Water audit decision support tool

Cubango-Okavango River Basin

REPORT INFORMATIONS

Title	Water audit decision support tool
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1 INTRODUCTION

The main objective of this document is to describe activities related to Component 5 of the Cubango-Okavango River Basin Water Audit. This Water Audit is part of the project "Coping with water scarcity – the role of agriculture: Developing National Water Audits in Africa" (GCP/INT/072/ITA), and is carried out in co-operation with OKACOM (Permanent Okavango River Basin Water Commission).

In particular, this document focuses on the update of a WEAP application for the basin, including review of an existing application, proposed updates, and discussion of results.

2 PROJECT BACKGROUND

A basin water audit has been identified as a priority by riparian countries and SADC. The purpose of the audit is to provide the Permanent Okavango River Basin Water Commission (OKACOM) with a comprehensive methodology for assessing, analysing and reporting of the use of scarce water resources that can be applied with regular intervals to monitor the state of a countries' water resource base.

The objectives of OKACOM as per 1994 agreement include:

1. Determine the long term safe yield of water available from the river,
2. Estimate reasonable water demand scenarios from consumers,
3. Prepare criteria for conservation, equitable allocation and sustainable utilization of water,
4. Undertake investigations related to water infrastructure,
5. Formulate recommended pollution prevention measures,
6. Develop measures for alleviation of short-term difficulties, such as temporary droughts and floods

The water audit initiative may provide substantive contributions to objectives 1, 2 & 3 and to some extent also inform 4.

In terms of water supply, the audit will provide updated information about the water availability. In terms of demand, the audit will identify final use quantities and, to the extent possible, quality evolution– together with projections of demand for basin planning purposes. The broad objectives of the audit are:

- To assess the current status of water resources, by examining trends in recorded rainfall, river discharges and groundwater levels.

- To evaluate water related demand trends, taking into consideration domestic, industrial and environmental water use, but with focus on agricultural water use because of the large share of water that agriculture takes and the complexity of the situation regarding the productivity of water used in agriculture.

- To study patterns of water related entitlements of social groups, in particular taking into account gender and social exclusion issues regarding access to water resources for both domestic and productive purposes.

- To assess the functionality of water related policies and institutions at different administrative levels including reviewing of water legislation and mapping of existing government institutions dealing with water.

- To provide decision makers with a comprehensive set of policy options to increase the capacity to cope with water scarcity and improve their water management in general and water productivity of agricultural production in particular.

Graphically, the different components of the project can be depicted as follows (Component 5, the main focus of this document, is highlighted in red):

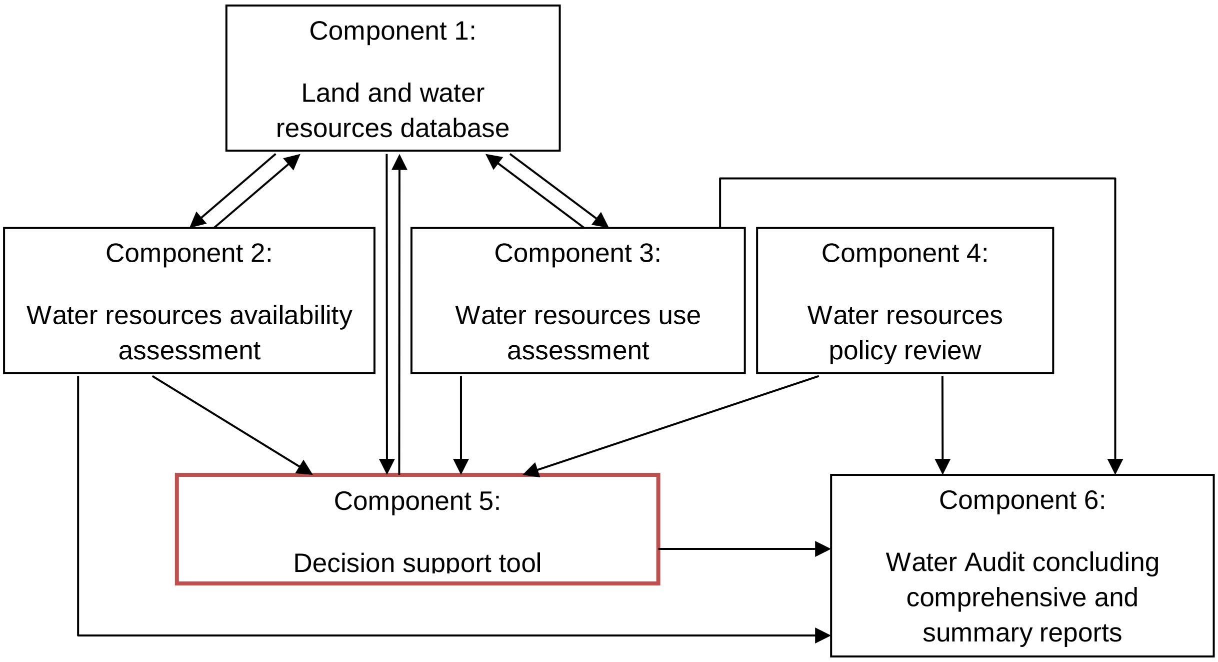


Figure 1 Schematic view of Water Audit components

Component 5. A spatially distributed decision support tool, linked to the upgraded database, applied for water resources scenarios including a users' manual and personnel trained in its operation. This output provides the information needed to evaluate the implications of changes in boundary conditions (population, climate and trade) for the performance of the existing and projected future water management infrastructure.

The activities for this output consist of:

- Review the WEAP-model as prepared for the TDA and compare, link and update its parameterization with the information as collected in the GIS-database for land and water resources (component 1) and the water use study (component 2);

- Prepare a user manual for the operation and parameterisation of the model including the
- use of different types of software (GIS-databases and WEAP-model);
- Prepare model based scenario analyses for possible future developments in the Okavango river basin;
- Carry out capacity building workshops for operators of the software.

3 TOOL SELECTION

The selection of the appropriate tool to undertake activities related to Component 5 of the Water Audit approach has been guided by the following criteria:

1. Tool outputs: management options under different scenarios.
2. Multi-sector approach: need to takes into account all water uses
3. Adaptable to available data and information gaps
4. Ensures continuity with former OKACOM - EPSMO project and consistency with current and future OKACOM projects
5. Strengthens existing capacities

Based on the above, the use of the WEAP application developed by the EPSMO project has been proposed and discussed with OKACOM task force members and OKASEC Executive Secretary. The project team and technical advisers have identified the Water Evaluation and Planning system (WEAP) as the appropriate software because of its policy orientation, flexibility and user-friendly interface, of its adoption during a previous FAO-lead project in the area (Environmental Protection and Sustainable Management of the Okavango River Basin – EPSMO project, GEF funded), and because its license if provided for free to public and research institutions in developing countries.

A rapid survey on the use of the WEAP application developed during the EPSMO project, revealed a lack of capacity within the three riparian countries institutions and especially in Namibia, where nobody from the Ministry of Agriculture, Water and Forestry, had been trained on its use. At the same time, a demand for a stronger institutional involvement at ministerial level in the decision support tool development was raised by OKASEC. It was then agreed to address these issues through capacity building for Angolan, Botswana and Namibian governmental institutions on the use of the Okavango WEAP application, with emphasis on methodologies for model update and scenario formulation. During a training workshop held in Windhoek in October 2012, the EPSMO application and proposed updates have been thoroughly discussed with national experts from the three riparian countries (workshop report in Annex).

3.1 WEAP BACKGROUND

WEAP is short for *Water Evaluation and Planning System* and is originally developed by the Stockholm Environment Institute at Boston, USA (SEI, 2005). WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems. WEAP is a laboratory for examining alternative water development and management strategies (SEI, 2005).

WEAP represents the system in terms of its various supply sources (e.g. rivers, creeks, groundwater, and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily customized to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The Current Accounts, which can be viewed as a calibration step in the development of an application, provide a snapshot of the actual water demand, pollution loads, resources and supplies for the system. Key assumptions may be built into the Current Accounts to represent policies, costs and factors that affect demand, pollution, supply and hydrology. Scenarios build on the Current Accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (SEI, 2005).

WEAP, in contrast to many other tools, is not optimisation oriented in the sense that the optimal water allocation will be presented. The entire approach is based on scenarios (alternatives) to ensure that stakeholders, water managers and policy makers are actively involved in the entire process of planning in order to guarantee the ownership feeling of the final decisions taken.

WEAP consists of five main views: Schematic, Data, Results, Overviews and Notes. A typical stepwise approach will be followed to develop WEAP for a particular area: (i) create a geographic representation of the area, (ii) enter the data for the different supply and demand sites, (iii) compare results with observations and if required update data, (iv) define scenarios and (v) compare and present the results of different scenarios. In general, the first three steps will be done by technical experts like hydrologists, while for the last two steps input and exchange with stakeholders, water managers and policy makers is essential. (http://www.weap21.org/)

4 OKAVANGO WEAP APPLICATION OVERVIEW

The Okavango WEAP application was developed for the Transboundary Diagnostic Assessment of the Okavango basin to derive scenarios of impacts on environmental flow. The CORBWA project[1] will make use of the model, integrating it with water demand and supply as updated on the basis of the corresponding CORBWA reports, and build scenarios of future developments to support decision making.

4.1 SCHEMATIC

The schematic view shows the delineation of main basin and catchments, rivers, demand sites (irrigation and domestic supply), reservoirs and run-of-river hydro stations as derived from GIS layers.

In total 24 rivers, 10 hydro stations, 3 reservoirs, 19 demand sites (3 domestic supply sites, 5 irrigation demand sites and 11 more in development scenarios) and 8 groundwater sites were identified (see schematic view , Figure 2).

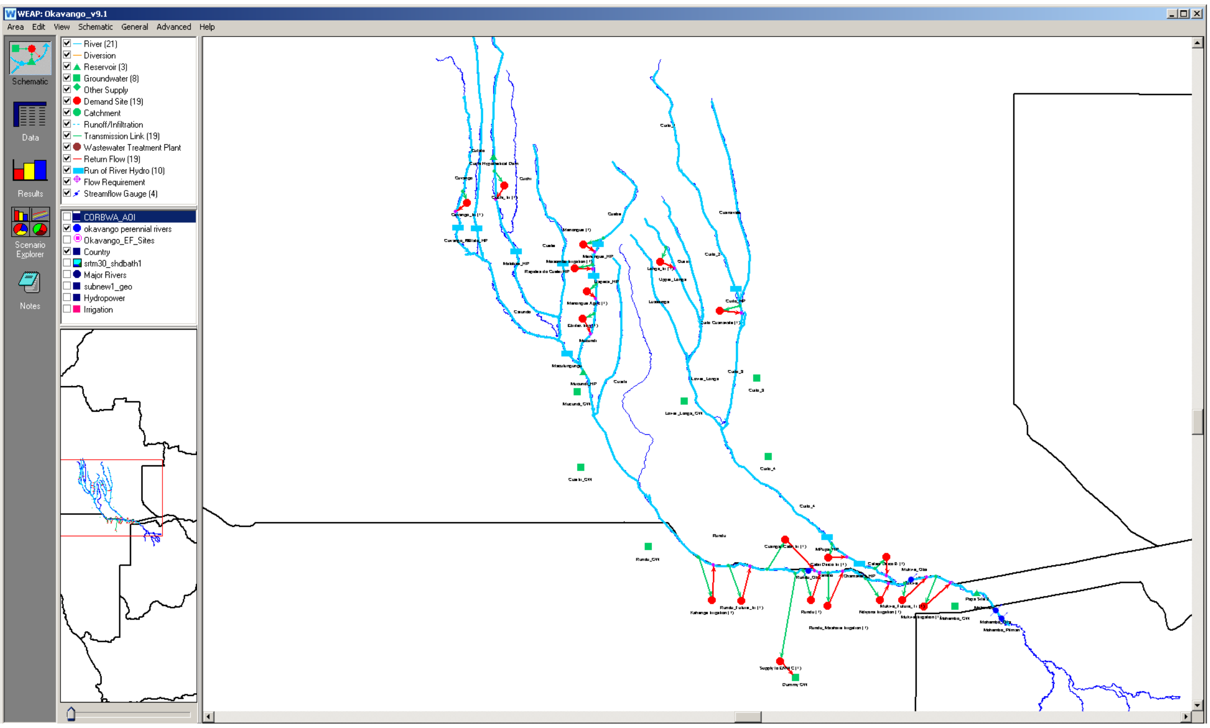


Figure 2 - Schematic view of Okavango_v9.1 application

4.2 INPUT DATA: SUPPLY

Estimates of naturalised (undeveloped) long-term runoff were obtained from an existing Pitman-based rainfall-runoff model developed as part of the EU funded WERRD project. The model was configured to provide runoff sequences at the outlets of 24 distinct sub-catchments

[1] Cubango/Okavango River Basin Water Audit

upstream of the Delta for the period 1959-2002. (EPSMO Hydrology report, 2009). The sequences were then analyzed through the "System model" (WEAP) to estimate impact of different scenarios on stream flows at eight different Ecological Flow Assessment sites. Outputs of the System model were used as input for specific delta models, as shown in the figure below.

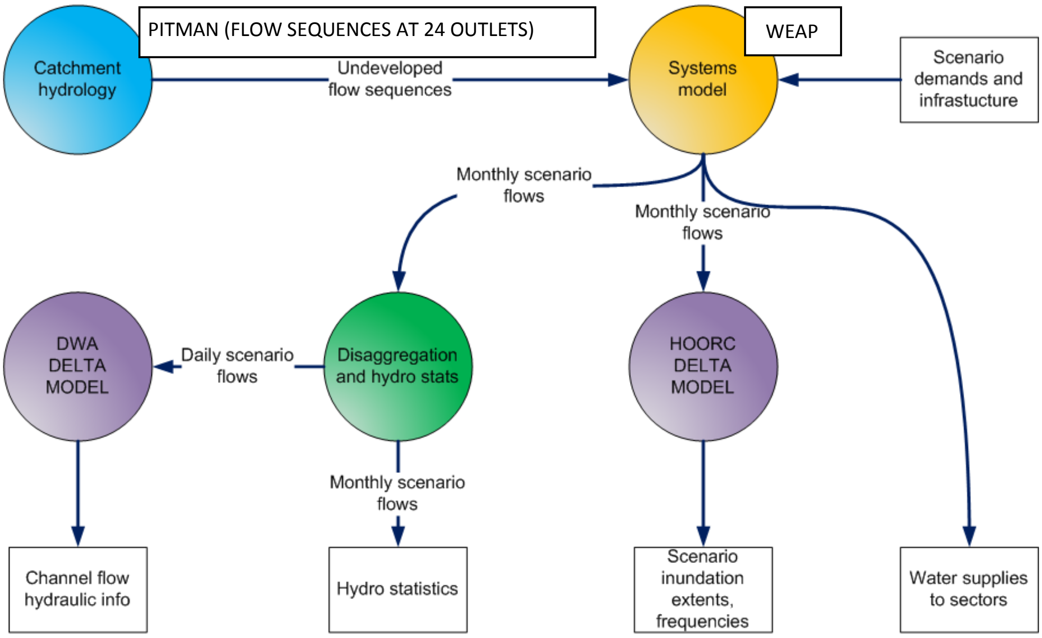


Figure 3 - EPSMO hydrological modeling overview (EPSMO, 2009)

4.3 INPUT DATA: DEMAND

EPSMO project's assessment of water demand in the basin consisted mainly of:

- The urban water demands of Menongue and Cuito Cuanavale (Angola), Rundu (Namibia)- not active in current account-, and Maun (Botswana)- outside of contributing area, and thus not included in the EPSMO WEAP;
- About 2 700 ha of irrigation in the Namibian portion of the basin, and 1,000 in Angola;
- Rural domestic and subsistence agricultural water demands and water demands of the tourism sector (Namibia and Botswana), all of which small compared to the irrigation and urban demands, were not included in the WEAP

4.4 CURRENT ACCOUNT AND REFERENCE SCENARIOS

The Current Accounts is the dataset from which the scenarios are built. Scenarios explore possible changes to the system on future years after the Current Accounts year. A default scenario, the "Reference scenario" carries forward the Current Accounts data into the entire project period specified and serves as a point of comparison for the other scenarios in which changes are made to the system data (SEI, 2005).

The year 1959 is chosen as the "Current Account" year, or base year, for this model and the project time horizon is set to 1960 - 2002. Three main development scenarios have been identified: High Development (*"As much irrigation as possible, one or more Angolan Dams for* *irrigation supply, development of all run-of-river hydropower, transfers to Central Namibia and implementation of the SOIWD")*, Medium and Low development Table 1 provides an overview of input data with regard to irrigation water demand.

Okavango_v9.1 input data: Agricultural water demand			
Angola			
Scenario	***Area extent (ha)***	***unit irrigation demand (m^3/ha)***	***Total Withdrawal (Mm ^{3}/y)***
Reference	1,000	12960	13
Low	43,000	7500* - 12960	475
Medium	198,000	7500 - 12960	1,638
High	338,000	7500 - 12960	3,452
Namibia			
Reference	2,247	15000	34
Low	3,077	15000	46
Medium	8,377	15000	126
High	14,895	15000	223

*7500 is for supplemental irrigation

Table 1- WEAP application agricultural water demand summary table (derived from Okavango_v9.1)

In addition, "wet" and "dry" circumstances were modelled in the development scenarios so that a total of 8 scenarios (Table 2) were represented in the latest available application developed for the EPSMO project (WEAP area named "Okavango_v9.1").

High - no storage
High Development
Low Development
Low Dry
Low Wet
Medium Development
Medium Dry
Medium Wet

Table 2 - EPSMO scenarios

4.5 EPSMO TDA RESULTS

The Transboundary Diagnostic Analysis Report (OKACOM, 2011) presents results of simulated impacts of water resources development in the three scenarios by looking at changes on six selected indicators: mean annual runoff, dry season duration, dry season minimum flow, flood season peak, flood season volume and flood season duration. These indicators are summarized in figure 4, where the impact on minimum flow it is clearly visible in the High development scenario.

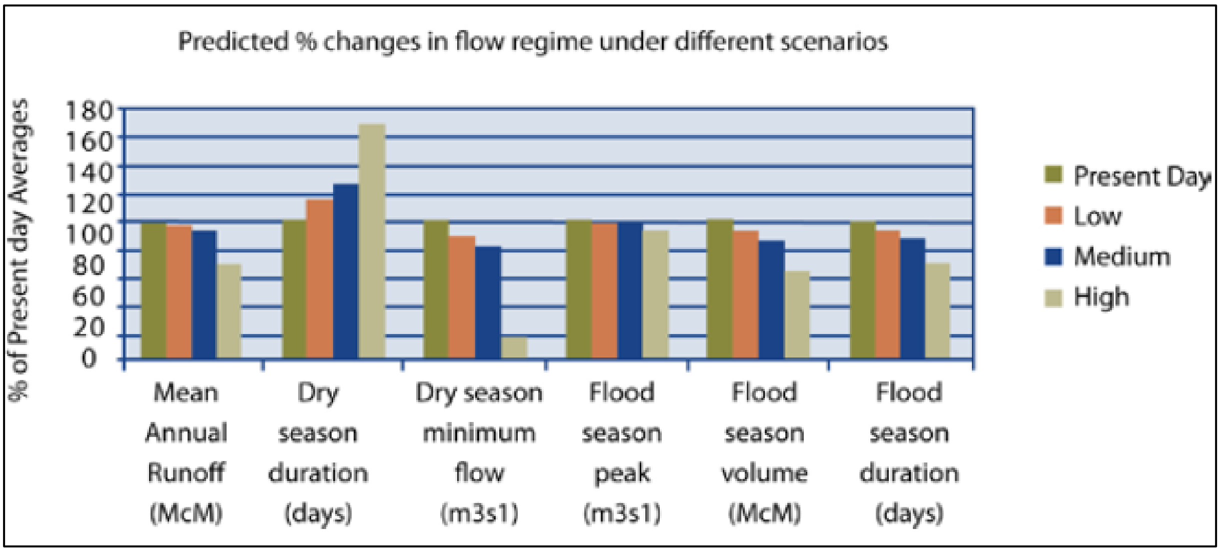


Figure 4: changes in flow regime under different scenarios (TDA report)

A consistent result comes from the WEAP application if one looks at decrease in flow from reference scenario (or Present Day), illustrated in figure 5.

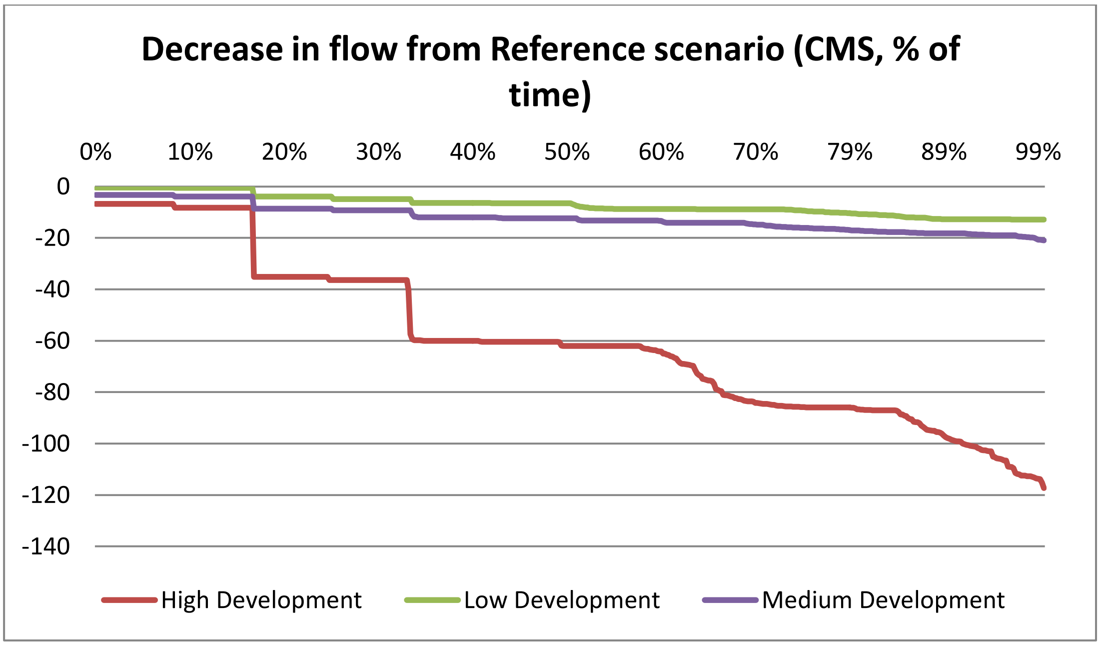


Figure 5: decrease in flow under different scenarios (EPSMO WEAP simulation output)

5 OPTIONS FOR CORBWA UPDATES / INTEGRATIONS

Areas of improvements and updates have been identified: i) taking into account EPSMO recommendations, ii) through consultations with OKASEC and OKACOM Hydrology Task Force members and, iii) constrained by time and –limited- availability of updated information and data.

5.1 EPSMO RECOMMENDATIONS

Conclusions and recommendations of the EPSMO hydrology report 05 - Data and Models (EPSMO, 2009) suggest that:

- An effort is made to improve peak flows: although the Pitman performs reasonably well, it tends to under-represent peak flows (20% estimated error)
- The model is extended to cover hydrological years from 2003 to as recent as possible: this would also allow modeling of the above-average floods of 2009

Unfortunately, lack of updated precipitation and flow data from the contributing area, made both these recommendations not applicable within CORBWA project duration.

The report also highlights the following model's constraints:

- The inability to include water quality in the model, due to lack of historical water quality measurements
- The absence of sediment transport model
- Too simplistic hydrological modeling of floodplains

5.2 CORBWA FOCUS

The River Basin Water Audit approach being developed by FAO and tested in this CORBWA analysis has a strong focus on agricultural water demand, being agriculture the largest water consuming sector globally. Although irrigated agriculture and livestock demand have currently little or no relevance in the Cubango-Okavango basin in terms of water consumption, it is nevertheless important to monitor the impact they have on water resources by providing a sound baseline on which changes can be tracked, and trends highlighted over time.

To this purpose, a specific review of the agricultural water demand assumptions used in the Okavango_v9.1EPSMO application has been carried out, as summarized below.

Parameter	Assumptions used in Okavango_v9.1 EPSMO application:	
	Angola	**Namibia**
Annual activity level (ha)	1000 in Ref Scenario, 338000 in High Development	2247 in Reference., and 14895 in High

		Development
Unit demand (m^3/ha/y)	12960 (or 7500 for supplemental irrigation)	15000
Return Flow	90% in Reference scenario, 15% in Development scenarios	15%
Monthly variations	See Figure 6	

Table 3 - Assumptions used in Okavango_v9.1

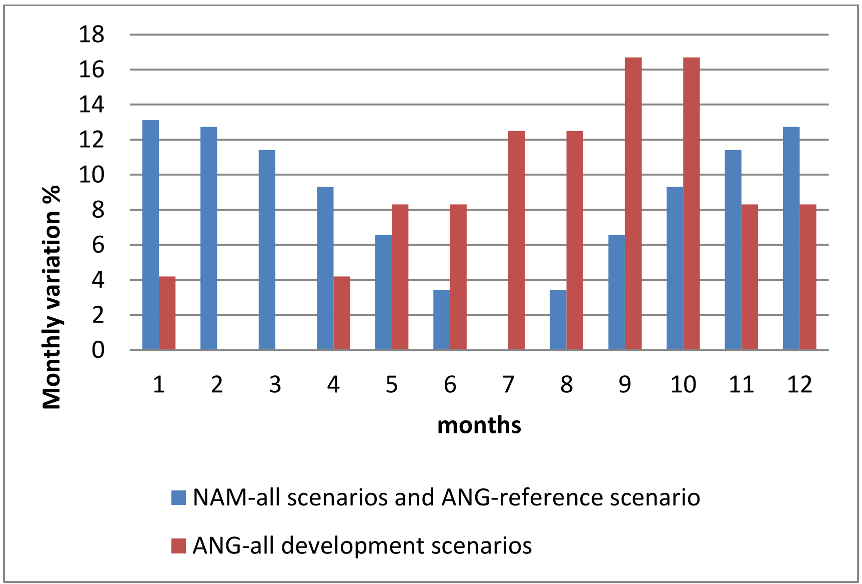


Figure 6-Monthly variation of Irrigation water requirement as defined in the Key assumptions of Okavango_v9.1

5.3 OPTIONS FOR MODEL UPDATES

Although the EPSMO report clearly recommends the model to be extended over time, it was decided to stick to the analysis's temporal extent mainly because of the lack of new data from the measuring stations in Angola. On the other hand, remote sensing based precipitation data, which was used by the EPSMO team to extend the analysis to 2002, could only be used after a time consuming calibration exercise (FAO, 2012b) which is beyond the scope and the duration of the CORBWA project. This might be done at a later stage through other OKACOM partnered projects.

The agricultural focus of the CORBWA analysis would also imply an assessment of the possible impacts of climate change on agricultural water supply and demand. As a matter of fact, the "wet" and "dry" Low and Medium development scenarios described in the EPSMO application reflect climate change by using modified runoff sequences from the Pitman, while no impact on agricultural water demand is accounted for. Unfortunately, update of climate change parameters has not been possible within the project timeframe, although a report has been commissioned to review findings of recent climate change studies in the basin and identify relevant modeling approaches (FAO, 2012b).

For these reasons, CORBWA updates only focus on demand, while keeping the supply part as developed by the EPSMO project. All changes and updates are treated as "CORBWA" scenarios based on the EPSMO Okavango application, to allow for an easier comparison.

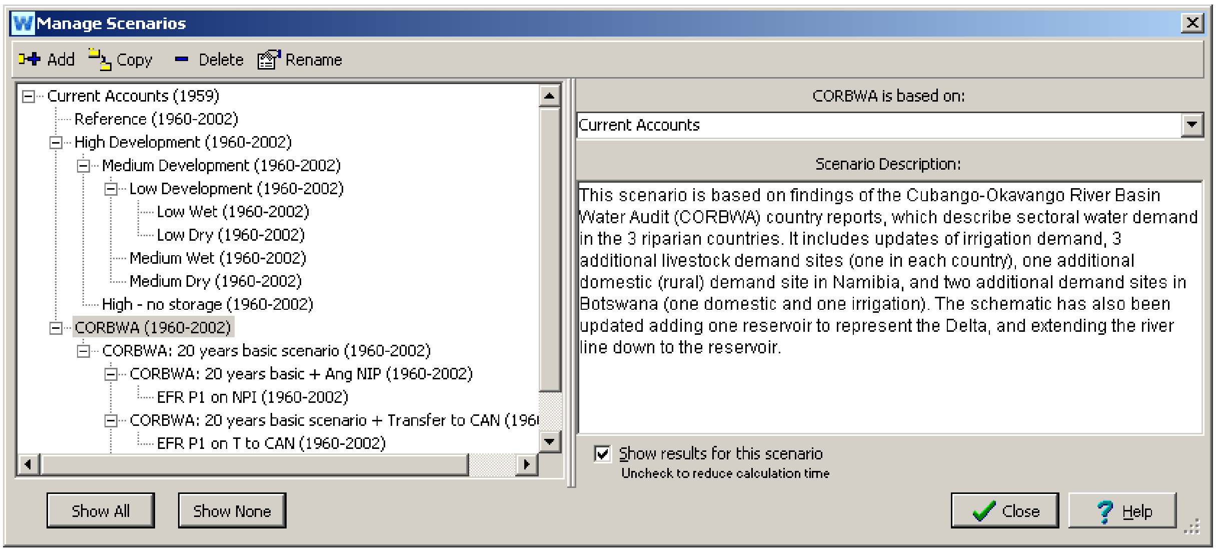


Figure 7 - Screenshot of CORBWA scenarios in WEAP

Updates of the Okavango WEAP application are proposed as follows:

1. <u>Agricultural water demand, irrigation:</u>

It is advisable to revise the monthly variation, taking into account average monthly precipitation and reference ET (Figure 9 shows averages for Rundu), and dominant cropping patterns.

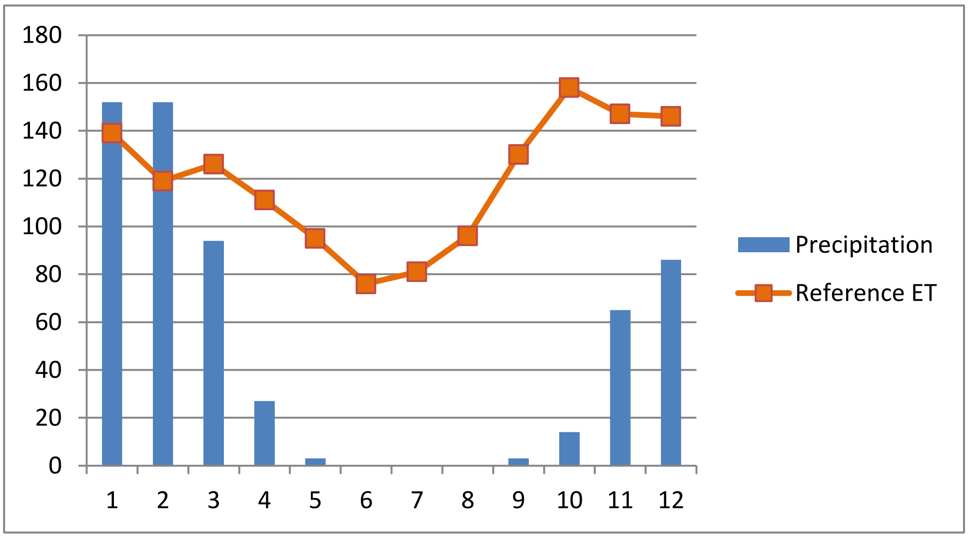


Figure 8- Monthly precipitation and ET-ref in Rundu, average 1961-1990

Also, return flow assumptions need to be revised to take into consideration efficiency of irrigation technologies commonly found in the area; revised parameters for irrigation water demand are summarized in Table 4.

WEAP Parameter	Angola	Namibia	Botswana
Annual activity level (ha)	2,280 ha	2,133 ha	119 ha
Unit demand (m/ha/y)	13,480 [2]	10,000[3]	14,000[4]
Monthly variation of irrigation requirement (%)-see Figure 6-	Oct, 0, Nov, 0, Dec, 0, Jan, 0, Feb, 1.5, Mar, 3.3, Apr, 8.9, May, 19.3, Jun, 16.6, Jul, 25.3, Aug, 25.2, Sep, 0[5]	Oct, 28, Nov, 20, Dec, 0, Jan, 0, Feb, 0, Mar, 0, Apr, 0, May, 0, Jun, 9, Jul, 8, Aug, 14, Sep, 22[6]	Oct, 5, Nov, 0, Dec, 0, Jan, 0, Feb, 0, Mar, 0, Apr, 5, May, 10, Jun, 20, Jul, 25, Aug, 25, Sep, 10
Return flow (%)	75%	30%[7]	50%

Table 4-Proposed parameters of agricultural water demand

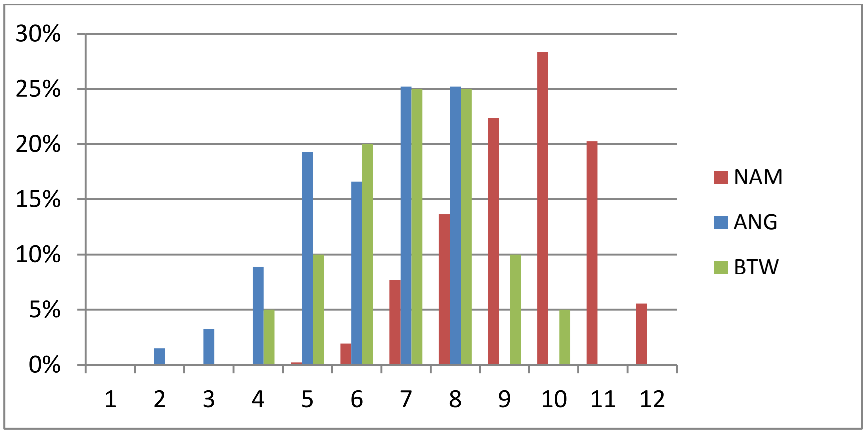


Figure 9: proposed monthly variation of irrigation requirement. Monthly crop water requirement has been calculated using FAO AQUASTAT Climate Info Tool.

2. Livestock demand

[2] Unit demand and monthly variations are based on crop water requirement for double cropping of vegetables in Menongue, calculated using AQUASTAT Climate Info Tool and CropWat, and assuming an irrigation efficiency of 25%.
[3] CORBWA – Namibia Water Demand Report suggests using 15,000 m³ for irrigation serviced by surface water and 12,000 for groundwater with reference to allocated quotas, but demand is in fact lower for the majority of crops.
[4] Crop water requirement is assumed to be equal to the Namibian, but higher unit demand (m³/ha) due to lower irrigation efficiency (and thereby higher return flow)
[5] Estimated on the basis of climatic conditions and crop calendars (double cropping, vegetables, in Menongue area)
[6] Based on climatic conditions near Rundu, and considering Alfalfa and wheat cultivation
[7] Based on average of irrigation efficiencies reported in CORBWA country water demand report.

Three livestock demand sites are added in the schematization, representing aggregated livestock water demand (as identified in the CORBWA demand reports) for the CORB area within each country, as summarized in Table 5. Livestock demand is represented in the model as surface water abstraction due to lack of data on groundwater resources, and only demand from the Omatako-Okavango basin has been accounted for in Namibia, leaving out other basins' demand due to uncertainties in linking them with CORB surface water resources.

Parameter	Angola	Namibia	Botswana
Annual activity level (unit)	601,000 WLU[8]	397,241 WLU[9]	272,044 WLU
Unit demand ($m^3/u/y$)	22 m^3 /y	24.6 m^3/y	21.9 m^3/y
Monthly variation		none	
Return flow (%)		80%	

Table 5 - Livestock water demand parameters

3. Domestic demand

Urban demand in Angola is aggregated into one site corresponding to Menongue (largest town, 200 thousand inhabitants, of which about 26% are serviced by distribution network), while rural demand is aggregated at Cuito Canavale site, the largest rural center, with 38 thousand inhabitants not connected to the distribution network. Urban demand in Namibia is represented at Rundu demand site (about 55 thousand inhabitants), and for rural demand a new demand site is added in the schematization. Domestic demand in Botswana is represented by one demand site "Botswana domestic" further disaggregated into rural and urban (Maun) demand. In order to include Botswana demand sites into the WEAP model, the schematization as drawn in the EPSMO, with the river line ending at Mohembo, has been modified extending the river line up to Sepupa / Seronga settlements. Domestic demand parameters are summarized in table 6.

Parameter	Angola	Namibia	Botswana
Annual activity level (cap)	62,000 urban and 306,000 rural[10]	63,398 urban, 211,000 rural[11]	40,000 urban, 80,000 rural
Unit demand ($m^3/p/y$)	18.25 m^3 /y urban, 9.125 rural	46.7 urban, 9.2 rural	40 urban, 20 rural
Monthly variation	none	none	none

[8] WLU = Water Livestock Unit. Similar to the Tropical Livestock Unit, a conversion factor has been applied to the different livestock types in accordance with their drinking water requirements. Therefore, cattle number is multiplied by 1 (60 l/d), goat and sheep by 0.2 (12 l/d), pig by 0.42 (25 l/d), poultry by 0.005 (0.33 l/d).

[9] Water Livestock Unit: see Angola (animal water demand in Namibia, based on IWRM 2010: cattle 67 l/u, sheep and goats 15 l/u)

[10] Based on Municipalities population data, and coverage of water distribution network in each municipality (Barbosa, 2012)

[11] Source of water for urban areas is stated in the CORBWA demand report and only surface water is considered here; whereas for rural areas, where the distinction among sources is not that clear, only demand in the Okavango-Omatako have been considered, while others national basin have been left out due to uncertainties in attributing water source.

Return flow (%)	80% urban, 70% rural	80% urban, 50% rural	50%[12]

Table 6 - Domestic demand parameters

4. Environmental demand

The environment is here represented similarly to other sectors, its water demand referring to the quality, quantity and timing required to maintain ecosystem goods and services. More than other sectors though, the parameters needed to model environmental water requirement are very complex, and their quantification often entails a high level of simplification.

However, key indicators need to be identified as a measure of the impact of selected scenarios. A recent report on the Strategic Environmental Assessment of the Okavango delta Ramsar site (SAREP, 2012) identifies as key impacts on the delta ecology the following:

- Reduction of low flow
- Modification of flood pulse
- Regulation of the river flows

The reduction of low flow has been taken into account by this CORBWA update by comparing the various scenarios' low flow to the modeled natural flow in October -in accordance to what suggested by the SEA report- and, in particular, by setting a Flow Requirement at Mohembo of 122 CMS (corresponding to the average of October flows in the Pitman sequence used for the Reference scenario)

Impact on flood pulse is difficult to assess by using a monthly time-step model, and regulation of the river flows by large reservoirs is not foreseen in the water management trends identified by CORBWA reports. . Hydrological modeling approach of the EPSMO project included specific delta models, simulating impact of flow variations on the delta system, which is beyond the scope of this Water Audit. However, in an attempt to estimate in WEAP the impact of future scenarios on the basin environment, an effort has been made to include a very simplified representation of the delta in the updated application. The spatial extent of the flooded area is an indication of the impact of changes of annual flows to the delta ecology, as reported in the Strategic Environmental Assessment for the Okavango delta Ramsar site (SAREP, 2012). It was thus decided to represent the delta as a reservoir, serving livestock and domestic demand in Botswana. Parameterization of the reservoir has been improved during the WEAP workshop in Windhoek in October 2012 with the support of national experts and SEI researchers. In particular, a new variable originally developed by SEI researchers has been added to the application, which estimates spatial extent of annual flooding by using the algorithm found in Gulbricht et al 2004. This algorithm was developed to predict flood extent with a few months in advance to its August peak and is therefore focused on the maximum flooded area, without modelling minimum extent. In order to assess also the impact of management scenarios on the minimum flooded area, CORBWA project team made an effort to model the monthly flooded area as a function of the discharge towards the floodplains at Popa. This has been achieved by assuming that profile of the floodplain is triangular with very slight slopes, and that the volume

[12]Return flow from rural domestic demand is set to 50% to account for evaporation losses, as suggested during WEAP workshop in Windhoek

of the flood plain can be considered as a pyramid with the top downwards. Following these assumptions, the area of the flood plain can be described as:

A = 2 h * l / a

Where A is the flooded area; l = length of floodplain; a = angle of the profile (in percentage); and h = water depth which equals the height of the pyramid.
Being a pyramid, the volume of the reservoir below the floodplain is described as:

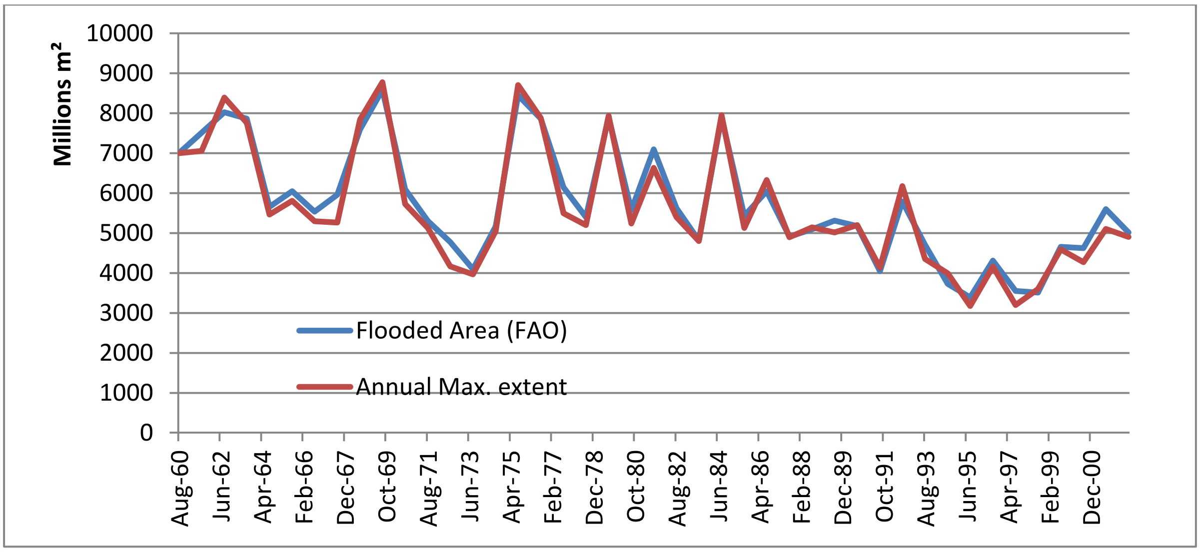
V = 1/3 * A * h

From which h can then be described as:

h = √ (V*a/l*3/2)

The Volume (V) can be calculated as the sum of the volume of the preceding month plus the change in volume stock (balance between the inflow and the precipitation and evaporation over the floodplain). The above mentioned equations have been calibrated against the maximum annual extent as calculated using the algorithm by Gumbricht (Figure 8).

Figure 10: Maximum annual extent of flooded area.



This was then translated in WEAP parameters as summarized in Table 7:

Delta reservoir parameters	
l (length of floodplain)	200 km
a (angle of the profile)	0.01 %
Storage capacity	15,000 Mm^3 [13]
Ai (initial area)	7000 km^2

[13] Source: Water in the Okavango Delta Fact Sheet 4/2007, University of Botswana http://www.orc.ub.bw/downloads/FS4_wbalance.pdf

KcOW(kc over open water)	1.37 (calibrated value)
Hi (initial height)	Ai *10^6/2*a/l
Vi (initial volume)	Ai*Hi/3
Precipitation (average 1960-1990)	Oct, 15, Nov, 51, Dec, 85, Jan, 117, Feb, 108, Mar, 63, Apr, 27, May, 3, Jun, 0, Jul, 0, Aug, 0, Sep, 3
Reference evapotranspiration (average)	Oct, 174, Nov, 167, Dec, 163, Jan, 155, Feb, 133, Mar, 140, Apr, 118, May, 101, Jun, 81, Jul, 86, Aug, 111, Sep, 148
Ds (change in volume stock)	Inflow+P_avg*If(And(TS = 1, Year = cay), Ai,PrevTSValue(Area)/1000)-(ETo_avg*(If(And(TS = 1, Year = cay), Ai, PrevTSValue(Area)*KcOW))/1000)
Volume	If(Year = cay,Vi, (PrevTSValue + Ds))
Height	Sqrt(Volume*10^6*a /l*3 /2)
Area (flooded area monthly)	2 h * l / a

Table 7 - Delta reservoir parameters

5. Other uses: Tourism, Mining, Energy

Inclusion of water demand by other sectors, namely Tourism and Mining, has been briefly discussed during the WEAP training workshop held in Windhoek in October 2012. Perception of participants was that both sectors are not likely to face any water shortage and, at the same time, will not have a significant impact on quantity of supply. It was suggested to include tourism in the domestic demand, and not to consider mining because it is currently not relevant and too little is known on its implications for water resources. Water demand for energy production is currently not relevant in the basin, while future plans consider small run-of-river in the upper catchment (included in EPSMO development scenarios).

5.4 PRELIMINARY RESULTS

The revised figures of sectoral demand provided by the CORBWA country reports have a significant impact on the model results in terms of total water withdrawals and, in particular, in its monthly variation as shown in the graphs below (Figure 11 to 13).

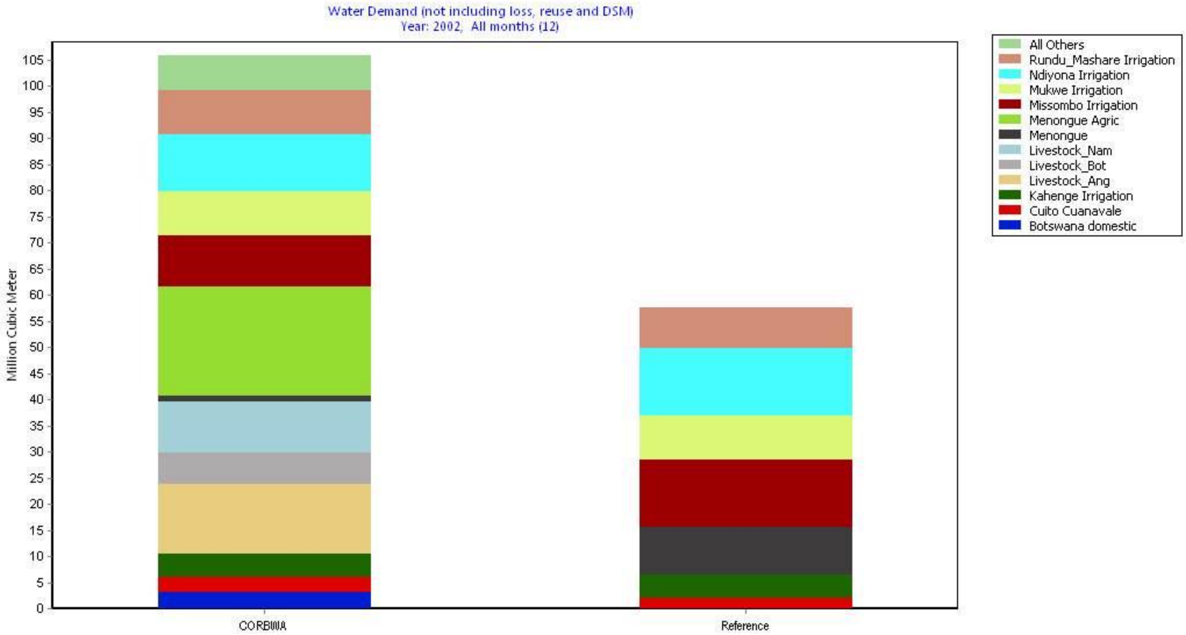


Figure 11-- Example of CORBWA scenario result: water demand in Mm^3, comparing CORBWA –left- and Reference (EPSMO) –right- scenarios.

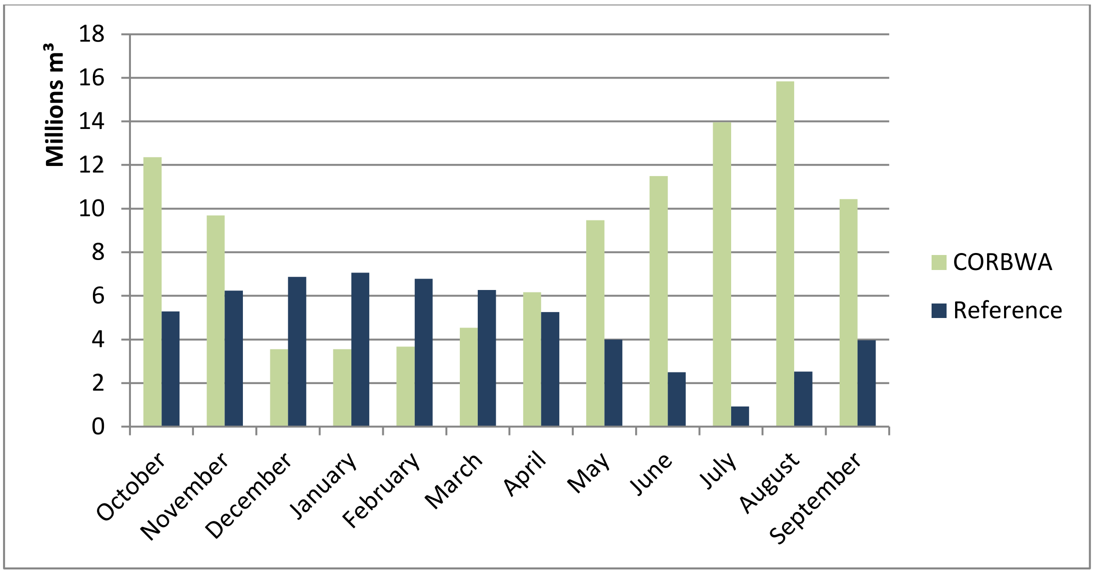


Figure 12 -Water demand in CORBWA and EPSMO Reference scenario, monthly average

The increase in total modeled demand though (from 60 Mm^3 recorded by EPSMO to 100 Mm^3 per year in the CORBWA version) has a negligible impact on total volumes of water reaching the delta. This is explained mainly by the scarce magnitude of demand compared to resources, but also to the fact that only a portion of the water abstracted is finally consumed without returning back into the system by runoff or percolation. The similarity of results is illustrated in the chart below, where very little decrease of volumes in low flow months, and increase in high flow months, can be observed in the CORBWA against the EPSMO results.

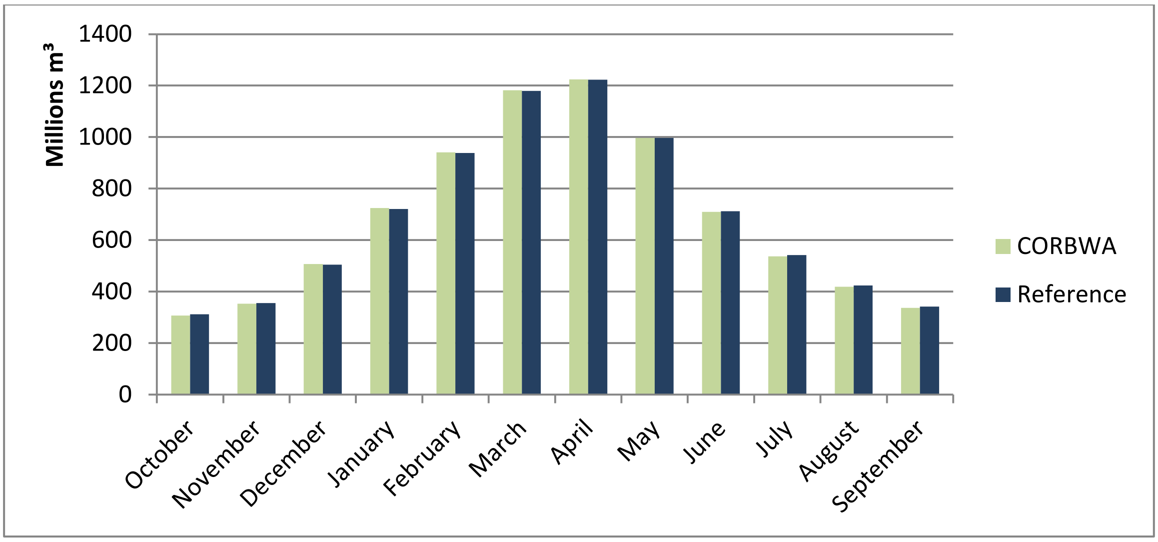


Figure 13 - Stream flow in CORBWA and EPSMO Reference scenarios, monthly average at Mohembo

6 IDENTIFICATION OF FUTURE SCENARIOS

Five hypothetical development options have been analyzed:

A. *Current trend*. Baseline scenario drawn on the basis of the basin wide report review of future sectoral development (Table 8).

Thousand m³	**2010**			**2030**		
	Angola	Namibia	Botswana	Angola	Namibia	Botswana
Irrigation	34,825	43,100	620	1,150	186,125	1,645
Livestock	13,164	14,500	4,900	26,328	14,500	4,900
Urban	767	5,990	2,450	3,285	13,960	5,710
Rural	1,840	2,230	4,400	5,840	2,460	5,969
Industry/Mining		0	0		9,080	5,200
Tourism	0	2530	280		3,980	743

Table 8 - Water demand by sector and by country in 2010 and 2030 (Source: FAO 2012c)

The trend is represented in the scenario by means of a multiplying factor for the different sectors over 20 years, simulating the impact of 2030's development forecasts on the Reference period (i.e. applying the scenario to the 1960-2002 hydrographic period).

B. *Current trend + transfer to CAN* (transfer to Central Area of Namibia for domestic supply). This scenario builds on working group activities held during the WEAP training workshop (Windhoek, October 2012). One of the working groups developed a scenario where transfer quantity was related to modeled demand variations, with a maximum of 40 Mm^3/year. Since design and planning of the transfer scheme are still at a very preliminary phase, a simplified continuous demand of 40 Mm^3/year is here used to represent this scenario.

C. *Current trend + Angola National Irrigation Plan (NIP) implementation*. This scenario makes reference to the Plano Nacional Director de Irrigacao, where land suitability and water supply/demand analyses are used to derive figures of possible irrigation increment by river basin. "Cenário 1" sets maximum extent of irrigated area in the Cubango basin to 484 thousand hectares, while the financial plan estimates that 60% of target could be reached in 25 years (equivalent to 290 thousand hectares) and assigns a secondary priority level to irrigation development in the area (COBA, 2010). It is translated into a WEAP scenario by applying a multiplying factor to Annual Activity Level (ha) of irrigation demand sites, while reducing the "water unit demand" from 13.5 to 5 thousand m^3/ha assuming a modernization of application technologies and thus a higher water requirement ratio (or consumption in WEAP). Current and realistic future levels of water resources development and infrastructures wouldn't allow for the fulfillment of such a level of water demand, and thus its impact downstream is primarily constrained by supply availability.

D. *Angola National Irrigation Plan – sugarcane.* Rather than a scenario based on future plans, this is an exploratory exercise aiming at showing the impact of agricultural policies and, in particular, of selection of crops with higher water requirements. It is based on a hypothetical switch of irrigated crops from vegetables and maize to sugarcane, which would imply a significantly higher annual irrigation water requirement and, more importantly for the dry flows, a different monthly distribution of such requirement. It is clearly an unrealistic scenario, implying about 290 thousand hectares of sugarcane in the upper catchment (there are currently about 4 thousand hectares equipped for irrigation).

E. *Priority to flow requirement*. This scenario explores the impacts of attributing a higher priority to (environmental) flow requirement at Mohembo - set to 122 CMS as discussed in section 5.3.4 -and a lower priority to irrigation demands. It is applied to the Angola NIP "sugarcane" scenario (D).

6.1 SCENARIO RESULTS DISCUSSION

A comparison of total water demand in the different scenarios places the CORBWA growth scenario -A) current trend- just below the EPSMO Low Development scenario, while the implementation of the Angolan irrigation plan –C)+full Angola NIP implementation- would bring the annual demand close to the EPSMO Medium Development scenario. It is worth noting though, that a significant portion of the demand goes unmet in dry months, especially in EPSMO Medium and High Development scenarios. As these are hypothetic and largely unrealistic scenarios, their water requirement would need to be addressed through massive infrastructural developments (storage), and supply and demand management. That is why the predicted demand is not covered by an equal amount of delivered supply in the chart below (Figure 14) . The "unmet demand" was partially addressed in the CORBWA scenarios C) and D) by assuming that irrigation schemes would be modernised and have lower withdrawals (5 000 m^3/ha/annum unit demand, with an irrigation efficiency of 70%). The impact scenarios have on modelled flow is of course driven by the supply delivered, rather than by demand.

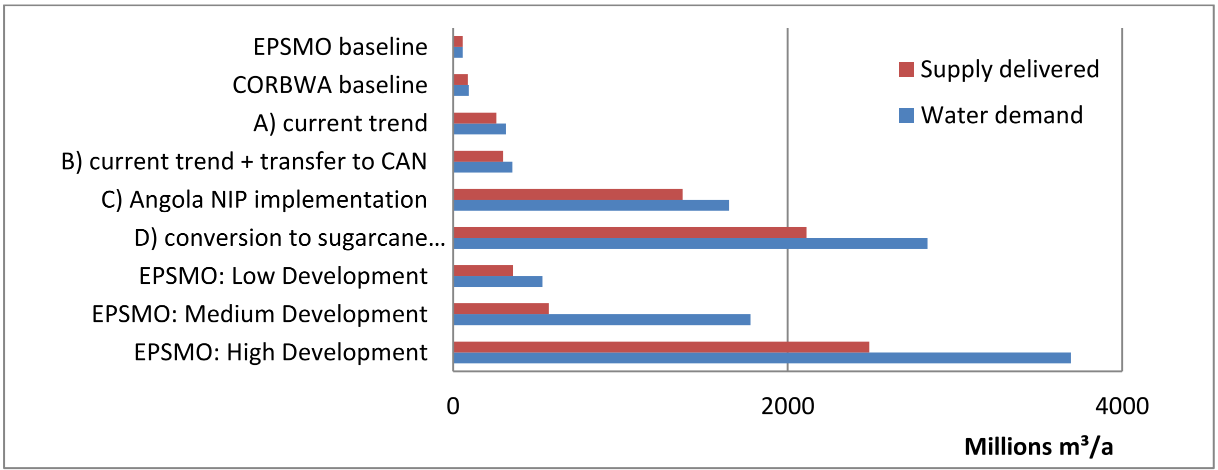


Figure 14- Comparison of total water demand in selected scenarios

Figure 15 shows the modeled impact of the different scenarios on streamflow below Mohembo, over a ten years period which includes the driest recorded flows.

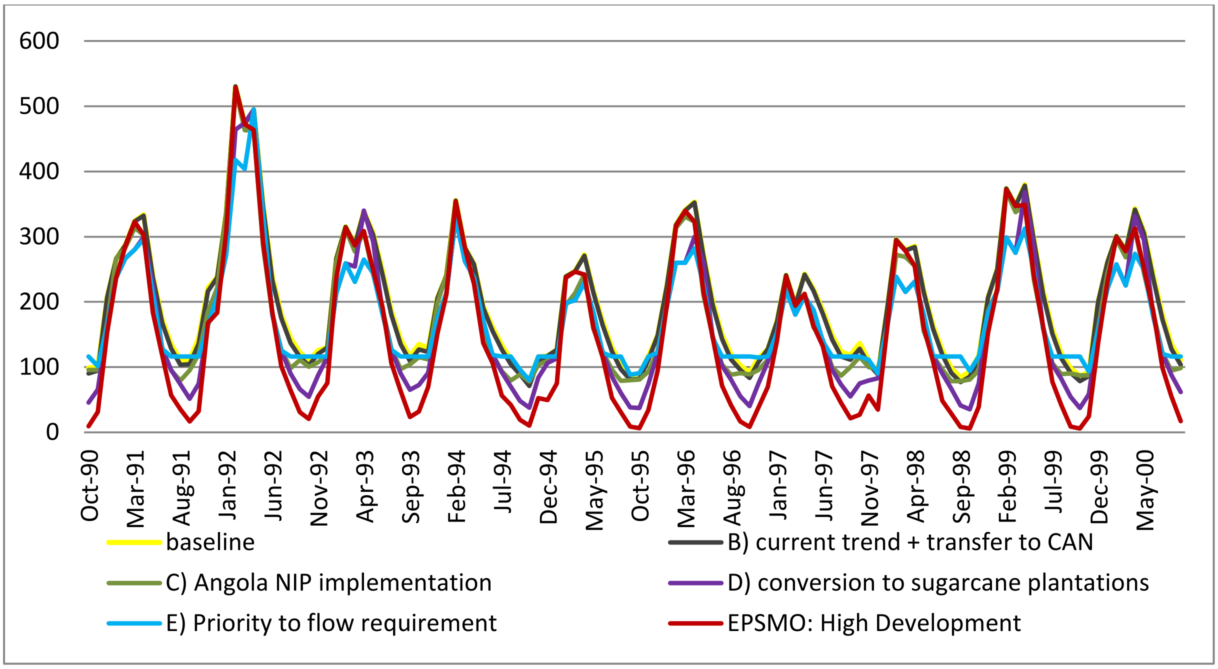


Figure 15 - Stream flow in selected scenarios

EPSMO High Development scenario clearly has the highest impact on dry flows, comparable to the CORBWA *D) conversion to sugarcane* scenario, whereas other CORBWA scenarios maintain a smaller variation from the baseline. The blue line represents the scenario *E) Priority to flow requirement* in which the Flow Requirement at Mohembo has a higher priority over irrigation demand and is thus able to maintain a minimum flow of 122 CMS (with the exception of dry months during which flow was lower than that,even in undeveloped circumstances).

Figure 16 shows the percentage of time during which such a flow requirement would be unmet –if its priority is left lower than other demands-, and the amplitude of shortage in CMS.

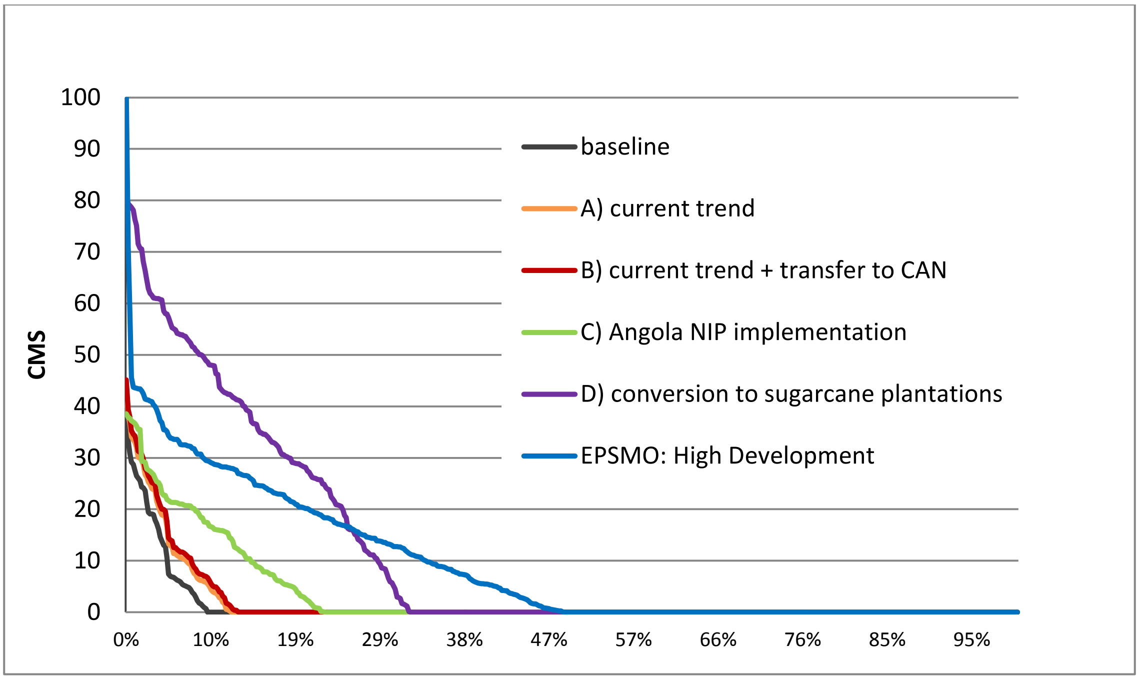


Figure 16 - Unmet flow requirement in selected scenarios (CMS, % Time exceeded)

A reduction in cumulated inflow would have an impact on extent of delta flooded area as shown in the Figure 17, implying a complete dry-up of the wetland in the D)+ "conversion to sugarcane" scenario in a very dry period (1994-2000).

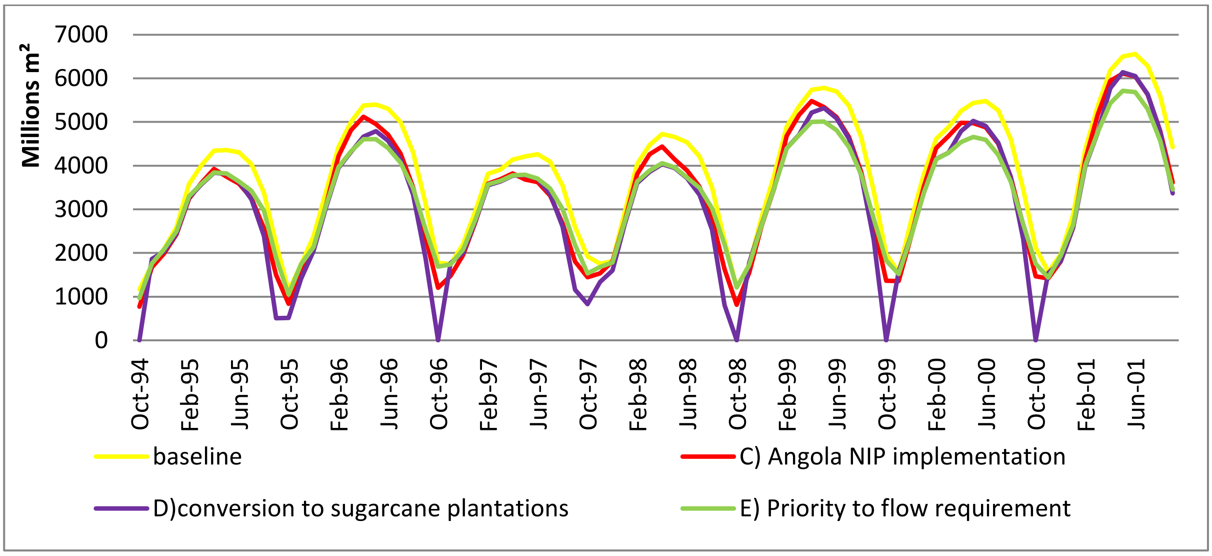


Figure 17 - Extent of area flooded in selected scenarios

Table 9 compares the reduction of lowest simulated flow between selected scenarios and the Reference (natural conditions). When the simulated reduction is compared to the range of "un-developed" flows in October (difference between maximum and minimum monthly flows in October over the period 1959-2202), it illustrates an overall impact of CORBWA scenarios which is well below the natural observed range of variation. On the contrary, the High Development scenario would affect the low flows beyond the so far recorded variability.

Scenario	Lowest simulated flow (Mm³/m)	Lowest flow reduction: difference from Reference scenario (Mm³)	Ratio between lowest flow reduction and range of October natural flows
Reference	212.19	-	-
CORBWA	207.30	4.89	2.6%
CORBWA: 20 years basic scenario	183.81	28.39	14.9%
CORBWA: 20 years basic scenario + Transfer to CAN	180.73	31.46	16.5%
CORBWA: 20 years basic + Angola NIP	199 .3	12.9	6.8%
CORBWA: 20 years basic + Ang NIP (sugarcane)	84.88	127.32	66.7%
EPSMO: Low Development	209.84	2.35	1.2%
EPSMO: Medium Development	198.00	14.19	7.4%
EPSMO: High Development	15.09	197.11	103.2%

Table 9 - Lowest simulated flows in the different scenarios

CONCLUSIONS AND RECOMMENDATIONS

Agricultural water demand, including consumptive and non-consumptive components, needs to be thoroughly analyzed since it has a significant impact on timing and quantity of downstream flows and, although the current extent of irrigation in the basin has a negligible impact on water resources, it remains a key component in estimating impact of future scenarios.

With regard to CORBWA scenarios, results would suggest that, although predicted impacts are still within natural historic variability of the system, the combined effect of increasing water demand and (possibly) increasing climate variability could at times severely affect the quantity and timing of water inflow to the delta. Only by taking into consideration an unrealistic scenario of extensive cultivation of a crop with very high and continuous water requirement (290 thousand hectares of sugarcane in this example) impacts on the amount and timing of flows reaching the delta would severely affect the environmental requirement as assumed in this study (low flows would go below historic average for more than 30% of time, and there would be a reduction of the minimum recorded flooded area of 21%). These impacts could, however, be addressed by assigning different allocation priorities to sectoral demands in the basin.

An effort should be made to improve the linkage between rainfall-runoff modeling component of the CORB to supply/demand analysis, currently addressed by separate models (Pitman and WEAP). Having the climatic data better embedded in the decision support tool would allow for:

- Improved assessment of agricultural water requirement, which depends on climatic conditions
- Extension of hydrological period beyond 2002 either by –preferably- using more recent monitoring stations data, or by performing a stochastic simulation of precipitation in future years, or by using other ad-hoc techniques
- Climate change impact analysis
- Land use change impact analysis

This could be achieved by using the rainfall-runoff soil moisture module available in WEAP or by customizing WEAP to easily change parameters in the Pitman and retrieving its output (being Pitman a locally calibrated rainfall-runoff model, this option would probably allow for a more robust hydrological analysis).

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ANNEXES

I. WEAP training workshop report (including list of workshop participants)
II. Discussion issues for WEAP model setup (WEAP training workshop / late Guido Van Langenhove, Hydrology Division, Namibia MAWF)

I. Workshop report

The workshop was entitled: CAPACITY BUILDING WORKSHOP FOR THE OKAVANGO RIVER BASIN ON THE WATER EVALUATION AND PLANNING SYSTEM (WEAP) and held in Windhoek, 22-26 October 2012.
The training workshop was part of the capacity building activities for the Cubango-Okavango River Basin Water Audit. This Water Audit is part of the project "Coping with water scarcity – the role of agriculture: Developing National Water Audits in Africa" (GCP/INT/072/ITA) and is carried out in co-operation with OKACOM (Permanent Okavango River Basin Commission).

The project "Coping with water scarcity – the role of agriculture: Developing National Water Audits in Africa" (GCP/INT/072/ITA) provides a country with a comprehensive methodology for assessing, analyzing and reporting of the use of scarce water resources. On the supply side, the audit will provide information about the water availability. On the demand side, it will give a detailed picture, on how the water is used, for which purpose, and with which value. Africa uses around 85% of its withdrawn freshwater resources for agriculture. Therefore, a detailed assessment of agricultural water use, including its productivity, its value-in-use, and its efficiency during the water use process, gives the countries a better insight in how to adapt their water policy and how to improve their water management in the future through strategic interventions to increase their capacity to cope with water scarcity.

One of the outputs of the project will be a decision support tool to estimate future scenarios of water demand and supply trends in the basin. The project team and technical advisers have identified the Water Evaluation and Planning system (WEAP) as the appropriate software for this output, because of its policy orientation, flexibility and user-friendly interface, of its adoption during a previous FAO-lead project in the area (Environmental Protection and Sustainable Management of the Okavango River Basin – EPSMO project, GEF funded), and because its license if provided for free to public and research institutions in developing countries.

A rapid survey on the use of the WEAP application developed during the EPSMO project, revealed a lack of capacity within the three riparian countries institutions and especially in Namibia, where nobody from the Ministry of Agriculture, Water and Forestry, had been trained on its use. At the same time, a demand for a stronger institutional involvement at ministerial level in the decision support tool development was raised by OKASEC. It was then agreed to address these issues through capacity building for Angolan, Botswana and Namibian governmental institutions on the use of the Okavango WEAP application, with emphasis on methodologies for model update and scenario formulation.

WEAP software developed and maintained by Stockholm Environment Institute – US Center, is a practical tool for water resources planning. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.

The training started on the 22nd of October in Windhoek at the Safari Hotel (agenda in Appendix), with an introductory presentation by Livia Peiser, FAO Technical Officer, on Project activities and training objectives, followed by opening remarks by Mr. Van Langenhove, MAWF, and self-introduction of participants.

SEI trainers, Charles Young and Brian Joyce, introduced themselves and provided an overview of the training structure.

Practical exercises on the Okavango River Basin application developed within the EPSMO project had been planned starting from the second day, to give participants the opportunity to familiarize with the model. Starting from Day 3, approximately half a day was dedicated to group work with the following objectives:

- Review structure and assumptions used in the existing Okavango model;
- Review model updates proposed by the CORBWA project;
- Identify relevant scenarios;
- Implement one or more of the identified scenarios and discuss results;

With regard to the model review and upgrading needs, the following suggestions were made:

- Environmental flow requirement should be added (at Mohembo), despite an inherent simplification of the ecological processes in the delta;
- Wildlife demand needs to be acknowledged (tourism and mining, on the contrary, were not suggested for inclusion in the model, due to similarity with domestic demand in the first case, and lack of knowledge for the second one);
- Sensitivity Analysis on varying levels of water demand
- Assigning priorities to agricultural demand
- Dams and water storage for irrigation
- Transfer to Central Namibia: 2 scenarios, 1 upstream and 1 downstream of Cuito confluence
- Demand needs to be updated: domestic is missing (Rundu, for example)
- Agricultural Demand refined and enriched with management options (application efficiency, priorities)
- Environmental flow requirement should capture monthly distribution of flow
- Climate change and variability
- Extend hydrology beyond 2002
- Look at different hydrological scenarios (stochastic)
- Reservoirs need to account better for evaporation
- Losses

A presentation and discussion on OKACOM related decision support system had been organized for the last day. The first presentation, by Kent Burger (ESRI) covered the LUCIS approach which has been identified by SAREP to analyze potential competition on land use in the basin. It is a GIS based tool that highlights areas suitable for different and potentially competing- uses, such as agriculture and conservation areas.
Livia Peiser made a presentation on CORBWA information resources in support to OKACOM decision making process. Projects outputs were listed and linked to OKACOM information requirements, with a particular emphasis on sharing protocols (such as FAO Geonetwork metadata standard, which facilitate integration with other spatial data catalogues) and the WEAP model on which the training week had focused.
Project outputs in support of OKACOM decision making process:

- *L&W Database: EPSMO GIS DB documented, distributed, and made accessible on internet sites;*
- *Basin wide water demand report: synthesis of 3 country reports on sectoral water demand in the basin;*
- *Basin wide water resources report: synthesis of 3 reports on status and trends of water resources in the basin;*
- *Basin wide water policy and institutions report: synthesis of 3 country reports;*
- *Basin wide water economics;*
- *Information protocol and recommendations for basin database;*
- *WA+, a Remote Sensing based rapid assessment of E and T in different land use classes (spatially distributed outputs and report);*
- *WEAP capacity building and CORBWA scenario (sectoral demand update), with recommendations for future model update.*

A discussion followed, moderated by Eben Chonguica, OKASEC Executive Secretary on the following issues:
The need to translate technical outputs into effective information for policy makers; the need to incorporate in the DSS tools some sort of benefit sharing mechanism that would solicit all countries participation; the problem of limited data and human resources (in particular in governmental institutions) to follow up on different projects/ approaches; and, finally, the need to have consistent scenarios among models to predict impacts starting from similar assumptions. The last point will benefit from recently approved SADC data disclosure policy,
In the afternoon working groups presented the results of their scenario exercise. The first group focused on developing a scenario for a Transfer link the Central Area of Namibia (CAN). According to this scenario, a pipeline would supply the central area of Namibia supply scheme with additional water for the manual artificial recharge of Windhoek aquifer. It is worth noting that more than 20% of water supply in Windhoek is currently covered by recycled water and, in order to fulfill projected demand, plans are ongoing to reduce the open reservoir storage (currently supplying almost 70% of the municipal water) in favor of groundwater storage to limit evaporation losses, which account for about one third of stored volume every year. The scenario developed by the working group looked at two alternatives: one with a constant abstraction of 100 M cubic meters per year, and one with on-demand abstraction based on shortfalls in the CAN supply system which, according to current estimates, will not go beyond a maximum of 40 M cubic meters per year. In both cases, abstraction was not predicted to affect significantly stream flow volumes, even using a stochastic approach to simulate future scenarios and taking the driest condition into account.

The second working grouped looked at hydropower production by means of an –hypothetic- 1000 Mm^3 reservoir on Cuchi River, in the upper catchment.
Third group looked at Environmental Flow Requirement and, in particular, performed a sensitivity analysis on the impact which different thresholds of reserved flow would have on unmet demand. The flow Requirement was calculated in % of average monthly flow at Mohembo during the modeling period (1959-2002).
The last group presented results of scenarios of different priorities set to agricultural water demand and environmental flow requirement.

During the group work, trainers provided participants with hints on how to customize the WEAP Okavango application with regards to developing user defined functions, and applying VB scripts to perform recurrent tasks.

The training proved to be very effective and the majority of participants reached a good level of understanding and use of the core WEAP functionalities. This was achieved thanks to the trainer's flexibility in accommodating the schedule to trainees' learning process, but also thanks

to the high level of commitments and technical expertise of the participants (Participants list in Appendix).
Some of the participants from Angola faced difficulties due to language as delay in confirmation of their attendance meant that it was difficult to arrange translation from English to Portuguese. In addition, two participants from Botswana arrived two days later due to delays in flight arrangements by the travel agent.

FAO office in Namibia supported the organization of the training very effectively and efficiently.

Trainers:

Charles Young	SEI senior scientist and WEAP trainer
Brian Joyce	SEI senior scientist and WEAP trainer

Resource persons:

Livia Peiser	FAO Technical Officer, Spatial Analysis, FAO Land & Water Division
Guido Van Langenhove	Head, Hydrology Division, MAWF Namibia
Eben Chonguica	OKASEC Executive Secretary
Kent Burger	ESRI - SAREP

Time	Day 1	Day 2	Day 3	Day 4	Day 5
8:00 – 10:00	Opening and Introduction Tutorial - WEAP in one hour	Tutorial – Refining the demand	Tutorial – Hydrology	Tutorial – Modeling agricultural water use in WEAP	Group work and/or optional WEAP tutorial
10:00 – 10: 30	Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
10:30 – 12: 00	Tutorial – Basic tools in WEAP	Exploring Okavango WEAP Model: Water supplies and demands First Okavango exercise	CORBWA scenario introduction and group project introduction	Group work and/or optional WEAP tutorial	OKACOM DSS: SAREP CORBWA Discussion
12:00 – 13:00	Lunch break	Lunch break	Lunch break	Lunch break	Lunch break
13:00 – 15:00	Tutorial – Scenario analysis in WEAP	Tutorial - Data, results and formatting Second Okavango exercise	Group work – scenario development	Group work and/or optional WEAP tutorial	Presentations of group work
15:00 – 15:30	Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
15:30 – 17:00	Tutorial - Refining the supply	Tutorial – Reservoirs and power production	Group work and brief presentation of proposed scenarios	Tutorial - Water quality	Workshop closing

Country	First Name	Surname	Organization	Position	E-mail
Angola	Mr Narciso Augusto	Ambrosio	DNRH/MINEA	Hydrologist	luimm_007@hotmail.com
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Namibia	Ms Aune	Amwaama	Hydrology Division (MAWF)	Chief-Hydrologist	AmwaamaA@mawf.gov.na
Namibia	Mr Hugh	Bruce	Kavango Transfer Study Team (LCE)	Chief-Engineer	bruceh@lce.com.na
Namibia	Ms Geraldine	Diergaardt	Hydrology Division (MAWF)	Chief-Hydrologist	PickeringG@mawf.gov.na
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Namibia	Ms Aune	Hatutale	NamWater	Hydrologist	HatutaleA@namwater.com.na
USA	Mr Brian	Joyce	SEI-US	Senior Scientist	Brian.Joyce@sei-us.org
Namibia	Mr Reinhold	Kambuli	Okavango Basin Management Committee	Basin Support Officer	rkambuli@yahoo.co.uk
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Namibia	Ms Belinda	Veii	NamWater	Hydrologist	VeiiB@namwater.com.na
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USA	Mr Charles	Young	SEI-US		cyoung@sei-us.org

II. DISCUSSION ISSUES FOR OKAVANGO WEAP MODEL SET-UP AND FOR FUTURE ANALYSES

The support of FAO for this workshop has been greatly appreciated.

The below and other issues should be considered to further build on the knowledge gained to improve the previously used WEAP model for the Okavango River Basin. The below are some of the issues for further discussion at HTF or OBSC level. They are from personal observations and neither exclusive nor inclusive.

1. Hydrological series

The hydrological series for the present Okavango River Basin model extend to 2002. It may be useful to add the additional ten years to date, in particular because of the very wet period at the end. But the knowledge regarding the Pitman model set-up is not readily available in the basin countries.

In the same context, scenarios for climate change and generation OF artificial longer time series by stochastic techniques might be considered for sensitivity analysis.

It may also be useful to add a more advanced model component for the Okavango Delta (Botswana) to show the annual flooding extents.

2. Environmental demands

The recently derived environmental demands for the Okavango Delta should be incorporated in the model.

It is unknown whether and from what source in-flow environmental demands for the rivers would be available. They seem to be missing at the moment.

3. Priorities for demands

The WEAP functionalities should be better exploited to assign selective priorities to different (groups of) demands, for instance domestic, environmental, mining, livestock, irrigation, hydro-power, recreation.

4. Irrigation demands

The irrigation demands should be modeled in a more scientific and consistent manner, to take into account availability and nature of soils, types of crops, area- and time-varying demands, the latter also dependent on actual rainfalls.

5. Hydro-power

Various options for installed capacities and operation of hydro-power (Angola) should be modeled.

6. Water transfers

The option for water transfers (Namibia) should be modeled to reflect the true variable demands, being function of the flows, dam contents and water shortages in the target area(s).

(late) Guido Van Langenhove, Hydrology Namibia

24 November 2012