary graphs for the irrigation schemes in the list. The data does not have a year filter and only displays the latest information uploaded. Example graphs of the following are displayed:

- Full quota allocation (Mm^3)
- Quota (m^3/ha)
- Scheduled area (ha)
- Average monthly loss (m^3)
- Average loss (%)

5.3.7.1 Features

- **Home:** Returns the user to the irrigation scheme list
- **Graph:** Select the type of graph to be displayed

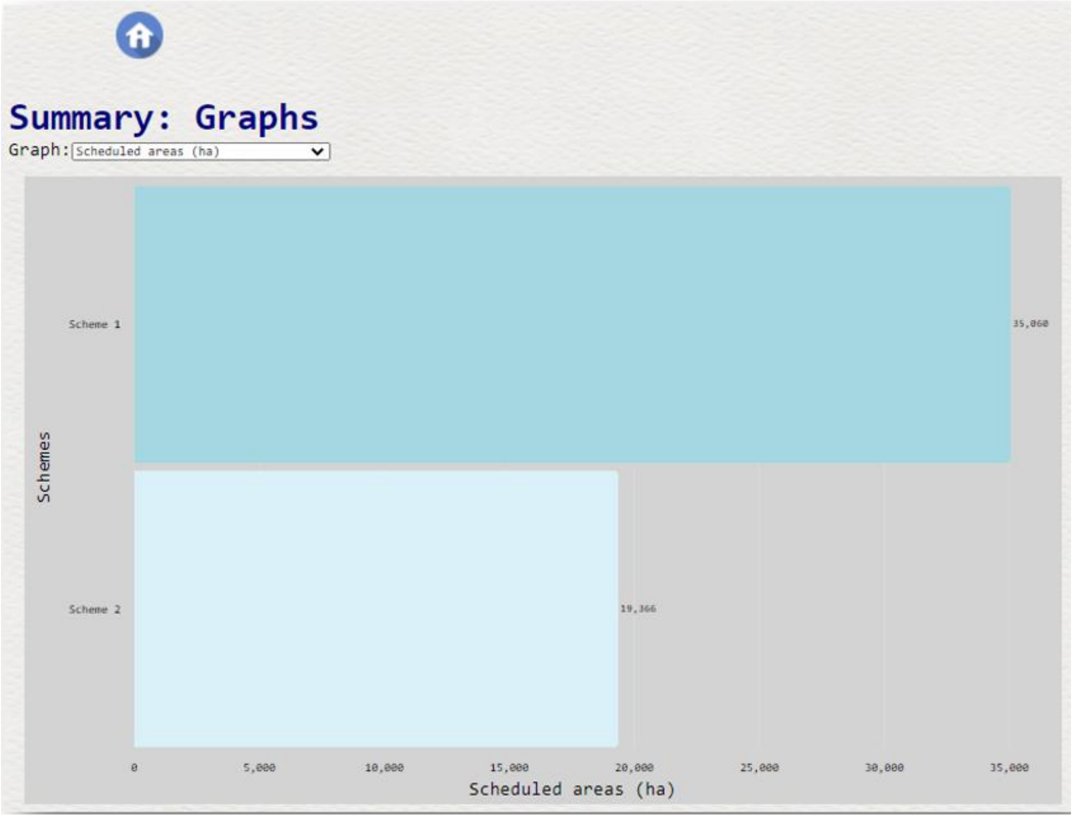


FIGURE 5.6 Example graph

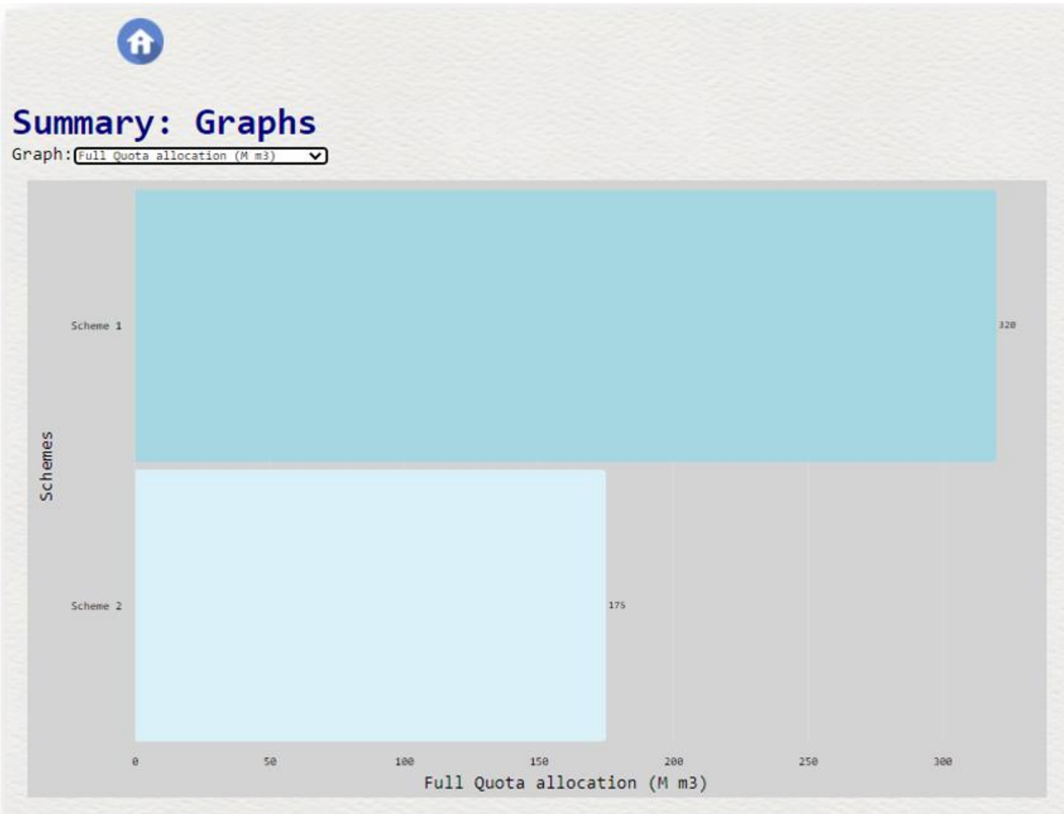


FIGURE 5.7 Full quota allocation (Mm^3)

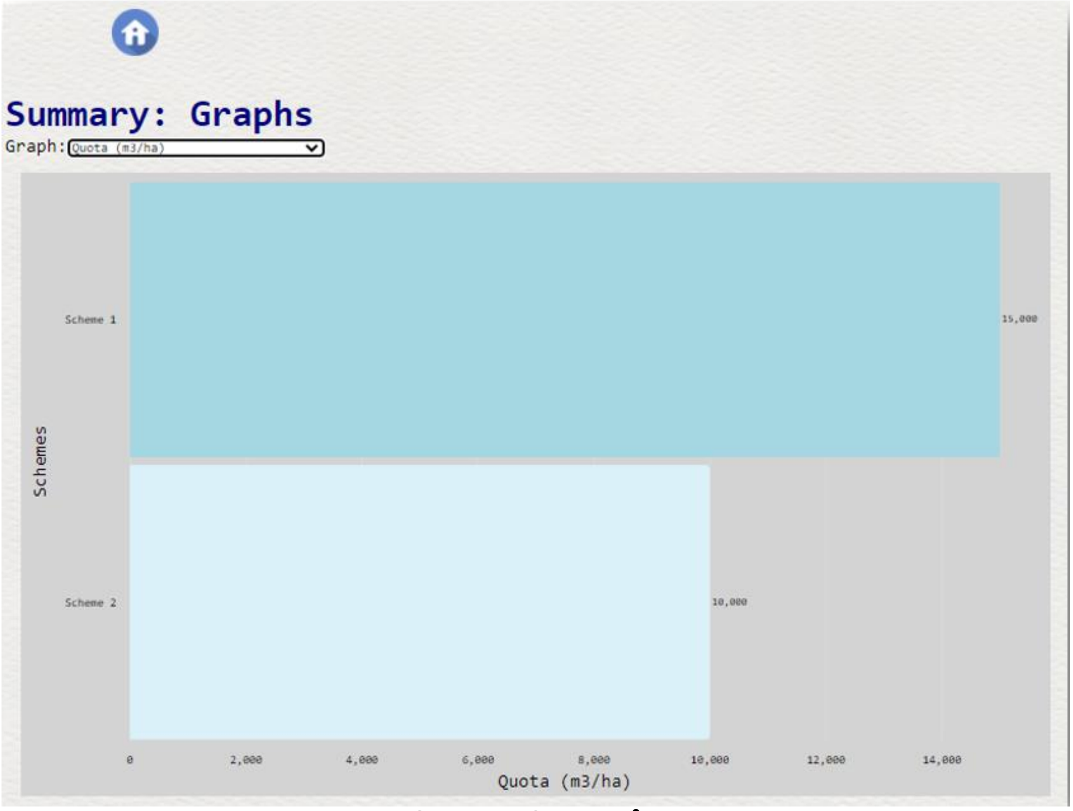


FIGURE 5.8 Quota (m³/ha)

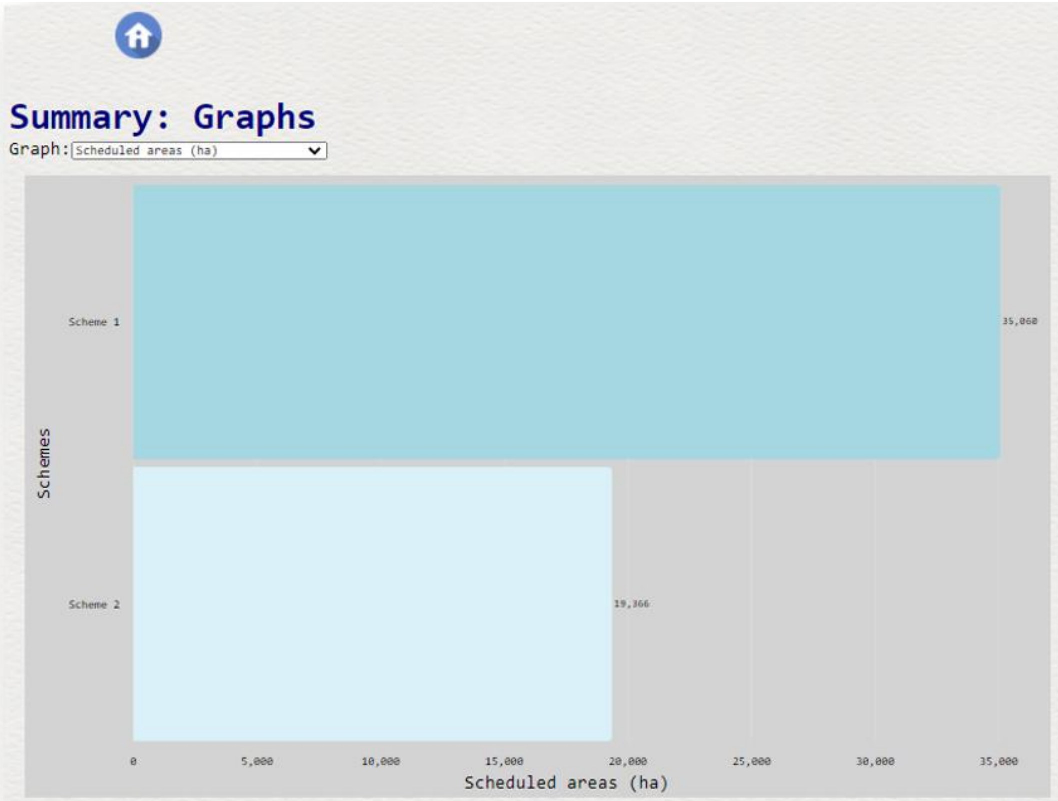


FIGURE 5.9 Scheduled area (ha)

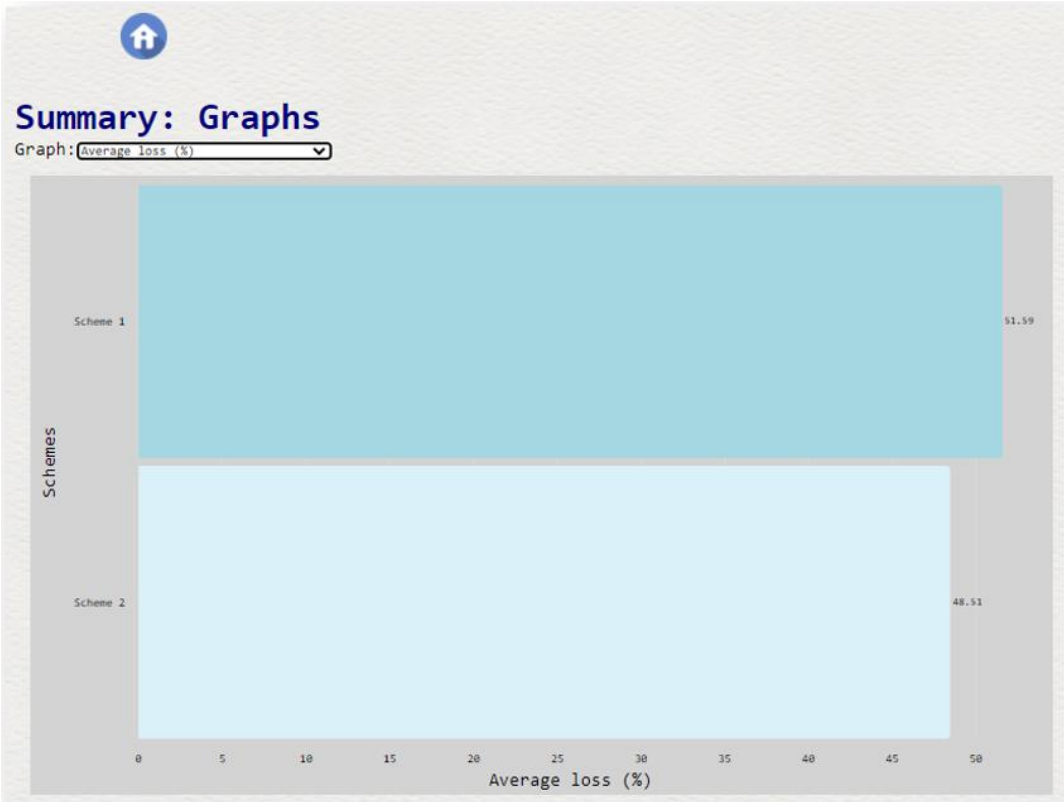


FIGURE 5.10 Average loss (%)

5.4 Discussion

An online platform for reporting water releases, deliveries, and losses for canal networks at South African irrigation schemes was developed. This platform is the foundation of the Irri-Drop Report framework , which will in future report on the same and the readiness of the irrigation schemes to deal with factors contributing to high water losses from their canal networks. The online platform will be expanded in due course to accommodate other components of the Irri-Drop Report framework (see Chapter 6 of the current report). The platform developed is capable of handling an unlimited number of subareas of a canal at an irrigation scheme provided adequate electronic data loggers are procured and installed at appropriate inflow and outflow positions on the canal network. Like other computer-based programs, the quality of the output from the online platform depends on the quality of the input data. It is also important to have realistic expectations of the online platform as it is not feasible to get some of the information that might be of interest. For example, it is not possible to get reports on disaggregated water loss types for the different subareas of a canal network due to several reasons.

While the major canal water loss components are theoretically known and enumerated as seepage, leakage, evaporation and operational, it is not practical to quantify them in the field. Seepage rates at specific points on a canal network can be measured; however, it is impractical to apply that on the entire canal network. The seepage measurements cannot be determined over a canal network. It is also impossible to measure leakage losses through the canal wall and cracks and joints on a canal network. It is theoretically possible to estimate evaporation losses from a canal surface, but it is impossible to accurately do so for a canal network, because of many factors, e.g. temperature, humidity, rainfall and wind speed, that vary with microclimate need to be considered. Theoretically, operational water losses of a canal system can be quantified by recording the opening and closing times and flow rates at all water abstraction points; however, water bailiffs cannot be expected to do the recordings and flow measurements accurately and consistently. Installation of electronic data loggers at every abstraction point in the canal network can remove the need for the error prone water bailiffs. However, electronic loggers are expensive devices which makes it economically impractical. In addition, the electronic loggers would need to be protected against thefts and vandalism.

Faced with these challenges, the best practical way to quantify water losses on a canal network is the mass balance approach, where the sum of the inflows, outflows and abstractions from the canal network are quantified. The difference between the inflows and outflows after accounting for the abstractions give the global or total water loss for that particular canal network. The global water loss is a sum of seepage, leakage, evaporation, operational and other losses. While the bills for the metered abstraction points are accurate, the same cannot be said of water delivery to farmers who have flumes at their abstraction points. Most of the flumes are old and have suffered significant wear over the years. Moreover, depth measurement plates/staves are missing at some points. Therefore, the only feasible way of estimating water delivery to farmers is to assume what they order is what they get. However, chances are that water deliveries are always underestimated because the farmers will always ensure they get what they ordered as a minimum.

5.5 Conclusions

The online platform developed is capable of reporting on water release, delivery and loss for individual irrigation schemes that are enlisted and also have the capacity to provide a summary for all the irrigation schemes on the list. This platform provides the infrastructure for a dynamic and automated monthly reporting system. It allows individual irrigation schemes to upload their own data. It also allows new irrigation schemes to be added to the list automatically. The water release data come from electronic data loggers installed on the main canals at the participating irrigation schemes; however, the state of water delivery and loss information displayed on the online platform depends on the frequency at which each irrigation schemes upload their data (such as water orders). The platform has no limitations when it comes to reporting on global water losses. The limitations are based on data availability (such as more detailed quantification of losses at the irrigation scheme level), which is largely a function of the incapacity of current technology.

CHAPTER 6: THE IRRI-DROP FRAMEWORK

6.1 Introduction

South Africa is a water scarce country facing a possible 17% water deficit by the year 2030 (WWF, 2017). In order to avert the disaster, measures to reduce the demand for water and to reduce wastages and pollution are needed in all water using sectors. Incentivised strategies to encourage higher water efficiencies have been found promising in wastewater and domestic water management systems of municipalities, where the Green-Drop Report, and Blue-Drop Report and in recent year the No-Drop Report, are used respectively. They have been utilized to evaluate and rate the performance of municipalities in terms of water use efficiency (WUE). Water deliveries and wastages are accounted for and the readiness of the municipalities to deal with water losses and other forms of wastage are also assessed. The assessment process can generate indices at two main levels, i.e. the municipality as an entity is the highest level and below it is the level of factors which are assessed during the evaluation process. Many socio-economic and technical factors are evaluated and an index is generated for each of them. The same factors are evaluated at all participating municipalities for uniformity which enables comparisons to be made across the municipalities. However, not all the factors may feature at some municipalities. The outcome indices for the factors at each municipality are combined into one index for the entity. More details about these frameworks are available in literature. What is important to note is that the indices generated are quantitative values depicting the level of performance. The entity indices are regarded the measures of WUE at the participating municipalities. These WUE indices are used to monitor progress in terms of meeting water management targets and for comparing performance levels of the participating municipalities in a transparent manner.

The Department of Water and Sanitation (DWS) of the Republic of South Africa made a call for a framework, similar to the Green-Drop, Blue-Drop and No-Drop Reports highlighted above, to be used for evaluating and rating the water use performance of irrigation schemes in the country. It is important to note that irrigation schemes consume the bulk of the water used in South Africa, but they also happen to be the worst culprits in terms of wastages of water. The request was for a tool that enable the evaluation and rating of water conveyance efficiency by the conveyance infrastructure at the irrigation schemes. The framework is also expected to evaluate how prepared the irrigation schemes are in terms of dealing with wastages of water. The name of the framework is Irri-Drop Report, and the framework mirrors the No-Drop Report. Therefore, the Irri-Drop Report also have several components (protocols and procedures for analysing factors) which generate indices for factors that are analysed. The outcomes of the components are also combined to generate an index for an irrigation scheme. It is important to mention that the indices are results of combining relative contributions from the factors and/or subfactors which are analysed. The Irri-Drop Report is also intended for use to explore opportunities to identify areas and subareas within the water conveyance infrastructure network and general water management plans that require improvement to achieve intended water conveyance efficiency (WCE) targets.

Therefore, the broad objective of the current project was to develop a general framework for evaluating the state of water losses and measures to improve water use efficiency on selected irrigation schemes of South Africa. This framework is what is referred to as the Irri-Drop Report in the current report. The Iri-Drop Report aims to provide the means for rating and comparing the performance of South African irrigation schemes in terms of water delivery and readiness to deal with water losses from the conveyance infrastructure.

6.2 Methodology

A series of meetings took place to discuss the Irri-Drop Report framework. The first meeting was for the project team members on 13th May 2019, at the ARC Silverton Campus offices. The second meeting was for the project team and selected members of staff from the Department of Water and Sanitation which took place on 20th May 2019 at the NB Systems offices in Montana Park, Pretoria. These were followed by project team visits to meet water managers at Vaalharts Water User Association (VWUA) and Loskop Irrigation Board (LIB) on 13th and 20th February 2020, respectively. The meetings with water managers at VWUA and LIB also discussed the general outlines of the respective irrigation schemes paying particular attention on the water infrastructure in place and canal network layout. More water managers were met during an online training session hosted by NB Systems for the irrigation schemes on 19th August 2021. At all these meetings, the concept for the Irri-

Drop Report framework was discussed; the discussions precipitated around the different water loss types from canals and how to practically quantify each one of them. Issues on assessing the readiness of irrigation schemes to deal with water losses were generally given lesser importance. In addition to these meetings, the project team also reviewed available literature relating to water loss measurements at irrigation schemes in South Africa and beyond. Particular focus was on the literature that dealt with assessment frameworks for WUE at irrigation schemes. Many ideas were generated during the meetings and a few frameworks were encountered in the literature. The project team settled for ideas that mirrored the No-Drop Report, in line with the request by DWS, which was also in use at municipalities within the country. It is also important to note the Water Administration System (WAS) is the only tool available for assessing WUE in South African irrigation schemes; hence, it was the only source available source of data for the Irri-Drop Report framework.

6.3 Results

The Irri-Drop Report is a set of components which are used to evaluate and rate the performance of irrigation schemes (i.e. WUA: Water User Associations, IB: Irrigation Boards and/or GWS: Government Water Schemes) in terms of efficiency in delivering water for irrigation purposes. Each component consists of several factors which are assessed in order to generate an index for the component. The factors may have their own subfactors; therefore, assessment will cascade to the lowest feasible level. The resultant index for a component is a result of weighted contributions by the factors (and subfactors, where applicable). Overlaps may exist in terms of factors (and/or subfactors) occurring in more than one component in the Irri-Drop Report framework, but assessment shall still be done at the level of individual components to generate performance indices according to each component. The individual component indices constitute inputs to the Irri-Drop Report framework, which then generate the Irri-Drop Report Index for a WUA, IB or GWS. The component contributions to the Irri-Drop Report Index are also weighted to reflect their relative influence on the index. Weighting is a very important step because factors do not exert similar levels of influence to the component index, neither do components exert similar levels of influence to the Irri-Drop Report Index.

Water conveyance efficiency is the main pillar of the Irri-Drop Report framework; hence, it is important to ensure that accounting for irrigation water withdrawal, usage and losses, and how the framework defines irrigation water use efficiency are in sync with internationally accepted standards. Figure 6.1 shows the framework for accounting for irrigation water withdrawal, use and losses developed by Perry (2007), which was endorsed by the International Commission on Irrigation and Drainage (ICID). The water balance approach to defining irrigation water use efficiency is illustrated in Figure 6.2. However, it is important to note that the Irri-Drop Report is only concerned with the water conveyance system. Therefore, the intended target of the water delivery for the Irri-Drop Report is the farm gate where water enters the farm and not the crop water use.

6.3.1 The Irri-Drop Report conceptual framework

Seven components were identified for the Irri-Drop Report framework through a survey of available literature and consultations of stakeholders as important for the Irri-Drop Report, namely Water balance Report, Water management Plan, Condition Assessment Report, Technical Competency Report, Budgeting Report, and Credibility and Regulation Enforcement Report. Therefore, the Irri-Drop Report Index is a function of the indices of these components. The components are assessed independent of each other and then their indices are combined into one Irri-Drop Report Index for the irrigation scheme over a specific monitoring period. The component contributions are weighted to reflect the importance of each one of them to the Irri-Drop Report Index. This is important because, as already alluded to, the components do not wield similar influence on the Irri-Drop Report Index. Each component has its own factors and subfactors which are assessed to generate the component index. The factor and subfactor contributions to the component index are also weighted. Figure 6.3 is a roadmap conceptual framework for the Irri-Drop Report. The seven components to be assessed. Some of the important factors to be assessed for each component are also presented. The ultimate output of the component assessments is the Irri-Drop Report Index as shown in the figure. Greater detail of the factors and subfactors to be assessed and weighted will be imbedded in the Irri-Drop Report model. The information flow diagram for the framework shall be provided when all the components and their interrelationships are fully developed.

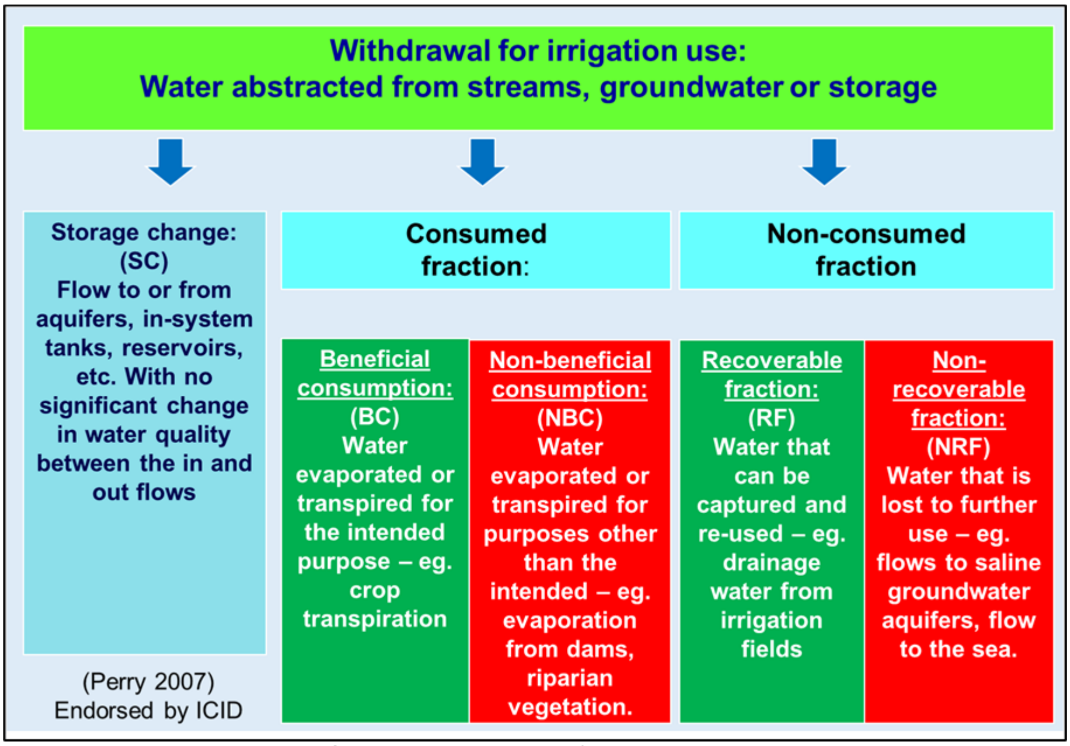


FIGURE 6.1 Withdrawal for Irrigation use

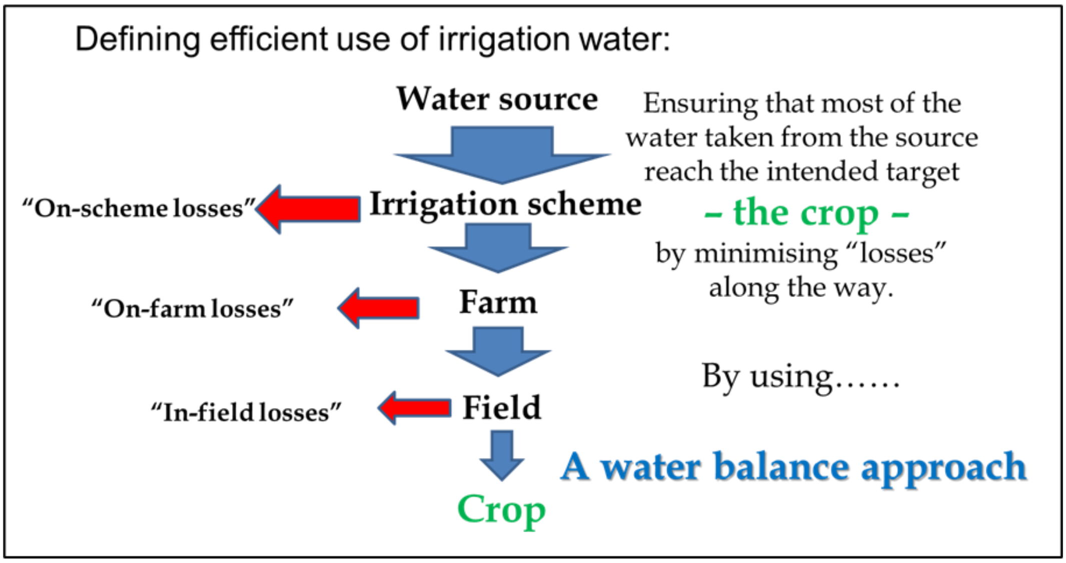


FIGURE 6.2 Defining efficient use of water

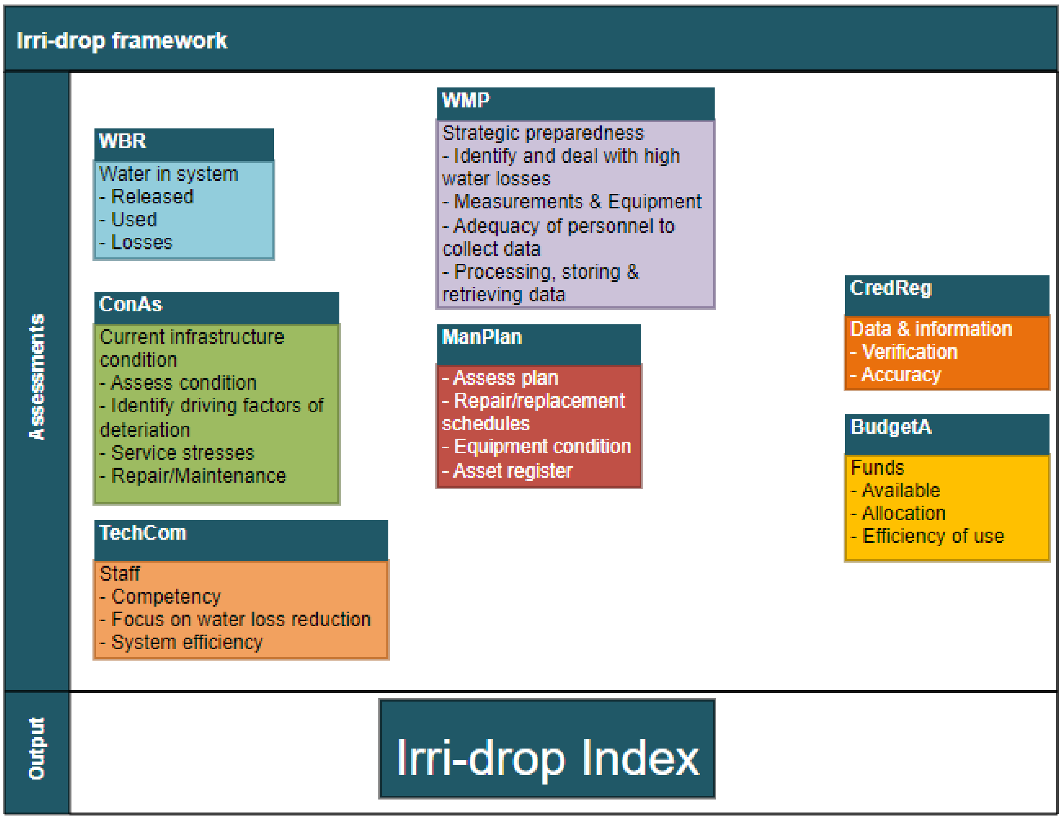


FIGURE 6.3 Roadmap to the Irri-drop Report conceptual framework

6.3.2 Requirements for the Irri-Drop Report framework

A review of the available literature on similar frameworks used in South Africa (i.e. the Green-Drop, Blue-Drop, and No-Drop Reports) gave rise to the list of components (often referred to as requirements or assessment criteria in those frameworks). However, the Irri-Drop Report mirrors the No Drop Report more than it does to the other two frameworks; as a result, the components were largely adapted from the No-Drop Report (DWS, 2015; 2014; DWA, 2011; 2010). The components adopted for the roadmap to the Irri-Drop Report conceptual framework are:

- Water Balance Report (*WBR*)
- Water Management Plan (*WMP*)
- Maintenance Plan (*ManPlan*)
- Condition Assessment Report (*ConAs*)
- Technical Competency Report (*TechCom*)
- Budgeting Report (*BudgetA*)
- Credibility and Regulation Enforcement Report (*CredReg*)

The acronyms used here are for the purposes of the current report and may not be applicable elsewhere. These components are analysed at the level of their factors, and subfactors where necessary. While these components were identified, more work still need to be done on all but one of them (the Water Balance Report Component). It can, however, be hastily mentioned that while all the components are important to generate the Irri-Drop index, irrigation schemes do not need to wait until all of them are ready to start implementing the Irri-Drop Report framework. Nevertheless, the Water Balance Report (*WBR*) is the minimum requirement without which the Irri-Drop Report framework cannot be implemented at an irrigation scheme. The Irri-Drop Report framework components are described briefly in the following sections.

6.3.2.1 Water Balance Report *(WBR)*

This is perhaps the most important component of the Irri-Drop Report framework. The *WBR* component measures water released into canal networks and the amount that is delivered to the farms. Therefore, it is used to account for the extent of water losses that occur in the canal network. Water conveyance efficiency of canal networks at the participating irrigation schemes is computed and used to generate the index for the component. The process for computing the canal network water losses is similar to what the WAS (www.wateradmin.co.za) is already reporting on at the irrigation schemes. Therefore, WAS is the basis for WBR. A detailed description of WAS adapted for the current project, its components, and how it was applied at test irrigation schemes (Vaalharts Water User Association and Loskop Irrigation Board) is presented after the brief descriptions.

6.3.2.2 Water Management Plan *(WMP)*

This is another critical pillar of the Irri-Drop Report framework. The *WMP* report assesses how strategically prepared a WUA, IB and/or GWS is to identify and deal with water losses from the supply canal networks. It reports on adequacy of readiness in terms of staff complement (having the right number of correctly trained people in correct positions), flow measurement plans and equipment (equipment in place and suitability for the purposes, and correct numbers in correct positions on the network), required data collection (how often data is collected), facilities for data processing, storing, and retrieving the data when needed.

Table 6.1 below compares the water management plans in place at Vaalharts WUA and Loskop IB against the standard laid down for them by the Water Management Implementation Guidelines developed by a consortium comprising of MBB Consulting Services Inc., Ninham Shand and CSIR (DWA, 2006). It is important to note irrigation schemes are unique, not only in the layout of their canal networks but also in terms of how water is managed. Therefore, huge deviations from the guidelines can be expected. The Irri-Drop Report framework takes cognizance of the differences that exist among the irrigation schemes.

6.3.2.3 Maintenance Plan *(ManPlan)*

The *ManPlan* report assesses the adequacy of plans to ensure that assets of the organization for supplying water, maintaining water supply canal networks, and measuring flow in the canals remain in good functional order. The components of this criterion include repair and replacement schedules; adequacy of equipment/assets to perform the planned works; asset registers and logbooks to control the risk of asset losses, etc.

6.3.2.4 Condition Assessment Report *(ConAs)*

The ConAs report assesses the condition state of water delivery and associated infrastructure, and identification of the main factors driving the condition state. Water losses from canal networks depend on many factors/elements including some which are due to the condition of the infrastructure. Condition is normally influenced by such activities as design to deal with in service stresses, repair/maintenance and/or replacement. Age also influences the condition of the infrastructure as wear and tear increase over time.

6.3.2.5 Technical Competency Report *(TechCom)*

The *TechCom* Report assesses and reports on the capacity and skills availability at the WUA, IB or GWS to be able to implement WAS, WMP, ManPlan and *ConAs*. The report gathers information that help to answer several questions; including are people assigned to WAS and WMP technically competent? Is achieving high water conveyance efficiency a part of the job descriptions of everyone involved in water supply starting with executive staff members? Is high water conveyance efficiency promoted and implemented in a coordinated manner?

6.3.2.6 Budgeting Report *(BudgetA)*

The *BudgetA* assesses and reports on the financial adequacy to be able to implement the plans and activities geared at supporting the rating of the water supply entity in line with the Irri-Drop Report framework, i.e. WAS, WMP, ManPlan, *ConAs* and *TechCom*. The Irri-Drop Report will evaluate the available budget and budget allocations for implementing or operationalizing the above Irri-Drop Report requirements; however, it will not concern itself with how the funds are raised.

TABLE 6.1 Water management plan guidelines for Vaalharts WUA and Loskop IB

Water management plan			
Requirement	**Minimum**	**Vaalharts WUA**	**Loskop IB**
Personnel layout	CEO Head Water Control Officer Water bailiffs Office staff (support & admin)	1 CEO 1 Head water control officer 7 Water bailiffs 5 Office workers	1 CEO 1 Head water control officer 4 Water bailiffs 3 Office workers
Scheduled area (ha)	-	29 562	16200
Full water quota (m^3/yr.)	-	270 202 164	145 811 813
Number of wards/sub-areas	-	21	8
[Ward #] area (ha)	-	[1] 1182 [9] 1757 [16]1826 [2] 792 [10] 2107 [17] 400 [4] 1205 [11] 2111 [24] 1141 [5] 1511 [12] 2309 [25] 1037 [6] 1486 [13] 1608 [26] 724 [7] 1324 [14] 1953 [27] 1528 [8] 1664 [15] 1718 [Unassigned] 181	[W1] 1721 [W6] 2543 [W7]1859 [W8] 2297 [W10] 2134 [E1] 1780 [SD1] 2238 [SD2] 1614
Responsibilities	- Based on size of the sub-areas, - Wards/sub-areas should be reasonably divided between water bailiffs	- Each water bailiff is responsible for multiple wards, reasonably divided among them - Head water control officer is responsible for some of the wards, but also manages the other water bailiffs	- There 5 water bailiffs each responsible for at least 1 ward and 2 responsible for more than that.
Duties	- Depending on scheme protocols, the office staff should capture water orders and water bailiffs should open and close sluices at specified intervals	- They capture water orders, generate distribution sheets - Water bailiffs open and close sluices of their wards, but only up until the community sluice - Community representatives are responsible for community sluices	- They capture the water orders, generate the distribution sheet - Water bailiffs open and close sluices of their wards
Water logging & ordering	- Water orders taken weekly and a week before water is needed - Meter readings taken monthly to track delivery - Electronic logger at inflow of canal system	- Water orders are captured weekly - Meter readings are captured monthly - Input into system is measured at canal network inflow with an electronic logger	- Water orders are captured weekly - Meter readings are captured weekly - Input into system is measured at canal network inflow with an electronic logger
Distribution method	- Distribution sheet method	- The orders are used to generate a distribution sheet each week	- The orders are used to generate a distribution sheet each week
Time & frequency of opening-closing sluices	- Sluices must be opened and closed at most on 12-hour intervals at specific times	- Sluices are opened and closed on intervals of 1 hour as required by the distribution sheet	- Sluices are opened and closed at 6:00 in the morning and at night

6.3.2.7 Credibility and Regulation Enforcement Report *(CredReg)*

The *CredReg* Report assesses and reports on the quality control strategies in place to ensure that the data collected and analysed by the water supplier are credible. Reports need to be based on corrected and true information, which also help in better decisions. The report also assesses the quality of regulations aimed at enhancing water supply efficiency and how these regulations are enforced. The general thrust is that the regulations should be enforced within the frameworks of national laws.

6.3.3 Operational recommendations for the Irri-Drop Report framework

As already alluded to, the assessment of each component is implemented individually at an irrigation scheme. This means that only those components that are ready for implementation at a particular irrigation scheme are assessed to generate the indices for those components. However, it is important to emphasise that WBR is the minimum requirement and, thus, should be the first component to be implemented at any irrigation scheme entertaining participation in the Irri-Drop Report. Therefore, irrigation schemes cannot choose not to be evaluated and rated on the basis of WBR. A step-by-step approach can be taken in terms of preparing for implementation of the other components (after WBR is already implemented) at a particular irrigation scheme until all the other components are ready and can be implemented. The best and overall Irri-Drop Report Index can only be obtained when all the components are implemented at an irrigation scheme.

6.3.4 The Water Balance Report (*WBR*)

The framework for the Water Balance Report (WBR) is shown in Figure 6.4.

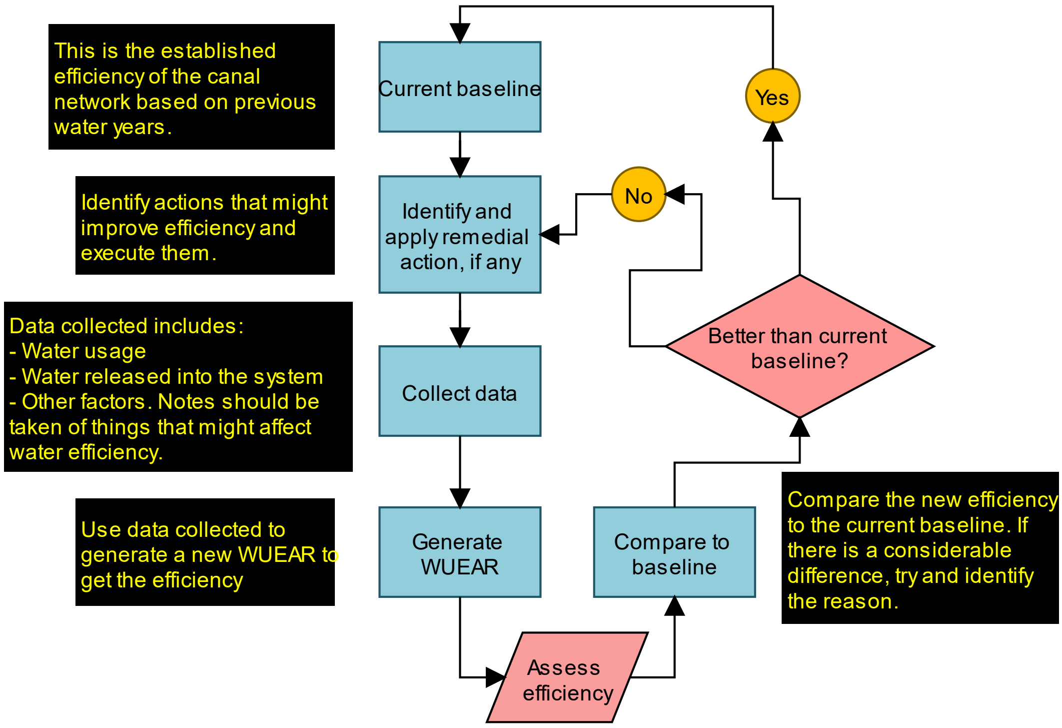


FIGURE 6.4 Detailed flow diagram for the Water Balance Report

The main goal of the water balance report, underpinned by the Water Administration System (WAS), is to identify opportunities for reducing water losses and to increase the water supply efficiency at irrigation schemes. It provides water suppliers with criteria and guidelines on the assessment of water use performance of the irrigation schemes. This includes things such as data collection, state of the conveyance system and maintenance, procedures and protocols regarding water management and canal operation, and reporting on efficiency. Once implemented on an irrigation scheme, the Water Balance Report framework uses the following steps:

- Assess whether the irrigation scheme meets the minimum requirements necessary to use the framework
- If necessary, set up scheme with whatever was lacking in step 1
- Start collecting data and generating reports
- Use this information to establish a baseline for the scheme
- Assess the conveyance system, procedures and protocols, and environmental conditions to try and explain the efficiency of the system
- Identify possible remedial action that can be taken
- Compare future results with baseline to assess whether the remedial actions were effective
- Implement the rest of the framework requirements in phases as the irrigation scheme is ready for them

The comparison and improvement steps should be followed until a reasonable and acceptable efficiency is achieved. At this point the comparison steps should be used to ensure that the system efficiency is maintained.

6.3.4.1 Requirements of the Water Balance Report *(WBR)*

There are a few elements of the Water Balance Report that an irrigation scheme needs before the framework can be implemented effectively. These requirements are:

- Water Administration System (Benadé and Benadé, 2021)
  - Admin module
  - Water order module
  - Measured data module
  - Report module
  - Water release module
- Measuring stations
- Electronic loggers

Water Administration System (WAS)
Since WBR is the main pillar of the Irri-Drop Report, it means WAS plays a critical role in the Irri-Drop Report framework because all the collected water flow data is gathered in its database. The WAS keeps track of the water release, delivery, and losses from the canal network of the scheme. It uses this data to generate water delivery efficiencies that are used for the Irri-Drop Report. WAS is divided into different modules that perform various functions. Most of these modules are necessary for the WAS framework; however, they do not necessarily need to be implemented all at the same time to start using the WAS.

Admin module
This module is used to administer the details of all water users/recipients on an irrigation scheme. The administration module is the core module that needs to be implemented before any of the other modules. Information managed by this module includes:

- Scheme setup
- List of registered entities (e.g. Close Corporation, PTY (LTD), Trust, etc.) and entity members
- User information (including aliases)
- Type of each water user (agriculture, municipal, house, livestock, industrial, etc.)
- Master users
- Extensions of master users
- Address and contact details including postal, owner and tenant information
- List of rateable areas (LRA)
- Scheduled areas
- Water years
- Water wards/Election wards
- Notes and reminders
- Cut-off list
- Images/photos
- Household meters, Household and livestock pipes installed on canals
- Industrial water quotas
- Maximum abstraction rights (MAR's)

Water order module
Water distribution on demand at an irrigation scheme or river system is driven by the capturing and processing of water orders. Once water orders have been captured in the WAS database everything else is generated or processed by the computer automatically. The water order module manages water orders from canal networks, pipelines and rivers and it keeps track of water delivery, water transfers between users/recipients and water quota available for individual users/recipients. Controls are in place in WAS preventing the accidental exceeding of allocated water quotas. Manual water transfers are possible between water users. Automatic water transfers are possible between a master user and an unlimited number of extensions that is linked to the specific master user. The WAS operates on a time scale of 52 weeks within a given water year. A weekly timetable is generated automatically for a given water year and user specified starting date. Water orders can be captured in four different ways which include:

- Standard water orders used by DWS and a few irrigation boards and water user associations. This water ordering method provides for original orders, additional orders, and cancellation of water.

- Water orders based on a flow rate and duration.
- Meter readings that can be captured on a weekly basis. The end reading of the previous week is automatically transferred to the start reading of the current week.
- Water orders can also be captured by the farmers themselves and uploaded to the Internet by using WAS-client web-app.

Measured data module

The Measured data module is used to capture/archive time series data from flow measuring stations into the WAS database. There is no limitation on the number of measuring stations that can be captured. The time series record includes the station id, date & time, flow depth and flow rate. The data sources can be from mechanical chart recorders, electronic data loggers and measuring plate readings. Measured water levels are automatically converted to flow rates by means of a discharge table for the specific measuring station. The module has the following functionality:

- Integrated discharge tables that are used to convert water levels to discharges and vice versa
- Importing of data in various formats
- Use flexible units for water levels and flow rates which include mm, m, m^3/s and m^3/hr.
- Export data to Microsoft Excel
- Calculation of volumes between user-specified dates
- Capture inflows and outflows for river systems
- Generate daily, weekly, monthly, and annually abstraction data
- Generate discharges for stations that are linked to an indicator site
- Generate recession curves
- Tools to add/subtract time series data
- Integrates with the Report modules including the Water Use Efficiency Accounting Reports (WUEAR)
- Display graphs for user-defined date and time ranges. The data of up to five measuring stations can be displayed on a single graph.
- Downloads and imports data from various loggers in the field

This module also has an Internet platform component, but this will be discussed in further detail later.

Report module

The Report module integrates with all the other modules and includes an extensive range of water reports and graphs including the following:

- User/recipient & Address information
- Scheduled areas
- List of Rateable Areas (LRA)
- Household and livestock pipes on canals
- Maximum abstraction right (MAR)
- Water orders
- Meter readings
- Water transfers
- Water cut-off list
- Weekly timetable
- Various types of distribution sheets
- Water balance reports
- Water balance sheets
- Monthly water delivery summary
- Measured data
- Weekly/monthly Water Use Efficiency Accounting Reports (WUEAR)
- Channel network detail
- Industrial water quotas

The reports are important for the management of the irrigation scheme's water and keeping track of orders and supplies. The WUEAR will, however, be the report that is used to determine the efficiency baseline and to do comparisons in the future.

Water release module

The water release module has two options available to be implemented. They are:

- Distribution sheet
- Channel network

Distribution sheet

The Distribution sheet hourly form is used to generate weekly water distribution sheets from water ordered on common canal networks or user specified groups. This sheet is programmable/customizable. It consists of codes, which determines the values to be loaded or calculated. It only needs to be set up once and can then be reused for each new week. Multiple sheets can also be created but these are saved outside of the database in a .csv file format. Once set up the sheet can be loaded automatically with values taken from the Orders or Repetitions table forms. Using the given codes, subtotals, totals, % and/or fixed loss and measuring plate readings can be calculated. All of this can then be printed to a pdf and uploaded to the www.wateradmin.co.za website. The distribution sheet option is the simpler of the two and is recommended as the first one to implement on an irrigation scheme. Irrigation schemes generate and publish distribution sheets anyway, so farmers can see when and where the water is being released into the canal network.

Channel network

The channel network links with the Water administration and Water order modules and it is used to:

- Minimize water distribution losses on canal networks
- Calculate water releases for the main canal including all branches allowing for lag times and water losses such as seepage and evaporation
- Determine operational procedures for a dam with varying downstream inflows and abstractions in a canal allowing for lag times, accruals, and water losses such as seepage and evaporation

A schematic layout of the total canal network is captured with details such as the cross-sectional properties, position of sluices and pumps, canal slope, measuring structures and canal capacities. Every reach of the canal network can be analysed and calibrated on its own. Global changes to the canal data are simplified by means of built-in tools. The module has the following functionality:

- Calculate water releases on a weekly basis. Water distribution on canal networks is normally done on a weekly basis.
- Discharges are converted to the corresponding measuring plate readings where needed
- Calculated water releases can be viewed on screen or printed
- Graphical output of all inflows, outflows can be viewed on the screen or printed
- Water release graphs, calculated with different settings, can be superimposed for comparison purposes
- Handles any type of cross-section including:
  - Rectangular
  - Trapezoidal
  - Parabolic
  - Parabolic sides with a flat bottom
  - Circular
  - User defined sections using XY-coordinates (used for river cross-sections)

This option is more comprehensive and accurate than the distribution sheet method, but it requires more expertise and time to implement and operate correctly. This is the recommended method; however, because of its level of complexity it should be used later, after the irrigation scheme has familiarized itself with the other features of WAS.

Measuring stations and electronic loggers

This is basically a continuation of the Measured data module, but regarding the measuring stations and the data collected there. To quantify water losses on an irrigation scheme, accurate and reliable inflow data into an irrigation scheme is non-negotiable. Cello loggers that are linked to the internet have proven to be a good option because:

- The data is reliable
- The data is easily accessible through the Internet
- An automatic import procedure is available in the WAS which connects to the internet directly. This enables a WAS operator to import the data from an unlimited number of measuring stations automatically.
- This data can come from different sources on the internet. Depending on your installation

- Zednet platform
- WAS server
- Flowcheck
- Flowmetrix
- MyCity
- Polar monitoring
- SMARTA
- SSE

It is, therefore, virtually impossible to import data into a wrong measuring station. This added functionality makes it very easy to import data from the Internet platform into the WAS database where after water loss reports can automatically be generated. For an irrigation scheme to able to use these loggers they need viable measuring stations at the inflows of the canal network, which is the minimum requirement to be able to generate the reports. The loggers can be placed at various points in the canal network. They can be placed at the outflows, for example, to increase the accuracy of the report. However, loggers are expensive and most of the time it is impractical to install them at all desired points. This is because most canal networks have many outflow points; too many to measure. However, it is enough to measure the inputs into the system and to capture the water delivery.

Data flow for WAS modules

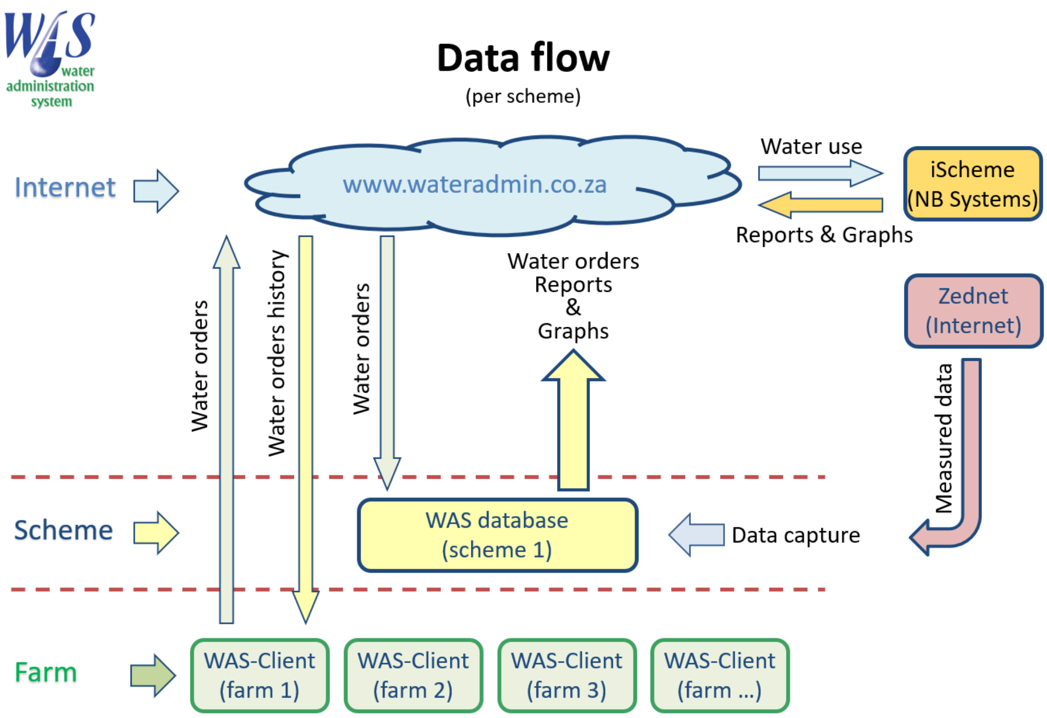


FIGURE 6.5 Data flow diagram for WAS modules

The diagram in Figure 6.5 illustrates how all the WAS modules fit together. It consists of three levels:

- Internet
- Scheme
- Farm

It starts on the scheme level where the WAS is implemented, and data is initially captured and collected. It is also on this level where most of the data is continually captured. From the scheme level data is consolidated and uploaded to the Internet level. This data includes reports and water orders. On the Internet level the data can be viewed on the www.wateradmin.co.za website. It can also be downloaded by NB Systems using *iScheme* to generate other reports and graphs. The water order-supply information can be downloaded by WAS-client software as well. This allows the farmer, on farm level, to view their water balances as well as upload water orders.

6.3.4.2 Minimum requirements for WBR

An irrigation scheme might not be able to implement all the above-mentioned requirements at once. Therefore, it is better for an irrigation scheme to implement the requirements in phases. At first only these minimum requirements need to be met:

- WAS
  - Admin module – just setup the scheme, user information and the scheduled areas.
  - Water order module – start capturing water ordered and metered data.
  - Measured data – Capture water released into the system.
  - Report module – WUEAR

- Measuring stations and electronic loggers – Install an electronic logger at the inflow of the system. It should be able to upload its data to the Internet. Preferably to one of the platforms that are already compatible with WAS.

After this first phase the other features in WAS can be added as the irrigation scheme is ready to use them. Extra loggers can also be added to increase accuracy of the reports overtime.

6.3.4.3 Delivery efficiency baseline

The first step in implementing WAS/WBR is to check whether an irrigation scheme meets the minimum requirements. As for the Irri-Drop Report framework, nothing can be done before WAS (WBR) is set up with at least one electronic logger at the inflow of the system. Once this is done the scheme can start capturing the water orders, releases, and deliveries. The setting up of WAS/WBR will already assist the irrigation scheme by removing the need for excel or some of the handwritten systems. This will save time and effort once it is in place. The baseline efficiency of an irrigation scheme is determined from the first WUEAR it generates using a complete water-year's release and delivery data. The information in this report will initially be used to determine whether an irrigation scheme's efficiency has improved or not after each year. During this project, WUEARs were generated for Loskop IB and Vaalharts WUA for the water years of 2019/2020 and 2020/2021, and the report for 2019/2020 was used as the baseline for each irrigation scheme.

TABLE 6.2 Vaalharts – WUEAR 2019/2020

		(x1000m^3)											%		
Year	Mnth	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Alloc used	Alloc avail	Non-revenue water	Used	Avail
2019	Apr	1542	10	1182	36	5181	1431	9383	17731	8348	2742	281518	47.08	1.0	99.0
2019	May	5263	6	1685	45	4078	7657	18733	21182	2449	9712	274548	11.56	3.4	96.6
2019	Jun	11177	13	966	36	5156	41	17389	21544	4155	21910	262350	19.29	7.7	92.3
2019	Jul	7357	10	1221	36	6432	22	15078	19251	4173	30520	253740	21.68	10.7	89.3
2019	Aug	21223	12	1317	45	8981	47	31624	39791	8167	53118	231142	20.52	18.7	81.3
2019	Sep	25507	22	1221	36	9931	43	36760	43899	7138	79912	204348	16.26	28.1	71.9
2019	Oct	41458	22	1603	45	15661	65	58853	71970	13116	123060	161200	18.23	43.3	56.7
2019	Nov	22764	44	1518	36	8470	43	32874	38649	5774	147429	136831	14.94	51.9	48.1
2019	Dec	26832	40	1017	36	9521	104	37549	45336	7786	175421	108839	17.18	61.7	38.3
2020	Jan	24068	49	1297	45	9430	40	34928	44141	9213	200875	83385	20.87	70.7	29.3
2020	Feb	11610	19	1393	36	10109	25	23191	24654	1463	213921	70339	5.93	75.3	24.7
2020	Mar	17334	25	1096	36	5042	99	23632	33737	10105	232475	51785	29.95	81.8	18.2
Totals		**216135**	**272**	**15516**	**468**	**97992**	**9617**	**339994**	**421885**	**81887**	**1291095**	**2120025**	**19.41**	**81.8**	**18.2**

TABLE 6.3 Loskop – Left bank WUEAR 2019/2020

		(x1000m³)											%		
Year	Mnth	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Alloc used	Alloc avail	Non-revenue water	Used	Avail
2019	May	4993	98	0	15	0	0	5106	7291	2185	5091	124618	29.97	3.9	96.1
2019	Jun	4715	67	0	12	0	0	4794	5771	976	9873	119836	16.93	7.6	92.4
2019	Jul	6868	93	0	12	0	0	6973	9386	2413	16834	112875	25.71	13.0	87.0
2019	Aug	11857	131	0	15	0	0	12003	15831	3827	28822	100887	24.18	22.2	77.8
2019	Sep	12784	93	0	12	0	0	12890	16925	4036	41699	88010	23.84	32.1	67.9
2019	Oct	14520	118	0	15	0	0	14653	19657	5004	56337	73372	25.46	43.4	56.6
2019	Nov	7449	70	0	12	0	0	7531	10089	2557	63856	65853	25.35	49.2	50.8
2019	Dec	6571	86	0	12	0	0	6670	9473	2803	70514	59196	29.59	54.4	45.6
2020	Jan	6764	100	0	15	0	0	6880	9232	2352	77378	52331	25.48	59.7	40.3
2020	Feb	7676	88	0	12	0	0	7776	10714	2938	85142	44567	27.42	65.6	34.4
2020	Mar	10066	96	0	12	0	0	10174	13590	3416	95304	34405	25.14	73.5	26.5
2020	Apr	7428	86	0	12	0	0	7526	9678	2152	102819	26891	22.24	79.3	20.7
Totals		**101691**	**1126**	**0**	**156**	**0**	**0**	**102976**	**137637**	**34659**	**653669**	**902841**	**25.18**	**79.3**	**20.7**

- **Year** – The year data was collected.
- **Month** – The month data was collected.
- **Revenue water: Agriculture** – Volume of water used for agriculture in m³. This value is obtained from water orders and/or meter readings.
- **Billed metered: Industrial** – Volume of water used for industrial in m³. This value is obtained from water orders and/or meter readings.
- **Billed metered: Municipality** – Volume of water used for municipality in m³. This value is obtained from water orders and/or meter readings.
- **Billed unmetered: Household** – Volume of water used for household in m³. This value is obtained based on pipe diameter assigned to the user.
- **Downstream** – Volume of water used downstream in m³. This value is obtained from water orders, and/or meter readings, and/or measuring stations.
- **Other** – Volume of water used downstream in m³. This value is obtained from water orders, and/or meter readings, and/or measuring stations.
- **Total water delivered** – Summation of all the water usages in m³.
- **System input volume** – Volume of water that was released into the system in m³. This is usually measured at a measuring station at the source of the canal.
- **Non-revenue water** – Volume of water that is the difference between total water used and system input in m³. This represents the water lost in the system.
- **Alloc used** – Allocation used. Cumulative volume of water used through the water year in m³.
- **Alloc avail** – Allocation available. Remaining volume of water in m³ after the alloc used has been subtracted from the total water allocation for the current water year.
- **Non-revenue water (%)** – Same as previous column field non-revenue water but calculated as a percentage of the system input volume.
- **Alloc used (%)** – Allocation used. Calculated as a percentage of the total water available for the current water year.
- **Alloc avail (%)** – Allocation available. Calculated as a percentage of the total water available for the current water year.

Tables 6.2 and 6.3 show that the baseline efficiencies for Vaalharts WUA and Loskop IB were 79.6% and 74.8% [3], respectively. It is important to note that these efficiencies cannot be considered alone and that the whole report is required to provide context for these values. No scheme's efficiency can be compared to that of another. There are many factors that affect it and they can be unique to each scheme, such as their procedures and protocols, as well as the age, condition and design of their canal system. These baseline values can however be compared to the results of any future WUEAR's that are generated for that scheme.

6.3.4.4 Initial assessment

In addition to the baseline results, there are other factors that need to be taken into consideration. These factors are important to provide further context. These factors include:

- Condition of canal system

- Procedures and protocols
- Environmental conditions

Each of them contributes to the overall efficiency of the system. The point is that, aside from the procedures and protocols, there are things outside the control of an irrigation scheme. Each scheme is unique and faces unique problems. Therefore, it is unreasonable to expect all of them to achieve a specific system efficiency. Each scheme has its own optimal efficiency that it can achieve within its own system constraints. If the maximum efficiency of the system is too low, then that would suggest that it might need an overhaul. That, however, is outside the scope of this framework.

Condition of canal system
The state of the canal is an important factor to take into consideration when looking at the performance of the system. Seepage and leakage are inevitable losses that an irrigation scheme must deal with. The worse the condition the canal is in; the more water is lost through seepage and leakage. Therefore, it is important to do regular maintenance on the canals. There are some canal systems that are very old. These can be hard to maintain due to financial constraints or because of frequent breakages.

Procedures and protocols
Each scheme has their own procedures and protocols with which they manage their water. There are standardized elements that all schemes have and use, but not everything. These could be things such as how they handle water orders. Some schemes receive the orders and then reschedule them according to their system requirements and then report the changes back to the farmers. Other schemes don't change the orders, but place constraints on the orders themselves like how much and when water can be ordered. Schemes also differ in how water is released in their system. These include when they open sluice gates, how frequently they change the settings, or who is responsible for opening what. In the case of Loskop IB and Vaalharts WUA, there was already a difference in the way they manage their systems, where Vaalharts WUA uses a "Segsman" system and Loskop IB doesn't, for instance.

Environmental factors
Environmental factors can contribute to a low efficiency but are out of the control of the irrigation scheme. This is one of the reasons different irrigation schemes cannot be compared with each other. Evaporation caused by the weather is already included in the total loss of the results. From a system's point of view, excessive rain is water that is not measured and can't be considered when calculating the water loss. The irrigation scheme might not release water into the system due to rain, but there are still water orders, which would cause the loss to be zero. This can result in an unusually low water loss for that water year. So, it is important to take this into consideration when comparing the results to the baseline or previous water year's results. Vegetation can also play a role. Plants near the canal might increase the water losses in the system. Sometimes plants like algae, can even grow in the canal. Vegetation growth is usually kept under control, but an irrigation scheme could have a situation where it is difficult to keep up with the speed of the plant growth. This could mean that despite the efforts of an irrigation scheme to control the plants, their water losses will still generally be higher.

6.3.4.5 Identifying possible remedial action

The initial assessment will provide the irrigation scheme with areas that can potentially be improved. The first thing an irrigation scheme can monitor is their basic management operations. WAS makes it easier for schemes to capture water release and delivery. It reduces mistakes and saves time. The addition of the electronic loggers and the water reports allows the scheme to identify discrepancies more easily in the data. This will show the schemes whether their current management is working effectively, and it can be monitored from week to week. If the assessment reveals any other areas that might have issues, then possible solutions or counter measures should be considered. This could be:

- Damaged areas in the canal network that were not identified before
- Possible lapses in procedure
- Farmers exceeding their quotas
- Water theft

There are various other issues that could be identified, but it should be easier with the tools the framework has suggested.

6.3.4.6 Compare to baseline

Each year, the next WUEAR result should be compared to the previous one as well as the baseline to see whether the efficiency was improved or maintained. This will inform the scheme if the steps taken have been effective or if other options need to be considered. In this project it was seen that Loskop IB and Vaalharts WUA did a great job of maintaining their system efficiencies. The results in Tables 6.4 and 6.5 show that for the water years of 2019/2020 and 2020/2021 both schemes had slight improvements. In Vaalharts' case the total water used, and release has decreased significantly, but it has increased for Loskop.

TABLE 6.4 Vaalharts total results comparison

Totals	2019/2020	2020/2021
Released (m^3)	421 885 000	362 031 000
Used (m^3)	339 994 000	294 394 000
Loss (m^3)	81 887 000	67 638 000
Loss %	19.4	18.7

TABLE 6.5 Loskop total results comparison

Totals	2019/2020	2020/2021
Released (m^3)	137 637 000	141 581 000
Used (m^3)	102 976 000	105 993 000
Loss (m^3)	34 659 000	35 589 000
Loss %	25.2	25.1

6.3.5 Determining major canal water loss types

The WAS, which is in use at more than 20 major irrigation schemes in South Africa, reports on global water losses for the entire canal network at each of the schemes every week. These reports are very important for the water managers because the amount of water they order from the sources such as dams need to factor in these losses so that adequate amounts of water eventually reach their clients who are mostly farmers. However, the reports do not indicate the different major water loss types that constitute the global losses. Moreover, the global water losses are for the main canals. Nevertheless, WAS is still a powerful tool with potential to report water losses at canal reach level. Within it is a water release module, which links the water administration and water modules. This module captures details such as cross-sectional properties of canals, positions of sluices, pumps, measuring structures, canal slopes and capacities. It can handle all types of cross-sections, including rectangular, trapezoidal, parabolic, parabolic side with a flat bottom, circular and user defined sections using XY-coordinates. The release calculation procedure starts at the end of the last reach in the main canal and move back towards the source, processing every reach by calculating the lag time, and adding the seepage and evaporation losses and abstraction for each specific reach.

- The following equation is used to calculate the lag time in a reach:

$$\textit{Lag time} = \frac{\textit{Reach length}}{\textit{Average velocity}} \qquad \textbf{Equation 5}$$

- The seepage loss in a reach is calculated using:

$$\textit{Seepage} = \textit{Seepage rate} \times \textit{Reach length} \times \textit{Wetted perimeter} \qquad \textbf{Equation 6}$$

The seepage rate is specified in *l/s per 1000 m^2* wetted area. It is important to indicate that the seepage loss here includes leakages.

- The evaporation loss in a reach is calculated using:

$$\textit{Evaporation} = \textit{Evaporation rate} \times \textit{Reach length} \times \textit{Water surface width} \qquad \textbf{Equation 7}$$

The evaporation rate is specified in mm/day.

In brief, the water release module is used to:
- minimize water distribution losses on canal networks and in river systems

- calculate water releases for the main canal including all branches allowing for lag times and water losses (such as seepage and evaporation)
- determine operational procedures for a dam with varying downstream inflows and abstractions allowing for lag times, accruals and water losses (such as seepage and evaporation)

The proposed Irri-Drop framework recognizes all this potential of this WAS program; hence, it will borrow heavily form this tool. Similar to WAS, the Irri-Drop framework also recognizes that canal flow is unsteady and non-uniform, meaning that discharge varies with both time and space. These variations influence the nature and relative importance of the dominant water loss types; how they are measured and how to calculate them. The Irri-Drop conceptual framework identifies five major water loss types, but final lists will be available when actual investigations and reporting take place as this will depend on the feasibility of disaggregating these loss types from the global losses. While evaporation might be easy to define and estimate, seepage and leakage might be difficult to separate when the water balance approach is used. In addition, measurement and operational losses are also not easy to separate because sometimes they can be up to human decisions as they seek to optimize the water supply and distribution. They can also be linked to some losses such as over-spilling, breaches and holes are due to (Arshad et al., 2009):

- irregular canal profiles and zigzag alignments of the banks
- variable cross sections of canal channels
- silt deposition that restricts water flow resulting in overtopping
- trees, shrubs and vegetation growing in watercourses, which also restrict flow
- canal damage caused by rodents and other animals
- many points of weakness due to poor workmanship during canal construction and maintenance

The water managers warmed up to the conceptual framework and promised full support. However, there were concerns on the practical ways to quantify some of the proposed water losses. While WAS estimates evaporation losses from evaporation pan data, it does not disaggregate leakage from seepage. The inflow-outflow approach only takes account of the water input, output and abstraction from a reach. There is no equipment in place to quantify seepage and/or leakage rates. The ponding method used in some studies to estimate seepage rates requires that water be ponded in the canals which is not possible because the current situation requires that canal flow is not significantly disturbed. Strategies relating to measurement and/or estimation of the separate loss types will be discussed at a later stage.

6.4 Discussion

There are many things that need to be set up and function properly for an irrigation scheme to achieve high efficiency in water delivery. In addition to the physical infrastructure that needs to be properly designed, installed, cleaned and maintained, there are other things that have a bearing on how prepared the irrigation scheme is when it comes to dealing with matters that affect water conveyance efficiency. The modules of the Irri-Drop Report framework try to cover all the important aspects which are common to all irrigation schemes. However, there are possibilities that some aspects which important to specific irrigation schemes may have been left out of the Irri-Drop Report framework. The onus is upon the irrigation scheme to include such in their own evaluation process; however, care is needed as the Irri-Drop Report also aim at comparing performance of irrigation schemes which can only be fair if the evaluation tool is applied uniformly across the board.

The Irri-Drop Report is a tool for assessing and rating the performance of bulk irrigation water suppliers; therefore, it is only concerned with infrastructure associated with water delivery (i.e. canals and associated components). The canal networks connect water sources (such as reservoirs and rivers) to the farms where the irrigated land is located. The Irri-Drop Report is not intended to cover the water sources (which are managed by DWS) and distribution canal networks on farms (which are managed by irrigators).

6.5 Conclusions

The Irri-Drop Report framework is an essential tool that DWS can use to evaluate and rate the water delivery performance of irrigation schemes in South Africa. It does not only assess water usage and losses at the irrigation schemes, but it also provides DWS with the opportunity to assess how prepared the irrigation scheme are in terms of identifying and dealing with water losses. The framework is also important to the irrigation schemes themselves as a tool they can use to identify areas within their water conveyance infrastructure and plans that require improvements to achieve high efficiency in water delivery.

CHAPTER 7: CAPACITY DEVELOPMENT & KNOWLEDGE DISSEMINATION

7.1 Introduction

Technological developments in South Africa and over the world dictates that irrigation scheme water management has to embrace tools that help to improve water use efficiency (WUE) at their irrigation schemes. The Water Use Efficiency Accounting Report (WUEAR), a part of the Water Administration System (WAS) software, is a computer-based program that has to keep improving in line technological developments. The WUEAR has been the primary tool for driving higher WUE at major irrigation schemes in South Africa for years. It is used for reporting water releases, deliveries, and losses from irrigation scheme water conveyance systems. The Irri-Drop Report, another computer-based tool, is entering the same arena seeking to go beyond accounting for water releases, deliveries and losses (i.e. the Water Balance Report: *WBR*), by evaluating the readiness of entire water management entities to deal with water losses from canal networks. As elaborated in Chapter 6 of the current, the Irri-Drop Report evaluates the Water Management (*WMP*) and Maintenance Plans (*ManPlan*) in place for the water conveyance infrastructure. In addition, it also evaluates the condition of the infrastructure (*ConAs*), technical competency of personal involved with running and managing the water delivery canal network (*TechCom*), the adequacy of the budget for implementing the plans in place (*BudgetA*), and the credibility of their rules/by-laws and capacity to enforce the rules (*CredReg*).

In order for the irrigation schemes to fully benefit from the new technological developments and the Irri-Drop Report capacity development is needed. The irrigation scheme water managers need, for example, the knowledge on latest developments on data acquisition and uploading. The water managers are an important constituent because the new developments have impacts on their work, and in turn their capacity influences the uptake of new technologies and the success of computer programs such as the Irri-Drop Report. Catch-up and outright new trainings would be needed to enhance the capacity development. In addition to water managers, future professionals in the field of irrigation water management, with a special focus on the capacity to manage and evaluate the performance of canals in terms of water conveyance, also need to be trained. The project prioritized postgraduates who already had the basic knowledge on water and/or hydraulic engineering, and an understanding of the research process. None of the two stakeholder constituencies are expected to be direct users of the Irri-Drop Report. The Department of Water and Sanitation will use the Irri-Drop Report to assess the performance efficiency of irrigation schemes; hence, a special capacity building program shall be put in place when the tool is ready for testing and implementation.

Apart from capacity development, dissemination of the knowledge and information on the Irri-Drop Report framework and other aspects of the project is important for the benefit of other stakeholders at national and international levels. Various platforms are available for knowledge and information dissemination. The choices of platforms to use depend on many factors that include researchers' tastes, and available opportunities and resources. Workshops, conferences and symposia where researchers have opportunities to make presentations on their work are important avenues for knowledge dissemination. The added advantage of attending workshops/ conferences/symposia is the possibility of meeting and interacting with like-minded researchers. Publishing papers in journals and magazines is another good avenue for dissemination knowledge and information. However, peer reviewed scientific journals are preferred for publishing research and scholarly works due to quality authenticity checks before an article can be published. Magazines and bulletins can be used when aiming to disseminate the knowledge and information to non-scholar audiences such as practitioners in specific fields. Nevertheless, the knowledge and information will still need to be authentic.

The current chapter reports on the activities carried out by the project team in efforts to enhance capacity development and knowledge dissemination over the project duration. It is important to indicate that capacity development and knowledge dissemination are likely to continue beyond the life of the current project.

7.2 Methodology

The activities reported in this chapter aimed at:

- Capacity development of water managers and postgraduates
- Disseminating knowledge and awareness raising about canal water losses and urgent need for appropriate remedial strategies

It is important to note that the Covid-19 pandemic kicked in during the time when the project was at a critical stage and it lingered until the end of the project. Therefore, many project activities could not be implemented the way they were initially planned.

7.2.1 Capacity development

Mass physical interactions were restricted for two years (early 2020 to early 2022) to curb the spread of the virus that causes Covid-19. Therefore, the project organized a virtually training of irrigation scheme water managers from Vaalharts and Loskop, their surrounding irrigation schemes. The invitation was extended to the following irrigation schemes:

- Loskop Irrigation Board
- Vaalharts Water Users Association
- Oranje-Riet Water User Association
- Hartbeespoort Irrigation Board
- Boegoeberg Water User Association
- Kakamas Water User Association
- Korente Vette Irrigation Board
- Sand-Vet Water User Association
- Impala Water User Association

The training centred on generating the water balance report sing the WUEAR on the WAS program. The MS Teams platform was used to contact the training.

7.2.2 Knowledge dissemination

One literature review paper was submitted and published in a renowned peer reviewed scientific journal. The process involved searching for published scientific materials that investigated the factors that contribute to canal water losses from channels located all over the world, building a database of the articles and water losses incurred as a result of the identified factors, analysing the database and drafting a paper, submitting the draft paper to the journal and attending to reviewer comments and finally getting the paper published.

Another write-up was published as a popular article in the AgrIng Bulletin circulated, which is published and circulated widely within South Africa by the ARC-NRE/Agricultural Engineering. The bulletin is circulated to around 40 direct readers via email. and about 20 hard copies are picked up from the ARC-NRE/Agricultural Engineering office reception. The bulletin is published twice a year, which translates to an annual direct readership of about 120 people.

Opportunities for oral presentations were very limited due to the Covid-19 pandemic over the last two years. Nevertheless, two oral presentations, one international and another one local, about the Irri-Drop Report framework were made at two conferences during the intervening period. The international conference was attended virtually while the local the locally conference was attended physically.

7.3 Results

7.3.1 Training of water irrigation scheme water managers

The training took place online (MS Teams platform) on 19th August 2021. A list all participants is attached in the Appendices. The following were covered during the training.

7.3.1.1 Water Administration System (WAS) Data flow

The WAS data flow (Figure 6.5 of the current report) was used to describe how information flows between different components of WAS which are used to generate a WUEAR. The first step is to capture data into the scheme level database. The data captures and frequency with which they take place are as follows:

- Once-off
  - User information
  - Addresses
  - List of rateable areas (LRA)
  - Distribution sheets
  - Canal network
  - Dams
- Weekly
  - Water orders
  - Water transfers
  - Dam levels
- Monthly
  - Measured data
  - Meter readings
- Yearly
  - Scheduled areas
  - Water quotas & tariffs
  - Household & Livestock pipes
  - Crops & planted areas

Data from electronic logger are imported into the system or can be downloaded from the electronic loggers and uploaded into the system manually. Once the data is captured, the software can process it and upload the information to the WAS server and website (www.wateradmin.co.za) This information includes, the water order history, user information and the water use summary reports. The water order history can be downloaded by the farmer on the farm level to their WAS-client or it can be accessed through the web-app. The farmer can order water through either platform, upload it to the Internet, where it can be imported into the WAS database for the specific irrigation scheme. This information is processed by the WAS and uploaded to the internet where it is accessed by *iScheme*, which generate summary reports and graphs for all the irrigation schemes. All the reports are uploaded to the Internet where they can be accessed by any interested parties.

The WUEAR retrieves information from the following areas in the WAS to generate the report:

- User information
- Household pipes
- Water orders
- Meter readings
- Measuring stations

It is uploaded to the online platform www.wateradmin.co.za (WAS-report). The WAS-report is the platform created for this project and it provides different formats for the report.

7.3.1.2 User information

Users are created in the WAS and their water usage type defined before any information is captured. Users represent various abstraction points on the canal network. This means that whenever a water order or meter reading is captured, the water volume is then placed into one of these columns in the report:

- **Agriculture**: Water used by farmers to irrigate their crops.
- **Industrial**: Water used for industrial purposes that is drawn from the canal.
- **Municipality**: Water supplied to Municipalities, who distribute their own water.
- **Household**: Water used by households that draw water from the canal, e.g. the farmers themselves.
- **Downstream use**: Water that was ordered and released, but the user is past the tail end of canal network.
- **Other**: Water used for reasons not defined by the other types.
- **Tail end**: Water that flows past the end point of the canal network and forms part of the water loss.

The *Users* form can be accessed at **Input/User information/Users** as seen in Figure 7.1 and 7.2.

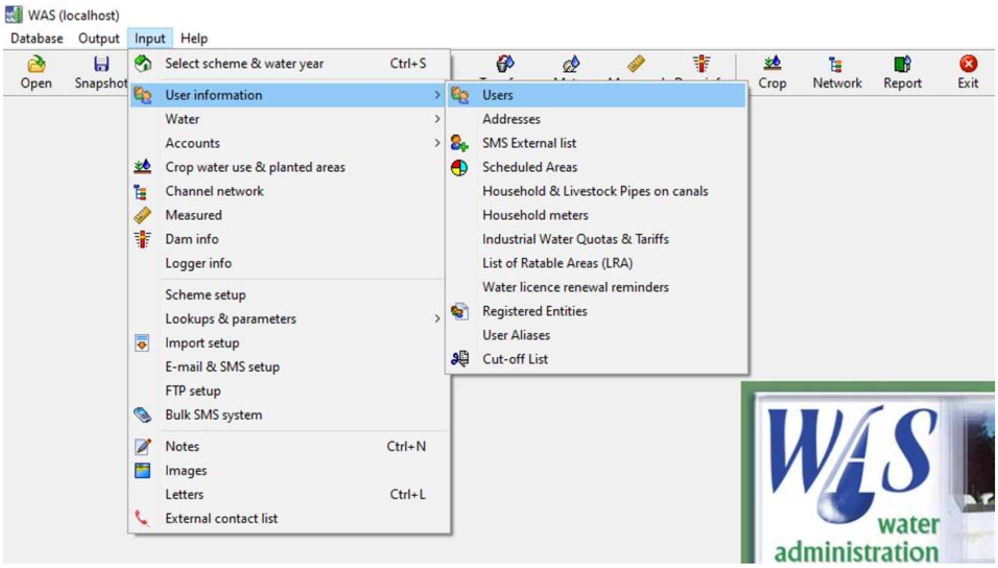


FIGURE 7.1 Users form-input options

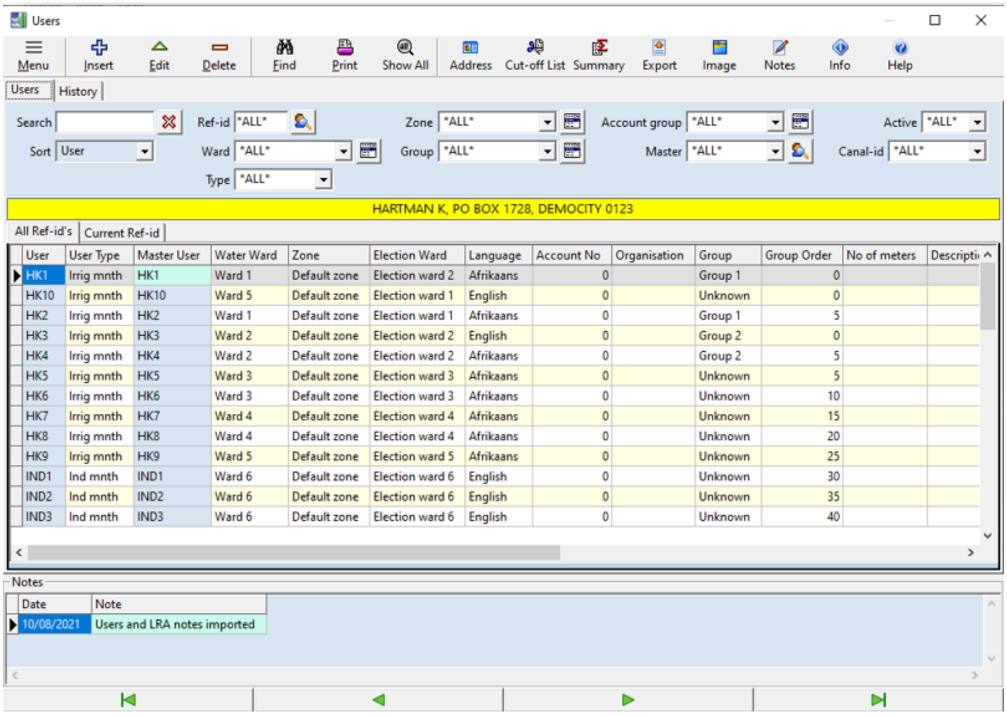


FIGURE 7.2 Users form-users and LRA notes imported

Usage type for each user record can be changed in the capturing screen by clicking on the *Edit* button in the toolbar (Figure 7.3).

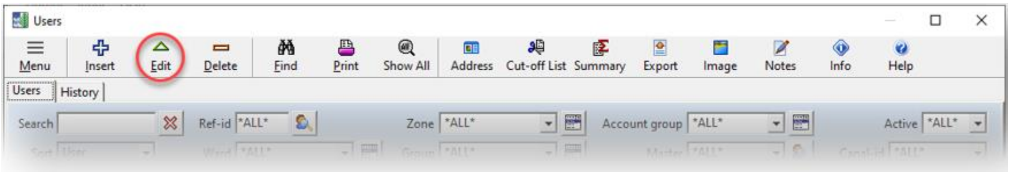


FIGURE 7.3 Users form toolbar

Once the user capturing screen (Figure 7.4) is set up correctly for each user, information can start to be captured.

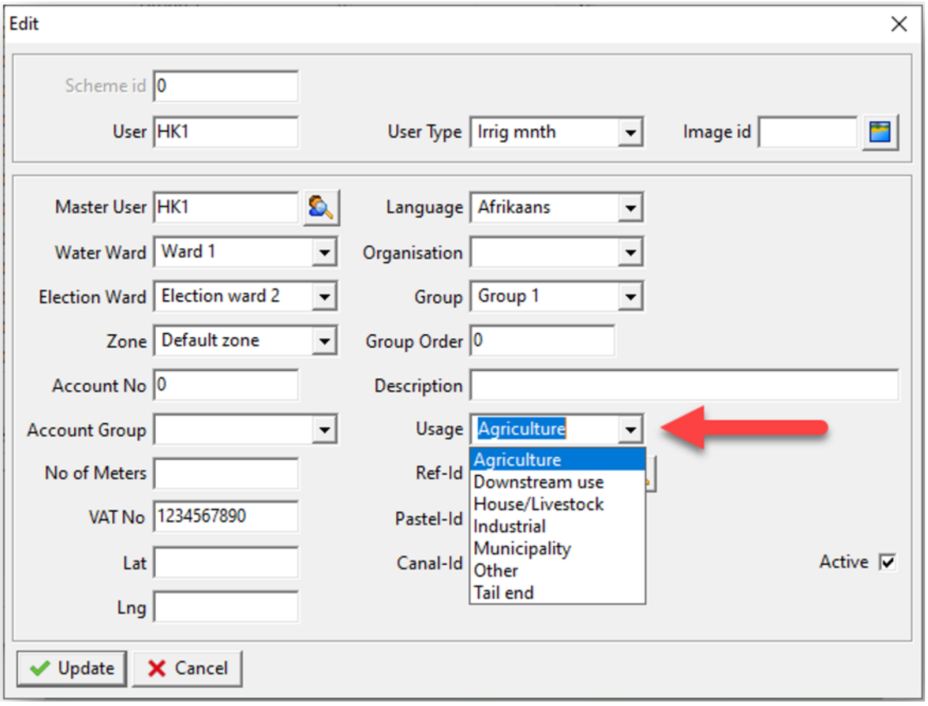


FIGURE 7.4 User capturing screen and usage field

7.3.1.3 Household pipes

Household and livestock pipes represent a usage that is calculated using the diameter of the pipe used to draw water from the canal. The pipe sizes are fixed (include 19, 25, 32, 38 and 50 mm pipe diameters). Each pipe has a fixed delivery rate in m^3/year (Figure 7.5), which is then divided by the total amount of weeks in the water year. The appropriately sized pipes need to be assigned to the users in the *Household & livestock pipes* form (Figure 7.6). This can be accessed at **Input/User information/Household & livestock pipes on canals** (Figure 7.7). There is no limit to the number of pipes that can be assigned to a single user. Once assigned, the usage is automatically included in the WUEAR.

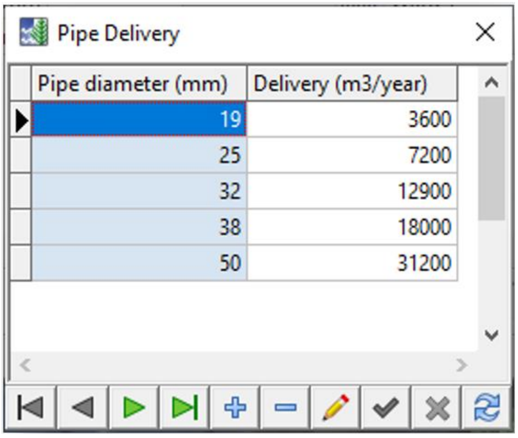


FIGURE 7.5 Pipe delivery volumes

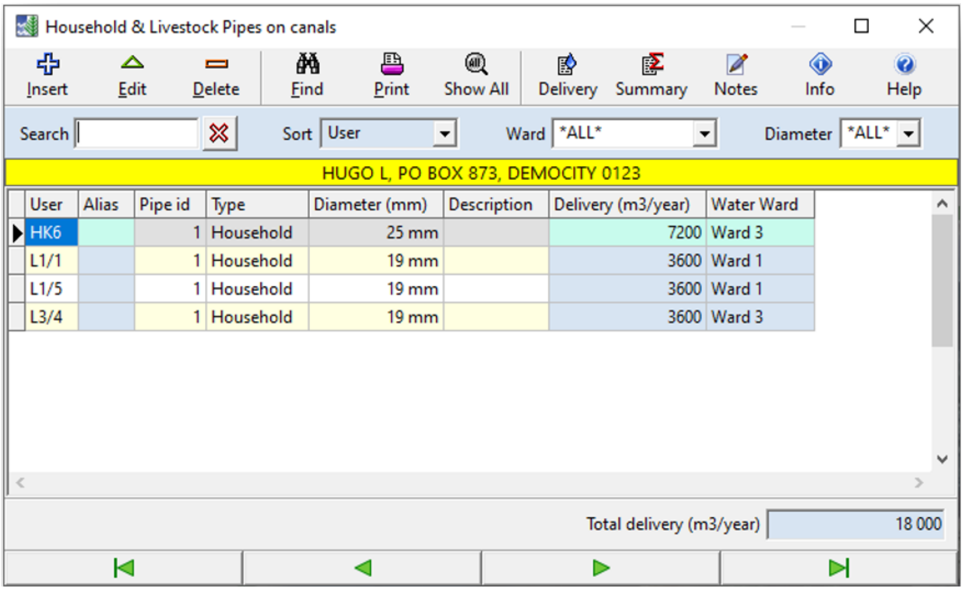


FIGURE 7.6 Household & livestock pipes form

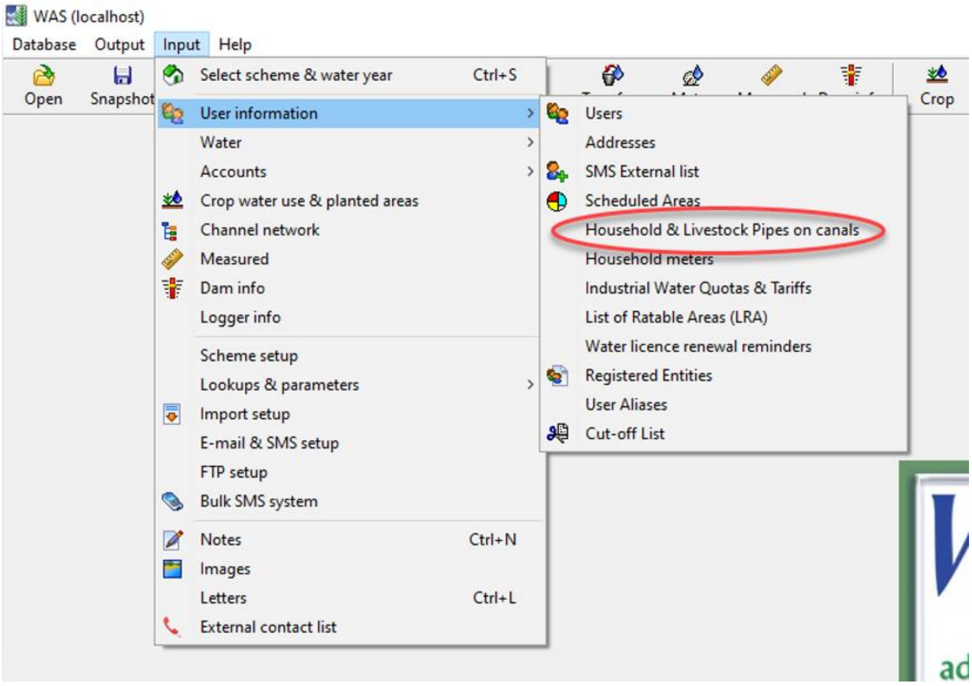


FIGURE 7.7 Accessing Household & livestock pipes in WAS

7.3.1.4 Water orders

The *Water orders* form (Figure 7.8) is used to capture and manage weekly water orders. The form displays a list of water orders depending on the filter settings. It can be accessed from the main form's toolbar using the *Orders*-button (Figure 7.9).

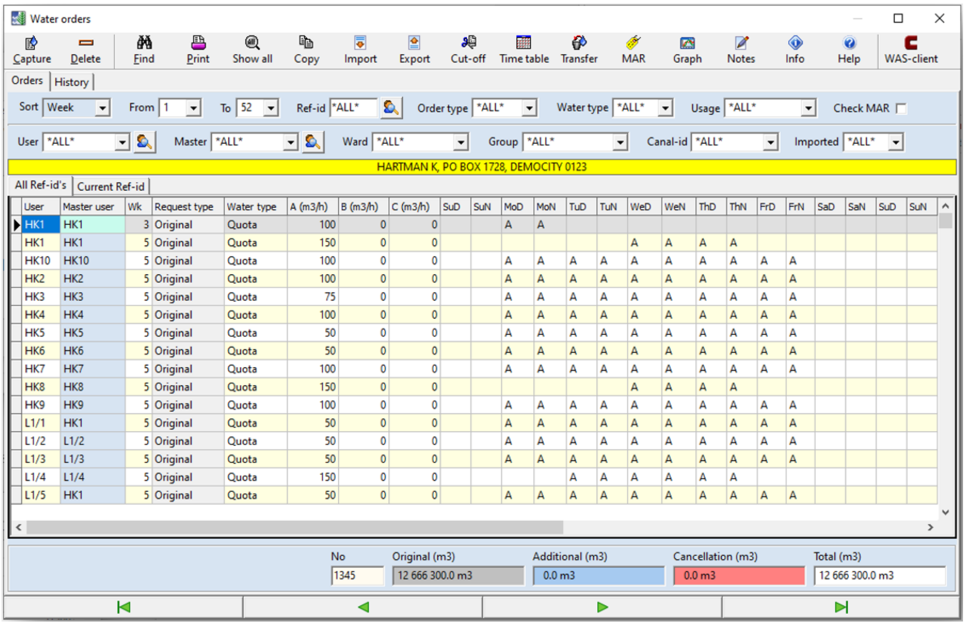


FIGURE 7.8 Water orders form

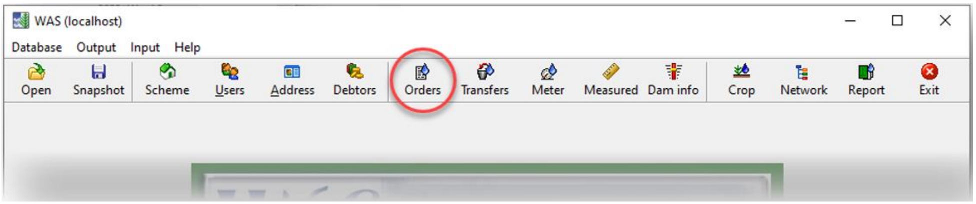


FIGURE 7.9 Orders button on WAS main form

The *Capture water orders* form (Figure 7.10) is used to capture all water orders on a weekly basis. The different water order types include *Original* orders, *Additional* orders and *Cancellations*. Three different flow rates (A, B and C) in m^3/hour can be used. The total volume and hours of water ordered are calculated and the water balances of every user are updated automatically.

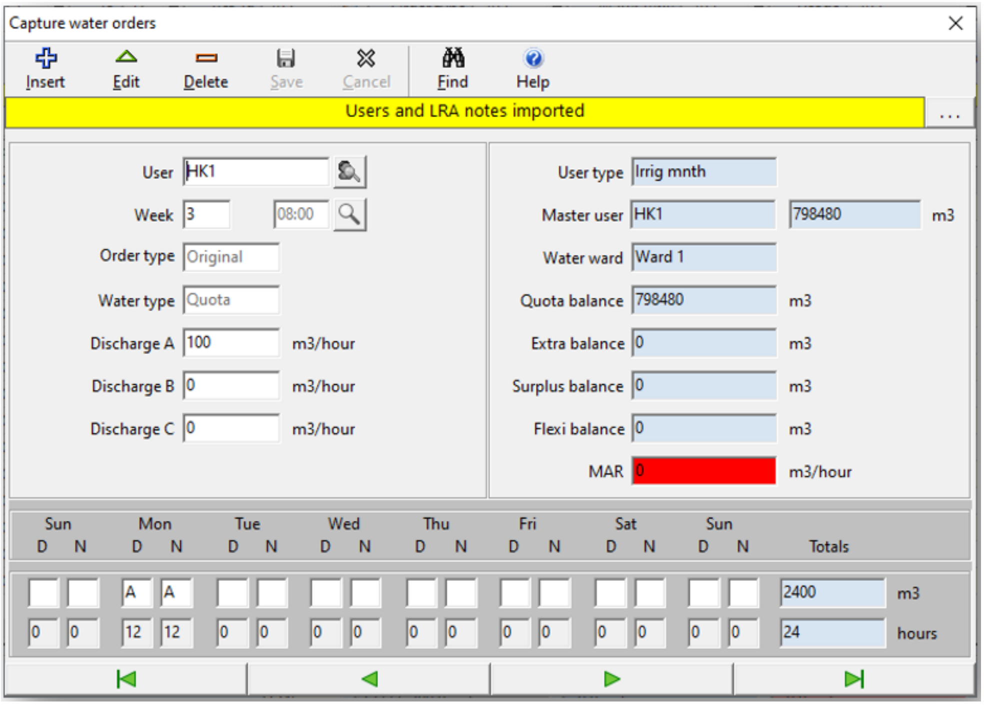


FIGURE 7.10 Orders capturing screen

Using filters and bottom right total blocks, the *Water orders* form can be used to verify values on the WUEAR and to search for any discrepancies.

7.3.1.5 Meter readings

The *Meter readings* form (Figure 7.11) is used to capture meter readings of water delivered through meters on a weekly or monthly basis.

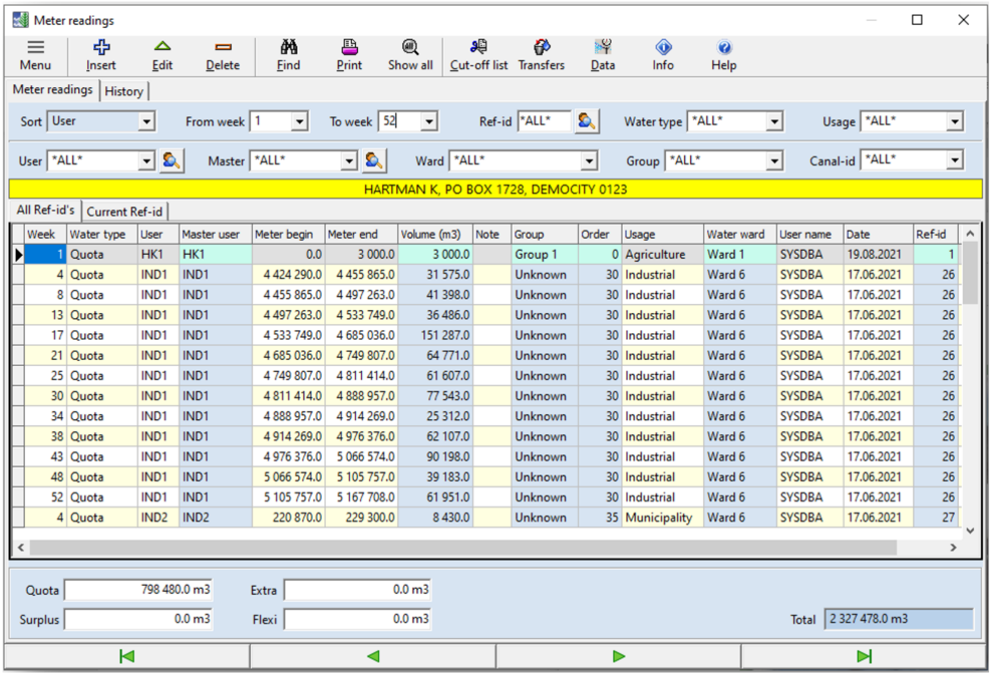


FIGURE 7.11 Meter readings form

Meter readings can be captured using the *Meter readings capturing* form (Figure 7.12). Volumes are calculated automatically using the difference between *begin* and *end* meter readings multiplied by a meter factor.

FIGURE 7.12 Meter readings button on main form's toolbar

Using the filters and the bottom right total blocks, the *Meter readings* form can be used to verify values on the WUEAR as well as search for any discrepancies. Meter data can also be downloaded & imported into the system on the *Metered data* form (Figure 7.13).

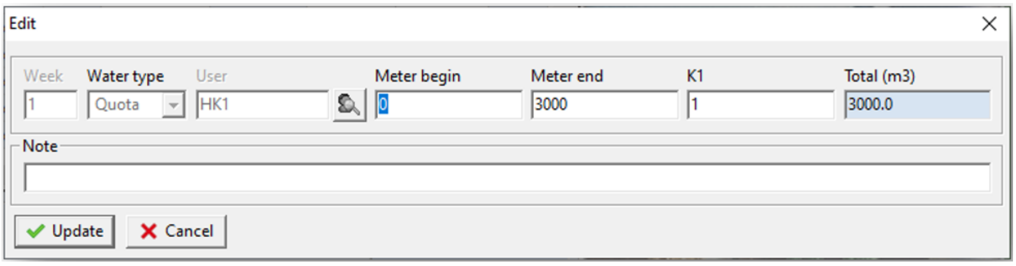


FIGURE 7.13 Meter readings capturing form

It can be accessed by clicking on the *Data*-button on the toolbar of the *Meter readings* form (Figure 7.14).

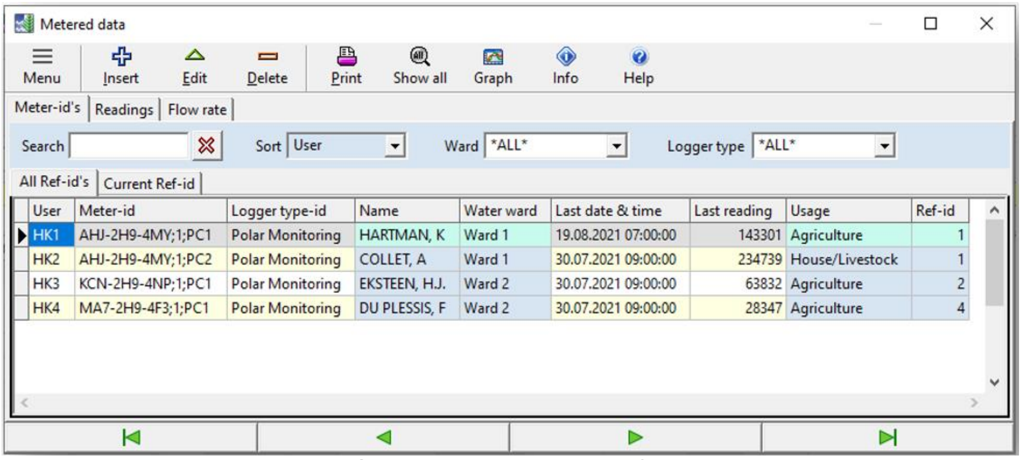


FIGURE 7.14 Metered data form

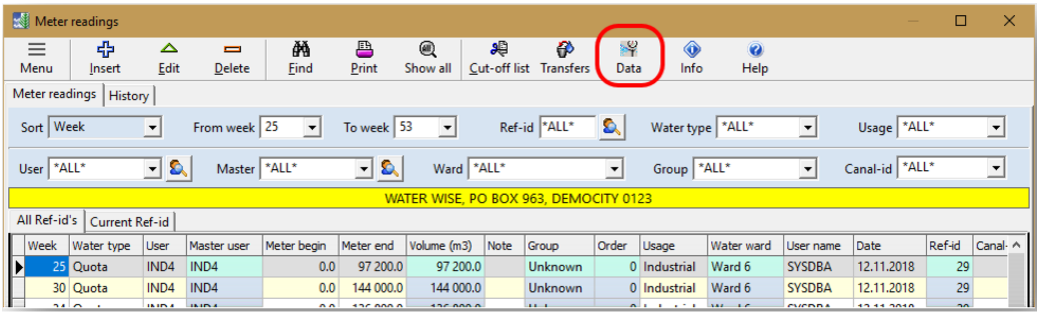


FIGURE 7.15 Data-button on Meter readings form's toolbar

The *Metered data* form is used to:

- Import cumulative water deliveries from comma delimited (*.csv) files or the Internet. These files are downloaded from data loggers that log cumulative water use electronically.
- Capture cumulative water use manually
- Draw a graph of the cumulative water use
- Generate meter readings which are automatically inserted into the corresponding week

The Cumulative volume on the *Readings* tab can be calculated using the *summation*-button, as shown in Figure 7.16. On the *Flow Rate* tab, it calculates the max flow rate for the filtered range.

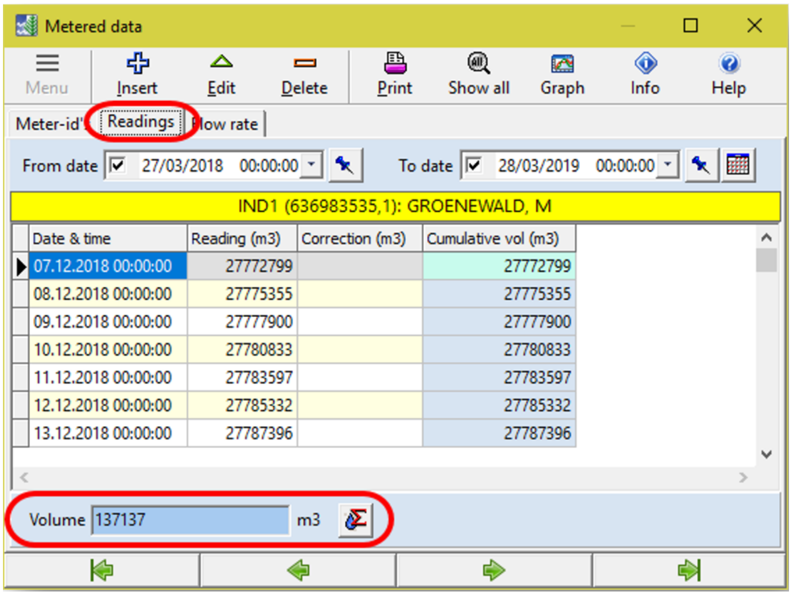


FIGURE 7.16 Metered data volume calculation

The data on the *Readings* tab can also be graphed (Figure 7.17) using the *Graph*-button on the *Metered data* form's toolbar.

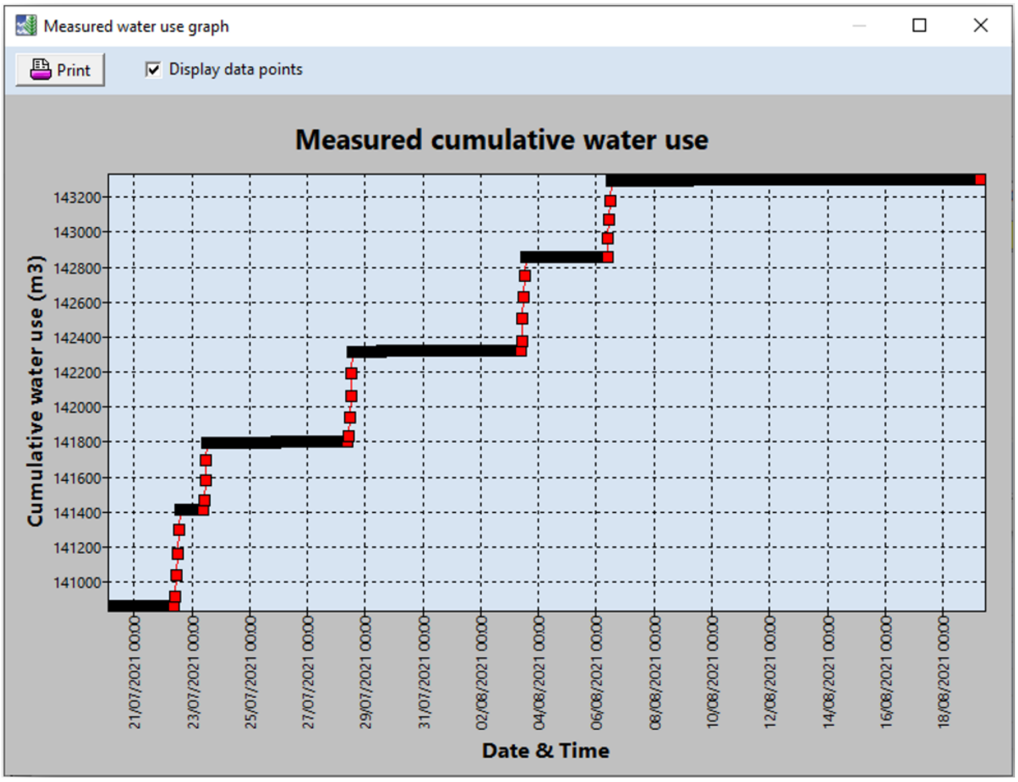


FIGURE 7.17 Metered data graph

The *Download & import* form can be opened from **Menu/Download & import** (Figure 7.18).

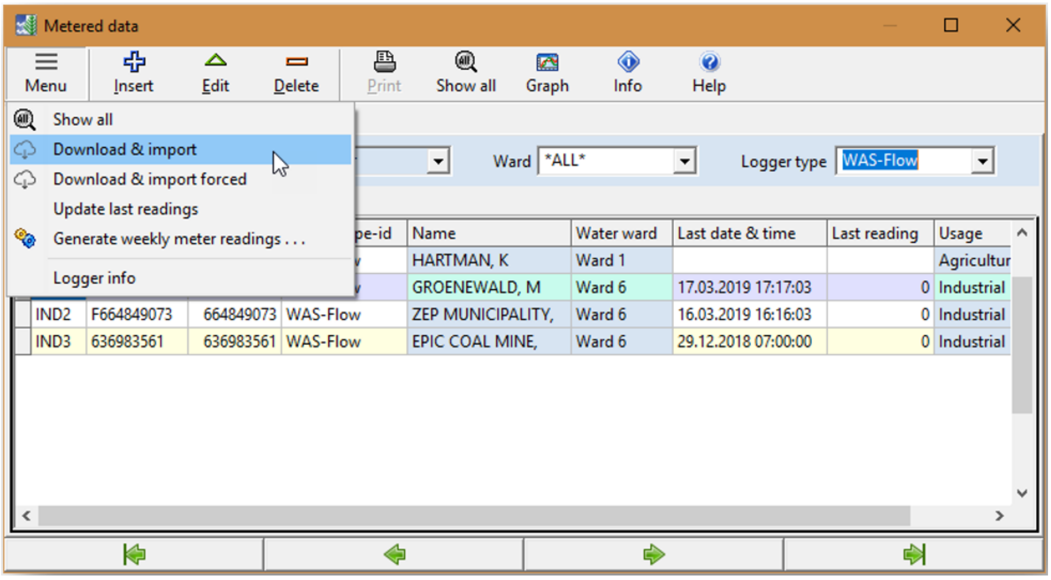


FIGURE 7.18 Download & import button on Metered data form

Meter data files can be downloaded and imported to the database from this form (Figure 7.19). Only the filtered meters are targeted when executing.

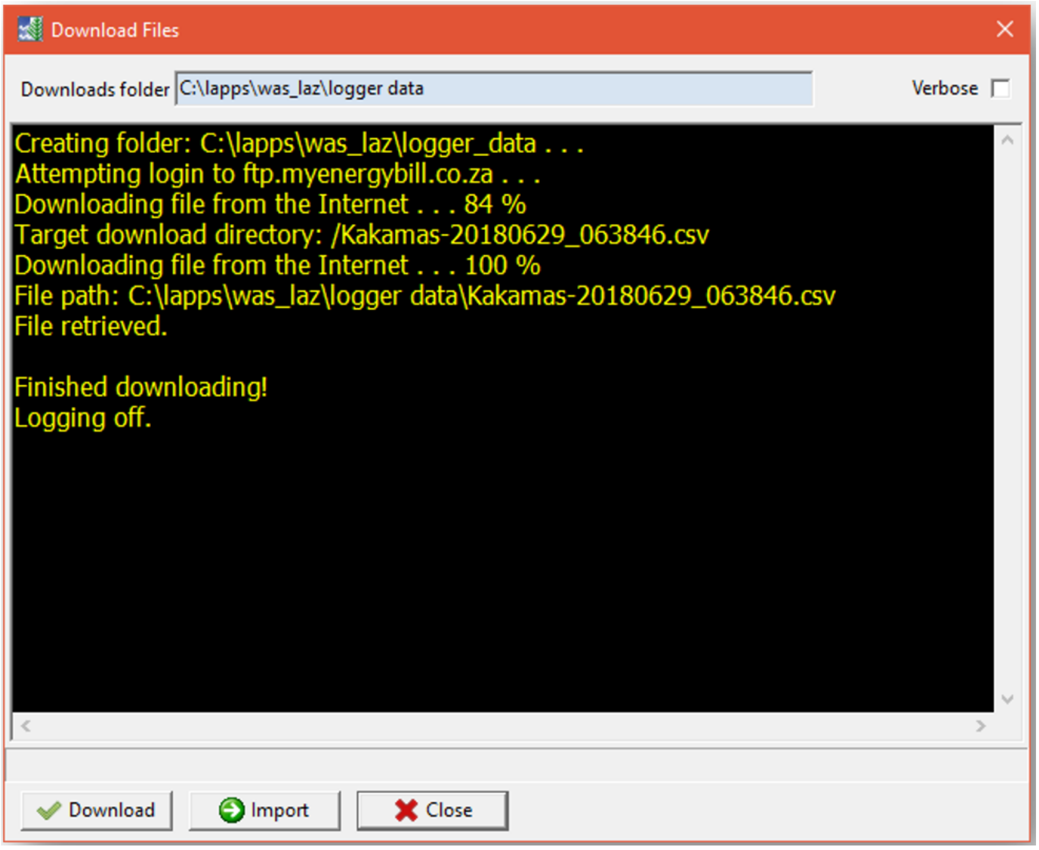


FIGURE 7.19 Download & import form for meter data

Once the data has been imported into the database, it can be used to generate the weekly meter readings on the *Meter readings* form. The software does this by calculating the volume of water delivered to each user for a specific week using their metered data and then inserting a record into the *Meter readings* form with that volume.

7.3.1.6 Measuring stations

The *Measured data* form (Figure 7.20) is used to capture time series data of water levels and flow rates

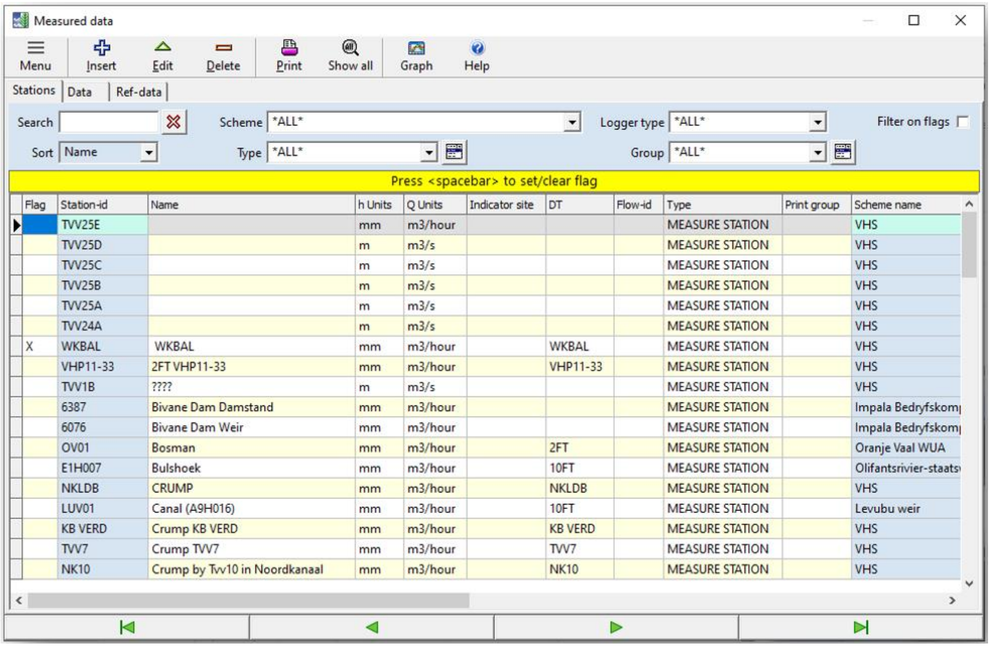


FIGURE 7.20 Measured data form

It can be accessed from the main form by clicking on the *Measured* button on the toolbar (Figure 7.21). The data can be captured manually or imported from electronic loggers.

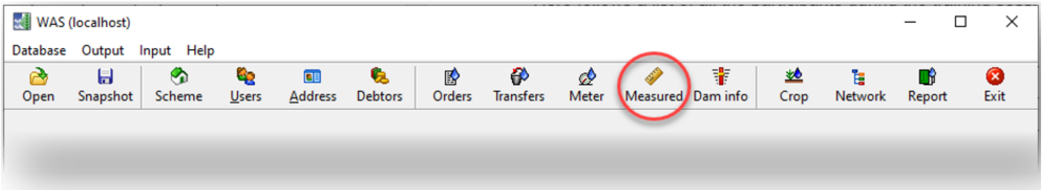


FIGURE 7.21 Measured button on main form's toolbar

Before any data can be captured a measuring station needs to be created. This can be done by click on the *Insert* button on the form's toolbar and using the capturing form as seen in Figure 7.22. The important fields in this case are the *Station Id, Name, Discharge table,* and the *Logger* details.

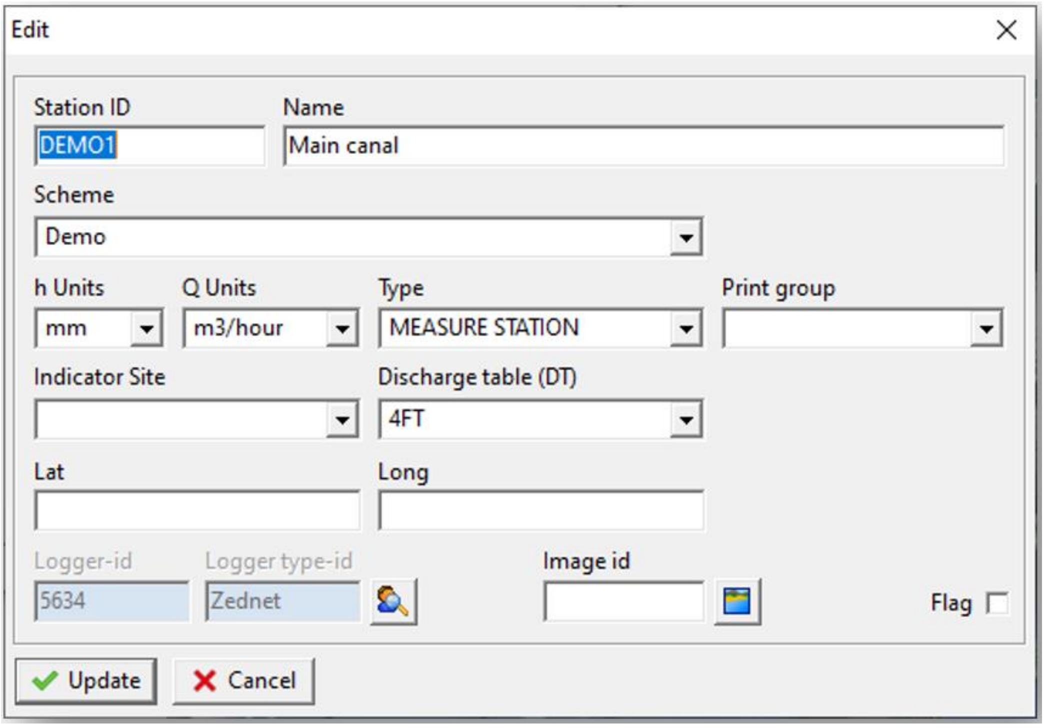


FIGURE 7.22 Measuring station capturing form

Once a measuring station has been created, data can be captured manually or imported from a *.csv file on the *Data* tab (Figure 7.23).

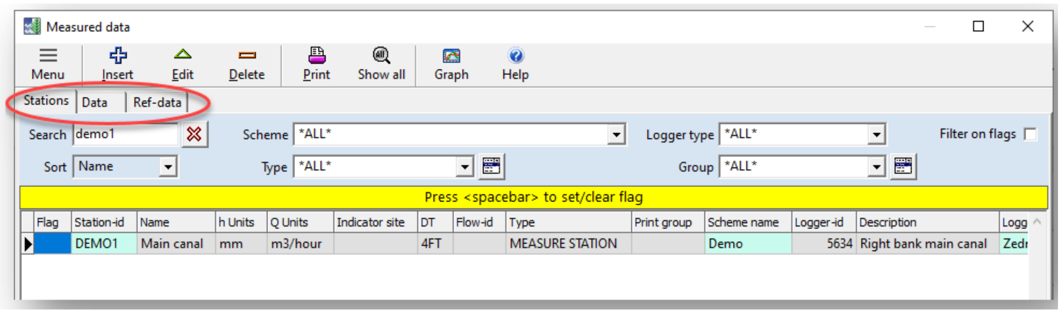


FIGURE 7.23 Measured data form's tabs

If the measuring station has an electronic logger that is connected to the Internet, then the data can be downloaded & imported from the *Stations* tab.

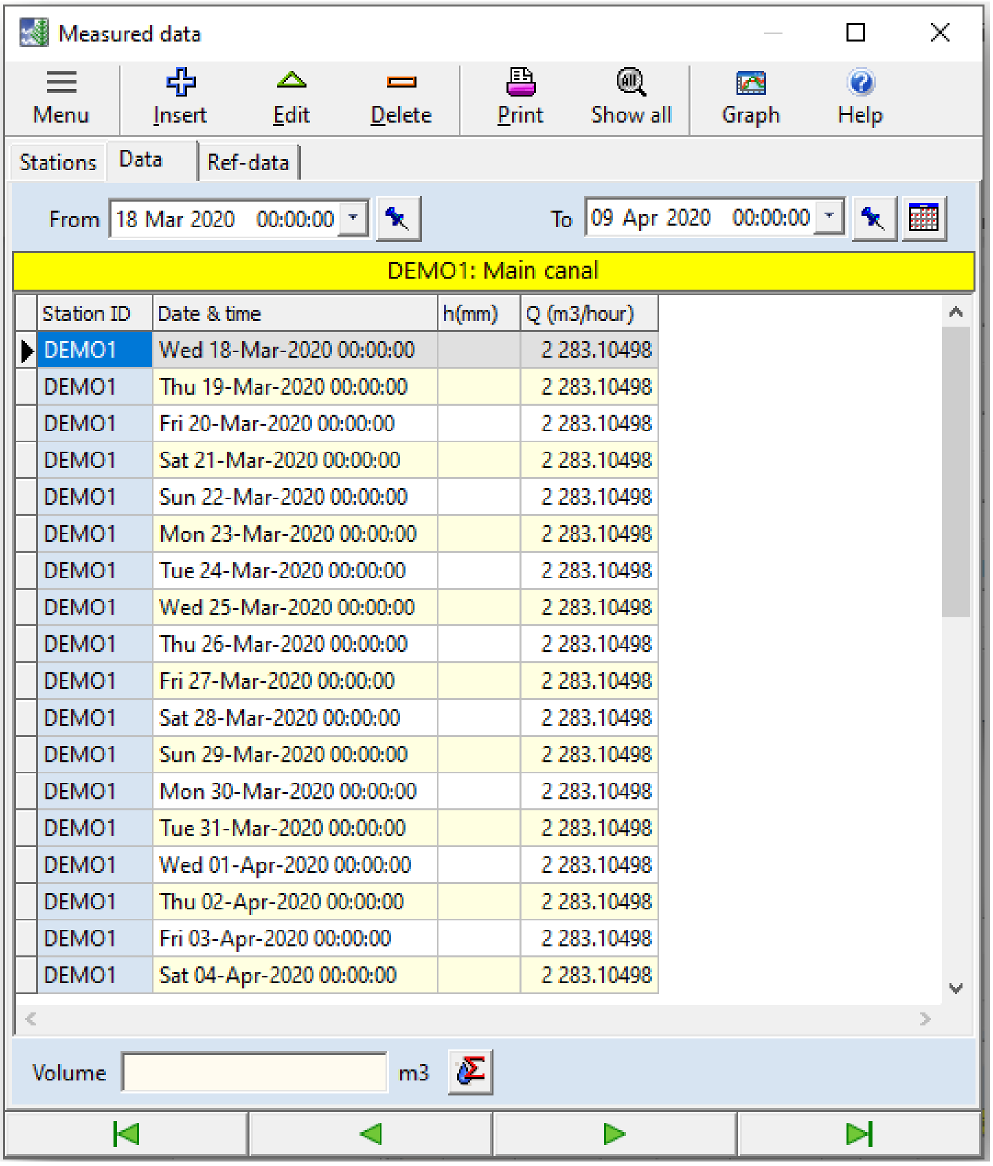


FIGURE 7.24 Measured data form's Data tab

7.3.1.7 Data capture

Manual

Data from a measuring station can be manually captured by going to the *Data* tab of the desired station and inserting the data points with the data capturing form (Figure 7.25).

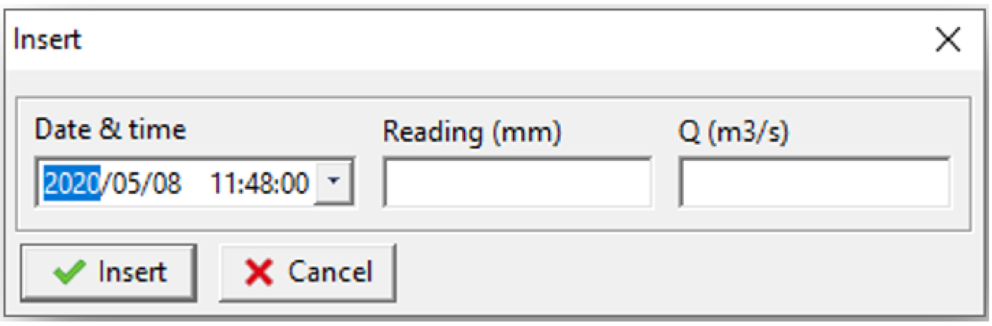


FIGURE 7.25 Measuring station data capturing form

The data from an electronic logger without internet connection can also be imported if its data has been downloaded from the logger itself and the file is in *.csv format. On the *Data* tab, the *Menu* button has an import option, *Generic*. This opens the *Import data* form. On this form an import method and the file to import are selected. The import method needs to be set up beforehand and it needs to match the data arrangement within the file for the import to work. This can be difficult but does allow for more flexibility in terms of the different data sources that can be used.

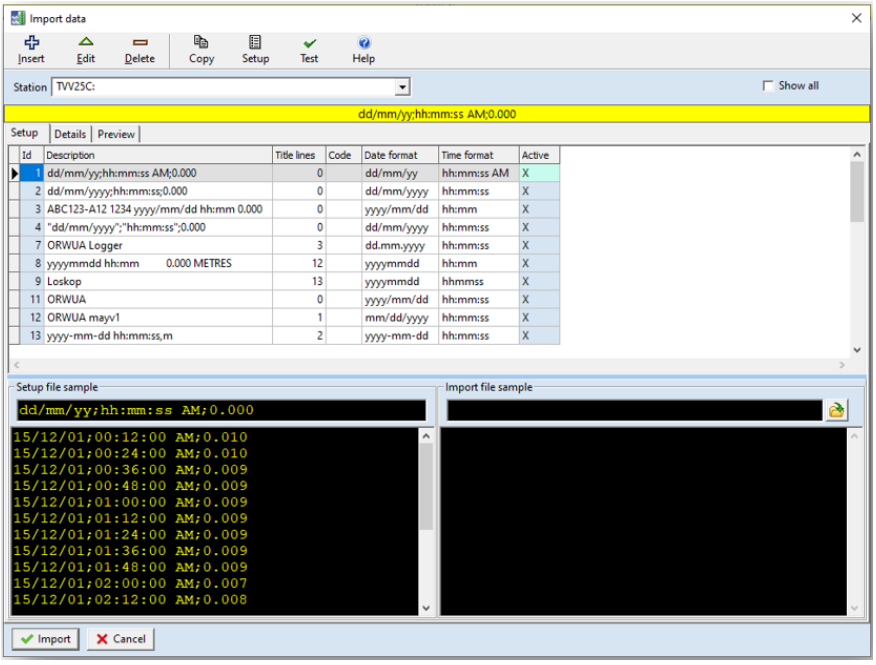


FIGURE 7.26 Import data form

Downloading & Importing

The data from an internet connected electronic logger can be downloaded & imported if connection details are known. This is the preferred method of getting data from a measuring station because it reduces errors.

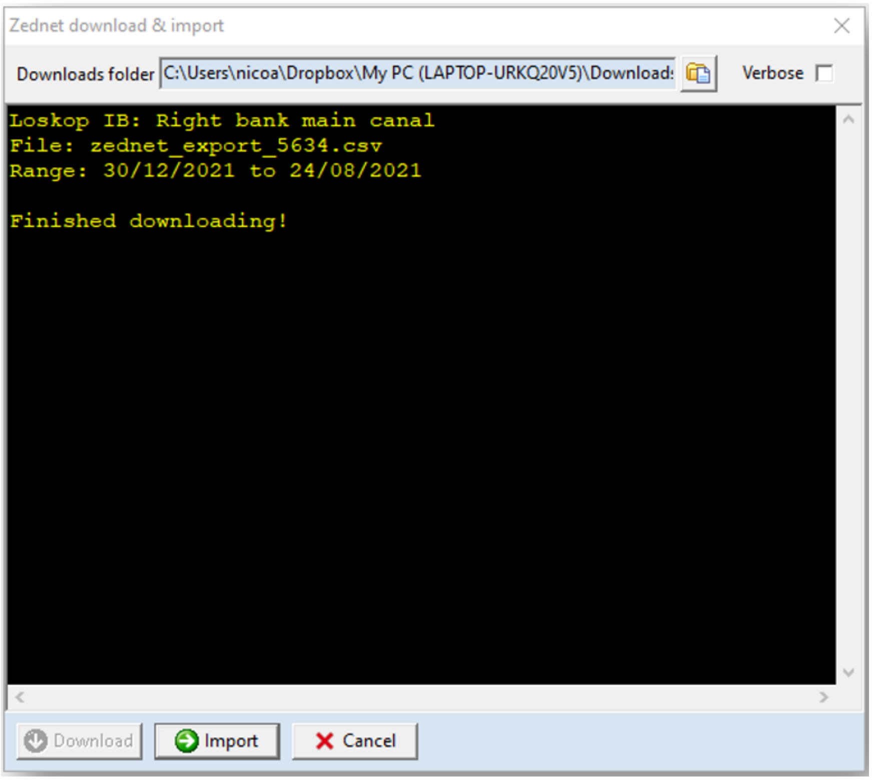


FIGURE 7.27 Measuring station – Download & import form

It is accessed on the *Stations* tab at either **Menu/Download & import Zednet loggers** or at **Menu/Download & import WAS loggers**. Either option retrieves data for corresponding logger types. They open the *Download & import* form (Figure 7.27. On this form when the *Download* button is clicked, the data files of the relevant logger types are downloaded. After the files have finished downloading, the *Import* button can be clicked, and the software will import all the downloaded files and associate the data with the correct measuring station.

7.3.1.8 Graph

The data of a measuring station can be graphed by going to the data of a station and clicking on the *Graph* button in the form's toolbar. This will open the *Graph* form as seen in Figure 7.28. The graph can be used to look for any discrepancies in the data. In either the graph pattern or the calculated volume.

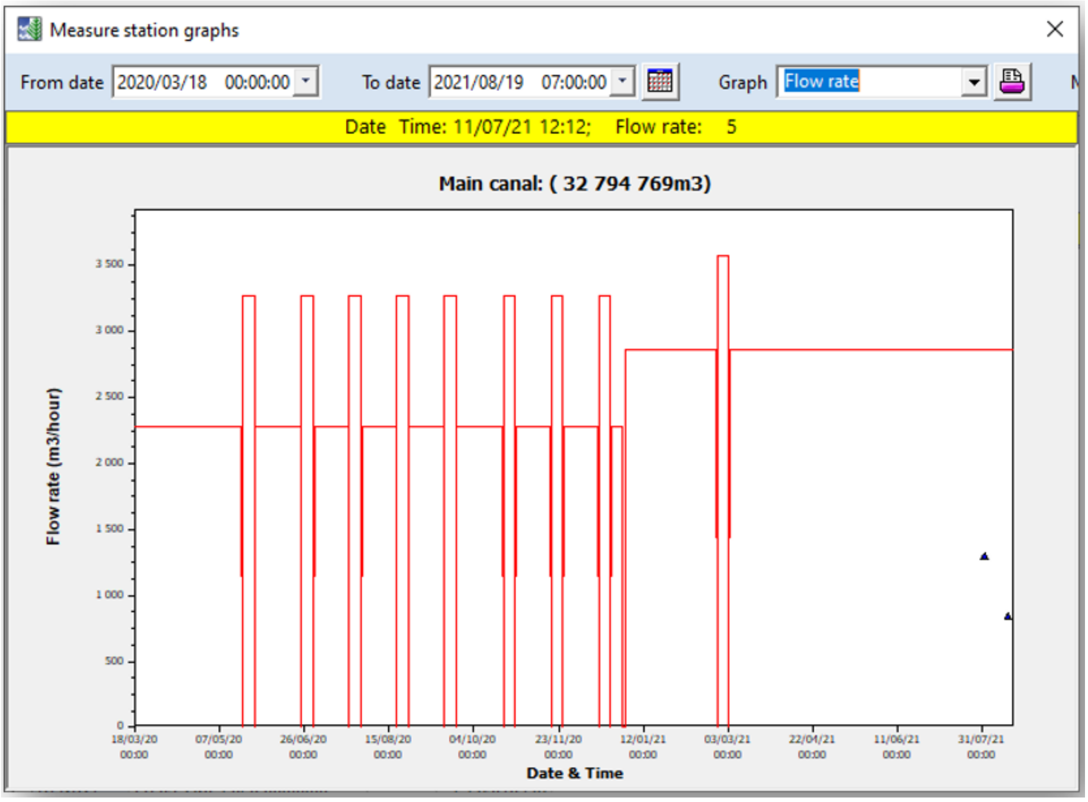


FIGURE 7.28 Measuring station – Graph

7.3.1.9 Volume calculation

The volume of a range of data can be calculated on the *Data* tab by using the *Summation* button as seen in Figure 7.29. The date filters should be used to filter out the desired range for which to calculate the volume. This can be used to verify data on the WUEA report.

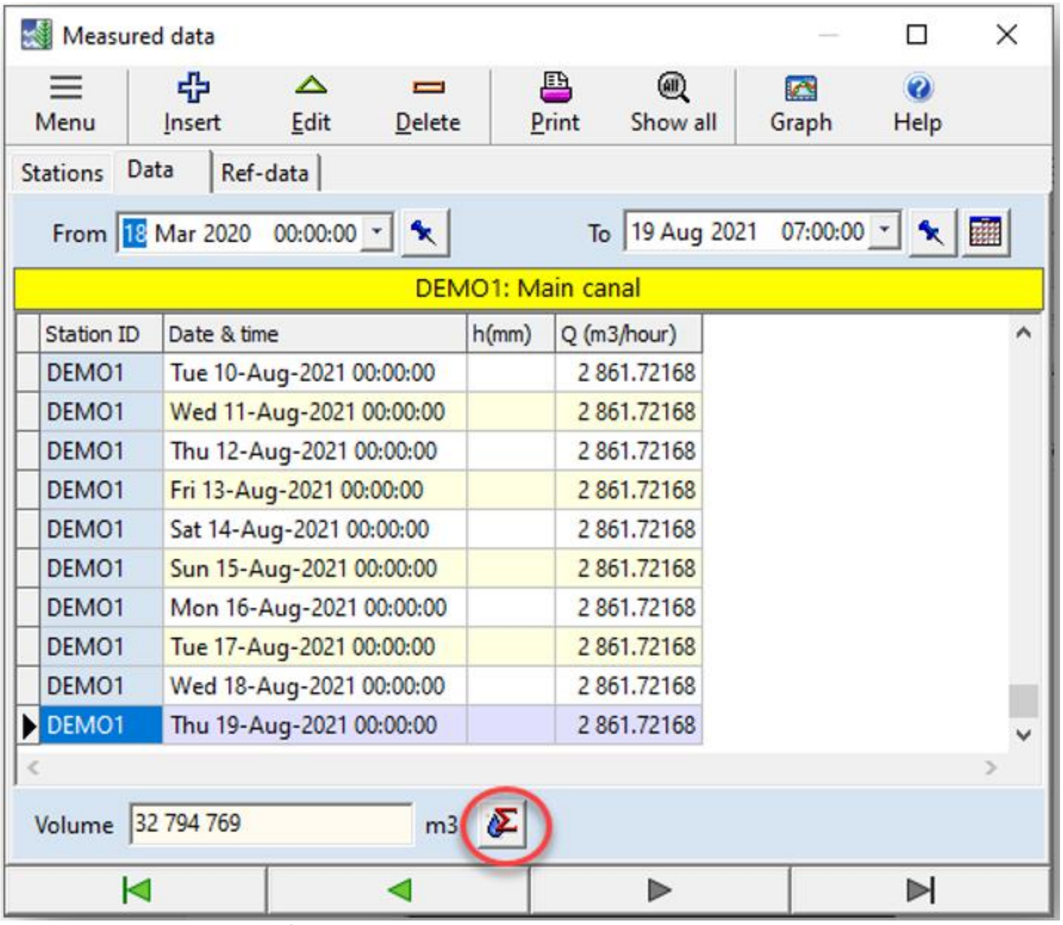


FIGURE 7.29 Measured data volume calculation

7.3.1.10 Reference data

The third tab, *Ref-data,* is used to capture single data points that were recorded in the field. Once captured the can be seen when the data is graphed (Figure 7.30).

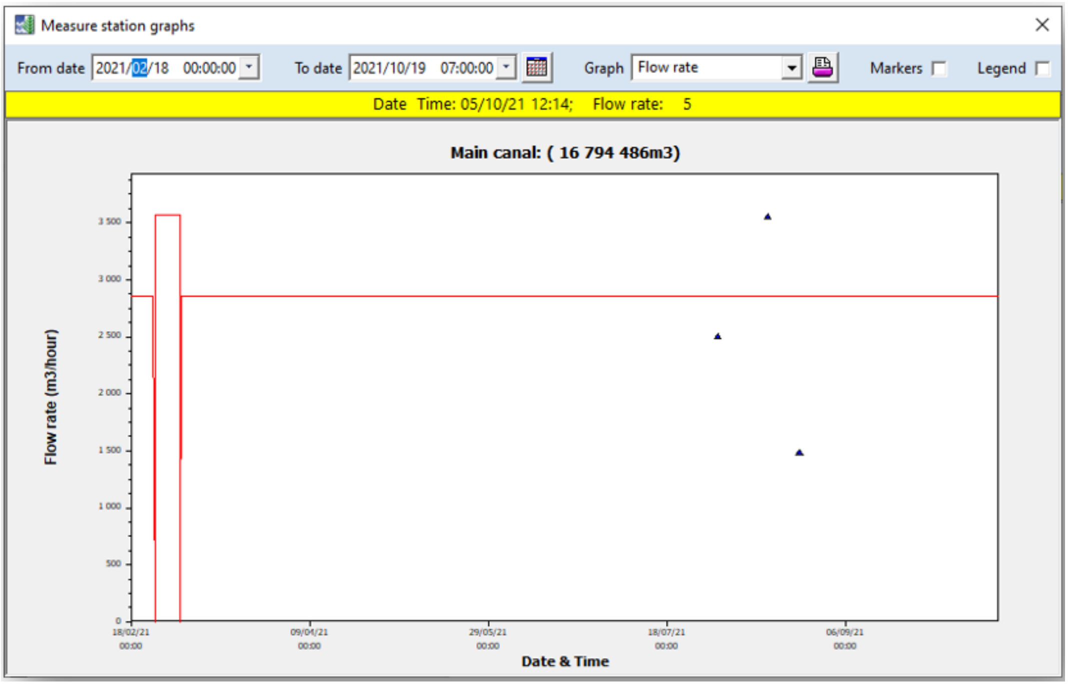


FIGURE 7.30 Measured reference data points

The blue triangles represent these data points and are used to verify whether the logger data is accurate or not. In the example indicated in Figure 7.30, the measuring station's logger appears to be inaccurate and requires calibration. If the blue triangles align with the red line, then it means that the data that the logger collected is still accurate, and it does not need to be adjusted.

7.3.1.11 Water Use Efficiency Accounting Report (WUEAR)

The WUEAR can be accessed from the main form at **Output/Water/Water Use Efficiency Accounting report** (Figure 7.31).

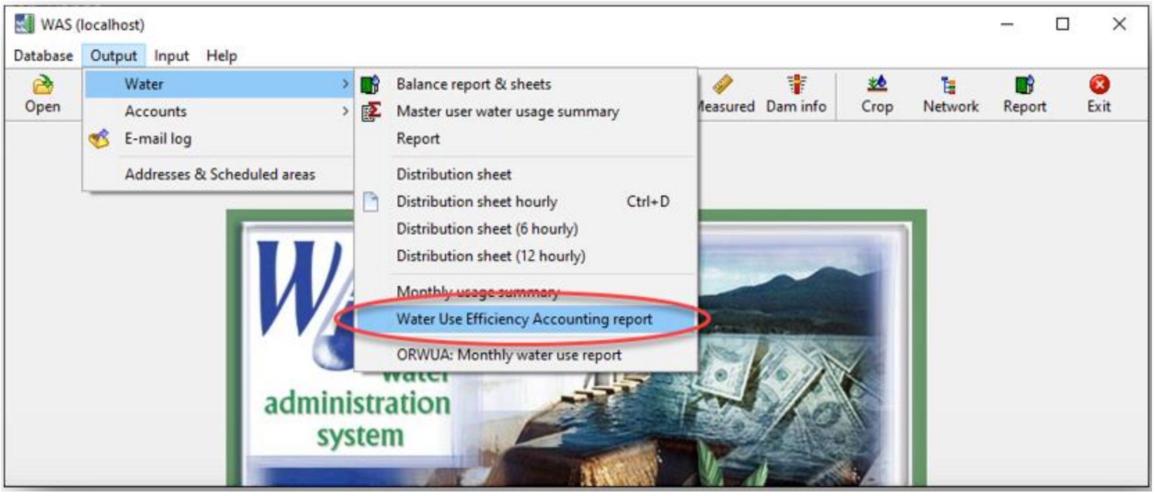


FIGURE 7.31 Access path for WUEAR from the main form

This will open the *Water Use Efficiency Accounting report* form (Figure 7.32).

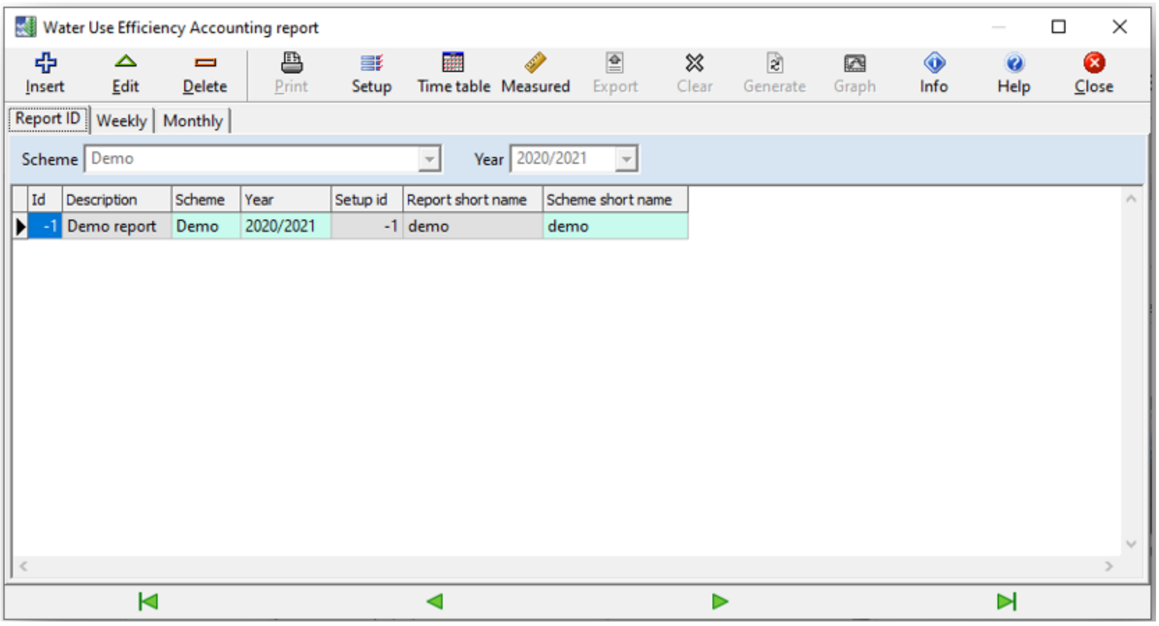


FIGURE 7.32 Water Use Efficiency Accounting report form

The WUEAR is used to account for water released, water delivered and lost at a specific irrigation scheme. The water orders, meter readings, and time series data from measuring stations are integrated into a single report. The WUEAR generates weekly volumes of water released and delivered for a specified weekly range within a specific water year. A monthly summary is generated automatically from the weekly values. A report can be regenerated at any time, and water released and delivered can be captured manually if necessary. The water uses defined in the WUEAR are:

- Agricultural
- Industrial

- Municipal
- Household
- Downstream use
- Other

Water volumes in the WUEAR are generated automatically provided that the following information is captured:

- Water orders
- Meter readings
- Household pipes and delivery rates for the different pipe sizes
- Date and time related data from all measuring stations
- Week timetable

Initial setup

In the main grid, the WUEAR that is of interest needs to be selected. If the report does not exist, click on the Insert-button to create a new report. There is no limitation to the number of reports that can be created for a specific water year. Reports can be created for individual canals or for the entire scheme.

- **Description**: The description or name of the report.
- **Scheme**: The current scheme name as selected in the *Scheme-drop-down* box.
- **Year**: The current water year as selected in the *Year-drop-down* box.
- **Setup id**: A unique numerical number that links a specific setup to the selected report. The default value is 1.
- **Report short name**: Shortened name to represent the WUEA report uploaded onto the Internet. This must be unique.
- **Scheme short name**: Shortened name to represent the irrigation scheme uploaded to the Internet. This must be unique, between schemes.

The generation of WUEA reports depends on predefined steps that are specified in the generation setup form (Figure 7.33). Each setup has a unique *Setup id* which is linked to a specific WUEAR. The default *Setup id* is 1. There is no limitation on the number of steps that can be inserted under one *Setup id*. Each step will be executed in sequence during the generation of the report and each step has a predefined task.

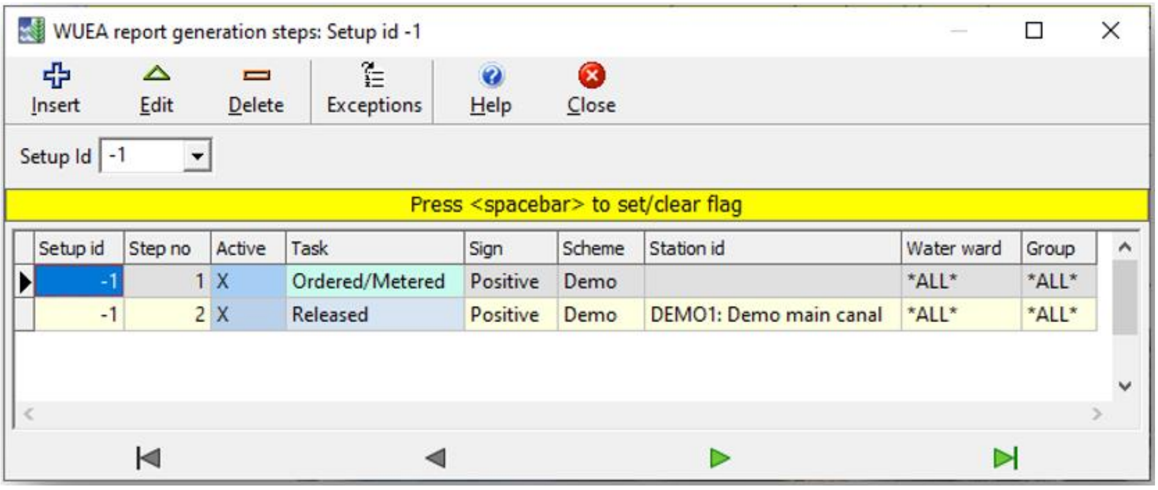


FIGURE 7.33 WUEAR generation setup

A step can be created by clicking on the *Insert* button and opening the capturing form (Figure 7.34).

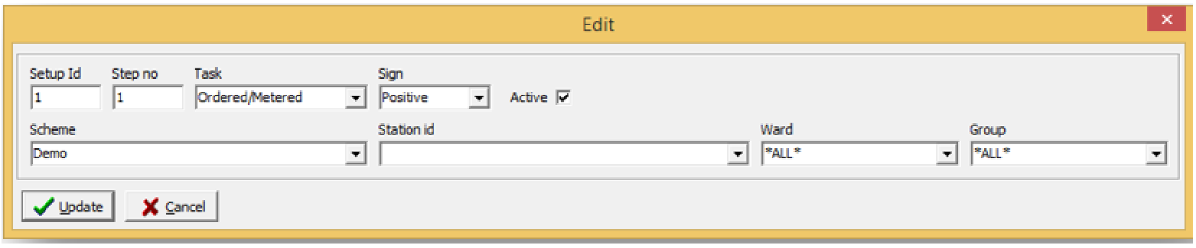


FIGURE 7.34 WUEAR setup step capturing form

The following fields need to be captured:

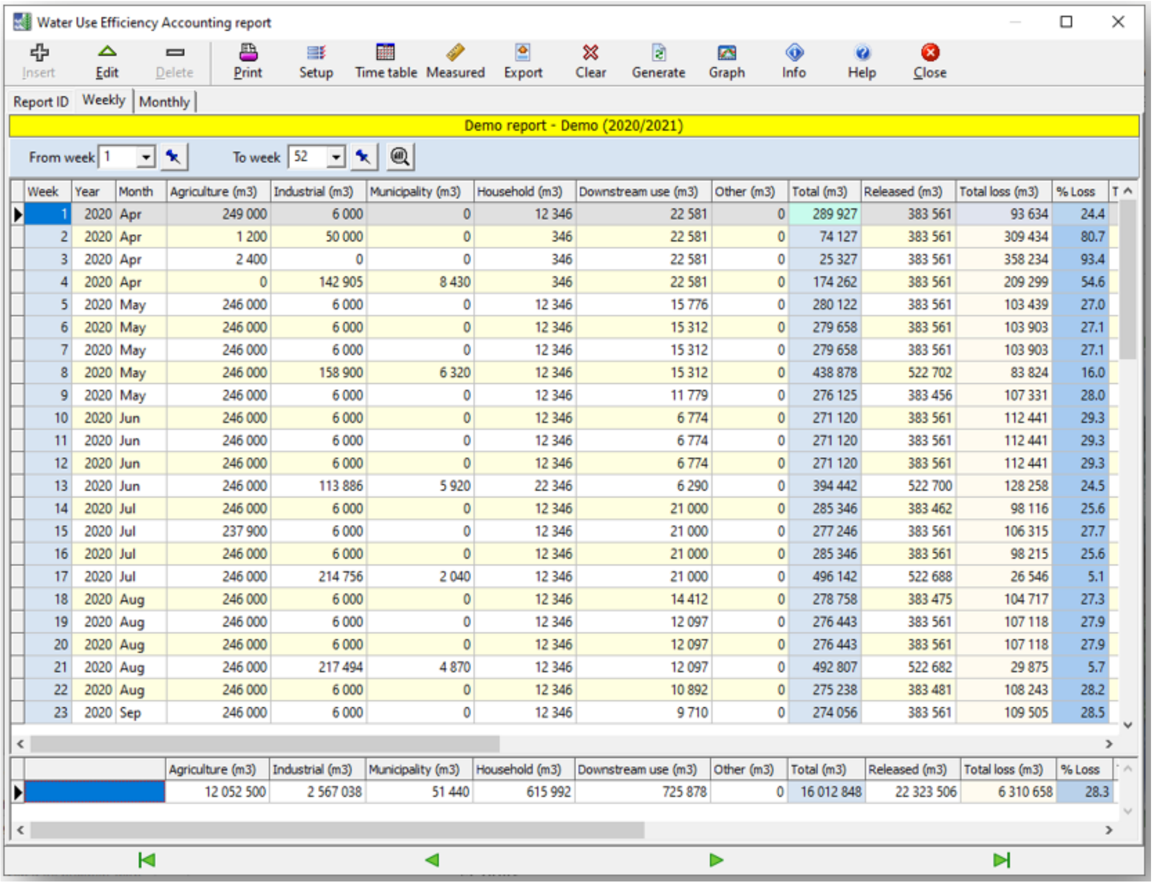
- **Setup id**: A numerical value used to identify a specific setup.
- **Step no**: Specifies the execution order.
- **Active**: Used to activate or deactivate a specific step. The spacebar can be used as a short cut.
- **Task**: The following tasks are available to choose from:
    - **Ordered/Metered**: Add all water orders and meter reading volumes according to the five different water usage types.
    - **Released**: Calculate the weekly release volumes related to the specified *Station id*.
    - **Downstream use**: Calculate the weekly downstream use volumes related to the specified *Station id*.
    - **Other**: Calculate the weekly other water use volumes related to the specified Station id.
    - **Tail end**: Calculate the weekly tail end water volumes related to the specified *Station id*.
    - **Crop used**: Calculate the weekly crop water use volumes related to the planted areas and the crop water use graph of each crop.
- **Sign**: Specifies the sign of the generated values. Values with a positive sign will be added and values with a negative sign will be subtracted.
- **Scheme**: Identifies the scheme related to the information to be processed.
- **Station id**: Identifies the measuring station to be used to generate the weekly values. The date ranges in the weekly timetable are used to calculate the corresponding weekly volumes. The *station id* is not used in the Ordered/Metered and Crop used tasks.
- **Water ward**: Filters the generated values according to the specified water ward. The *ALL* option includes all wards. Water wards are captured as part of the user information.
- **Group**: Filters the generated values according to the specified group. The *ALL* option includes all groups. Groups are captured as part of the user information.

Weekly report

The steps to generate a weekly WUEA report are the following:

1. Ensure the following has been done:
    - Water usage types have been assigned under user information (Refer to the specific help file for details).
    - Water use for different household and livestock pipe sizes has been captured (Refer to the specific help file for details).
    - A Setup id has been assigned to the specific report and that the generation steps have been captured.
    - Weekly timetable has been generated for the specific water year.
    - Water orders have been captured.
    - Meter readings have been captured.
    - Measuring station data has been imported or captured.
    - Crop water use information has been captured.
2. Select the weekly page by clicking on the *Weekly* tab as shown below. The WUEA report *Weekly* tab shows the volumes and % loss on a weekly basis. All the volumes except for the *Total*, *Difference* and the %*Loss* can be generated or captured manually.
3. Set the *From*- and *To*-week values for the weeks that you want to generate the report for. Valid values are from week 1 to 53.
4. Click on the *Generate*-button to open the *Generate WUEA report* form. Ensure that the manually captured boxes are checked to prevent captured values from being replaced during generation. Click on the *OK*-button to generate the report.
5. Use the *Edit*-button to capture values that have not been generated automatically.
6. Set the *From* week value back to 1 to display the complete report from the start up to the current week.

The result will be something like Figure 7.35.



Week	Year	Month	Agriculture (m3)	Industrial (m3)	Municipality (m3)	Household (m3)	Downstream use (m3)	Other (m3)	Total (m3)	Released (m3)	Total loss (m3)	% Loss
1	2020	Apr	249 000	6 000	0	12 346	22 581	0	289 927	383 561	93 634	24.4
2	2020	Apr	1 200	50 000	0	346	22 581	0	74 127	383 561	309 434	80.7
3	2020	Apr	2 400	0	0	346	22 581	0	25 327	383 561	358 234	93.4
4	2020	Apr	0	142 905	8 430	346	22 581	0	174 262	383 561	209 299	54.6
5	2020	May	246 000	6 000	0	12 346	15 776	0	280 122	383 561	103 439	27.0
6	2020	May	246 000	6 000	0	12 346	15 312	0	279 658	383 561	103 903	27.1
7	2020	May	246 000	6 000	0	12 346	15 312	0	279 658	383 561	103 903	27.1
8	2020	May	246 000	158 900	6 320	12 346	15 312	0	438 878	522 702	83 824	16.0
9	2020	May	246 000	6 000	0	12 346	11 779	0	276 125	383 456	107 331	28.0
10	2020	Jun	246 000	6 000	0	12 346	6 774	0	271 120	383 561	112 441	29.3
11	2020	Jun	246 000	6 000	0	12 346	6 774	0	271 120	383 561	112 441	29.3
12	2020	Jun	246 000	6 000	0	12 346	6 774	0	271 120	383 561	112 441	29.3
13	2020	Jun	246 000	113 886	5 920	22 346	6 290	0	394 442	522 700	128 258	24.5
14	2020	Jul	246 000	6 000	0	12 346	21 000	0	285 346	383 462	98 116	25.6
15	2020	Jul	237 900	6 000	0	12 346	21 000	0	277 246	383 561	106 315	27.7
16	2020	Jul	246 000	6 000	0	12 346	21 000	0	285 346	383 561	98 215	25.6
17	2020	Jul	246 000	214 756	2 040	12 346	21 000	0	496 142	522 688	26 546	5.1
18	2020	Aug	246 000	6 000	0	12 346	14 412	0	278 758	383 475	104 717	27.3
19	2020	Aug	246 000	6 000	0	12 346	12 097	0	276 443	383 561	107 118	27.9
20	2020	Aug	246 000	6 000	0	12 346	12 097	0	276 443	383 561	107 118	27.9
21	2020	Aug	246 000	217 494	4 870	12 346	12 097	0	492 807	522 682	29 875	5.7
22	2020	Aug	246 000	6 000	0	12 346	10 892	0	275 238	383 481	108 243	28.2
23	2020	Sep	246 000	6 000	0	12 346	9 710	0	274 056	383 561	109 505	28.5

	Agriculture (m3)	Industrial (m3)	Municipality (m3)	Household (m3)	Downstream use (m3)	Other (m3)	Total (m3)	Released (m3)	Total loss (m3)	% Loss
	12 052 500	2 567 038	51 440	615 992	725 878	0	16 012 848	22 323 506	6 310 658	28.3

FIGURE 7.35 Weekly WUEA report

The weekly WUEAR consists of the following fields:

- **Week**: The week number is automatically generated for the specified weeks in the *From*- and *To*-week input boxes.
- **Year**: The actual year within the specific water year. This is automatically generated using the weekly timetable.
- **Month**: The corresponding month within the actual year. This is automatically generated using the weekly timetable.
- **Agriculture (m^3)**: Water used for agriculture for the specific week which can be captured manually or generated.
- **Industrial (m^3)**: Industrial water used for the specific week which can be captured manually or generated.
- **Municipality (m^3)**: Water used by municipalities for the specific week which can be captured manually or generated.
- **Household (m^3)**: Household water used for the specific week which can be captured manually or generated. Household pipes with a corresponding pipe diameter are captured in WAS for each water user. A fixed delivery volume in m^3/year is captured for each pipe diameter. This volume is converted to an average weekly volume which is used to generate the WUEAR. The total household volume for a given water year is divided by 52.
- **Downstream (m^3)**: Water volume that is released for a specific user downstream of the scheme.
- **Other (m^3)**: Other water use for the specific week that does not belong to any of the previous water usage types. This water usage type can be captured manually or generated.
- **Total (m^3)**: Total water used per week which is the sum of all the different water usage types. This value is calculated automatically and cannot be captured manually.
- **Released (m^3)**: The total water released per week can be captured or generated.
- **Total loss (m^3)**: The Total loss is calculated by subtracting the total water used from the total water released per week.
- **% Loss**: The % Loss per week is calculated automatically using the following equation:

$$Loss = \frac{Water\ released - Water\ used}{Water\ released} \times 100 \qquad \textbf{Equation 8}$$

- **Tail end loss (m³)**: Water volume that passes over the tail end of a canal. This water can only be considered as a water use if it is released for a specific user downstream otherwise it should be considered as a loss.
- **Tail end loss (%)**: The tail end loss calculated as a percentage loss.
- **Water allocation used (m³)**: Total water allocation used for the specific week.
- **Water allocation avail (m³)**: Water allocation available for the specific week.
- **% Used**: Water allocation used calculated as a percentage.
- **% Available**: Water allocation available calculated as a percentage.

Monthly report

The monthly report is automatically calculated from the weekly values, and it is, therefore, important to generate the weekly report first before moving on to the monthly report. The monthly report displays all the same volumes as the weekly report divided by 1000 and summed up to monthly values. The report can be printed and exported in a comma delimited (*.csv) format that can be opened in Microsoft Excel.

Graphs

There are also graphs available that are created from the information in the report. They can be accessed from the *Graph* button in the form's toolbar. There are different graphs available on the *Weekly*- and *Monthly* tabs, respectively. The graphs below were generated during the training using data from Loskop Irrigation Board for the water year 2020/2021.

Graphs for the *Weekly* reports

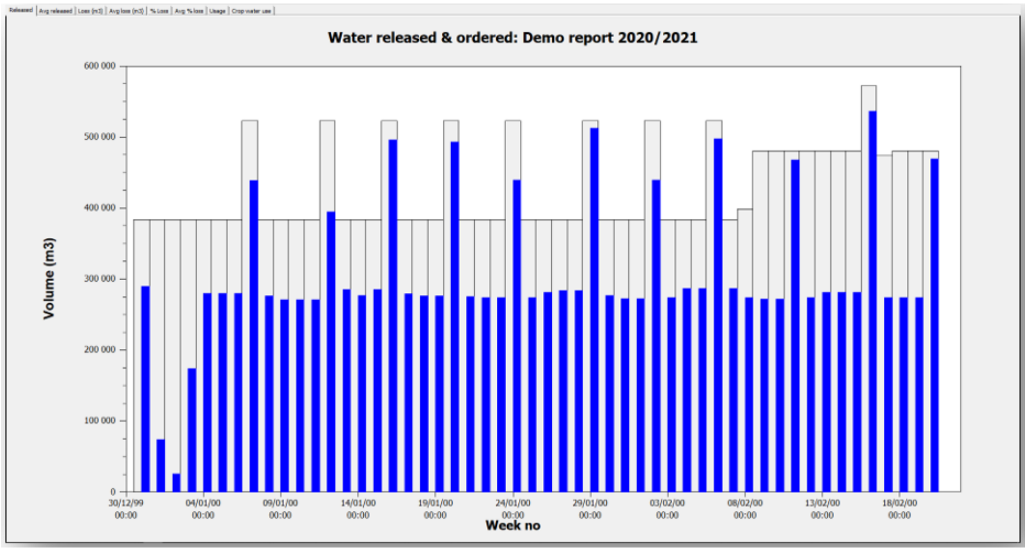


FIGURE 7.36 Weekly – Water released & ordered graph

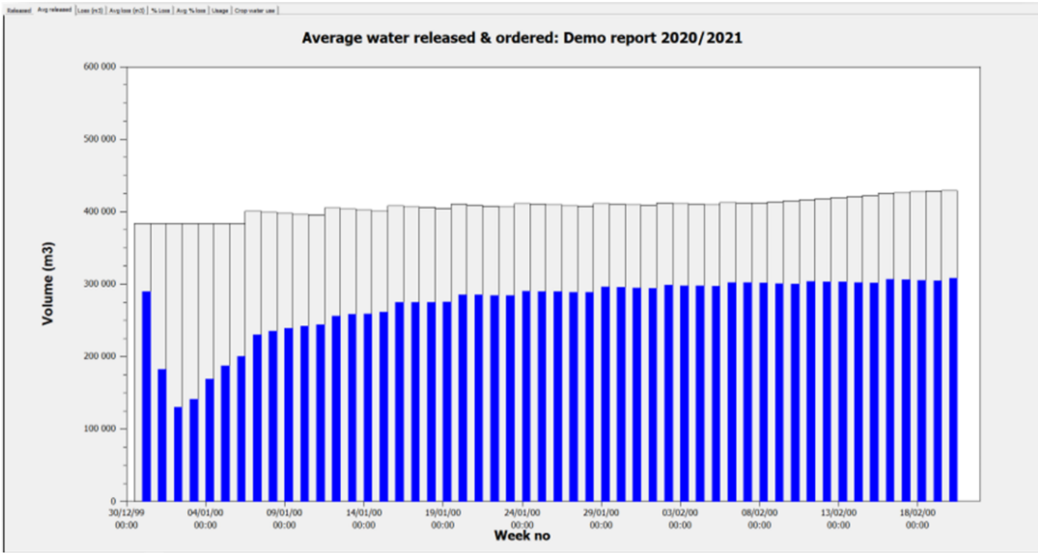


FIGURE 7.37 Weekly – Average water released & ordered graph

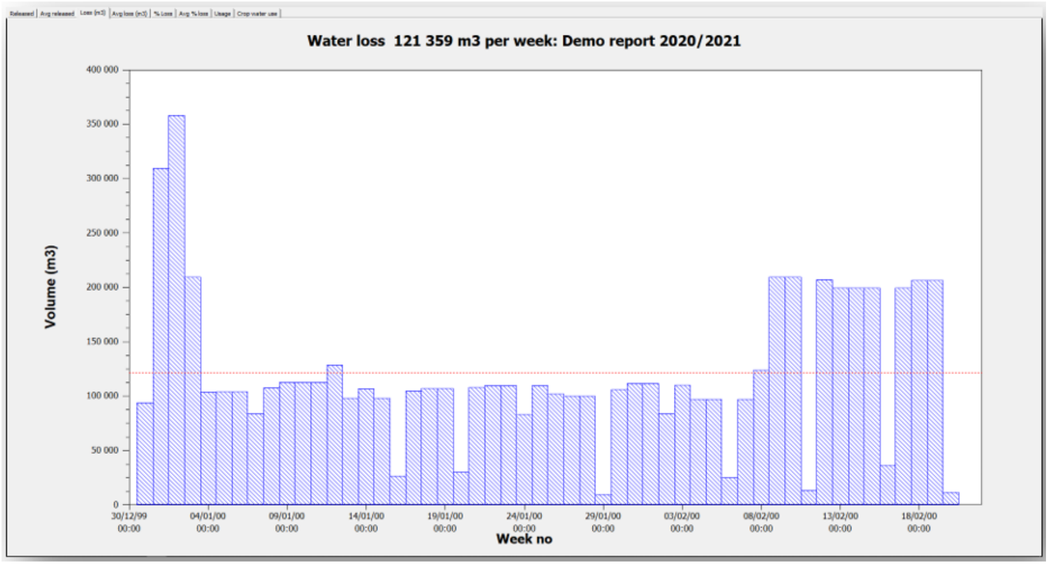


FIGURE 7.38 Weekly – Water loss m^3 graph

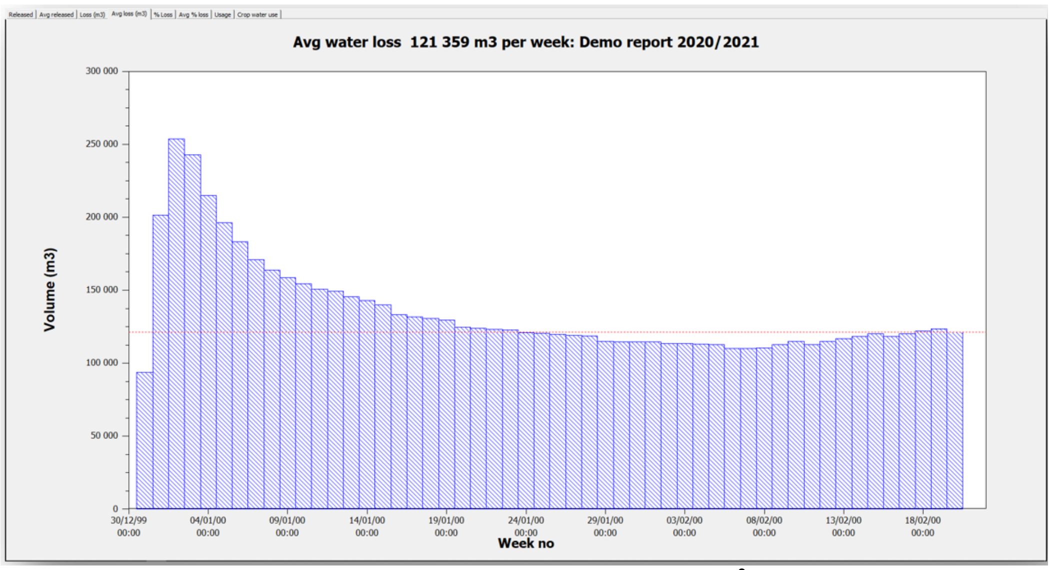


FIGURE 7.39 Weekly – Average water loss m^3 graph

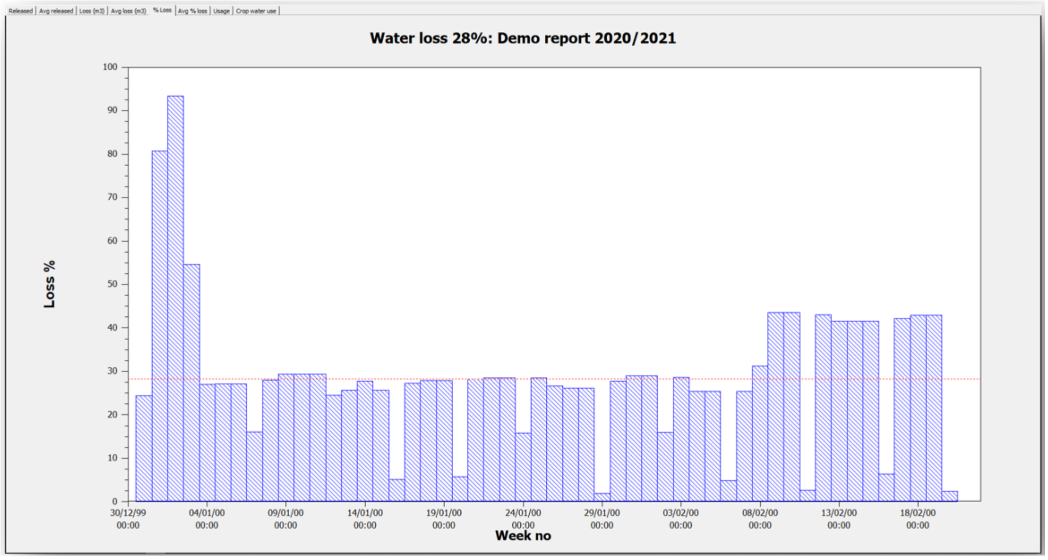


FIGURE 7.40 Weekly – Water loss % graph

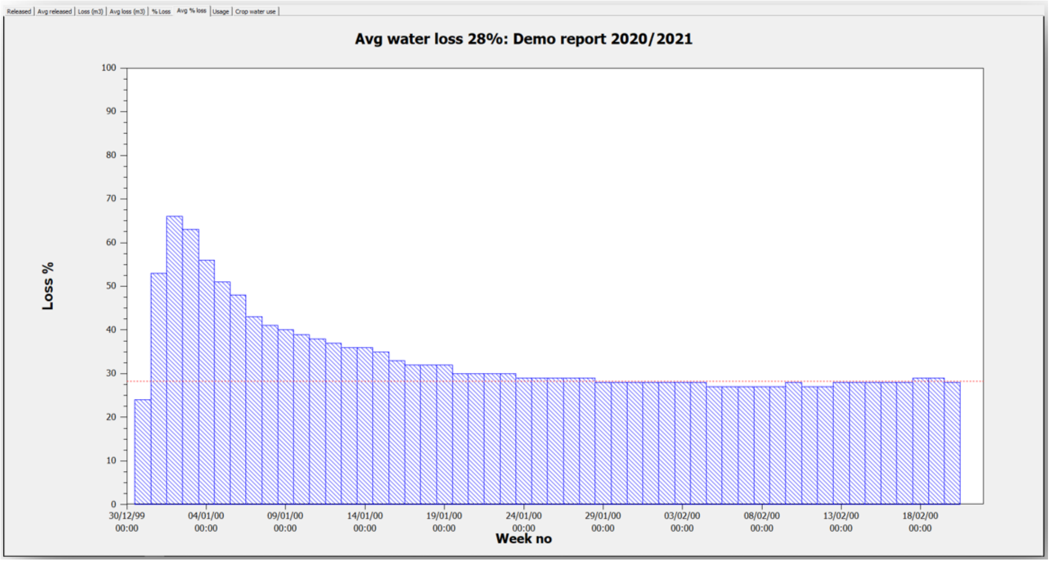


FIGURE 7.41 Weekly – Average water loss % graph

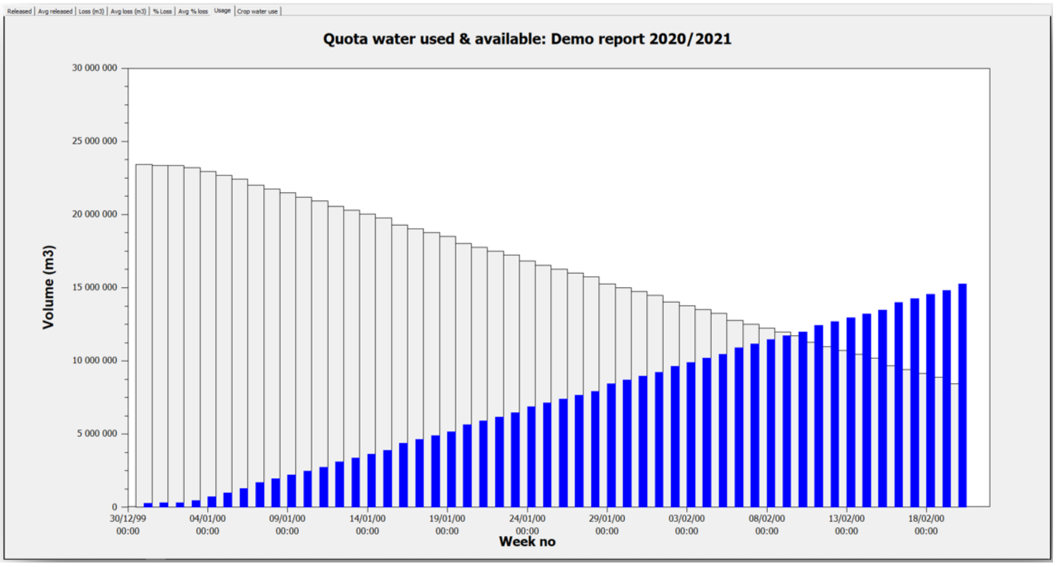


FIGURE 7.42 Weekly – Quota water used & available graph

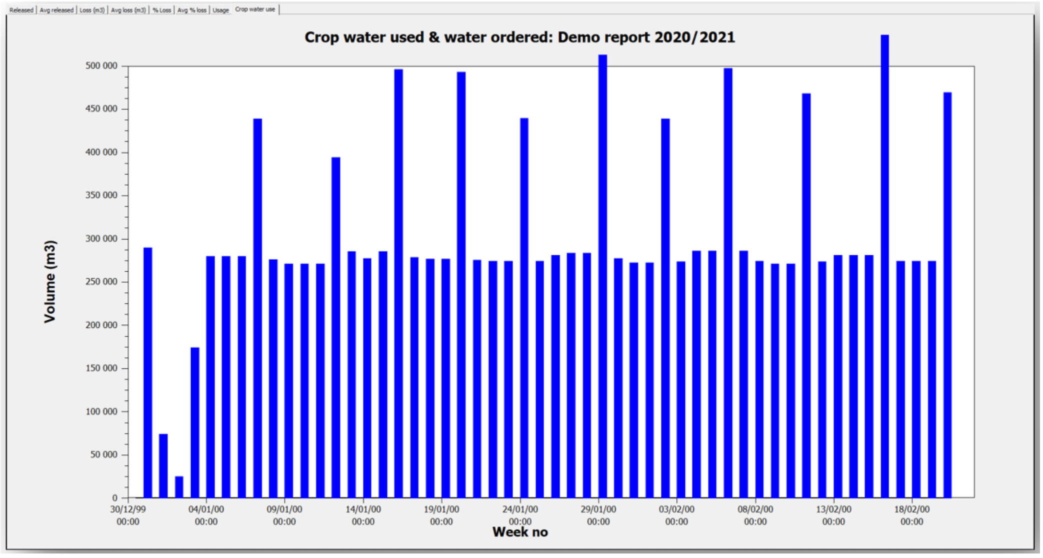


FIGURE 7.43 Weekly – Crop water used & water ordered graph

Graphs for the *Monthly* reports:

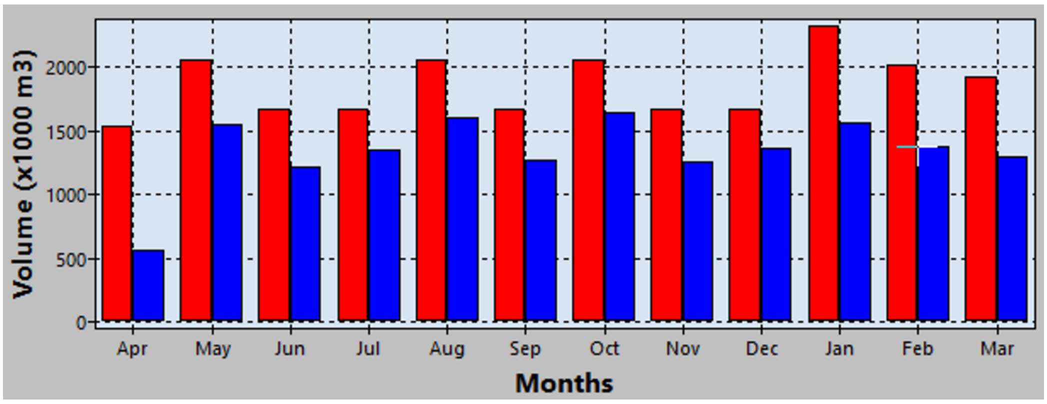


FIGURE 7.44 Monthly – Released & delivered (m^3) graph

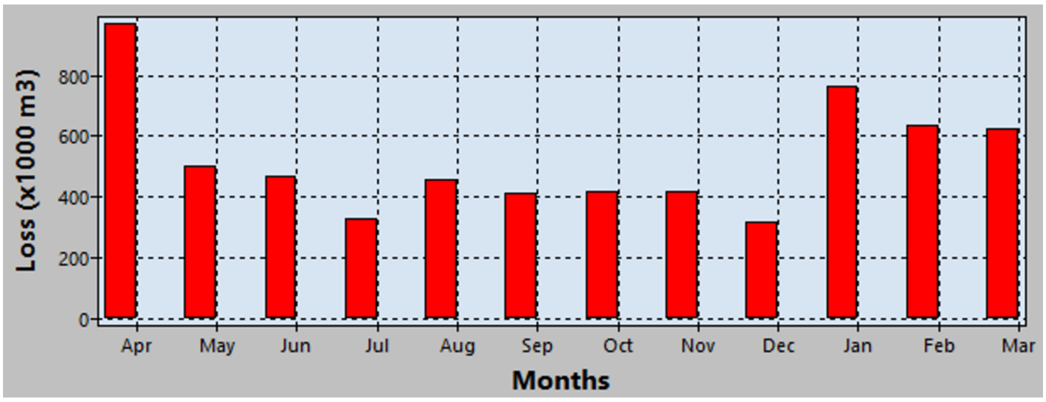


FIGURE 7.45 Monthly – Volume loss m^3 graph

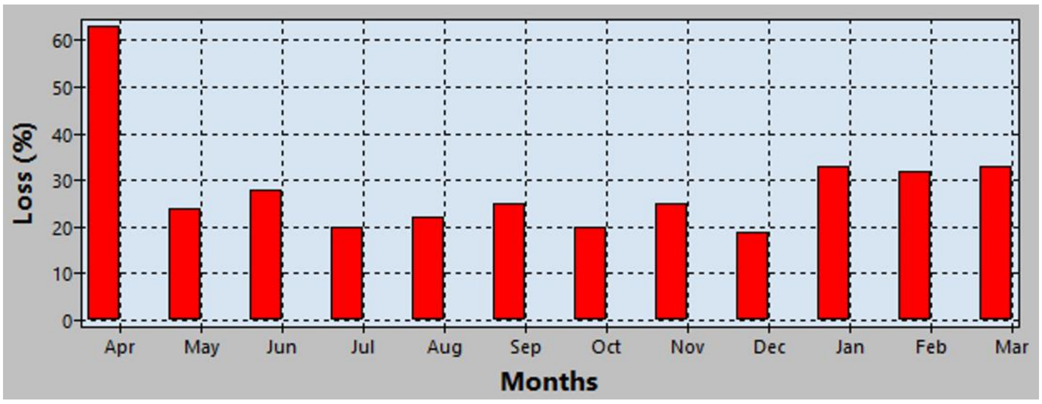


FIGURE 7.46 Monthly – Water loss % graph

7.3.1.12 Online platforms

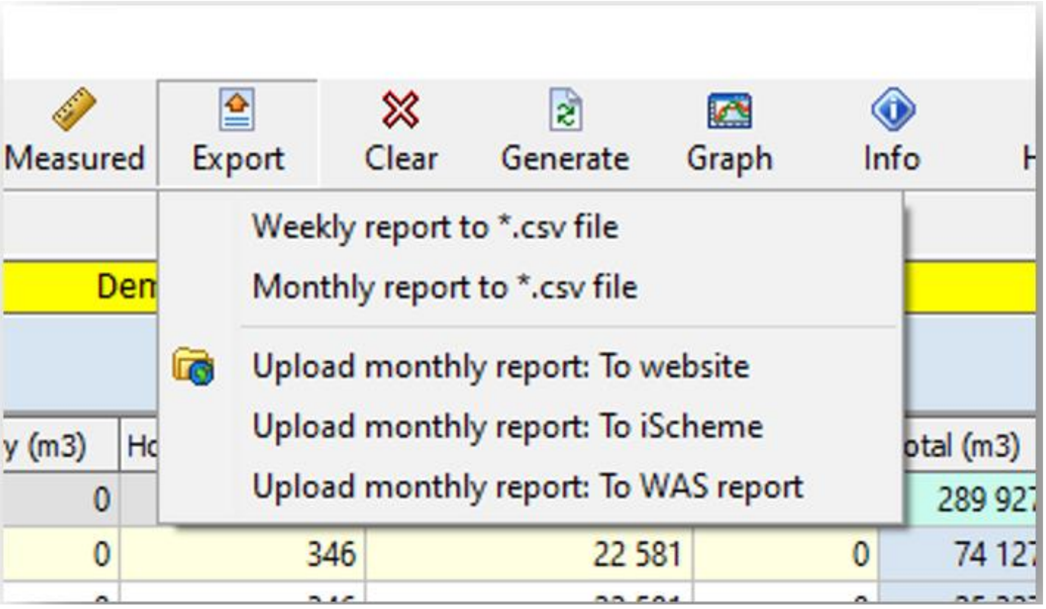


FIGURE 7.47 WUEAR export menu

The graphs and WUEAR can be uploaded to the Internet and *iScheme*. This can be done from the *Export* menu by clicking on the *Export* button in the form's toolbar. The export options on this menu are seen in Figure 7.47. The first two options are to export the reports to *.csv files. The last three options export the data to the Internet.

- *To website* sends it to www.wateradmin.co.za
- *To iScheme* sends it to an ftp server where it can be accessed by the *iScheme* software.
- *To WAS-report* sends it to the new online platform that was developed for this project.

The uploaded report can be viewed on the WAS website by going to the home page www.wateradmin.co.za and clicking on the *Irrigation Schemes* link (Figure 7.48).

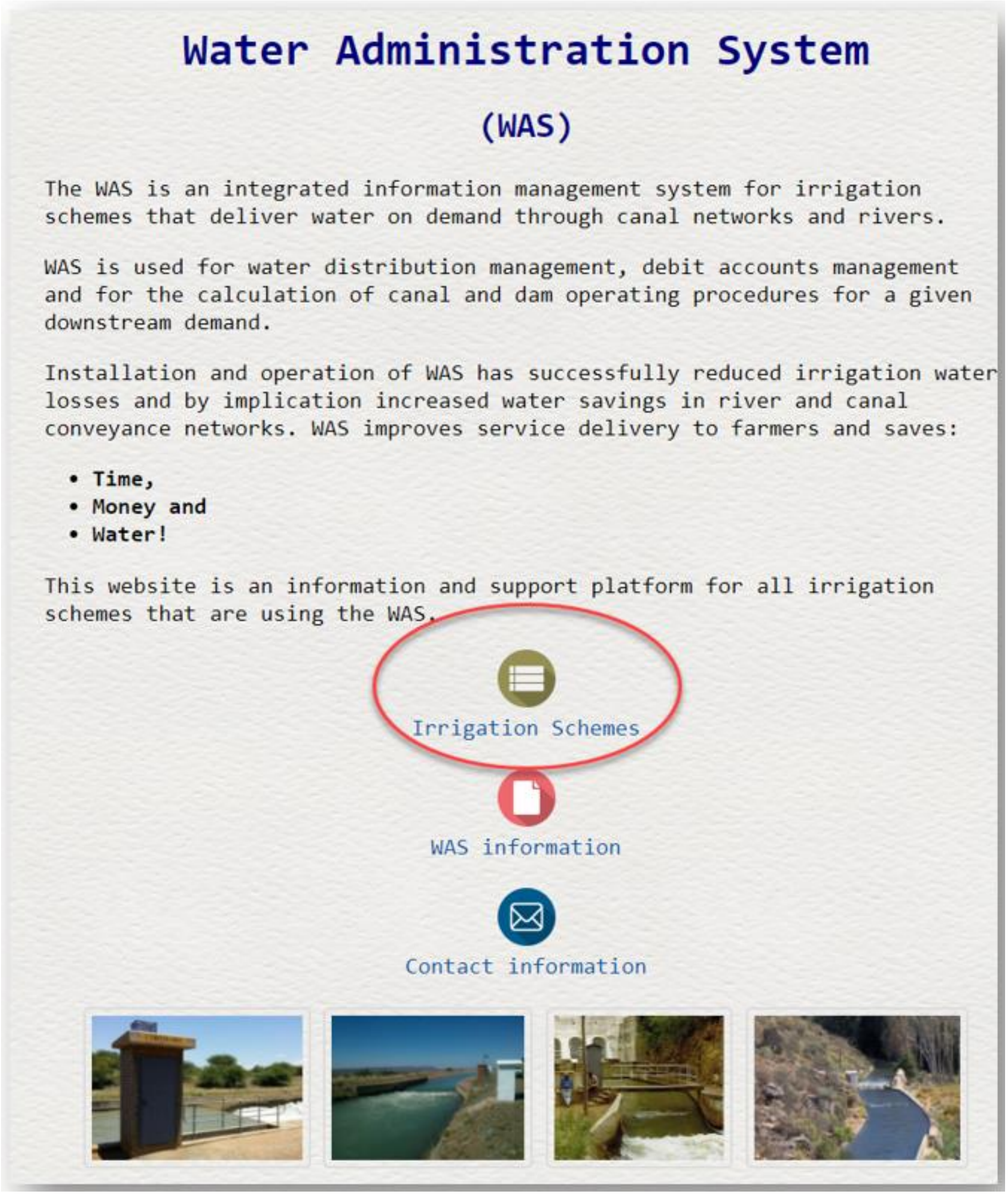


FIGURE 7.48 WaterAdmin homepage

This will open to a page with a list of all the irrigation schemes on the platform. You click onto the desired irrigation scheme's name.

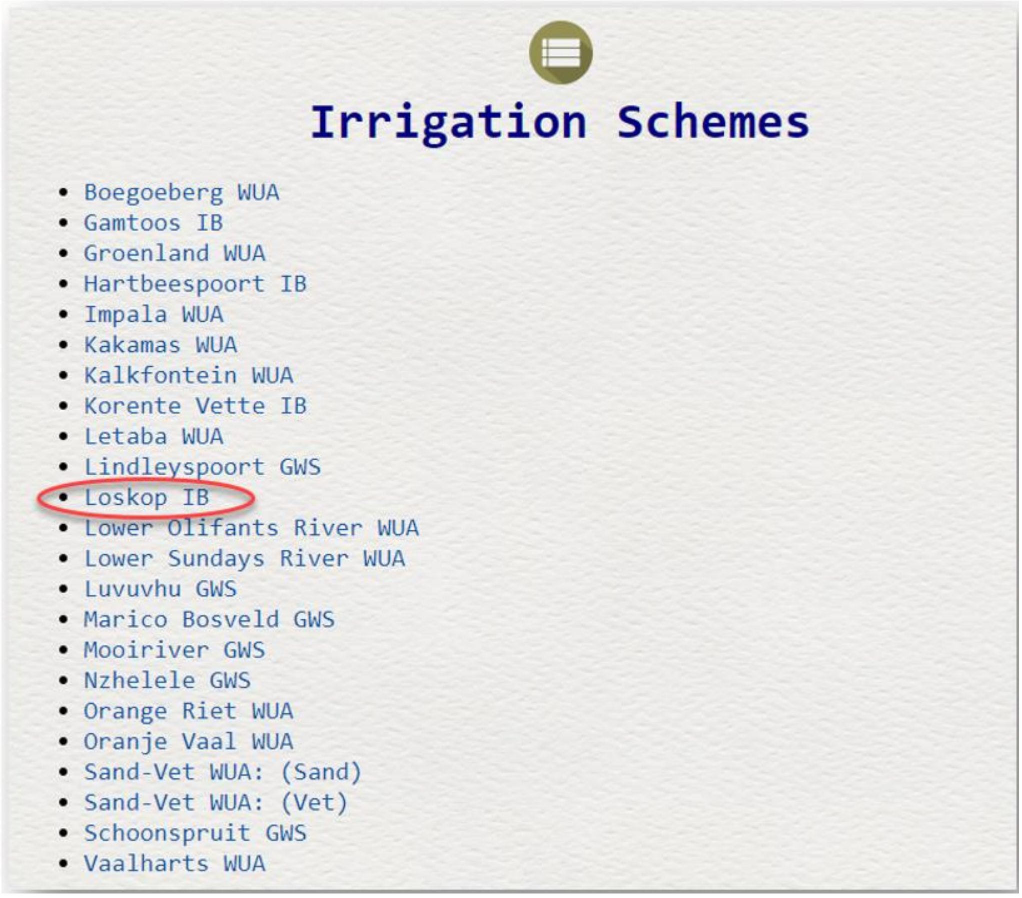


FIGURE 7.49 WaterAdmin irrigation scheme list page

This will open the scheme specific page from where the WUEAR can be opened.

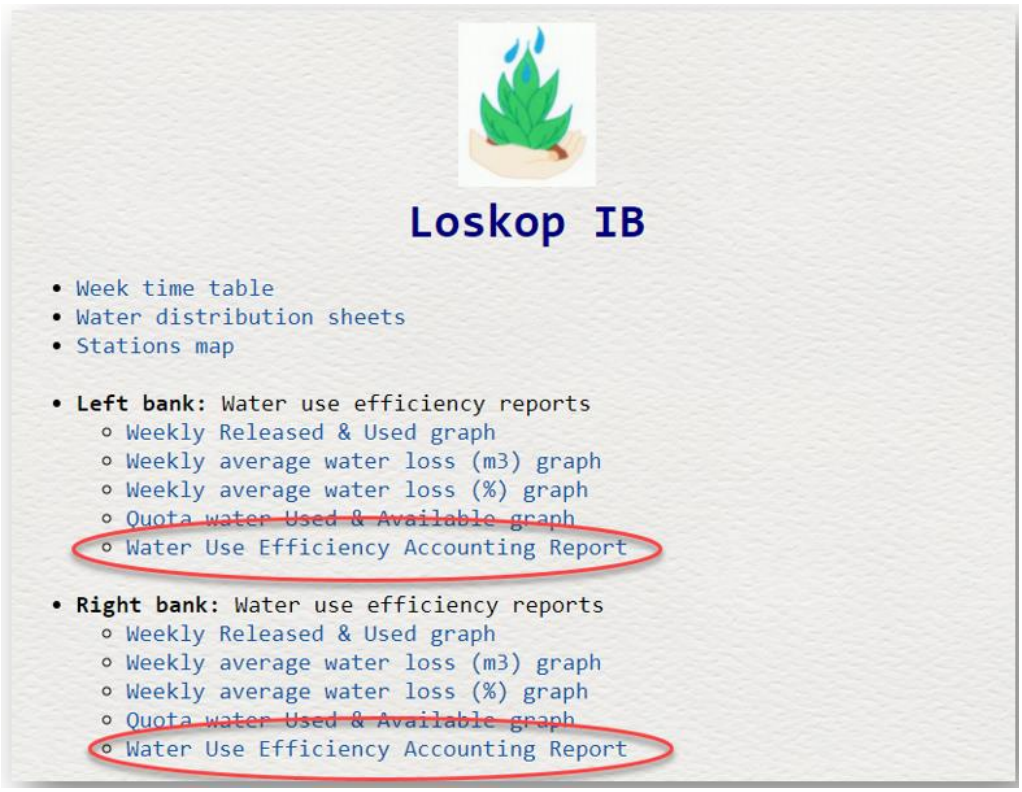


FIGURE 7.50 WaterAdmin – Loskop IB page

The uploaded WUEAR is available (on *iScheme* and WAS) by clicking on the WUEAR link under the desired scheme to open a page with access to all uploaded reports. WUEAR comes in three different formats:

TABLE 7.1 WAS-report – WUEAR format 1

Demo WUEAR

Report: Demo report
Water year: 2020/2021
Format: Format 1

Year	Mnth	Agriculture ($x1000m^3$)	Industrial ($x1000m^3$)	Municipality ($x1000m^3$)	Houshold ($x1000m^3$)	Downstream ($x1000m^3$)	Other ($x1000m^3$)	Total used ($x1000m^3$)	Released ($x1000m^3$)	Total loss ($x1000m^3$)	Loss (%)	Alloc used ($x1000m^3$)	Alloc avail ($x1000m^3$)	Used (%)	Avail (%)
2020	Apr	253	199	8	13	90	0	564	1534	971	63.23	472	23212	2.0	98.0
2020	May	1230	183	6	62	73	0	1554	2057	502	24.45	1951	21733	8.2	91.8
2020	Jun	984	132	6	59	27	0	1208	1673	466	27.79	3121	20563	13.2	86.8
2020	Jul	976	233	2	49	84	0	1344	1673	329	19.67	4380	19304	18.5	81.5
2020	Aug	1230	241	5	62	62	0	1600	2057	457	22.22	5916	17768	25.0	75.0
2020	Sep	984	186	3	49	39	0	1262	1673	411	24.57	7138	16546	30.1	69.9
2020	Oct	1230	256	4	62	87	0	1638	2057	419	20.37	8687	14997	36.7	63.3
2020	Nov	984	188	3	49	33	0	1257	1673	416	24.87	9910	13774	41.8	58.2
2020	Dec	984	232	3	49	88	0	1356	1673	317	18.95	11177	12507	47.2	52.8
2021	Jan	1230	223	3	62	40	0	1558	2321	763	32.87	12694	10990	53.6	46.4
2021	Feb	984	278	4	49	64	0	1380	2015	635	31.51	14008	9676	59.1	40.9
2021	Mar	984	216	3	49	39	0	1292	1916	624	32.57	15259	8425	64.4	35.6
Totals		12053	2567	50	614	726	0	16013	22322	6310	28.27	94713	189495	64.4	35.6

TABLE 7.2 WAS-report – WUEAR format 2

		($x1000m^3$)											%		
Year	Mnth	Revenue water: Agriculture	Billed metered: Industrial	Billed metered: Municipality	Billed unmetered: Household	Downstream	Other	Total water used	System input volume	Non-revenue water	Alloc used	Alloc avail	Non-revenue water	Used	Avail
2020	Apr	253	199	8	13	90	0	564	1534	971	472	23212	63.23	2.0	98.0
2020	May	1230	183	6	62	73	0	1554	2057	502	1951	21733	24.45	8.2	91.8
2020	Jun	984	132	6	59	27	0	1208	1673	466	3121	20563	27.79	13.2	86.8
2020	Jul	976	233	2	49	84	0	1344	1673	329	4380	19304	19.67	18.5	81.5
2020	Aug	1230	241	5	62	62	0	1600	2057	457	5916	17768	22.22	25.0	75.0
2020	Sep	984	186	3	49	39	0	1262	1673	411	7138	16546	24.57	30.1	69.9
2020	Oct	1230	256	4	62	87	0	1638	2057	419	8687	14997	20.37	36.7	63.3
2020	Nov	984	188	3	49	33	0	1257	1673	416	9910	13774	24.87	41.8	58.2
2020	Dec	984	232	3	49	88	0	1356	1673	317	11177	12507	18.95	47.2	52.8
2021	Jan	1230	223	3	62	40	0	1558	2321	763	12694	10990	32.87	53.6	46.4
2021	Feb	984	278	4	49	64	0	1380	2015	635	14008	9676	31.51	59.1	40.9
2021	Mar	984	216	3	49	39	0	1292	1916	624	15259	8425	32.57	64.4	35.6
Totals		12053	2567	50	614	726	0	16013	22322	6310	94713	189495	28.27	64.4	35.6

TABLE 7.3 WAS-report – WUEAR format 3

Irrigation scheme	Demo											
Province	Gauteng											
No of Irrigators	39											
Household offtakes	5											
Length of conveyance system	53.3km											
Input data												
Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
System input volume ($x1000m^3$)	1534	2057	1673	1673	2057	1673	2057	1673	1673	2321	2015	1916
Billed metered consumption ($x1000m^3$)	207	189	138	235	246	189	260	191	235	226	282	219
Billed unmetered consumption ($x1000m^3$)	103	135	86	133	124	88	149	82	137	102	113	88
Water balance calculations												
Revenue water ($x1000m^3$)	253	1230	984	976	1230	984	1230	984	984	1230	984	984
Non-revenue water ($x1000m^3$)	971	502	466	329	457	411	419	416	317	763	635	624
% Non-revenue water	63.23	24.45	27.79	19.67	22.22	24.57	20.37	24.87	18.95	32.87	31.51	32.57

Formats 1 and 2 are very similar, but column titles are. The main difference is that column titles *Released* and *Loss* have been replaced with *System input volume* and *Non-revenue water*, respectively. In format 3, the data has been rearranged but the values correspond with the other two formats:

- System input volume = Released
- Billed metered consumption = Industrial + Municipality
- Billed unmetered consumption = Household + Other + Downstream

- Revenue water = Agriculture
- Non-revenue water = Loss
- % Non-revenue water = %Loss

7.3.2 Capacity development of postgraduate learners

Two postgraduate learners at the level of Masters (Appendix C) were part of the project. Both of them registered with the University of Venda for MSc degree in Agriculture (Agricultural Mechanization). The two learners first registered for their MSc program in early 2020; unfortunately, that is also the year when the Covid-19 pandemic struck and their progress was negatively impacted on with, for example, travel restrictions prohibiting free travel to research sites. Both learners successfully presented their research proposals and they both met the university criteria to continue with research-based studies in 2021. The titles of their research proposals were "*Assessment of water losses from the canal systems at Vaalharts and Loskop irrigation schemes*" and "*Condition assessment of the conveyance canal systems at Loskop and Vaalharts irrigation schemes*." However, their progress was sluggish compared to normal expectations due in greater part to the travel restrictions imposed to contain the Covid-19 pandemic. Travel outside province was not allowed until late 2021 to early 2022, which pave the way for travel to Vaalharts and Loskop irrigation schemes for field data collection. Unfortunately, by the time the travel restrictions were lifted one of the learners had withdrawn from their studies to pursue other interests. The remaining learner analysing her field data and drafting the MSc thesis at the time the project ended. The target was to be able to submit the thesis to the University of Venda by mid-2023 at the latest. The research outcomes shall be disseminated by means of the thesis, at least one planned journal publication and oral presentations at conferences.

7.3.3 Knowledge dissemination

7.3.3.1 Publications

Two project related publications were achieved during the life of the project; one was a publication in a peer reviewed journal (Appendix D) and the other one was a publication in a local bulletin (Appendix E).

Peer reviewed article
The peer reviewed article is a literature review paper published in the Irrigation & Drainage as "*Mutema, M. & Dhavu, K. (2022) Review of factors affecting canal water losses: A meta-analysis based on worldwide data. Irrigation and Drainage, 1-15. Available from https://doi:org/ 10.1002/ ird.2689*." Irrigation & Drainage is the flagship journal of the International Commission on Irrigation and Drainage (ICID), which has an international appeal amongst irrigators, other water users, water scientists and engineers, decision and policy makers on water issues across the world. Therefore, the target was the international community in its entirety. The paper elucidates the key physical factors that affect seepage, leakage and evaporation loss from open canals. The results of the literature study are important to those stakeholders tasked with deployment of scarce resources such as money for maintenance and repairs of irrigation water conveyance infrastructure. The results are also useful to farmers and irrigation water managers in their efforts to reduce water losses along canal networks. The results might also find use in academia, in fields that focus on training of irrigation engineers and practitioners. Below is the abstract from the paper.

Non-peer reviewed article
The non-peer reviewed article was published in the 7th edition of the AgrIng Bulletin, a newsletter published two times every year by the Agricultural Research Council-Natural Resources and Engineering, Agricultural Engineering (ARC-NRE/AE) Silverton campus. The article was published as "*Mutema, M (2022) Quantifying Irrigation water losses is important for improved water use. AgrIng Bulletin Volume 1 Issue 7, December 2021*." The newsletter is circulated widely in South Africa with at least 56 direct recipients across the country. It is hoped the direct recipients further circulate the newsletter. The stakeholders on the receiving list include farmer organisations, irrigation schemes, government departments, academic institutions, funding agencies with an interest in irrigation water and private consultancies. The article highlights the challenges associate with the current condition state of canals in the major irrigation schemes and how this possibly links to water losses. It includes to current efforts aimed at quantifying the water losses through the Water Administration Systems applied to most major irrigation schemes in the country and involvement of ARC-NRE. It also covers some of

the challenges associated with physical measurements in the canals, and finally some of the losses which are difficult to quantify including water poaching and direct consumption by livestock.

The article only focuses on the efforts of NB Systems (developers of the Water Administration System) and ARC-NRE Agricultural Engineering. There is probably many other entities trying to achieve the same in other corners of the country, which are not known to the current partnership funded by the Water Research Commission. The aim of the partnership is to develop a framework for reporting the canal water losses, which will be applied on all the irrigation schemes in the country. The aim of the article published in the AgrIng Bulleting was to raise awareness on the need to quantify water losses in irrigation scheme canals. This is then anticipated to stimulate greater interest culminating into actions among a wide spectrum of stakeholders in irrigation systems and irrigation water management. The article is inserted below for ease of reference.

7.3.3.2 Oral presentations

The presentation at the global summit took place on 25 August 2022 (Appendix F), while presentation at the local symposium took place on 21 September 2022 (Appendix G). The two oral presentations focussed on the Irri-Drop Report as a framework for quantifying and reporting on water losses from canals. In fact, the presentations only covered the Water Balance Report (WBR) component of the Irri-Drop Report, which mirrors the WUEAR of the WAS programme. The other modules of the Irri-Drop Report framework could not be covered because they were not yet ready.

At the Global Sumit on Agriculture and Organic Farming, the participants consisted of mainly scientists from many different disciplines and agricultural practitioners. It was not easy to pick the total number of attendees and where they came from. On the other hand, the participants at the SAIAE symposium were mainly from South Africa with a few dignitaries from abroad. The participants mainly came from local universities and government departments with an interest in the broad field of agricultural engineering.

7.4 Discussion

The online training session for irrigation scheme managers was successful, although Vaalharts irrigation scheme did not show up. This particular organisation had taken a similar training in the months preceding the training facilitated by the project. Moreover, Vaalharts WUA are proficient in the WUEAR because they one of the pioneers of the WAS program and have been consistently uploading their reports for years. No negative feedback was received during and after the training session. Online training has proven to be a very effective and productive method for training and should be encouraged. However, there are still some challenges associated with access of suitable equipment by participants and also poor internet connect connectivity in some parts of the country. These factors had negative effect on the invitation list for the training. Experience elsewhere has shown that one-on-one training remains the best mode of training and should always be prioritized.

Opportunities for knowledge dissemination were restricted by the Covid-19 pandemic during a greater part of the life of the project. At some point there was a global total ban on gatherings of any sort. Even when the bans were lifted, some countries remained shut as a strategy to continue restricting the potential recurrence of the pandemic. Under these circumstances, conferences that required physical presence were hardly accessible to people from developing countries. Online platforms opened much later for conferences and symposia. In many instances, the online platforms were over-subscribed which further limited chances for the project team participation. However, the project team managed to participate in two conferences: one international albeit virtually and another one a local conference. Nevertheless, the project will continue to share their research experiences and results from the project that yielded the Irri-Drop Report well beyond the life of the current project through participation at conferences if opportunities arise.

With the wrapping up of the project, more peer reviewed and non-peer reviewed publications are expected from the project team. The remaining postgraduate learner is expected to publish at least one peer reviewed article on the water losses from irrigation scheme canals. On the other hand, the project researchers will publish a peer reviewed paper on literature review of the frameworks used for assessing and reporting on water use efficiencies from irrigation and other water-based systems.

7.5 Conclusions

While capacity development during the life of the project focussed on irrigation scheme water managers from a few irrigation schemes, the activity will increase to include direct users of the Irri-Drop Report (the Department of Water and sanitation) and water managers at all major irrigation schemes in the country. This will happen when the tool is ready to roll out. Other stakeholders with vested interests in the tool shall also be trained. They rest of the stakeholders shall be reached by means of awareness raising campaigns through oral presentations at appropriate fora and publications through the relevant media. The scientific community shall be targeted through peer reviewed journals, while irrigators and other practitioners shall be targeted through magazines and bulletins.

CHAPTER 8: CONCLUSIONS & RECOMMENDATIONS

8.1 Conclusions

Several conclusions can be drawn out of the current project but there are two that stand. The first one is that it is feasible to develop an incentive-based tool, the Irri-Drop Report, for the Department of Water and Sanitation (DWS) to use in assessing the water conveyance performance of irrigation schemes in the country. The tool is in the same mould as the No Drop Report, which DWS is already using on local governments across the country. Thus, the Irri-Drop Report is the tool that DWS can use to encourage high water conveyance efficiency among irrigation schemes and to enhance irrigation scheme preparedness to deal with recurrent and emergent water losses. The seven components identified for the Irri-Drop Report conceptual framework are geared at assessing water canal network water losses on the basis of available data on water releases and deliveries to irrigators, and the competencies of the irrigation schemes in managing the water schemes. In the later thrust, the Irri-Drop Report assesses staff compliments (comparing filled vacancies against staff requirements), technical skills (qualifications and job experiences of the position holders), water management and maintenance plans, and enforcement of regulations, and adequacy of budgets.

The second conclusion is that global water loss data reported by the Water Use Efficiency Accounting Report (WUEAR) of the Water Administration System (WAS) program (www.wateradmin.co.za) are adequate and can be used to initiate Irri-Drop Reports at irrigation schemes where water release and delivery to farmers and other users are already being collected. The Irri-Drop Reports can be initiated with only this data in place because the Water Balance Report component of the Irri-Drop Report is the minimum requirement. Global water loss data is concluded to be adequate because it is currently not practically feasible to disaggregate the major canal water loss types (identified by the project as: seepage, leakage, evaporation and operational losses) under normal operation using available technology. Nevertheless, the other Irri-Drop Report framework components still need to be implemented at the irrigation schemes for more comprehensive assessment and rating of their performance and readiness to deal with water losses.

8.2 Innovations and Products

The main innovation generated by the project is the roadmap conceptual framework for the Irri-Drop Report, which is described in chapter 6 of the current report. The Irri-Drop Report consists of seven components, namely: the Water Balance Report (*WBR*), Condition Assessment Report (*ConAs*), Water management Plan (*WMP*), Maintenance Plan (*ManPlan*), Technical Competency Report (*TechCom*), Budgeting Report (*BudgetA*), and Credibility and Regulation Enforcement Report (*CredReg*). The first two components (*WBR* and *ConAs*) assess the performance and condition of the physical infrastructure, respectively. *WBR* assesses conveyance efficiency by accounting for water release and delivery volumes and then computing losses on the canal network as the difference between the two after accounting for other abstractions. *ConAs* assesses the condition of the physical infrastructure because condition affects water losses The other components of the Irri-Drop Report assess non-physical issues that measure the general readiness of the irrigation schemes to deal with water losses from the canal networks. *WMP* and *ManPlan* assess the adequacy of human resource and maintenance plans and implementation. The plans are also compared against expected standards. *TechCom* assesses the skills base (qualifications and job experiences) of staffers in terms of how they measure against expectations for the kind of work involved to ensure high water conveyance efficiency. *BudgetA* assesses the adequacy of budget/s in place to implement and sustain the irrigation scheme plans. Lastly, *CredReg* assesses the credibility of procedures and processes (regulation enforcement, data collection, handling, analysis and storage, etc.) in place.

Each component of the Irri-Drop Report framework is unique with its own set of factors to be evaluated during the assessments. The outputs of the factor assessments are weighted and used to generate component indices. The component indices are also weighted and used to the Irri-Drop Report Index for an irrigation scheme for a specific assessment period. Weighting is a very important procedure because factors, and also the components, do not exert similar levels of influence on the outcomes of assessments. The Irri-Drop Report is earmarked for use by the Department of Water and Sanitation on irrigation schemes in the same way they use the No-Drop on local governments.

Another key highlight from the project is the Water Balance Report (*WBR*) component of the roadmap conceptual framework to the Irri-Drop Report, which was developed based on the water release, delivery and loss data reported by the Water Use Efficiency Accounting Report (WUEAR) of the Water Administration System (WAS) program. The WBR recognises the impracticality of disaggregating major water loss types from a canal network in normal operation due to lack of appropriate technology to achieve that. Therefore, global water losses (which are a sum of seepage, leakage, evaporation and operational losses) for canal networks and/or their subareas are adequate for *WBR* at irrigation schemes. The global water losses for Vaalharts and Loskop irrigation schemes for two water years (2019/2020 and 2020/2021) and found to be 19.4 and 18.7%, respectively, for Vaalharts, and 25.2 and 25.1%, respectively, for Loskop, which translated to 81.9 and 67.6 Mm^3/yr for Vaalharts and 34.7 and 35.6 Mm^3/yr for Loskop. These are big losses for a water scarce country; however, these water loss quantities need to be evaluated in their proper contexts by considering all factors of influence including the sizes of the irrigation schemes and the many factors considered in the literature review. Moreover, a full understanding of the state of water losses at an irrigation scheme can only be grasped by considering historical water loss reports outside the current project life span.

8.3 Recommendations

Capacity development of irrigation scheme water managers is important for continuous improvements in water conveyance efficiency at the irrigation schemes. A lot of technological developments continue to take place, some of them, with a direct bearing on how data should be managed. It was concluded from the training that was facilitated by the project that more frequent and shorter training sessions would be handy as the water managers grapple with many other chores on a daily basis. The trainings should always focus on ways to harness new technologies. The Department of Water and Sanitation, as the custodian of water resources and end-user of the Irri-Drop Report when it is ready, is recommended for capacity development. Competent people who can comprehensively interpret the reports generated and uploaded on the online platforms can make better use of the information for policy and decision making.

While the current project deciphered the state of water losses and water conveyance efficiency at irrigation scheme canal network level, the same could not be achieved for the different subareas of the canal networks due to lack of measurement stations and equipment at desired positions. Therefore, it is recommended for irrigation schemes to intensify data collection by installing new gauging stations and accurate measuring equipment at positions of canal networks that distinctly define the subareas into, for example, main, secondary, tertiary, and community canals. Automatic data loggers are recommended as the means for data collection because they reduce labour requirements and human-induced errors when they handle large data. Analysis of water losses at subarea level offers opportunities for identifying problem areas within canal networks, which can significantly enhance maintenance plans and budgets.

If the recommendation for expanded data collection is adopted, then it would also be recommended that the Water Balance Report (WBR) component of the Irri-Drop Report framework be refined to accommodate the new data collection structure. Moreover, further work is recommended on this component until it gets to a stage when assessment indices can be generated. Moreover, the Irri-Drop Report framework as a tool is still work in progress as its other components are yet to be comprehensively developed. The other recommendation relating to the Irri-Drop Report and its components is a need for a host website where all the reports and data shall be posted for access by the stakeholders.

It is also recommended that the Irri-Drop Report concept be expanded to, at least, include water conveyance networks on the farms. The call for the current project directed focus on the water conveyance network only, which means other water infrastructure on the irrigation schemes were left out. This recommendation is important because irrigation water losses on the farmers' fields are also significant. The Irri-Drop Report Index for an irrigation scheme would also be more comprehensive if the water application efficiency on the farmers' fields are included. The other recommendations for improved water conveyance efficiency at the irrigation schemes are obvious things that people often ignore. For instance, improper management of water distribution systems such as failure by water bailiffs to stick to the prescribed times for opening and closing he sluice gates could be a source of big water losses from the canal network. There are many reasons water bailiffs fail to adhere to the times, but in most circumstances, it is to the benefit farmers otherwise there would be outcries as irrigators would not accept less water than they ordered. The best way to deal with such operational losses would be to at least install automatic measurement and control devices at the offtake points. Another recommendation to irrigation schemes is to adhere to infrastructural maintenance schedules, especially to attend to leakage losses from damaged canals and sluices. The gaps between slabs that are used to construct the canal walls and beds need to be sealed using appropriate materials such as bitumen. The lining materials also need to be replaced timeously when worn out or damaged.

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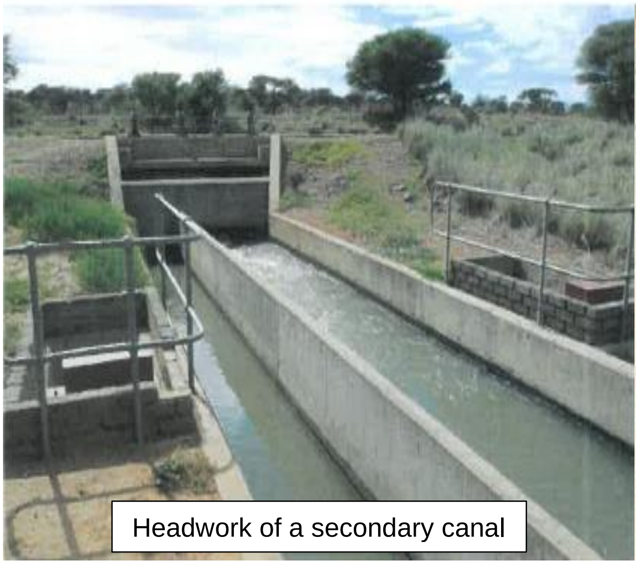
APPENDIX A: Selected canal sections from Vaalharts

Offtake point from a main canal section

Section of a main canal in the upper reach



Headwork of a secondary canal

Electronic data logger box at the inlet of a secondary canal

Grass growing in a main canal section

Section of a main canal which is badly silted


Secondary canal leaking badly


Big hole and cracks on main canal wall


Tree encroaching into the main canal


Tertiary canal kept well

APPENDIX B: Selected canal sections from Loskop

Worn out secondary

Broken secondary canal

Worn out and heavily leaking secondary canal

A lot of algae in tertiary canal

A lot of grass growing in secondary

A lot of grass growing in tertiary canal


Grass choking a tertiary canal


Badly leaking tertiary canal


Grassy and badly leaking tertiary canal

APPENDIX C: Details of postgraduate learners on the project

Name of student:	*Pembelani Sivhagi*
Gender:	*Male*
Nationality:	*South African*
Institution/University:	*University of Venda*
Year of registration:	*2020*
Degree program:	*MSc Agriculture (Agricultural Mechanization)*
Research topic:	*Condition assessment of the conveyance canal systems at Loskop and Vaalharts irrigation schemes*

Name of student:	*Mosibudi C Sekgala*
Gender:	*Female*
Nationality:	*South African*
Institution/University:	*University of Venda*
Year of registration:	*2020*
Degree program:	*MSc Agriculture (Agricultural Mechanization)*
Research topic:	*Assessment of water losses from the canal systems at Loskop and Vaalharts irrigation schemes*

APPENDIX D: Literature review paper published in Irrigation & Drainage

Received: 27 April 2021 | Revised: 21 July 2021 | Accepted: 24 January 2022
DOI: 10.1002/ird.2689

REVIEW ARTICLE

WILEY

Review of factors affecting canal water losses based on a meta-analysis of worldwide data

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Water Research Commission, Grant/Award Number: WRC K5/2970/4

Abstract

Irrigation water conveyance relies heavily on canal networks because they transport the water cheaply. However, water losses are high, which is a major concern in the face of soaring demand and dwindling new water sources. While researchers have investigated canal water losses and water loss types at irrigation scheme level, their variability and the main factors of influence at a global scale are still not clear. Thus, this study aims to elucidate the effects of canal water flow and soil characteristics on water losses globally. Data for 1388 canal reaches from 45 published articles are used. The results confirm that evaporation is so negligibly smaller than seepage and other water loss types that it can safely be ignored when analysing major water losses from canals. The study results also confirm that canal water losses decrease with soil clay content, due to decreasing permeability. The methods used for assessing water losses show significant influence on water losses; for example, the inflow–outflow method exhibits significantly higher water losses than the ponding technique. The current study results also show that canal shape, wetted perimeter and wetted area have a significant influence on water losses. It can be concluded from the study results that consideration of the physical mechanisms of water losses and different water loss types involved is important in future studies. It is recommended that future canal water loss studies, especially those focusing on losses via evaporation, also assess the effects of factors such as canal embankment height and depth of freeboard on the losses. These results are important for water scientists, engineers and practitioners.

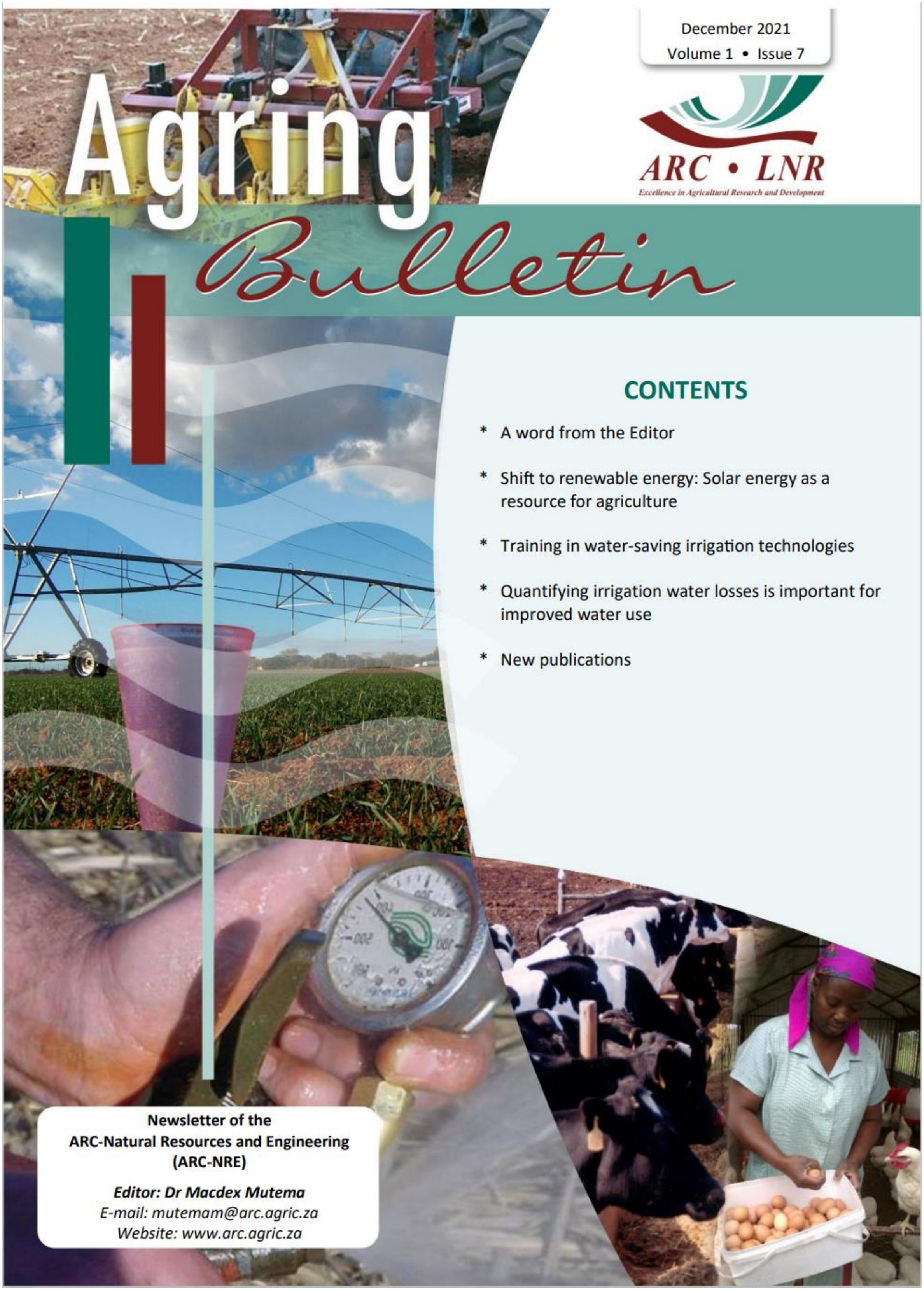
KEYWORDS
canals, conveyance efficiency, maintenance, water losses, waterlogging

Résumé

Le transport d'eau d'irrigation dépend fortement des réseaux de canaux parce qu'ils transportent l'eau à bon marché. Cependant, les pertes d'eau sont élevées, ce qui est une préoccupation majeure face à la hausse de la

Article title in French: Examen des facteurs qui influent sur les pertes d'eau dans les canaux à partir d'une méta-analyse des données mondiales.

APPENDIX E: Article published in AgrIng Bulletin


December 2021
Volume 1 • Issue 7

ARC • LNR
Excellence in Agricultural Research and Development

Agring Bulletin

CONTENTS

Newsletter of the
ARC-Natural Resources and Engineering
(ARC-NRE)

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Quantifying irrigation water losses is important for improved water use - by Dr Macdex Mutema

It is common knowledge that agriculture consumes the bulk of water used in countries that strongly depend on agriculture for food, jobs and poverty reduction. Most of this water goes into irrigated crop production. Unfortunately, irrigation systems waste a lot of water. In South Africa, they are estimated to waste around 43% of the water supplied. It is now mandatory in this country that irrigation systems report on water usage and losses. Irrigation water losses occur at different levels of the irrigation systems, but there is growing interest in losses that occur during conveyance and at the field level.

Conveyance water losses are those losses that occur when the water is in transit from sources (e.g. dams and rivers) to the intended destinations (i.e. farms, where the water is used to irrigate crops). A significant number of big irrigation schemes in South Africa use canals to move water from the sources to the farms. Water is lost along the canals through seepage, leakage, evaporation and other means. Most canals at the irrigation schemes are in a deteriorated condition due to *inter alia* old age and poor maintenance, exacerbating the water losses.

***Figure 1:** Photos illustrating the condition of some sections of the canals at Vaalharts and Loskop irrigation schemes. Sections showing deteriorated conditions were found across all canal levels, i.e. main, secondary and tertiary canals.*

Quantifying irrigation water losses article continued from previous page …

While most South African irrigation scheme canals are acknowledged to be aged and probably losing a lot of water, there is no initiative tracking these losses continuously. The Water Administration System (www.wateradmin.co.za) that reports water losses from irrigation systems in South Africa only records the total losses, i.e. lumping together transit losses and those at the farm level. That makes it difficult to allocate the canal share of the losses, which only succeeds in keeping the water managers at the irrigation schemes relaxed because any losses observed can easily be passed on to the water users. Unfortunately, with that relaxation also comes a lack of knowledge on priority canal components to target for upgrading and/or maintenance. The current practice is to target dilapidated sections for repairs.

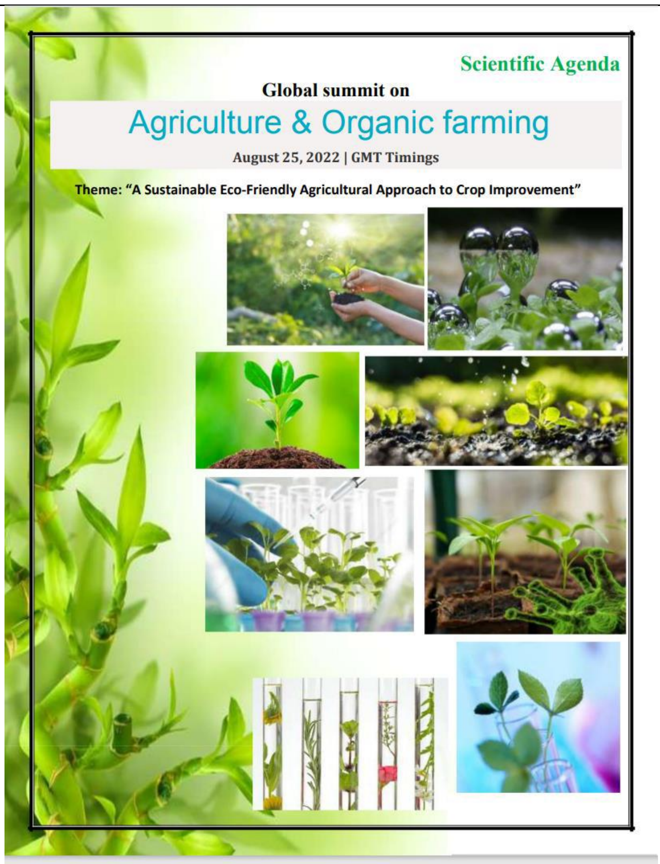
Information on canal water losses is not only important to water managers, but also to farmers and other water users who pay for the water losses, either directly or indirectly.

ARC-NRE is implementing a project at the Vaalharts and Loskop irrigation schemes, funded by the Water Research Commission. The project aims to develop a framework for reporting water losses from irrigation scheme canals. As already alluded to, data on water losses from canals is not readily available, which stifles the process of developing the framework. The Water Administration System cannot provide the data required. Therefore, ARC-NRE is engaged in an ongoing campaign to perform manual flow measurements from the canals with a view to generating information that will shed some light on the quantitative water losses from the different canal levels at the irrigation schemes. A water balance approach will be adopted in determining the water losses.

Manual measurement of water flow in the canals using hand-held flow meters faces some major challenges. The first hurdle is to find a way of dealing with the strong water flows occurring at some points in the canals. Flow depths can be greater than 2 m in the main canals, where flow velocities can exceed 2 m/s which creates a very strong force on the measuring equipment.

***Figure 2:** Photos showing an improvised support system to the flow meter pole (left) and the broken wooden support (right). The breakage was caused by the strong water flow in the main canal at Vaalharts irrigation scheme. The flow depth was greater than 2 m and the flow velocity was almost 2 m/s.*

APPENDIX F: Programme for the Global Sumit on Agriculture & organic farming



GMT Time	Name	Title
		Keynote Sessions
08:15-08:45	**J. C. Tarafdar** Central Arid Zone Research Institute, India	Microbial Synthesized Nanoparticles and Its Use in Agriculture
08:45-09:15	**Shuisen Chen** Guangzhou Institute of Geography, china	Remote Sensing Monitoring Methods for Agricultural Typhoon Disasters: A Case Study of South China
		Poster Presentations
09:15- 09:45	**ONG Socheath** Royal university of Agriculture, Cambodia	Efficacy Of Bacillus Subtilis, Trichoderma Harzianum, Kocide For Controlliing The Bacterial Wilt On Tomato
09:45- 10:15	**Rajwinder kaur** Department Of Soil And Water Conservation, India	Efficient Irrigation Management For Sustainability Of Agriculture And Environment
		Keynote Sessions
10:15- 10:45	**Maria Beihaghi** Kavian Institute of Higher Education, Mashhad, Iran	In silico analysis and in planta production of recombinant ccl21/IL1β protein and characterization of its in vitro anti-tumor and immunogenic activity
10:45- 11:45	**Amritpal Kaur** Guru Nanak Dev University, India	Preparation of ready-to-cook carrot halwa from dried carrot shreds
		Oral Sessions
12:00- 12:30	**Lev Elkonin** Federal Centre of Agriculture Research, Russia	Improvement of nutritional value of sorghum grain using site-directed mutagenesis of kafirin genes
12:30- 13:00	**Macdex Mutema** Agricultural Research Council-Natural Resources and Engineering, South Africa	Irri Drop Report: Framework for quantifying and reporting canal water losses
13:00- 13:30	**Neha Sharma** IILM College of Engineering and Technology, India	Serological Identification, In silico comparison and Validation of Partial Coat Protein (CP) Gene of Zucchini Yellow Mosaic Virus (ZYMV) infecting summer squash in India
		Keynote Sessions
13:30- 14:00	**Magdalena Szymura** Wrocław University of Environmental and Life Sciences, Poland	Environment-friendly restoration of land degraded by invasive plants
14:00- 14:30	**George Kantor** Carnegie Mellon University Robotics Institute, USA	Artificial Intelligence and Robotics: Current and Future Tools for Organic Agriculture

APPENDIX G: Programme for the SAIAE symposium

APPENDIX H: Attendance list for the water managers' capacity development training session

Participants to the water managers training

Attendance list

Name & Surname	Company
Nico Benade	NB Systems
Nicolaas Benade	NB Systems
Macdex Mutema	ARC
Felix Reinders	ARC
Stephanus Vorster	ARC
Khumbulani Dhavu	ARC
Rishi Fakeer	Sand-Vet WUA
Joseline Kriel	Kakamas WUA
Annemarie Bezuidenhoudt	Loskop IB
Edward Ford	Oranje-Riet WUA
Norman Kok	Oranje-Riet WUA