Evaluation of Irrigation System Operation and Management Using the MASSCOTE Approach: A Case Study of Bura Irrigation Scheme, Kenya

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Abstract: ***The main aim of this study has been to assess the performance of Bura Irrigation and Settlement Scheme using the MASSCOTE approach and advise on some improvement options for the Bura Irrigation & Settlement Scheme. Furthermore, the study was also aimed at evaluating the applicability of MASSCOTE approach in assessment of its current performance and suggesting possible changes and modifications required. Field observations, oral farmer and staff interviews helped understand the functioning of the irrigation scheme. DUFLOW model was used to schematize the canal network and obtained operational requirements of the structures while the water balance was analyzed with CROPWAT 8.0 model. The findings revealed that the water use efficiency is currently at average of 7,056 kg/m^3 and can be improved to 18,910kg/m^3 by improving irrigation efficiency. By improving the field irrigation efficiency from 9% to over 75%, more water would be available and the area under irrigation can be increased from the current 2500ha to 6700ha representing an increase of 168% of irrigated land if farmers continue the conventional maize cultivation technique (surface irrigation). The improvement options for the irrigation scheme is the modernization by partial lining of the canals and reshaping of the tertiary and field canals at a cost of million US$ 7,355,829 (According to NIB cost for construction of the 26km gravity canal and rehabilitation of the existing 64km canal, 2013). This can also be done through construction of a gravity canal upstream of the existing pumping station. This will save the money currently being used for fueling the two pumps at Nanighi costing at US$ 180,411 annually and will in a long way realize the losses the irrigation scheme has been going through since it was revived. The study recommended that the use of MASSCOTE approach for performance assessment and modernization proves to be vital and effective, therefore it needs to be widely used in the Bura irrigation and settlement scheme. It is believed that investment on improvements of physical infrastructure, management and operation of the schemes at all levels will bring substantial improvement of performance of all the Public irrigation scheme. Further studies should be done on all the blocks of the Bura Irrigation and Settlement Scheme with more focus on the current performance of the main canals, secondary and tertiary canals and advise on the general efficiency of irrigation water use.***

Keywords: Irrigation and Drainage Networks, Masscote, Rapid Appraisal Procedure, Perturbation

1. Introduction

The ever-growing population in the world is estimated to be nearly one billion every decade worldwide and is the greatest today hence causing a lot of pressure on the available land water resources. This has caused challenges such as food insecurity in the developing countries like Kenya. Irrigation and drainage networks play a major role in mitigating these challenges. The country has spent a huge percentage of the public budget in the recent years in order to ensure food security. Optimal operation of the irrigation infrastructure needs continuous supervision, application of the emerging new technologies and techniques and also provision of the required funds to implement proposed programs. The development of the existing physical irrigation infrastructure is one of the major challenges and in most cases, the social conditions and traditional operation systems are ignored. Consequently, the developed systems have been found to have weaknesses, which cause problems in optimal operation of the irrigation networks. These among others lead to failure in achieving expected goals of high yield not only at the farm level but also at national level. Low water distribution efficiency, dilapidated irrigation infrastructure, fragmentation of agricultural land, lack of empowerment to farmers, lack of proper irrigation practices, inappropriate crop pattern and density of cultivation and inappropriate water tariffs are the most important reasons for low productivity at the farm level. Therefore, there is need for proper diagnosis of the infrastructure of operation, maintenance and management in order to improve the current situation.

Bura irrigation is the second largest Public Irrigation scheme in Kenya after MweaTebere irrigation scheme covering 6700 hectares and is located in Tana River County, within coordinates 39° 20’’E; & 30’’00°45’’S and 1°30’’S; with an elevation of 105m. investigations have shown that despite huge investments by the national government, its performance is far from the optimal in comparison with other systems. One of the methods of evaluation that have been used in this study and which have been recommended by FAO is the Masscote (Mapping System and Services for

Canal Operation Techniques) methodology. This approach includes a multi-step process such as rapid appraisal, mapping the system capacity and sensitivity, perturbation, water supply operation and maintenance costs etc. by implementing this method in a step by step manner, the complexity of working through the elements would become simpler and the results of each step would be documented in the conclusion. Through the Masscote methodology, the performance evaluation of Bura irrigation system was done. The detailed description of this method and results of investigation will be discussed here.

2. Project Description

2.1 Study area

The Bura Irrigation and Settlement scheme with a gross command area of 6700ha and a net command area of 2500ha (Figure 1) is the second largest irrigation scheme in Kenya which has been in operation since its inception in 1977. The scheme abstracts irrigation water from River Tana about 50 Km by pumping using diesel fueled generators and pump sets with a discharge capacity of 2.7m^3/sec. Once the irrigation water is lifted from the river, it flows by gravity through all the distribution system to the farms where farmers use siphons for applying in their fields. The annual irrigation supply per unit command area is 12,000m^3/ha while the annual irrigation supply per unit irrigated area is 49,180m3/ha. The irrigation water is channeled through the 50km main canal which has a conveyance efficiency of 62%. The main crops grown within the irrigation scheme are commercial maize, seed maize and cereals. Research for rice which will sustain the current situation is being introduced to supplement the maize crop which is the main crop after the collapse of the cotton industry. The irrigation scheme has a network of road, 24km of secondary canals and 40.5km of tertiary canals. The main characteristics of the BISS are illustrated in table 1.

Table 1: Main Characteristics of Bura Irrigation & Settlement Scheme

1	Gross command area (ha)	6,700
2	Net command area (ha)	2,500
3	Secondary Canals (no./length in km)	8/45
4	Tertiary Canals (no./length in km)	16/40.5
5	Main canal off-takes to secondary canal (no)	8
6	Main canal and secondary canal offtakes to tertiary canal (no)	19
7	Direct field off-takes on tertiary canals (no)	4
8	Drainage system (length in km)	50
9	Diversion and intake structures (Headworks)	1
10	Main Pumping station (no of pumps)	2

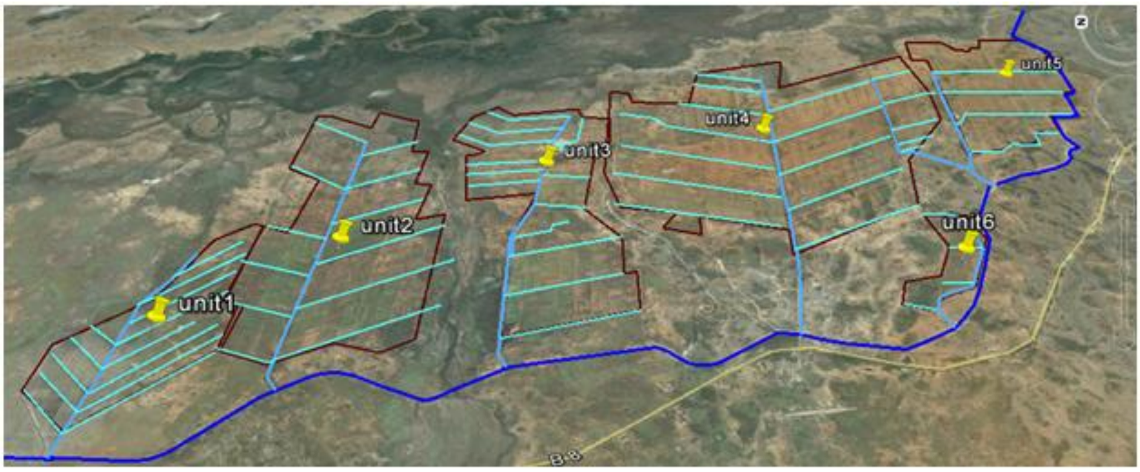


Figure 1: Digitized map of Bura Irrigation & Settlement Scheme

3. Research Methodology

3.1 Introduction

Evaluation of the existing performance of the irrigation canal systems operation and management was conducted between November 2015 and June 2017 using the Rapid Appraisal Procedure (RAP). The outcome of the RAP evaluation process was utilized to generate and advise on the improvement options for the BISS canal systems and services.

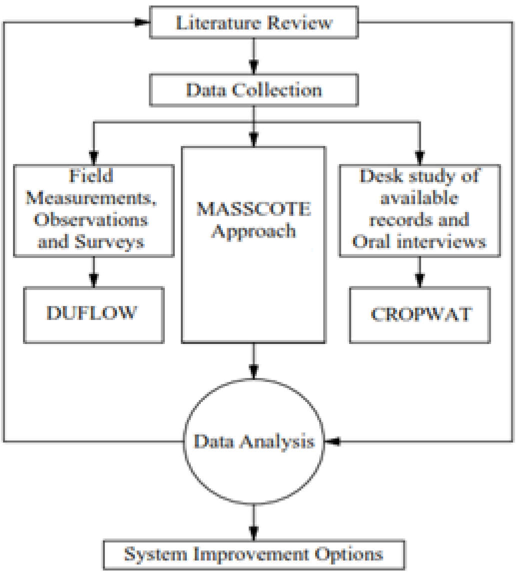


Figure 2: Methodology conceptual framework

Data collection

The data collection and analysis in this conceptual framework were as follows; -

Questioners and interviews

The main data collection was done in the office and in the field. These were either through interviews or through records which has been stored with the NIB offices. This kind of data was ranging from rainfall data which was obtained at the proposed research area. The other batch of data like the fuel consumptions and other related data were obtained both from the office and at the field office in Nanighi.

Field measurements

Field measurements, observations and surveys were analyzed by DUFLOW software. The field surveys were done through physical measurements in the canals in question to get the real lengths and the water flows for further determination of critical data for use in the spreadsheets

Desk study

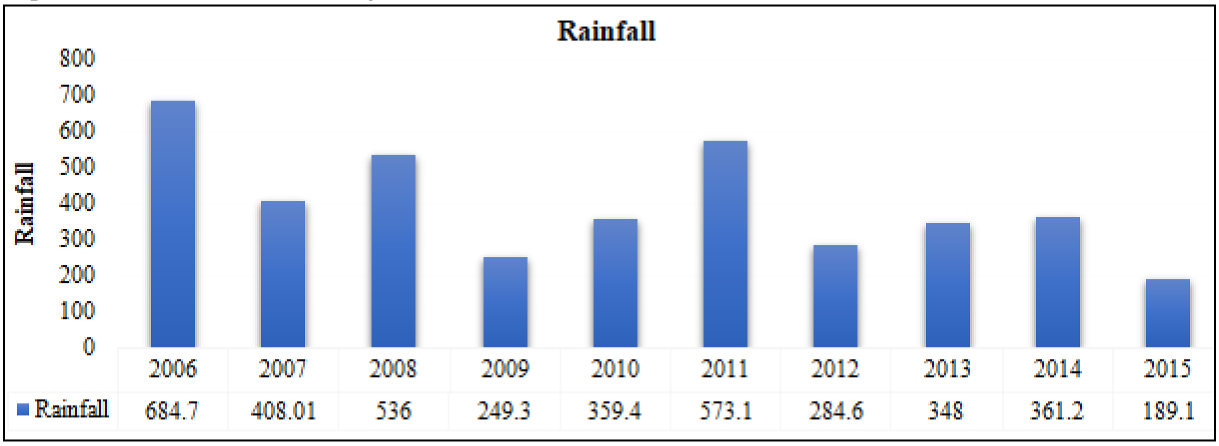
Desk study of the available records and oral interviews were analyzed using the CROP 8.0 model. This type of data includes the agronomic data, the financial data for analysis of the O&M of the project and other related data.

The systems analysis was carried out and the compiled data was fed into the RAP excel spread sheets and results were analyzed with the aim of the getting options for BISS system improvement'

Climatic data:

Month	Min temperature (^oC)	Max temp (^oC)	Relative humidity (%)	Wind speed (km day$^{-1)}$	Avg. sun shine (hrs)	Avg. radiation (MJm^{-2} day	ETo (mm day^{-1})
January	24.8	34.9	44.6	6.1	7.7	19.6	3.77
February	24.8	33.6	43.2	5.8	6.8	22.0	3.72
March	25.0	33.8	68.4	35.4	7.9	16.9	4.64
April	25.3	34.2	48.2	4.8	7.9	19.0	4.08
May	24.8	31.7	49.5	5.0	7.3	17.0	3.61
June	30.5	25.5	48	14.1	6.9	16	3.50
July	22.7	26.2	46.9	346.8	6.4	16.4	6.16
August	22.5	26.6	43	443.4	7.4	18.5	7.25
September	21.6	26.2	47.9	462.5	7.3	18.1	7.01
October	22.2	26.1	41.6	484.1	6.8	19.0	7.55
November	23.4	26.6	49.9	243.8	6.9	21.2	5.45
December	22.9	32.8	48.3	1.4	7.2	20.1	3.36
Average	23.8	30.3	48	171	7.2	19.8	5.01

Rainfall patterns in Tana River County:



Conveyance efficiency

The efficiencies of irrigation schemes are computed by conducting field measurements. To measure the conveyance efficiency of the schemes, the discharge is measured at different points. The measurement starts just after the headworks of Nanighi and measurements continues at all points with permanently placed measuring structures which mainly consists of broad crested weirs, Parshall flumes, gauged drop structures and double orifices and also where the primary canals are branching to the secondary canals.

3.2 Evaluation methodology

The technique was used for evaluating the irrigation performance and was mainly to describe the water conveyance of the main canal and the subsequent secondary canals. The main decisions on which canals to be studied and which one to omit was arrived based on:

- Water source
- Extensive size of the irrigation scheme and also the accessibility of all the canals in the scheme

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- Lack of measuring and control structures in some canals in the scheme
- Channel geometry
- Variables such as soil type, location within the maize belt
- Slope and lateral length of the canals

Due to the extensiveness of the irrigation scheme, only four canals comprising of all the classes was studied. These were selected for study on the basis of the availability of the discharge measuring facilities along the canals. This made the study more convenient and less tiresome.

The figure below describes the schematic arrangement of the scheme from the intake at Nanighi through the three active irrigation commands (Bura, Chewele and Pumwani), which was used in the selection of which canal to be evaluated for conveyance and distribution performance.

The relationship was found between the amount of water required per crop and the entire acreage of the area covered by BISS. In trying to evaluate conveyance losses, the amount of water supplied was compared with the actual water consumed by the crops in the irrigation scheme. By doing this, any discrepancies was identified and necessary conclusions was arrived at.
The amount of water demanded by the specific crops to be irrigated, which is called the Crop Water Requirement (CWR), was established first.

The total irrigation water requirements is a sum of the CWR and the losses either in the field or during conveyance from the abstraction or intake point. The sum of the two can be termed as the irrigation water demand.

Losses = Total Demand Q – CWR

Comparing the gross demand and the gross supply by the canals, the losses was also established.

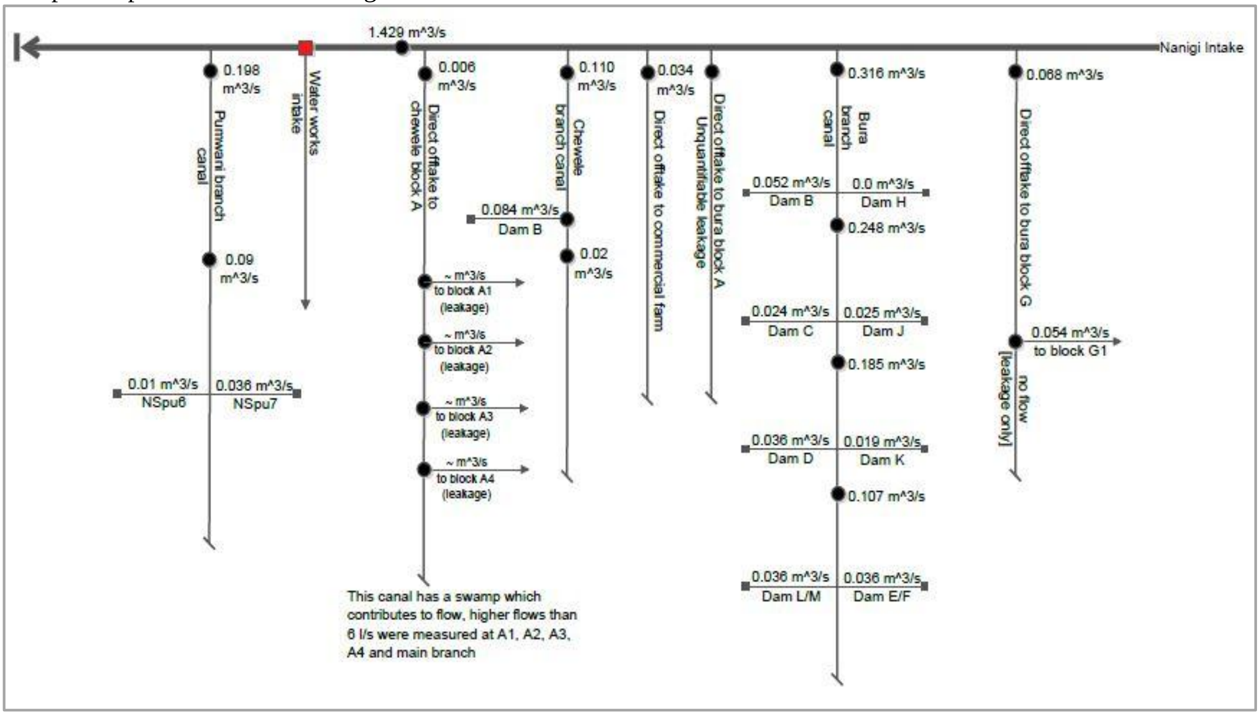

Figure 3: BISS Flow diagram

Crop Water Requirement (C.W.R.)
Reference Evapotranspiration. (Eto)
This represents the potential evaporation of a well-watered grass crop. The water needs of other crops are directly linked to this climatic parameter. The model employs the Penman-Monteith method to determine ETo and utilizes the following climatic data which will be collected from the Bura Irrigation and settlement scheme research centre (Meteorological data collection centre) to be used in this study.

- Temperature
- Humidity
- Sunshine
- Wind speed
- Rainfall data

The model was used to analyze long term rainfall data from the BISS station and to compute the effective rainfall that will directly contribute to the CWR after rainfall losses due to surface run-off and deep percolation has been accounted for. In the computation of the effective rainfall the rainfall in wet, normal and dry years i.e. rainfall with a respectively 20, 50, 80% probability of exceedance was determined.

The different steps involved in processing the rainfall data are; -
(i) Tabulate yearly rainfall totals for a given period
(ii) Arrange data in descending order
(iii) Tabulate plotting position according to:

$$\mathbf{F\alpha} = \frac{\mathbf{100(i)}}{\mathbf{n+1}}$$

Where:
n=number of records

i= rank number
Fα=plotting position
(iv) Plot values on log-normal scale and obtain logarithmic regression equation.
(v) Calculate year values at 20, 50 and 80% probability. P80, 950 AND P20.
(vi) Determine monthly values for the dry and wet year according to the following relationship.

$\mathbf{P_{idry}} = \mathbf{P_{iav}} * (\mathbf{Pdry/Pav})$

Where:
$\mathbf{P_{iav}}$ = average monthly rainfall for month i
$\mathbf{P_{idry}}$ = monthly rainfall dry year for month i
$\mathbf{P_{av}}$ = average yearly rainfall
$\mathbf{P_{dry}}$ = yearly rainfall at 80% probability of exceedance

Canal flow measurements

In this study, an inflow-outflow method was used, which showed the loss occurring during water conveyance in the open canals, but at the same time allowed sufficiently accurate measurements. With this method, the following formula was used to calculate water conveyance loss in defined canal sections of sufficient length:

$\mathbf{S = Q_i - Q_o}$

Where:
S is conveyance loss in the canal segment (l s^{-1}),
$\mathbf{Q_i}$ is inflow to the segment (l s^{-1}),
$\mathbf{Q_o}$ is outflow from the segment (l s^{-1}),

Velocity

Velocities were measured for each subsection by the application of the 2-point method, i.e. at 0.2d and 0.8d, where d signifies the depth of the sub-section. The average of these two velocities was found from the following relationship;

$$\mathbf{V=(V_1+V_2)/2}$$

Where V1 and V2 denote the velocities at 0.2d and 0.8d respectively.

For shallow water with a depth >0.5m, the six-tenths method, using a calibrated propeller current meter was used. Flow velocity at the measurement points was calculated in relation to the revolutions of an Ott-type current meter over a period of 60 seconds. Flow velocity was calculated using the following equation:

$$\boldsymbol{v = 0.2541n - 0.014}$$

Where;
0.2541- is the coefficient of the propeller type and
0.014- is the coefficient of the friction of the propeller,
n - is the number of revolutions per second of the propeller, and
v - is the flow velocity of the water (m s-1).

Canal flow measurements obtained by use of current metre (Discharge measurements)

Distance [m]	Depth [m]	Time [sec]	Revolutions	Rev/sec	Velocity [m/s]	Width	Discharge [m^3/s]
0.00	0.74	30	109	3.63	0.402		0.000
0.40	0.74	30	114	3.80	0.419	0.40	0.124
0.80	0.74	30	102	3.40	0.377	0.40	0.112
1.20	0.74	30	108	3.60	0.398	0.40	0.118
1.60	0.74	30	99	3.30	0.367	0.40	0.109
2.00	0.74	30	109	3.63	0.402	0.40	0.119
2.50	0.74	30	79	2.63	0.297	0.50	0.110

Cropping Programmes for commercial maize

	BISS CROPPING CALENDAR						
Season	Bura command		Chewele command		Pumwani command		Total
	Acres	Ha	Acres	Ha	Acres	Ha	
2012/2013	402	163	602	244	301	122	529
2013/2014	432	175	903	366	502	204	745
2014/2015	602	244	803	325	833	338	907
2015/2016	853	346	702	285	402	163	794

Water quality analysis for the irrigation water

WATER QUALITY DATA										
Water quality parameters	BIS/-BC	Inlet			Mid field			Drain		
Code/parameter		101	102	103	201	202	203	301	302	303
pH		7.15	7.13	7.14	7.37	7.39	7.4	7.04	7.02	7.03
Color (Mg pt l)										
Turbidity N.T.U		554	551	550	306	308	301	211.3	213.5	210.3
Alkalinity (ppm $CaCo_3$)(diluted x10)		0.7	0.7	0.8	0.4	0.4	0.3	0.5	0.7	0.6
Conductivity (μs/cm)		190	190	190	208	208	207	245	244	244
Iron (mg/l Fe)		14.2528	14.3282	14.3376	11.5268	11.5098	11.5023	6.5236	6.5047	6.5481
Calcium (mg/l Ca)		3.7134	3.88	3.8378	6.1704	6.6576	6.5627	7.2629	7.3873	7.5687
Magnesium (mg/l Mg)		1.1846	1.1835	1.183	1.1907	1.1931	1.1906	1.2077	1.2104	1.2062
Hardness (mg/l $CaCo_3$)		3.9	4.2	3.8	4.2	4.1	4	4.2	4.1	4
Chloride (mg/l Cl)										
Fluoride (mg/l F)		0.9	0.9	0.9	0.93	0.93	0.93	1.28	1.28	1.28

Nitrates (mg/l NO_3)										
Free CO_2 (mg/l CO_2)		17.6	19.36	19.36	15.84	17.6	17.6	14.08	14.08	14.08
TDS		109.5			135.1			116.3		

Income statements for BISS & WUAS

	FINANCIAL YEARS			
	2013	**2014**	**2015**	**2016**
Total income	635,093,530.00	20,376,823.60	37,932,704.55	37,932,704.55
Total expenditure	1,031,828,706.00	593,176,871.82	1,163,961,966.73	1,220,729,788.36

3.3 Masscote application in Bura irrigation &Settlement scheme

The MASSCOTE approach which was developed by the Land and Water Division (AGLW) of FAO on the basis of its experience in modernizing irrigation management in Asia was used to generate the baseline information for performance evaluation of the BISS. The Masscote methodology comprises of tools such as the rapid appraisal procedure (RAP) and benchmarking to enable a complete sequencing of diagnosis of external and internal performance indicators and the design of practical solutions for improved management, which implies numerous aspects that have to be combined in a consistent manner. These aspects are:

- Service to users;
- Cost of providing the services;
- Performance monitoring and evaluation (M&E);
- Constraints and opportunities in water resources management; and
- Constraints and opportunities of physical systems.

The methodology aims to organize project development in a stepwise revolving frame. The steps of this approach are described in detail in table 2 including the description and the results of each step.

Table 2: The eleven steps of MASSCOTE methodology

S/NO	Methodology	Phase A – Baseline information
1	Mapping of the Rapid Appraisal Procedure (RAP*)*	The initial step is the rapid system diagnosis and performance assessment through the RAP. The primary objective of the RAP is to help determine systematically and quickly key indicators of the system in order to identify and prioritize modernization improvements. The second objective is to start mobilizing the energy of the actors for modernization. The third objective is to generate a baseline assessment, against which progress can be measured.
2	Mapping of the capacity and sensitivity of the system	This will involve the assessment of the physical capacity of irrigation structures to perform their function of conveyance, control, measurement, etc. the assessment of the sensitivity of irrigation structures (off takes and cross-regulators), identification of singular points. Mapping the sensitivity of the system
3	Mapping of the perturbations	This step will involve perturbation analysis; causes, magnitudes, frequency and options for coping.
4	Mapping of the networks and Water Balances	This step will consist the assessment of hierarchical structure and the main features of the irrigation and drainage networks, on the basis of which water balances at the system and subsystem levels can be determined. The surface and ground water mapping of the opportunities and constraints.
5	Mapping of the cost of Operation and Management	This step will involve the mapping of the costs associated with the existing/current operational techniques and the resulting services, disaggregating the different costs elements; costs analysis of options for various levels of services with current techniques and improved techniques
	Methodology	**Phase B – Vision of SOM & modernization of canal operations**
6	Mapping of the services to users	This step will involve the mapping and economic analysis of the potential range of services to be provided to users.
7	Mapping of the management units	This step will involve the irrigation system and the service area being subdivided into sub-units (sub-systems and/or units areas for service) that will be uniform and/or separate from one another with well-defined boundaries.
8	Mapping for the demand for operation	This step will involve the assessment of the resources, opportunities and demand for improved canal operation. A spatial analysis of the entire service area, with preliminary identification of subsystem units (management, service, Operation and management (O&M), etc.)
9	Mapping for the options for canal operation improvements/units	This step will involve the identification of improvements options (service and economic feasibility) for each unit for: (i) Water management (ii) Water control, and (iii) Canal operation
10	Mapping for the integration of SOM options	This step will involve the integration of the preferred options at the system level, and functional cohesiveness check. Consolidations and design of an overall information management system for supporting operation.
11	Mapping for the vision and plan for modernization and monitoring & evaluation (M&E)	This step will involve the consolidation of a vison for the irrigation scheme. Finalizing modernization strategy and progressive capacity development. Selecting/choosing/deciding/phasing the options for improvements. I will develop a plan for M&E of the project inputs and outcomes.

Source: FAO

4. Results and Discussion

4.1 Rapid Appraisal Procedure (RAP) in BISS

The main objective of RAP in this research is to make an initial diagnosis and thorough assessment in order to obtain an initial sense of what and where the problems affecting the performance are and how they should be mobilized through the main actors (WUA's) for generation of a baseline of progress assessment for modernization of the scheme. This procedure focusses more on the operation and management of the irrigation.

The agronomic data required to analyze the irrigation schemes performance like crop production, measurements of flow and canal dimension were also obtained from MIAD, the WUAs and Bura irrigation scheme management. This agronomic data indicated the type of the crops grown, the area covered by the crops, the income obtained, and the number of beneficiaries participated. The cropping calendar obtained were for financial years 2012/2013, 2013/2014, 2014/2015 and 2015/2016 for all the command areas. This data was filled in the water balance excel sheets for the MASSCOTE approach RAP section. The bulky of the RAP data was obtained through interviews, actual measurements, discussions and repeated field visits and observations in the irrigation scheme.

The key end products of RAP are the internal indicators, external indicators, the IPTRID indicators and the world bank BMTI indicators as stated in the RAP excel worksheets. The RAP products were obtained for the whole research period.

External indicators

The external indicators are meant to describe the performance of an irrigation system through comparison of the input and output in the system. The indicators express various forms of efficiency. They are normally used to compare the performance of different irrigation projects, nationally or internationally. Once computed, they can also be used to benchmark for monitoring the impact of modernization on improvements in the overall performance.

The results of the RAP process are summarized following the Benchmarking Technical Indicators (BMTI) as described by Burt (2002). They are categorized as water balance indicators, financial indicators and agricultural productivity and economic indicators (Burt, 2002). A summary of the considered indicators is given in table below:

Table 3: External indicators

Indicators	BISS
Output per Cropped Area (USD/ha)	1,608,790
Output per Unit Irrigation Supply (USD/m3)	134.07
Relative water supply	169.33
Relative Irrigation supply	15.07
Main canal water delivery capacity (%)	2.0
O and M fees collected (%)	2
Irrigation efficiency	9

4.2 Systems capacity and sensitivity

Conveyance capacity of the main system

Analysis of the canal hydraulics showed that some sections along the existing canal bed gradient was unable to convey the design discharge due to invasion of the Mathenge plant, siltation, inadequate width of the canal sections under passes (inverted siphon) and cross regulators. Absence of continuous bunds along the main canal also causes overflows from the canal to the surrounding swampy areas. The other factors are the flat topography and the Mathenge invasion which has increased the roughness coefficient of the canals hence reducing the hydraulic efficiency of the canals.

Canal conveyance and structures capacity of secondary and tertiary canal system

From the analysis, the conveyance capacity of the secondary canal and tertiary canal structures are generally not able to provide the design discharges. These canals and structures have failed to meet the current needs of water supply for high yielding varieties and farm mechanization. Several structures such the tertiary canal-offtake pipes provided to release water to farms are too small to provide timely water supply to the farms with faster land preparation. This has caused the farmers to find other means to tap water from the tertiary canals by use of plastic siphons.

Sensitivity of the main canal individual structures and sub-system

The main canal has 4 Cross-regulators which are operated manually with the help of mechanical system installed and function as downstream control cross regulator structures but most of them have failed to function as intended. Most of these structures are designed as orifice-takes, they have proved to be no sensitive to water level fluctuations in the parent canal.

Sensitivity of secondary and tertiary canal structures and sub-system

Bura irrigation and settlement scheme has 8 secondary canals with a total of 29km and a maximum length of 8km. the cross regulators along the secondary canals are undershot structures with short side weirs and hence have high sensitivity. Modification by lengthening the side weirs is suggested for the purpose of reducing the high sensitivity of these regulators. The tertiary canals are 16 in number with a total length of 78km. the lengths for the tertiary canals are ranging from 0.5km to 2.5km. all the irrigation fields off-takes to the individual lots are being tapped directly from the tertiary canals. The use of plastic siphon without proper control of flow results in chaotic management in the tertiary canal and have been causing inequity of water delivery. The siphoning is sensitivities to water level fluctuation in the tertiary canals.

4.3 Perturbations

Perturbations along the feeder and main canal

The perturbations along the main canal is caused by discharge and the water level variations as a result of operation of the main intake and flows from the Tana river catchment and surrounding laggas to the main canal system. The supply is stable during the rainy season from Nanighi, but the local rainfall causes slight increase in the main canal system due to inflows from the laggas. This is currently handled by 1 gated spillway structure next to the Hirimanilagga through the operation of the escape gate.

Perturbation along secondary canal

The perturbations along the secondary canals are mainly caused by improper control and inaccurate flow measurement and illegal tapping. Other perturbations are caused by collapsing of the earthen banks along the secondary canal. Provision of proper flow measurement equipment and proper control of flow by the operators can control the perturbations. One of the options is to absorb the positive perturbations in the secondary canal itself through raising the canal banks and storing the water temporarily.

Perturbation along tertiary canal

The water levels and discharge fluctuations along the tertiary canal are caused by illegal off-takes or failure of farmers to tap water based on their respective water allocation. Most of these problems are related to the water utilization using the plastic siphons for field off-takes. The fluctuations of water levels are also caused by the temporary weirs built by the farmers themselves to raise water level in the absence of proper water control structures hence causing extremely high perturbations for downstream users.

4.4 Mapping water networks and water balance/ accounting

Water resources

The main water source of the irrigation supply is the river Tana. The irrigation water supply headworks is station at Nanighi, 50km away from the irrigation scheme. The Nanighi pumping station supplies all the water to the scheme downstream. The design capacity of the main conveyance canal in terms of discharge is 8.6 m^3/s. The other minor sources of water are from rainfall and the small laggas. The controlled drainage water is another source available during irrigation supply. Since the scheme depend on the river and has no reservoir, the irrigation supply during low flows is insufficient to meet the crop water demand. It is suggested that for the demand to be met, reuse and recycling by pumping of water from the drainage system should be encouraged.

The main sources of water in the sub-units are from the canal and sometimes from the low rainfall. Recycling of water from the drainage system unlike other irrigation schemes like Ahero has not been practiced in BISS. The recycling will require installation of pumping stations within each tertiary canal which increase the investment costs and annual operation costs.

4.5 Mapping the cost of operation and maintenance

The annual operation and maintenance costs for the BISS are estimated at **KES 1,347,797.42** per ha. Concrete lining of the secondary canals will reduce the maintenance costs but require high initial cost of investment. Transferring the management component from NIB to the water user associations will reduce staff requirements which are currently managing the secondary and tertiary canals. Capacity building the farmers organization financially and technically will enable the transfer of management especially third levels.

4.6 Service to users

Water delivery service to the farmers at tertiary canal system. The water delivery service within the Bura irrigation scheme consists of different levels as indicated in the RAP evaluation results. Bura irrigation scheme is managed under the National Irrigation Board who takes the responsibility of operation and maintenance. The RAP evaluation results indicate the general service quality at the tertiary level canals up to the individual farmers in terms of flow measurements, equity, reliability and flexibility as compared to the delivery service from the main canal to the secondary canals. Since the operation and maintenance of tertiary canals system involves small canals directly operated by the individual farmers, it is advisable that they are managed by the farmers through the water user associations. These groups will then be strengthened and guided through their WUAs so that they can have sufficient financial resources and means of operating and organizing the system and organizing the development of the associations.

4.7 Mapping the management units – a subunit approach

The Bura Irrigation and Settlement Scheme is divided into four commands with a gazetted command area of 29,653acres and a total area of **8,649**ha under irrigation. The active command areas are Bura, Chewele and Pumwani. Masabubu has not been active ever since the growing of cotton ceases many years ago. The scheme has a tenant population of 2,245 farmers settled in 10 villages where each farmer has 1.25Ha for main crops and 0.05Ha for vegetables garden. There are established committees in every village with an over committee for the scheme as a mediator between the farmers and the national irrigation board (NIB). The operation of the main canal, secondary canals and tertiary canals off-takes are carried out by the irrigation scheme employees. Land preparation is done by individual farmers with assistance from the Board employees and water is also paid for by the individual farmers while the scheduling is done by the board.

For the scheme to achieve flexibility in providing services to users, managerial efficiency, responsibility and professional in the definition of management levels, the current management of tertiary canal system needs to be restructured in form of sub-units for them to be able to be efficient in management. These can be tasked to manage the tertiary canals for efficiency improvement.

4.8 Mapping the demand for canal operation

4.8.1 Level of service

The demand for operation depend on the agreed service at the main system and at the sub-unit levels. The main purpose for formation of the water user associations (WUAs) for the demand for canal operation for the main and secondary canals within the command area is to provide the required demand to the tertiary canal as requested by the group as agreed upon. Supply of water will be done according to the agreed schedule with the flexibility to change flows subjected to individual farmers' request through the respective WUAs, with an advance notice of 5 days

4.8.2 The perturbations

Perturbations along the main and secondary canals is normally related to the runoff during low flows which affects the entire system with similar intensity. When there are high flows along the canals, the perturbations can be managed through proper operation of the main intake structures, gated spillways and the main canal regulators. The other form of perturbations along the main canal is the seepage loss which affects mainly the downstream users hence there should be prior differentiation of demand between the reaches with respect to this criterion.

In the secondary and tertiary canals, perturbations are normally caused by off-take operations. Longer canals have more off-takes hence need for more effort for proper management of the water flows and ensuring that the tail-enders are receiving fair share. This means that the length of the secondary and tertiary networks can be regarded as a criterion of differentiating the demand for operation. The demand for canal operations can be reduced by providing good flow controls and measurements of off-takes and water level structures in the secondary and tertiary canals. It is also proposed to redesign and line the main canal system and the regulators for the purpose of reducing perturbations. Additional regulators can be installed along the main canal, provision of real time measurements and water level monitoring with GIS systems in the main canal can also be done. The introduction of the GIS system for timely and synchronized operations of a series of cross-regulators with real time data of flow rate and the water levels monitoring will really help the managers to deal with the perturbations. The other option is to reduce the operation time of the cross-regulators by mechanizing and automating the operation.

4.8.3 The sensitivity

The main canal is the most sensitive part of the irrigation system starting from the head works, the spillways and to the cross-regulators. The head works including the intake structure and the weir are sensitive to changes in the flow of the river and obstruction caused by floating debris which requires regular operation and cleaning which also demands higher operation. The other structures which are sensitive to the changes of discharge and water level along the main canal are the spillways and regulators. These require high demand of service. The other sensitive structures along the secondary and tertiary canals are mainly the cross-regulators which are mainly designed for undershoots instead of the preferred undershoot type of water level controls. It is therefore recommended to replace all these structures with overshoot ones to reduce the sensitivity and also reduce the demand for canal operations.

4.8.4 Recycling

Unlike Ahero irrigation scheme where the irrigation water is recycled in nature, Bura irrigation scheme was not designed to recycle the used water instead it goes to waste. Recycling is therefore needed in all the sub-command areas for the purpose of allocating efforts for operating the tertiary systems. Recycling is very important since it will reduce the efforts needed for operations and controlling water devices on upstream side.

4.9 Mapping options for canal operation improvements and sub-unit improvements

Proposed improvements for Bura Irrigation & Settlement Scheme

Water management improvement strategy to increase water productivity

Water management for any irrigation scheme is very crucial for increasing water productivity and efficiency. It also helps to reduce water losses, managing perturbations and consolidation of flow control throughout the irrigation scheme. Most of the regulators in the secondary off takes are unable to provide the required water control to meet the water requirement at the farm level.

The practice of using siphons at the unit level has changed the original practice along the tertiary canals where water was supplied rotationally. The farmers are now using siphons indiscriminately hence causing low equity along the tertiary canals and waste of water through runoff flows from the field to the drains. There is need to employ new strategies for water management at the irrigation scheme and tertiary canals.

Improvement for cost effectiveness

From the results obtained, it is clear that operation is very high and accounts for a major cost in management. The options for improving the effectiveness are through reducing the frequency of adjustments of new design of regulators and offtake structures, mechanizing the gate operations of the main gated structures and utilize an effective information management system.

Improvement in water control

Options for improving cost effectiveness are mainly through reducing the frequency of adjustments of new design of offtakes and regulators structures by automating of mechanization the gates operation of main gated structures and utilization of an effective information management system.

The control of waterneed to be improved based on the results of the internal indicators. The following are the proposed water control improvements

1) Redesigning the field offtakes
2) Provision of water ordering and delivering procedures
3) Provision of flow measurement and water level measurements mostly along the main canal and at the pumping station
4) Modification from the existing undershot to overshot type.

Conjunctive use of water

The proposals for conjunctive use of water, rainfall and recycling of water from the drainage canals or regulating reservoir for the scheme through the construction of regulating reservours and storages, recycling water from drainage system and separation of irrigation canal and drainage system for preventing the inflow of acidic water from the swamp area.

Improving sub-unit operation

The management of water for tertiary system require extra attention due to its important role to provide excellence water delivery service to support high production of both commercial and seed maize and associated farm management. The sub-unit operation is closely related to on-farm water use and management, hence should be considered together. For this purpose, a research through a pilot project is therefore proposed to identify most appropriate design of the structures and management system at this level. The conjunctive use of water from the drainage system through the provision of recycling pumping stations at the tertiary canal system is also proposed to increase water productivity and fast response to crop water needs.

4.10 Integrating service-oriented management options

Aggregating the rationale of subunits at upper level will demand water management, service and operation at the compartment and tertiary canal level to be subjected to the current and future needs for cultivation of high yielding maize cultivation, application of precision farming and irrigation, utilization of modern machines to increase farm efficiency, increase water use efficiency at tertiary and on farm level, optimization of "effective rainfall" and control of chemical flow to the drainage system through surface runoff and seepage. This requires equitable, reliable and flexible supply from the main canal and to secondary canal system. The management of water service delivery from the main canal to secondary and tertiary canals need to be improved through various physical and managerial interventions.

4.11 Reaching a comprise between costs and service

Reaching a compromise between the technical opportunities and constraints, farmers desires influenced by the agricultural system, and cost of operation incurred are very difficult to achieve within a limited timeline. This is because it requires some extensive negotiations between the farmers and the National Irrigation Board, represented by the Ministry of Water and Irrigation. For us to encourage farmers to increase commercial maize production, various incentives have to be introduced by the government, including provision of better irrigation and drainage infrastructure to support the drive. When this opportunity is taken seriously, the plan for modernization through government allocation will ensure increased water delivery service quality to make it convenient for farmers to accept the responsibility and obligations after benefitting from the better service provision.

4.12 Service agreements

Right now, there is no proper service management which has been put in place in the Bura Irrigation and Settlement Scheme between the users and the service provider. This needs to be formed immediately in consultation of the WUA management and National Irrigation Board BISS management. This will successfully be formulated when the farmers are consulted and appropriately represented in the process.

4.13 Modernization Plans for BISS

The modernization plans for the Bura Irrigation system were arrived after a thorough inspection of the irrigation schemes systems. The plans were divided into three different phases based on short term plans, midterm plans and long-term plans. These recommendations were arrived at through the stakeholders' opinions which were sought through interviews and group discussions of both the staff and the farmers on the ground. The modernization plans were set according to the following three categories; -

(i) Short term modernization plans

- Reshaping of all the farm canals
- Desilting all canals
- Repair badly damaged sections of the main and branch canals
- Provision of any additional necessary structures
- Replacement of control structures and gates
- Carrying out preventive maintenance of the Irrigation System
- Carrying out routine maintenance of structure bass on the scheduled program
- Considering of famers benefits and gives enough information to them to decide crop pattern by marketing needs
- Recovering of water charge to MOM Cost
- Volumetric selling of water to farmers
- Evaluation of various cost elements of current operation techniques and services for controlling annual budget to improve the investment
- Financial management in order to reduce the costs and make the system more productive
- Minor repairs of the Nanighi head works

Table 4: The RAP internal indicators results

RAP Internal Indicators		
Internal Indicator	Term	Score
Social order	Social "order" in the canal system operated by paid employees	1.6
	Degree to which deliveries are not taken when not allowed, or at flow rates greater than allowed	4.0
	Noticeable non-existence of unauthorized turnouts from canals	3.0
	Lack of vandalism	0.0
Service to farmers (canal)	Actual water delivery service to individual ownership units (e.g. field or farm)	1.6
	Measurement of volumes	0.0
	Flexibility	3.0
	Reliability	2.0
	Apparent quality	1.0
Service to main canal	Water delivery service by main canal to the second level canals	2.0
	Flexibility	3.0
	Reliability	1.0
	Equity	3.0
	Control of flow rates to the sub-maim	2.0
Main level canals	Cross regulator hardware (main canals)	0.6
	Turnouts from the main canals	1.7
	Regulating reservoirs in the main canals	0.0

	Communications for the main canals	2.1
	Existence and frequency of remote monitoring (either automatic or manual) at key spill points, including the end of the canal	2.8
Second level canals	General conditions	2.4
	Cross regulator hardware (second level canals)	2.3
	Turnouts from the second level canals	2.0
	Regulating reservoirs in the second level canals	0.0
	Communications for the second level canals	2.2
	Existence and frequency of remote monitoring (either automatic or manual) at key spill points, including the end of the canal	0.0
	General conditions	2.4
	Operation of the second level canals	2.0

(ii) Midterm modernization plans

- Desilting all the drains
- Replacement and/or repair of all broken structures
- Minor repairs of the headworks at Nanighi
- Reshaping all the tertiary canals
- Providing additional structures along the main canals
- 100% Lining of the 50km main canal
- Selective lining of about 50% of the main canals
- Selective lining of at least 40% of all secondary canals
- Mapping of sensitivity of offtakes and cross regulators for providing well services to users.
- Professional training of operators to better operation system
- Different range of water fee in day and night in order to encourage farmers to irrigate during the night hours.

(iii) Long term modernization plans

- Construction of a gravity intake on river Tana upstream of the existing pumping station.
- Physical development of the irrigation system
- Capacity building of NIB staff and farmers
- Automation of systems to new technology for controlling and measurement of water flows
- Establishment of WUAs under secondary canals and effort to promote the mission to higher level
- Enhancement of operation and maintenance equipments
- Improvement of crops variety to adapt with local climatic conditions towards higher production, more tolerant to high temperatures, water stress.
- Construction of a gravity canal
- Reshaping of tertiary canals
- Replacement and/or repair of all underperforming structures
- Provision of additional structures
- Minor repairs and desilting of the main canal
- Lining of the main canal to minimize water losses through seepage
- Lining all the secondary canals to minimize water losses through seepage
- Development of greenhouse for controlling of water saving and better marketing

4.14 Monitoring and Evaluation

For purposes of monitoring and evaluation of BISS, the following three activities have been planned:

a) Conducting RAP three months after the end of each Development Plan and Mid Term Review of all the Plans.
b) Benchmarking of the Irrigation Scheme every year
c) Continuous monitoring for all aspects of irrigation management.

5. Conclusions and Recommendations

5.1 Conclusions

The following are the main conclusions drawn from this study; -

The current level of canal operation and maintenance

1) The water use efficiency is currently at average of 7,056 kg/m3 and can be improved to 18,910kg/m3 by improving irrigation efficiency.
2) The relative irrigation supply (RIS) stands at an average of 15 % which indicates twice as much needed water for irrigation requirement as being supplied
3) The field irrigation efficiency is 9% which attributed to over irrigation and poor maintenance of the canals.
4) By improving the field irrigation efficiency from 9% to over 75%, more water would be available and the area under irrigation can be increased from the current 2500ha to 6700ha representing an increase of 168% in irrigated land if farmers continue the conventional maize cultivation technique (surface irrigation).
5) The current system abstracts about 2.7m^3/s which is assumed to represents 100% of the water from all surface sources.
6) A guaranteed service of discharge q=±10% at the offtakes can be achieved by allowing a head variation of between 50mm and 100mm at the main canal.
7) Farmers are currently paying US$ 13,730/ha as operation and maintenance fees of which the government should be subsidizing some costs as a relief to the farmers.

The Contribution of maize to food security

1) Under the current canal operation and maintenance, the irrigation scheme is producing an average of 134,066 Metric tons of maize per year which is 3.7% of the national maize consumption estimated by the ministry of agriculture as 3,592,688 Metric Tons a year.
2) Under improved canal operation and maintenance, and considering that farmers grow the commercial maize, the production can be increased to 359,297 Metric tonnes per year which translates to 10% of the national maize production.

Improvement options

1) The improved water control and measurement coupled with volumetric water pricing can increase the efficiency of irrigation system from 9% to 75%
2) The system can be modernized by partial lining of the canals and reshaping of the tertiary and field canals at a cost of million US$ 7,355,829 (According to a NIB for construction of the 26km gravity canal and rehabilitation of the existing 64km canal, 2013).
3) The modernization of the system also be done through construction of a gravity canal upstream of the existing pumping station. This will save the money currently

being used for fueling the two pumps at Nanighi costing at US$ 180,411 annually. This will in a long way realize the losses the irrigation scheme has been going through since it was revived.

5.2 Recommendations

The main aim of irrigation development is to bring about increased agricultural production and consequently improve the economic, social and environmental wellbeing of rural population. Irrigated agriculture plays a significant role in meeting the growing demand for food and achieve long-term food security. The high yields of irrigated agriculture bring about benefits such as increased incomes, employment creation and food security which are indicators of sustainable agriculture and economic development without severe effect to the environment.

The following is a summary of the recommendations that have come out of the study of BISS, which are important for the modernization of public irrigation schemes: -

1) Service Oriented Management (SOM) of irrigation schemes should be adopted in Bura Irrigation & Settlement Scheme. Modernization efforts should be aimed at ensuring a guaranteed service to farmers which is reliable and ensures equity in water distribution.
2) The government should encourage growing of high yield maize varieties by way of providing some incentives to farmers.
3) More focus should be put on farmers satisfaction in the service by irrigation agencies in public schemes to ensure a sustainable cost pricing to avoid government subsidies in the schemes.
4) Conjunctive use of both surface and underground water should be given much more attention to ease pressure on surface water resources by way of adopting integrated water management.
5) Provision of service should be separated from regulation to guarantee performance on the part of the service provider.
6) The government should be prepared to compensate farmers in case of crisis with contracted service provisions. An emergency fund should be proposed for this purpose.
7) The use of MASSCOTE approach for performance assessment and modernization proves to be vital and effective, therefore it needs to be widely used
8) It is believed that investment on improvements on physical infrastructure, management and operation of the schemes at all levels will bring substantial improvement of performance of the irrigation scheme.

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