

Revised Research Article

Decision Support System for Runoff Water Harvesting and Irrigation

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Abstract

Recurring droughts and dry spells severely disrupt food production and financial attainability in several areas of Sub-Saharan Africa (SSA). The problem is exacerbated by poor or lack of planning for storing rainwater and sizing of irrigation fields based on catchment areas. Versatile agro-hydrological Decision Support Systems (DSSs) are, hence, needed by farmers for effective synchronization of runoff affecting rainfall and catchment factors, reservoir capacity and irrigation field area. The study, therefore, focused on designing and validating a DSS, by adding water reservoir and irrigation sub-routines to an Agro-hydrological Nedbor Afstromnings Model (NAM), to assist in screening best-bet options for crop field area or reservoir sizes using a case study of common beans (*Phaseolus vulgaris*, L.) and Ukwé Area in Malawi. Pre-DSS gross margin analysis, indicated that 2.42 times more crop returns were obtained from irrigated than rain-fed bean crops despite additional costs associated with reservoir maintenance and irrigation operations. Using Microsoft excel spreadsheet (MS excel) to compute cumulative runoff inflows into the dam, seasonal open surface water storage water losses and withdrawal, 9931 m³ was displayed as the dam water available for the bean crop. With input of crop water use, crop land area of 16.9 ha, crop water productivity of 0.7, and irrigable area of 1.6 ha were calculated. Use of NAM with addendum of water loss, irrigation and water balance subroutines, simulated irrigable land area of 17ha, crop water productivity of 0.7 g/L and potential crop command field area of 1.5 ha were achieved. The simulated synchronization values were in agreement with calculated values. The DSS is, hence, recommendable to potential users.

Rewrite comprehensive and crisp abstract

Key words: Runoff, reservoir, irrigation, storage, simulation and synchronization

1. Introduction

Recurring and cumulative damage from drought has reduced the yield of crops in many regions (Kamthonkiat, 2008). The negative impacts of droughts and dry spells on crop production in sub-

Saharan Africa (SSA) strongly call for supplementary or sole irrigation which needs proper sizing of water reservoir with respect to cropped area or vice-versa. Computerized decision support systems allow users to combine technical knowledge of models that combine crop growth, environmental diversity and economic considerations to make proper implementation of decisions for synchronization of water reservoirs and field sizes (Oteng-Darko *et al.*, 2013).

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Yalewa *et al.* (2014) in South Africa reported that ecosystem services assessment requires an integrated approach, as it is influenced by elements such as climate, hydrology and socio-economics, which in turn influence one another. In Germany, determination of people's willingness to pay, for an improvement of environmental quality and effects of the hydro-morphological measures within the different water bodies, was followed by an economic value assessment for decision making for water framework directive (Hirschfeld *et al.*, 2005). Literature search has revealed a number of models, on which to design and validate a DSS instead of developing a completely new one. Despite the existence of agro-hydrological DSSs, Malawi has not embraced their use in catchment analysis due to lack of reliable hydrological parameter framework and poor understanding of their application in water storage and irrigation (Njoloma, 2010). Most of the models are prohibitive for establishing appropriate variable combinations of catchment area, hydrological parameters and crop water productivity or costly in implementation (Table 1). The current study intended to address this

gap. Of WHAT?

Table 1: Highlights of potentiality and limitations of some agro-hydrological models for utility in drought prone SSA countries.

Model	Potentiality	Limitations
Why not write expansions of the nmodels?		
GOSSYM /COMAX expert	Application of N, irrigation &	Costly for resource-poor

system	growth regulators (Boote <i>et al.</i> , 1996; Newman <i>et al.</i> , 2000)	farmers, time & resource demanding in Code adding (modification) to cater for specific aspect deficient
CERES, CROPGRO and CROPSIM model series	Include CROPGRO-dry bean (<i>Phaseolus</i>) , ie, the current study test crop	Not versatile in simulation of soil moisture on crops & not combining rainwater harvesting and irrigation
DSSAT	Integrates soil and crop effects, weather and management options allowing users to ask "what if" questions and simulate results (Wani <i>et al.</i> , 2011).	Needs use of CERES, CROPGRO and CROPSIM model series - not versatile on Rain water harvesting, long term reservoir water storage & soil moisture on crops.
APSIM	-Integrates sub-models from fragmented agricultural research efforts - provides means for comparison of models or sub-models -powerful tool for exploring agronomic adaptations	Not yet effective in Rain water harvesting
AQUACROP	-Versatile model -Simulates soil and in-situ water variables	- Deficient in water harvesting – for- irrigation component -hence limited utility in drought prone SSA countries
PARCHED THIRST (PT)	-Simulates crop, soil, land and water management, climatology -Provides for planning and designing of RWH systems (RIU, 2007; Tumbo <i>et al.</i> , 2006)	Not yet for long term water storage
Nedbor Afstromnings Model (NAM)	-Simple & reliable in operation - Versatile and adaptable to sub-Saharan African geo-climatic and crop conditions.	Tested for Southern Africa but not verified and adopted

52 Some specific problem domain DSS's have not been comprehensive in hydrological, agricultural and
53 socio-economic sectors (Larbi, 2011).

54 The models with important hydrological processes, using physical parameters that are readily
55 available or easily measured, and used in water harvesting and irrigation, do not yet have long term
56 water storage and legume irrigation components. This was the other gap the study aimed at
57 addressing.

58

The objective of the study, therefore, was to design and validate a DSS to provide 'what if' solutions emanating from relationships between volume of stored water, irrigation and crop area socio-economic aspects for strategic and tactical decision making. It focused on possibility of extending NAM model sub-routines, using simple and few data of precipitation, potential evapotranspiration and temperature to simulate runoff to encompass DSS parameters.

2. Materials and Methods

2.1. Analysis of runoff, Reservoir water and crop water requirement

The reservoir inflows (daily discharges from the catchment area) were measured using a calibrated gauge installed in the reservoir (MIWD, 2011). The volume of water in the reservoir was equated to the seasonal field crop water use. This was related to actual and potential water use yields. Reservoir water balance was based on losses due to seepage, evaporation and livestock consumption. The reservoir water volume balance (after losses through evaporation and seepage, and abstraction by livestock, up to crop harvest week) divided by total seasonal crop water requirement over a hectare provided the total area (ha) the reservoir water could irrigate. The foregoing relationship in turn established optimum sizing of either area or reservoir for maximizing crop productivity based on the runoff generating catchment attributes and climatic conditions. Crop yield and crop-water productivity was established were, hence, achieved.

How was it done? Write method

2.2 Socio-economic analysis of bean irrigation at Ukwe

In order to advise a farmer as to whether to grow a crop using irrigation or rely on rainfall a comparative socio-economic analysis needs to be carried-out. Once water harvesting and irrigation prove beneficial then the Decision Support System can be employed to determine appropriate

relationships among runoff, reservoir capacity and crop land area with respect to seasonal rainfall and catchment characteristics for water harvesting. Economic data measured, for the study, included labour use, production costs, amount of water applied to each treatment and grain yields. Comparative gross margin analysis and break-even analysis were conducted on rain-fed and reservoir based irrigated bean crops. The gross margin return analysis was conducted to indicate profit margin for a farming family, while break-even analysis was conducted to demonstrate a minimum yield a farming family needed to achieve in order to recover money spent on the bean production. Break-even price (or gross return?) is described as the minimum output price beyond which the farmer is likely to make profit (Kadyampakeni, *et al.*, 2010).

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Willingness to pay is a measure of largest sum of money an individual is agreeable to pay for a product in question. Literature shows a number of approaches to measure willingness-to-pay with differential conceptual foundations and methodological implications (Breidert, *et al.*, 2006). In this case, farmers were interviewed to know their willingness to pay for runoff water harvesting and irrigation (Table 4.5). The cost calculated by the dam committee, which an irrigation household was paying for water preservation, was MK5 000 (US\$16.67). A range of values were offered to farmers above and below this value. The choice of the survey method used in the study to highlight willingness-to-pay, as a supplementary analysis, was based on its simplicity and literacy level of the respondents.

102

103 2.3 Calibration of the Decision Support System

104 2.3.1 Case study location and bean crop production

The study site, Ukwe, is located in Lilongwe North-West in Malawi. The area is about 1150 m above sea level, 13° 46' S and 33° 37' E to 13° 55' S and 33° 38' E, extending 13° 46' S and 33° 31' E to 13° 50' S and 33° 32' E, occupying flat *dambo* margins. Temperatures range from 18 to 24°C rising to

29°C just before the start of rains (October to November). Rainfall in Malawi is of unimodal pattern, starting December and terminating in April. Ninety percent of the rain falls from January to March. The national mean rainfall varies from 760 mm during low rainfall year to 1430 mm during high rainfall year. However, in a drought prone areas, including Ukwé, only 400 to 650mm mean annual rainfall is experienced. To meet seasonal bean crop water requirement, whose minimum is 660 mm, therefore, farmers use harvested runoff from small catchments (10 - 15 ha) stored in small reservoirs or where possible, some perennial small streams. At Ukwé, farmers have formed a club irrigating common dwarf bean (*Kalima* variety) from June to November when there is no rainfall using water from a small Kalembe dam with catchment area of 16 ha. Justify why the study

was undertaken on common bean, instead of anyother crop

The weekly irrigation water depth was 50mm, following pre-planting water application of 100 mm. All agronomic and pathological practices to avoid allelopathy, and biocides for the crop's potential growth and protection recommended by the Ministry of Agriculture, Irrigation and Water Development (MAFS, 2012) were followed. These included planting in 2 rows (1 seed per station) at 10 cm apart, on ridges 75 cm apart. Fertilizer of type 23: 21: 0 + 4 (NPKS) was applied at 100 kg/ha and cypermethelin (20 ec) insecticide was applied 7 weeks after planting.

Biweekly crop sampling was carried-out for biomass yield with respect to irrigation regimes. Readily available moisture (RAM) at early growth (less than 3 trifoliate), active vegetative stage (3 to 5 trifoliate) and flowering stages were determined at standard allowable depletion (P) of 50%. Two

weeding operations were carried out, 2 and 6 weeks after planting. The reservoir water was also consumed by 102 heads of cattle and 143 goats. All domestic water was supplied by shallow wells hence reservoir water was not used for domestic chores.

2.3.2 Study site data calibration using data from other sites

Rainfall data from Lumbadzi, Kandiya and Bunda, 8 km North-east, 12 km East and 30 km South-west of Ukwé respectively, were used to calibrate the MS excel based DSS output for Ukwé site. The model calibration was based on parameter and time constants with respect to climatic values to predict catchment runoff for a given rain storm on daily basis. The reservoir water levels were recorded on weekly time step basis in line with the irrigation water abstraction. A local sensitivity of change in reservoir capacity was obtained from cumulative irrigation withdrawal multiplied by the area irrigated. System behaviour and criteria for selecting optimum reservoir capacity and cumulative irrigation withdrawal as the dry season progressed was established.

2.4 Decision support system framework

The Design of the decision support system followed the framework depicted in Figure 1.

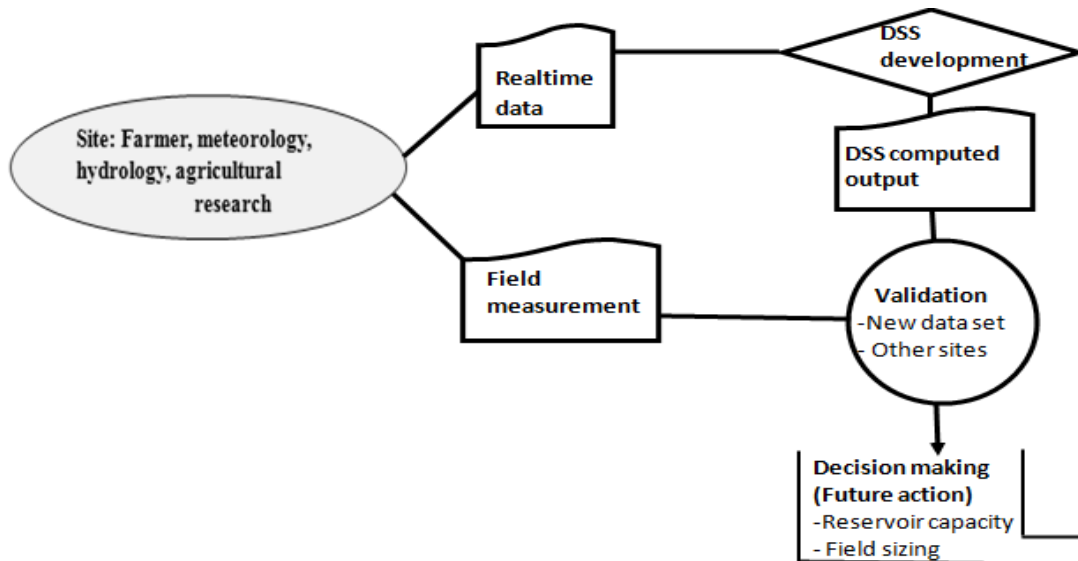


Figure 1: Study framework for the decision support system design

Why this fig should be not be in computer language
symbol and flow chart, as suggested earlier

2.5 Input Data to develop a decision support system

The formulated NAM based DSS is a system requiring limited data input. Three input data files, namely meteorological station data file (potential evapotranspiration, temperature and precipitation), Hydrological Department data file (reservoir evaporation and seepage) and agricultural extensionist/farmer data file (head of cattle, goats/sheep, number of persons using the water, irrigation water depth,) are needed for the system to be operational. Collection of data is simple because the meteorological and hydrological data stations in SSA are spread in a number of the agro-ecological zones where weather predictions are made on daily basis. The DSS operation is based on Excel software operation.

In Malawi, the Hydrology Section in the Water Division of the Water Resources Department (Ministry of Irrigation and Water Development), located in the same agro-ecological zone of Ukwe area, is a strong data quality control institution with package of a purpose-built, Windows-based database and analysis system for processing the hydro-meteorological data (HYDATA software), a powerful tool for hydrological data storage, analysis and routine processing (Njoloma, 2010). Rainfall data collection, coordination and storage, in Malawi, is the responsibility of Meteorological and Climate Change Department (Ministry of Transport and Communication) which also trains personnel manning gauging stations on daily basis. For this study, data for DSS validation were sourced from four stations, Lumbadzi, Ukwe, Kandiya and Bunda in the drought prone plateau region of Central Malawi, within the agro-ecological zone of the study area (Figures 2 and 3).



Figure 2: South Central Malawi agro- ecological zone weather stations
(Source: Malawi Meteorological Services, 2006)

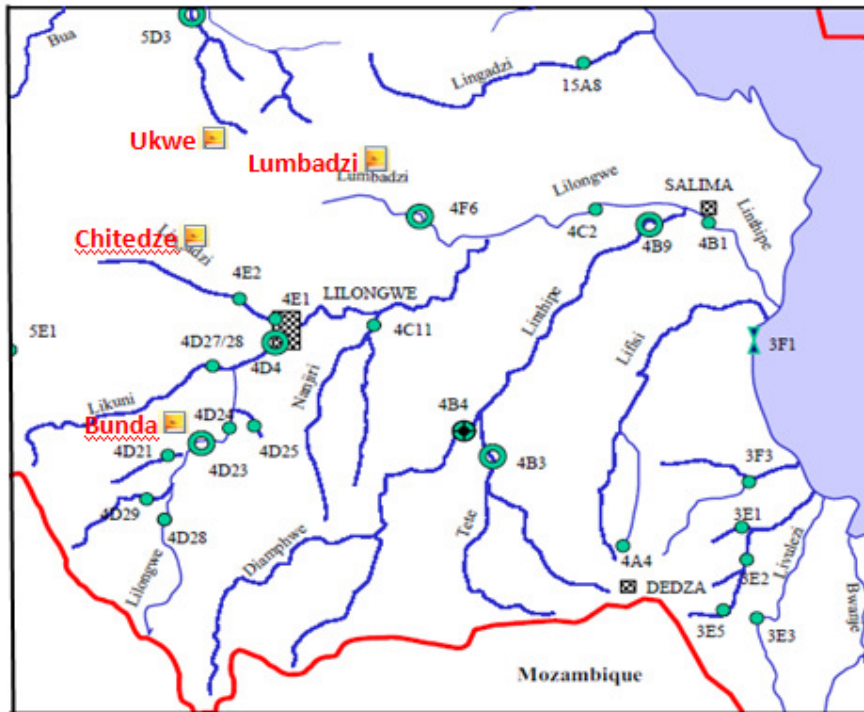


Figure 3: South-Central Malawi, showing model validation data sites (Ukwe, Lumbadzi, Chitedze and Bunda).

As a new addition, where do you use this Fig? is not coming up in the study

2.7 Rainfall data screening and operation of the DSS

Rainfall is a vital component of the runoff water harvesting, storage and irrigation. Therefore, initially, the design of the DSS followed test for data consistency and homogeneity, i.e. if data be used for DSS design and validation with confidence. The accumulated mean rainfall data from Ukwe, as it contributed to runoff, was tested against accumulated means from Bunda, Kandiya and Lumbadzi using Double Mass curve method to test reliability of data (Ali, 2011). Mass analysis showed a spurious relationship indicating data inconsistency and non-homogeneity (Figure 4). It would, hence, not be reliable, therefore, to use the Ukwe data for development of the DSS unless the source of anomaly is established to be a station other than Uwe.

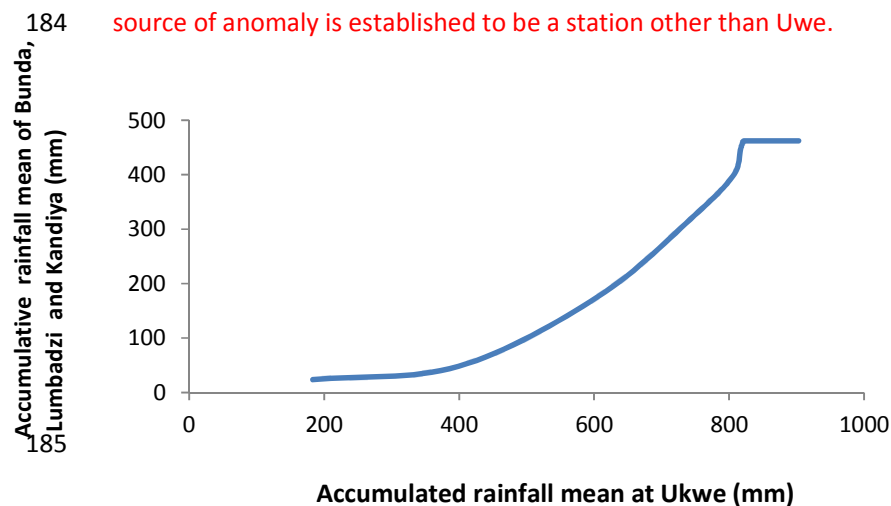
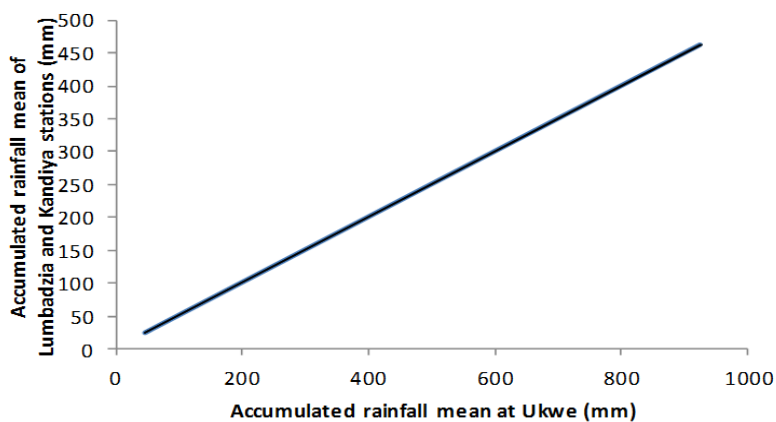


Figure 4: Rainfall double mass analysis of all the stations including Bunda

Although Bunda, Kandiya and Lumbadzi are in the same agro-ecological and agro-hydrological zones, the daily rainfall data from each site was eliminated during each analysis to trace source of the anomaly. Errors were discovered in the Bunda data. In fact, Bunda site is far removed (50 km) from

the rest and is between two mountains, hence it was suspected to have some rainfall variations during some seasons. Generally, weather conditions are reported to gradually change over distances of 50 to 150 km (MARS, 2014). Double mass analysis test was hence run, excluding this Bunda site. A straight line relationship revealing absence of spurious trends was obtained (Figure 5). It is worthy pointing-out that Double Mass analysis interpretation is dependent on data line shape rather than use of coefficient of determination (R^2). The analysis, therefore, demonstrated that the Ukwe rainfall



data were valid for runoff and water storage analysis, hence used for the DSS development.

Figure 5: Rainfal double mass analysis of all stations excluding Bunda

2.8 Decision Support System Development

2.8.1 Development procedure of the Decision Support System

Development of the DSS followed the trend of operation of the system. Initially the system operation requires three main input data sets. Firstly, it requires catchment parameters and time constants, precipitation and potential evaporation so that it can simulate land water storages, and flows which are routed to the reservoir as output. Secondly, it requires data of evaporation and seepage, livestock number and domestic water use (if any) before it displays reservoir water balance for irrigation. Thirdly, it needs crop water use entry for it to display the required land area to be prepared. The Microsoft (MS) Excel version 1997-2003 NAM based procedure followed the structure depicted in Figure 4.

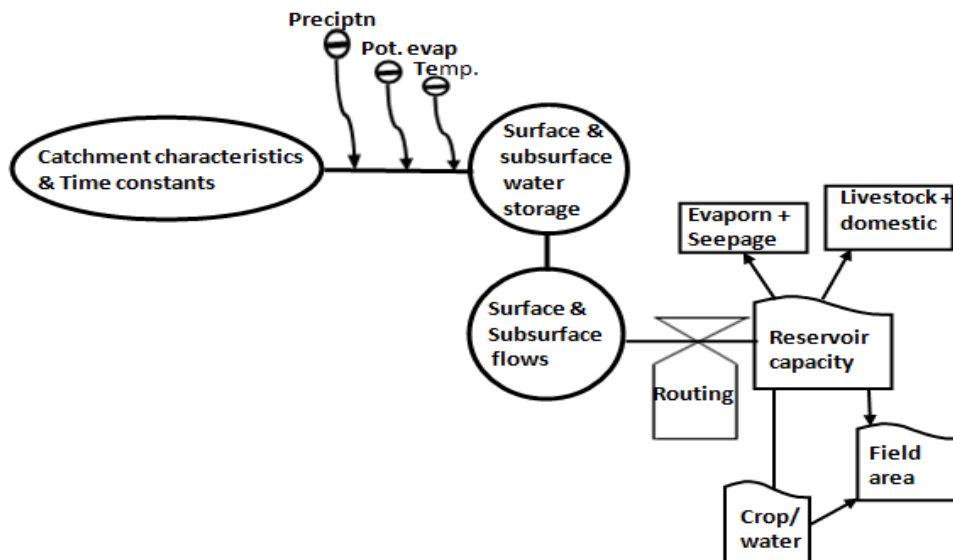


Figure 4: DSS flowchart as per excel based NAM spreadsheet programmed commands

This should be Fig 6?

FOR DSS WHY NOT USE COMPUTER APPLICATION

TERMS, USED SYMBOLS AND FLOW CHART?

**** Mathematical basis for the DSS and MODIFIED DSS**

you are going to use in your study for which you will

show the Excel spread sheet.

Also write how you maximize the function?

2.8.2 Catchment characteristic factors

225 Impacts of the catchment characteristics on runoff and reservoir capacity, as simulated by the
 226 modified NAM DSS excel spreadsheet, are quantified by parameterization. The optimized model
 227 catchment parameters and routing constants were then used in the design and validation of the DSS
 228 (Tables 1 and 2).

229

230 Where to use values listed in Table1 and Table 2 to
 231 predict runoff from the catchments?

232 **Table 1: Model Parameter constants as commands in the spreadsheet***

Parameter	Name	Constants
Lower zone storage capacity: maximum water storage in the root zone	Lmax	> 0
Upper zone storage capacity: maximum water content in the surface storage.	Umax	> 0 First estimate Umax=0.1Lmax.
Snow melt coefficient	Cmelt	0 for Ukwé site
Overland flow runoff coefficient: extent to which excess rainfall runs off as overland flow and the quantity that infiltrates.	CQOF	0 – 1. Since Ukwé catchment is small, small values with low, permeable soils are as expected.
Interflow runoff coefficient: proportion of the surface storage that runs off through horizontal leakage.	CQIF	0 – 1. For catchment with a flat topography the value is very close to zero.
Threshold value interflow:	CLIF	0 – 1
Threshold value overland flow	CLOF	0 – 1
Time Constants for Routing Overland and interflow: both flows together are routed through a linear reservoir	CK1	> 0
Stream flow: flow is routed through a linear reservoir.	CK2	> 0
Upper groundwater flow	CKBFU	> 0

Lower groundwater flow

CKBFL > 0

*Original 'parameter categorization' and 'name abbreviation' from Njoloma, 2010

Table 2: Ukwe DSS adjusted catchment parameters and time constants

Fixed catchment parameters				Time constants	
Lmax	115.000			CK1	0.5
Umax	10.000			CK2	0.4
Cmelt	0.000			CKBFU	0.4
CQOF	0.300			CKBFL	90.0
CQIF	0.025				
CBFL	0.200				
CLIF	0				
CLOF	0.6				
CLG	0.2				

2.10 Decision Support System Validation

Factors of water routing (modified function of total flows), storage and crop water use and productivity have been incorporated to the NAM based operation using an excel spreadsheet version 2007. Table 3 shows the spreadsheet data input, merged computer simulation (simulatn) columns, cumulative (cummul) dam inflows and dam water balance (dwb). At this point the DSS operator inputs data of pot evaporation (Pot evap), seepage and abstractions by livestock and persons.

Table 3: Decision support system operational design spreadsheet

Date	Computer			Water losses		Water withdrawals			Computer	Crop		Potential
	Simulation	Cummul	DWB	Pot	Seepage	Goat	Cattle	Persons	simulatn	available	Appld	irrigable
	→	dam		evap					→	water	water	Area
		inflows	(m ³)	mm	(m ³)	(m ³)	(m ³)	(m ³)		(m ³)	(cm)	(ha)

How the runoff is generated that should have come

from the mathematical basis of simulation.

How depth is converted in volume?

How seepage volume was measured?

These things should be explained in method

Also give details from where the bean yield 1400kg/ha was considered as optimum.

2. Results and Discussion

First give the technical results, the main focus of the study then go to the sociological aspect

3.1 Socio-economic analysis

3.1.1 Gross margin and break-even analyses

Gross margin and break-even analysis was conducted on the grain yield of rain-fed and reservoir water irrigated beans, as a determinant of need to develop the DSS. Variable cost data included production, processing (drying, threshing, treatment) and transportation costs, while fixed costs included contribution towards annual reservoir maintenance (Table 4). Output was in terms of grain yields.

The gross margins were higher under (with) irrigation (2.42 times) than with rain-fed bean production despite additional costs associated with reservoir maintenance and irrigation operations. Controlled water application during high dry season temperature, with less pest incidences, tends to make irrigated beans yield higher than rain-fed crop (Kadyampakeni, 2004).

Table 4: Gross margin and break-even analysis for rainfed and irrigated beans

Details	Unit	Without irrigation			With irrigation		
		Quantity	Unit price	Total cost	Quantity	Unit price	Total cost
		Kg	MK	MK	kg	MK	MK
Output value	kg	8 012	150	120 000	1 400	165	231 000

FIXED COSTS

Reservoir contribution	Annual fee	-	-	-	-	-	5 000
Irrigation	Mandays	-	-	-	346	157	54 352
Sub total							59 352

VARIABLE COSTS**INPUTS**

Seed	kgs	75	250	18 750	75	250	18 750
Insecticides	litres	10	1 500	15 000	10	1 500	15 000
Fungicide	kgs	25	1 000	25 000	25	1 000	25 000
Sub-total (inputs)				58 750			58 750

LABOUR

Land preparation	Mandays	42	200	8 400	42	200	8 400
Planting	Mandays	15	200	3 000	15	200	3 000
Supply	Mandays	3	200	600	3	200	6 000
Weeding/banking	Mandays	23	200	4 600	23	200	4 600
Harvesting/drying/threshing	Mandays	36	200	7 200	40	200	8 000
Drying/packing/loading	Mandays	15	200	3 000	20	200	4 000
Subtotal for labour	Mandays			26 800			28 600

OTHER COSTS

Sacks	50 kg bag	12	80	960	30	80	2 400
Transport	bags	12	100	1 200	30	120	3 600
Sub total				2 160			6 000
Total Cost				87 710			152 702
Gross Margin (A-B)	MK/ha			32 290			78 298
A. Break-even Yield	MK/ha			585			925
B. Break-even Price	MK/ha			110			109

270

271 Break-even yield was lower for irrigated crop than the achieved yield, and break-even price (or

272 gross return?) lower for irrigated crop than from the rain-fed crop, showing that the

273 bean producers made a profit and that irrigated bean crop was more returns. (Why and274 How?) Computation of crop water productivity gave the value of 0.7g/L, lower than values of275 1g/L reported from experiments elsewhere (Hashim, *et al.*, 2012). (Why ?) The study has

shown the benefits of irrigation in comparison to rain-fed farming in the challenging face of frequent droughts and dry spells.

3.1.2 Willingness to invest in irrigation

Farmers were interviewed to know their willingness to pay for runoff water harvesting and irrigation (Table 5). The cost calculated by the dam committee, which an irrigation household was paying for water preservation, is MK5 000 (US\$16.67).

How you assessed it ?

Table 5: Maximum willingness to pay for reservoir construction, maintenance and irrigation

Maximum willingness to pay		Percent
MK	US\$	
< 5 000	<16.67	48.20
5 000 – 10 000	16.67 – 33.34	25.30
10 000 – 15 000	33.34 – 50.01	18.10
>15 000	>50.01	8.40
TOTAL		100.00

Forty-eight percent of farmers wished to pay less than the equivalent US\$16.67. With the need to reforest the catchment area and dam peripheral, only less than 26% of the total number of households would be willing to pay. The rest of the farmers (74 %) would rather do the work themselves as self-help operations. The expectation was that somebody else, either the non-governmental organization or the government, should assist them in paying for such operations. The unwillingness of the small-holder farmers to invest in irrigation infrastructure was similarly reported by Kadyampakeni, *et al.*, (2010).

3.1.3 Simulation spreadsheet for the Decision Support System Operation

The process of adjusted catchment parameters and time constants as indicated in Table 2 above

294 was meant to confirm whether the calibrated parameters would indeed reproduce the observed runoff
295 values. Simulation results found reliability in the DSS prediction of runoff, hence dam volume
296 objective function (obj. func.).

Detailed operational spreadsheet work book (inputs and variables) are shown in Table 6. For sake of clarity results of validation based on 2011-2012 data (with hidden command rows and command

299 **Table 6: Computer simulation for the decision support system**

Date, Time		DATA		Stream		Roof		ROUTING		SFU		Factual Data		Actual Data																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
Date	Time	Flow (m³/s)	Runoff (mm)	Pa.Ev (mm)	Pa.Ev (mm)	Ev	U	U _{max}	Pr	Q	Q _{01F}	Q _{02F}	Q _{03F}	Q _{04F}	Q _{05F}	Q _{06F}	Q _{07F}	Q _{08F}	Q _{09F}	Q _{10F}	Q _{11F}	Q _{12F}	Q _{13F}	Q _{14F}	Q _{15F}	Q _{16F}	Q _{17F}	Q _{18F}	Q _{19F}	Q _{20F}	Q _{21F}	Q _{22F}	Q _{23F}	Q _{24F}	Q _{25F}	Q _{26F}	Q _{27F}	Q _{28F}	Q _{29F}	Q _{30F}	Q _{31F}	Q _{32F}	Q _{33F}	Q _{34F}	Q _{35F}	Q _{36F}	Q _{37F}	Q _{38F}	Q _{39F}	Q _{40F}	Q _{41F}	Q _{42F}	Q _{43F}	Q _{44F}	Q _{45F}	Q _{46F}	Q _{47F}	Q _{48F}	Q _{49F}	Q _{50F}	Q _{51F}	Q _{52F}	Q _{53F}	Q _{54F}	Q _{55F}	Q _{56F}	Q _{57F}	Q _{58F}	Q _{59F}	Q _{60F}	Q _{61F}	Q _{62F}	Q _{63F}	Q _{64F}	Q _{65F}	Q _{66F}	Q _{67F}	Q _{68F}	Q _{69F}	Q _{70F}	Q _{71F}	Q _{72F}	Q _{73F}	Q _{74F}	Q _{75F}	Q _{76F}	Q _{77F}	Q _{78F}	Q _{79F}	Q _{80F}	Q _{81F}	Q _{82F}	Q _{83F}	Q _{84F}	Q _{85F}	Q _{86F}	Q _{87F}	Q _{88F}	Q _{89F}	Q _{90F}	Q _{91F}	Q _{92F}	Q _{93F}	Q _{94F}	Q _{95F}	Q _{96F}	Q _{97F}	Q _{98F}	Q _{99F}	Q _{100F}	Q _{101F}	Q _{102F}	Q _{103F}	Q _{104F}	Q _{105F}	Q _{106F}	Q _{107F}	Q _{108F}	Q _{109F}	Q _{110F}	Q _{111F}	Q _{112F}	Q _{113F}	Q _{114F}	Q _{115F}	Q _{116F}	Q _{117F}	Q _{118F}	Q _{119F}	Q _{120F}	Q _{121F}	Q _{122F}	Q _{123F}	Q _{124F}	Q _{125F}	Q _{126F}	Q _{127F}	Q _{128F}	Q _{129F}	Q _{130F}	Q _{131F}	Q _{132F}	Q _{133F}	Q _{134F}	Q _{135F}	Q _{136F}	Q _{137F}	Q _{138F}	Q _{139F}	Q _{140F}	Q _{141F}	Q _{142F}	Q _{143F}	Q _{144F}	Q _{145F}	Q _{146F}	Q _{147F}	Q _{148F}	Q _{149F}	Q _{150F}	Q _{151F}	Q _{152F}	Q _{153F}	Q _{154F}	Q _{155F}	Q _{156F}	Q _{157F}	Q _{158F}	Q _{159F}	Q _{160F}	Q _{161F}	Q _{162F}	Q _{163F}	Q _{164F}	Q _{165F}	Q _{166F}	Q _{167F}	Q _{168F}	Q _{169F}	Q _{170F}	Q _{171F}	Q _{172F}	Q _{173F}	Q _{174F}	Q _{175F}	Q _{176F}	Q _{177F}	Q _{178F}	Q _{179F}	Q _{180F}	Q _{181F}	Q _{182F}	Q _{183F}	Q _{184F}	Q _{185F}	Q _{186F}	Q _{187F}	Q _{188F}	Q _{189F}	Q _{190F}	Q _{191F}	Q _{192F}	Q _{193F}	Q _{194F}	Q _{195F}	Q _{196F}	Q _{197F}	Q _{198F}	Q _{199F}	Q _{200F}	Q _{201F}	Q _{202F}	Q _{203F}	Q _{204F}	Q _{205F}	Q _{206F}	Q _{207F}	Q _{208F}	Q _{209F}	Q _{210F}	Q _{211F}	Q _{212F}	Q _{213F}	Q _{214F}	Q _{215F}	Q _{216F}	Q _{217F}	Q _{218F}	Q _{219F}	Q _{220F}	Q _{221F}	Q _{222F}	Q _{223F}	Q _{224F}	Q _{225F}	Q _{226F}	Q _{227F}	Q _{228F}	Q _{229F}	Q _{230F}	Q _{231F}	Q _{232F}	Q _{233F}	Q _{234F}	Q _{235F}	Q _{236F}	Q _{237F}	Q _{238F}	Q _{239F}	Q _{240F}	Q _{241F}	Q _{242F}	Q _{243F}	Q _{244F}	Q _{245F}	Q _{246F}	Q _{247F}	Q _{248F}	Q _{249F}	Q _{250F}	Q _{251F}	Q _{252F}	Q _{253F}	Q _{254F}	Q _{255F}	Q _{256F}	Q _{257F}	Q _{258F}	Q _{259F}	Q _{260F}	Q _{261F}	Q _{262F}	Q _{263F}	Q _{264F}	Q _{265F}	Q _{266F}	Q _{267F}	Q _{268F}	Q _{269F}	Q _{270F}	Q _{271F}	Q _{272F}	Q _{273F}	Q _{274F}	Q _{275F}	Q _{276F}	Q _{277F}	Q _{278F}	Q _{279F}	Q _{280F}	Q _{281F}	Q _{282F}	Q _{283F}	Q _{284F}	Q _{285F}	Q _{286F}	Q _{287F}	Q _{288F}	Q _{289F}	Q _{290F}	Q _{291F}	Q _{292F}	Q _{293F}	Q _{294F}	Q _{295F}	Q _{296F}	Q _{297F}	Q _{298F}	Q _{299F}	Q _{300F}	Q _{301F}	Q _{302F}	Q _{303F}	Q _{304F}	Q _{305F}	Q _{306F}	Q _{307F}	Q _{308F}	Q _{309F}	Q _{310F}	Q _{311F}	Q _{312F}	Q _{313F}	Q _{314F}	Q _{315F}	Q _{316F}	Q _{317F}	Q _{318F}	Q _{319F}	Q _{320F}	Q _{321F}	Q _{322F}	Q _{323F}	Q _{324F}	Q _{325F}	Q _{326F}	Q _{327F}	Q _{328F}	Q _{329F}	Q _{330F}	Q _{331F}	Q _{332F}	Q _{333F}	Q _{334F}	Q _{335F}	Q _{336F}	Q _{337F}	Q _{338F}	Q _{339F}	Q _{340F}	Q _{341F}	Q _{342F}	Q _{343F}	Q _{344F}	Q _{345F}	Q _{346F}	Q _{347F}	Q _{348F}	Q _{349F}	Q _{350F}	Q _{351F}	Q _{352F}	Q _{353F}	Q _{354F}	Q _{355F}	Q _{356F}	Q _{357F}	Q _{358F}	Q _{359F}	Q _{360F}	Q _{361F}	Q _{362F}	Q _{363F}	Q _{364F}	Q _{365F}	Q _{366F}	Q _{367F}	Q _{368F}	Q _{369F}	Q _{370F}	Q _{371F}	Q _{372F}	Q _{373F}	Q _{374F}	Q _{375F}	Q _{376F}	Q _{377F}	Q _{378F}	Q _{379F}	Q _{380F}	Q _{381F}	Q _{382F}	Q _{383F}	Q _{384F}	Q _{385F}	Q _{386F}	Q _{387F}	Q _{388F}	Q _{389F}	Q _{390F}	Q _{391F}	Q _{392F}	Q _{393F}	Q _{394F}	Q _{395F}	Q _{396F}	Q _{397F}	Q _{398F}	Q _{399F}	Q _{400F}	Q _{401F}	Q _{402F}	Q _{403F}	Q _{404F}	Q _{405F}	Q _{406F}	Q _{407F}	Q _{408F}	Q _{409F}	Q _{410F}	Q _{411F}	Q _{412F}	Q _{413F}	Q _{414F}	Q _{415F}	Q _{416F}	Q _{417F}	Q _{418F}	Q _{419F}	Q _{420F}	Q _{421F}	Q _{422F}	Q _{423F}	Q _{424F}	Q _{425F}	Q _{426F}	Q _{427F}	Q _{428F}	Q _{429F}	Q _{430F}	Q _{431F}	Q _{432F}	Q _{433F}	Q _{434F}	Q _{435F}	Q _{436F}	Q _{437F}	Q _{438F}	Q _{439F}	Q _{440F}	Q _{441F}	Q _{442F}	Q _{443F}	Q _{444F}	Q _{445F}	Q _{446F}	Q _{447F}	Q _{448F}	Q _{449F}	Q _{450F}	Q _{451F}	Q _{452F}	Q _{453F}	Q _{454F}	Q _{455F}	Q _{456F}	Q _{457F}	Q _{458F}	Q _{459F}	Q _{460F}	Q _{461F}	Q _{462F}	Q _{463F}	Q _{464F}	Q _{465F}	Q _{466F}	Q _{467F}	Q _{468F}	Q _{469F}	Q _{470F}	Q _{471F}	Q _{472F}	Q _{473F}	Q _{474F}	Q _{475F}	Q _{476F}	Q _{477F}	Q _{478F}	Q _{479F}	Q _{480F}	Q _{481F}	Q _{482F}	Q _{483F}	Q _{484F}	Q _{485F}	Q _{486F}	Q _{487F}	Q _{488F}	Q _{489F}	Q _{490F}	Q _{491F}	Q _{492F}	Q _{493F}	Q _{494F}	Q _{495F}	Q _{496F}	Q _{497F}	Q _{498F}	Q _{499F}	Q _{500F}	Q _{501F}	Q _{502F}	Q _{503F}	Q _{504F}	Q _{505F}	Q _{506F}	Q _{507F}	Q _{508F}	Q _{509F}	Q _{510F}	Q _{511F}	Q _{512F}	Q _{513F}	Q _{514F}	Q _{515F}	Q _{516F}	Q _{517F}	Q _{518F}	Q _{519F}	Q _{520F}	Q _{521F}	Q _{522F}	Q _{523F}	Q _{524F}	Q _{525F}	Q _{526F}	Q _{527F}	Q _{528F}	Q _{529F}	Q _{530F}	Q _{531F}	Q _{532F}	Q _{533F}	Q _{534F}	Q _{535F}	Q _{536F}	Q _{537F}	Q _{538F}	Q _{539F}	Q _{540F}	Q _{541F}	Q _{542F}	Q _{543F}	Q _{544F}	Q _{545F}	Q _{546F}	Q _{547F}	Q _{548F}	Q _{549F}	Q _{550F}	Q _{551F}	Q _{552F}	Q _{553F}	Q _{554F}	Q _{555F}	Q _{556F}	Q _{557F}	Q _{558F}	Q _{559F}	Q _{560F}	Q _{561F}	Q _{562F}	Q _{563F}	Q _{564F}	Q _{565F}	Q _{566F}	Q _{567F}	Q _{568F}	Q _{569F}	Q _{570F}	Q _{571F}	Q _{572F}	Q _{573F}	Q _{574F}	Q _{575F}	Q _{576F}	Q _{577F}	Q _{578F}	Q _{579F}	Q _{580F}	Q _{581F}	Q _{582F}	Q _{583F}	Q _{584F}	Q _{585F}	Q _{586F}	Q _{587F}	Q _{588F}	Q _{589F}	Q _{590F}	Q _{591F}	Q _{592F}	Q _{593F}	Q _{594F}	Q _{595F}	Q _{596F}	Q _{597F}	Q _{598F}	Q _{599F}	Q _{600F}	Q _{601F}	Q _{602F}	Q _{603F}	Q _{604F}	Q _{605F}	Q _{606F}	Q _{607F}	Q _{608F}	Q _{609F}	Q _{610F}	Q _{611F}	Q _{612F}	Q _{613F}	Q _{614F}	Q _{615F}	Q _{616F}	Q _{617F}	Q _{618F}	Q _{619F}	Q _{620F}	Q _{621F}	Q _{622F}	Q _{623F}	Q _{624F}	Q _{625F}	Q _{626F}	Q _{627F}	Q _{628F}	Q _{629F}	Q _{630F}	Q _{631F}	Q _{632F}	Q _{633F}	Q _{634F}	Q _{635F}	Q _{636F}	Q _{637F}	Q _{638F}	Q _{639F}	Q _{640F}	Q _{641F}	Q _{642F}	Q _{643F}	Q _{644F}	Q _{645F}	Q _{646F}	Q _{647F}	Q _{648F}	Q _{649F}	Q _{650F}	Q _{651F}	Q _{652F}	Q _{653F}	Q _{654F}	Q _{655F}	Q _{656F}	Q _{657F}	Q _{658F}	Q _{659F}	Q _{660F}	Q _{661F}	Q _{662F}	Q _{663F}	Q _{664F}	Q _{665F}	Q _{666F}	Q _{667F}	Q _{668F}	Q _{669F}	Q _{670F}	Q _{671F}	Q _{672F}	Q _{673F}	Q _{674F}	Q _{675F}	Q _{676F}	Q _{677F}	Q _{678F}	Q _{679F}	Q _{680F}	Q _{681F}	Q _{682F}	Q _{683F}	Q _{684F}	Q _{685F}	Q _{686F}	Q _{687F}	Q _{688F}	Q _{689F}	Q _{690F}	Q _{691F}	Q _{692F}	Q _{693F}	Q _{694F}	Q _{695F}	Q _{696F}	Q _{697F}	Q _{698F}	Q _{699F}	Q _{700F}	Q _{701F}	Q _{702F}	Q _{703F}	Q _{704F}	Q _{705F}	Q _{706F}	Q _{707F}	Q _{708F}	Q _{709F}	Q _{710F}	Q _{711F}	Q _{712F}	Q _{713F}	Q _{714F}	Q _{715F}	Q _{716F}	Q _{717F}	Q _{718F}	Q _{719F}	Q _{720F}	Q _{721F}	Q _{722F}	Q _{723F}	Q _{724F}	Q _{725F}	Q _{726F}	Q _{727F}	Q _{728F}	Q _{729F}	Q _{730F}	Q _{731F}	Q _{732F}	Q _{733F}	Q _{734F}	Q _{735F}	Q _{736F}	Q _{737F}	Q _{738F}	Q _{739F}	Q _{740F}	Q _{741F}	Q _{742F}	Q _{743F}	Q _{744F}	Q _{745F}	Q _{746F}	Q _{747F}	Q _{748F}	Q _{749F}	Q _{750F}	Q _{751F}	Q _{752F}	Q _{753F}	Q _{754F}	Q _{755F}	Q _{756F}	Q _{757F}	Q _{758F}	Q _{759F}	Q _{760F}	Q _{761F}	Q _{762F}	Q _{763F}	Q _{764F}	Q _{765F}	Q _{766F}	Q _{767F}	Q _{768F}	Q _{769F}	Q _{770F}	Q _{771F}	Q _{772F}	Q _{773F}	Q _{774F}	Q _{775F}	Q _{776F}	Q _{777F}	Q _{778F}	Q _{779F}	Q _{780F}	Q _{781F}	Q _{782F}	Q _{783F}	Q _{784F}	Q _{785F}	Q _{786F}	Q _{787F}	Q _{788F}	Q _{789F}	Q _{790F}	Q _{791F}	Q _{792F}	Q _{793F}	Q _{794F}	Q _{795F}	Q _{796F}	Q _{797F}	Q _{798F}	Q _{799F}	Q _{800F}	Q _{801F}	Q _{802F}	Q _{803F}	Q _{804F}	Q _{805F}	Q _{806F}	Q _{807F}	Q _{808F}	Q _{809F}	Q _{810F}	Q _{811F}	Q _{812F}	Q _{813F}	Q _{814F}	Q _{815F}	Q _{816F}	Q _{817F}	Q _{818F}	Q _{819F}	Q _{820F}	Q ₈₂₁

301 Hopefully, this table will be readable?

columns for December 2, 2011 to December 31, 2012) displaying hidden computer dam simulation are shown in Table 7. The results of validation based on 2011-2012 data (with hidden command rows and columns for December 2, 2011 to December 31, 2012) displaying Dam Water Balance (DWB) and potential irrigable area are highlighted.

Table 7: Operational spreadsheet workbook simulation highlight for computer simulated and available reservoir water (m³) and potential field area

Date	Factors	Comp			Water losses	Water withdrawals				
------	---------	------	--	--	--------------	-------------------	--	--	--	--

Plantg Dec. Time step (day) ↓ End Season	Climate Land	Simuln →	Cumml dam inflows (m ³ /dy)	DWB (m ³)	Pot evap mm	Spg (m ³)	Goat (m ³)	Cattle (m ³)	Human (m ³)	Computer Simuln →	Crop Availab Water (m ³)	Applied Water (cm)	Potel Irrigb Area (ha)
Dec. 31	Results highlight												ha 16.9
	Temp & Pot evap	→	10796	10087	1.69	5.7	27.5	122	0	→	9931	7990	

308 Your spread sheet needs some modification. The
 309 computer simulated headis should be at the top not as a
 310 column.It will be better to give s.no for each column.

311

312 It has been demonstrated that reservoir water capacities can be more clearly defined and crop
 313 water productivity known once water losses and abstraction rates are identified.

314 In addition to simulation of seasonal reservoir water balance and irrigation command (irrigable) area
 315 after input of data for water losses and crop water uses, using the spreadsheet commands, the DSS
 316 is able to simulate expected yield value and crop water productivity (prdcty) as shown in Table 7.

317 **Table 7: NAM addendum spreadsheet based water loss, irrigation and water balance**

318 Crop	319 Measured	320	321	322	323	324	325	326	327	328	329	330
Growth	dam vol.	Evapor	Seepage	Field use	Water	Dam	Simulate	Water	Bean			
(wks)	m ³	m ³	m ³	m ³ /ha	m ³ /ha	Balance	Irrigable	Yield	Prdcty			
						(m ³)	crop Area (ha)	(kg/ha)	g/L			
Pre-planting	9978	6	11	500	517							
1 to 2	9015	9	16	1500	1525							
5 to 9	4646	10	19	2000	2029							
6 to 10	2541	8	15	2000	2023							

325	TOTAL	0	33	61	6000	6094	3884	17	1400.0	0.7
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326 The DSS simulated synchronization of reservoir water and land area (1.5 ha) is equivalent to
 327 the calculated area (1.6 ha) based on the research recommended bean crop irrigation depth of
 328 5 cm per week, if static application rate is followed. This validates the DSS for utilization to
 329 establish reservoir capacity and/or corresponding crop land area. Using the MS Excel
 330 operation, the developed DSS reliably relates runoff rainwater harvesting, its seasonal open
 331 surface storage and irrigation to crop water productivity. Use of the developed DSS can
 332 provide stakeholders with information to make decisions in planning field area for farmers
 333 based on reservoir capacity or build a reservoir to suffice crop land area to mitigate drought
 334 and dry spell impacts.

335 It should have been better to give simulated output
 336 results in graphical form for a sample year.

337 3. Conclusions and Recommendations

338 It will be dilemma whether technology of decision
 339 support should preceed the society acceptance of
 340 vice versa?

341 Discussion ?????

342 4.1 Conclusions

343 Socio-economic analysis has indicated clear benefits for the farmers producing the common beans
 344 (*Phaseolus vulgaris*, L.) using stored runoff water. Availability of a decision support system to help in
 345 determination of required crop field area in relation to the reservoir water capacity or vice-versa is

vital. The structure and spreadsheet entries of the DSS have been designed and validated. Two dry season crop production cycles, at crop water productivity of 0.7 g/L, as the case at Ukwe Area, would require potential crop command field area of 1.5 ha. The DSS has comparative advantage to others, developed for rainwater harvesting for irrigation, because apart from using simple data entry it is versatile in simulating runoff, long term surface water storage capacity and synchronized crop land area farmers need to prepare to meet the recommended crop water requirement.

Is this research able to find relation between catchment area: water harvesting size of water storage : dam: irrigation areas for beans???

Fig 3 , Table 1, table 2 use is not displayed

At national level, the Early Warning Section of the Ministry of Agriculture and Food Security anticipates using the DSS, given climate forecasts, to predict crop yield and mitigate drought and dry spell impacts. The DSS provides stakeholders such as farmers and agricultural research and extension workers, a simplified procedure for determination of reservoir water capacities, given climatic forecasts, catchment characteristics and crop water requirement, in order to plan for dry season crop field sizing.

4.2 Recommendations

It is recommended that it be further validated on different crops, apart from common beans, and other agro-ecological zones, apart from Lilongwe Plateau Area, for wide-scale utilization. Furthermore, in addition to spreadsheet data entry operational structure, a computer interface be

developed. The user can perform progressive interactive data entry starting with fixed catchment parameters and time constants as the DSS data base memory to evoke prominent catchments used for water harvesting. Then a window should display a request for predicted precipitation entry, then potential evaporation value followed by temperature to achieve seasonal reservoir volume display. The user will be asked to enter seepage, then evaporation values to get a new reservoir balance and get crop water application interface. Once a figure is entered the computer interface will display the field area to be prepared. The procedure would be an option to the presented excels spread sheet data entry used in this study.

At agricultural academic institutions in SSA the DSS can be included in curricula modules and research projects. Evaluation and monitoring by the academic and Ministry of Agriculture and Food Security's irrigation Department may form the foundation for a follow-up on the use of the DSS. This would be done at national level in agro-hydrological zones.

First Perfect your research then go for recommendation

5. Acknowledgement

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459 **7. List of acronyms and abbreviations**

460 AQUACROP Crop water productivity model which simulates yield response to water

461 APSIM Agricultural Production Simulator

462 CERES Crop Environment Resource Synthesis

463 Commul Cumulating

464 Crop availab Crop available water

465	CROPGRO	Crop growth model
466	CROPSIM	Package with functions for dynamic & mechanistic simulation of crop
467		growth and development in response to inputs
468	CWP	Crop water productivity
469	CWR	Crop water requirement
470	D	Maximum water depth
471	DSS	Decision Support System
472	DSSAT	Decision Support System for Agro-technology Transfer
473	DWB	Dam Water Balance
474	DGPS	Differential Global Position System
475	EV	Evaporated water volume (m ³)
476	Evapn	Evaporation
477	E _{reservoir}	Reservoir evaporation
478	GEV	General extreme value
479	ha	hectare
480	HYDATA	Purpose-built, Windows-based database and analysis system for processing
481		hydrometeorological data
482	H & S	Harvested and stored respectively
483	ICRISAT	International Centre for Research in semi-Arid Tropics

Incorrect

484 name

485	IDRC	International Development Research Centre
486	IFAD	International Food and Agricultural Development
487	ITDG	Intermediate Technology Development Group
488	IWMI	International Water Management Institute
489	m ²	Square metres
490	MAFS	Ministry of Agriculture and Food Security
491	MIWD	Ministry of Irrigation and Water Development
492	NAM	<i>Nedbor Afstromnings</i> Model
493	PARCHED -THIRST	Predicting Arable Resource Capture in Hostile Environments
494		During the Harvesting of Incident Rainfall in the Semi-arid
495		Tropics
496	Pot evap	Potential evaporation

497	Pot irrigb	Potential irrigable area
498	Res. Balance	Reservoir balance
499	RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
500	SADC	Southern African Development Community
501	Spg	Seepage
502	SSA	Sub-Saharan Africa
503	Temp	Temperature
504	US\$	United States Dollar
505	VEMAP	Vegetation/Ecosystem Modeling and Analysis Program