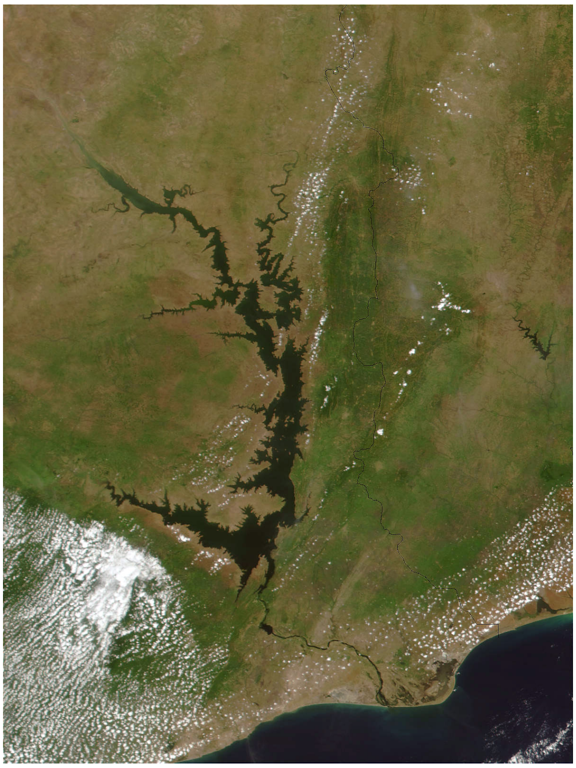
DECISION-SUPPORT TOOL FOR WATER ALLOCATION IN THE VOLTA BASIN



Lake Volta (MODIS image)

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CGIAR Challenge Program on Water and Food

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Content

Abstract

This paper presents a first version of a decision-support tool for management of the transboundary water resource of the Volta Basin. For this purpose, two modelling entities are coupled: the hydrologic spreadsheet of Kirby et al. and the software *Water Evaluation And Planning* (WEAP) developed by the *Stockholm Environment Institute*. Five categories of water use are considered: (*i*) irrigation from large reservoirs, (*ii*) hydropower at large hydroelectric dams, (*iii*) water stored in informal / private small reservoirs in the upstream part of the Basin, (*iv*) domestic for urban zones and (*v*) river-side irrigations and livestock consumptions. Both models are parameterised so as to reproduce observed river flows and water stored in hydroelectric reservoirs.

As an application, we focus on the downstream Akosombo hydropower scheme (the Lake Volta + the Akosombo dam) in Ghana and analyse consequences of two types of scenario: (*i*) possible future climate changes – a drier and a wetter climate – by mimicking the change in rainfall that occurred in the Basin around 1970 and (*ii*) development of upstream small reservoirs in Burkina Faso. In both types of scenario, water levels in the Lake Volta are highly sensitive to the inter-annual rainfall variations. Outcome of the climate changes scenario is that, with respect to all the limitations / assumptions taken in this work, (*i*) climate changes similar to those that have been observed in the recent past would have a critical impact on the Lake Volta, and (*ii*) hydropower generation at Akosombo up to the level observed in late 1990's would only be sustainable in the wetter scenario. Comparatively, the scenario of development of small reservoirs has a negligible impact on the Akosombo scheme during the span of the scenario. However, at the end of this scenario, inflows to the Lake Volta are reduced by about 3%, which is subtracted to hydropower production.

Our decision-support tool will be handed to the *Volta Basin Authority*. The Authority is a platform for consultation at the basin scale and needs this kind of tool to illustrate situations the Basin is very likely to face soon. As a final caveat, it must be kept in mind that our tool was parameterised and calibrated for the Basin with limited data on river flows and water uses, hence its utilisation for a particular scenario may require further tuning with specific data.

I. Introduction

The Volta Basin is located in West Africa within latitudes 5°45’ N and 14°10’ N and longitudes 2°17’ E and 5°20’ W. It is a transboundary watershed of 394,100 km², which lies mainly in Burkina Faso (42%), Ghana (42%) and has minor parts in Benin, Côte d’Ivoire, Mali and Togo. This work will focus on the upstream Burkinabe and the downstream Ghanaian parts of the Basin.

The climate of the region is contrasted, from tropical in the south of the Basin (around 1,500 mm/year of rainfall distributed in two rain seasons) to semi-arid in its northern part (less than 500 mm/year). Many African rivers (Nile, Niger, Senegal, Chari) flow from a humid upstream basin to a drier lower basin. They provide surface water to dry regions. On the contrary, the upper Volta drains in the North a semi-arid region where river flow is seasonal, and is progressively enriched with large tributaries from much more humid lower sub basins. Except in the upper part of the Black Volta (Mouhoun), rivers do not convey water to drier areas. There is thus a priority to conserve water in the upper basin in Burkina Faso where there are numerous small reservoirs. Besides, the status of populations is quite different in the two main countries, with a much greater proportion living in cities in Ghana and a significantly better human development index. While Burkina Faso ranks among the poorest countries in the world, Ghana stands about forty countries ahead.

A dominating feature of the basin is the Lake Volta, which is the largest man-made lake in Africa, and one of the largest in the world in terms of surface area. The lake was created to generate hydropower at the Akosombo dam (1,020 MW) and to meet the rapidly increasing demand for electricity by industries and populations in Ghana and neighbouring countries (Andah at al. 2004; Owusu et al. 2008).

This paper presents results from the *Basin Focal Project - Volta*, a part of the CGIAR *Challenge Program on Water and Food*. As water resource plays a vital role in the development of Burkina Faso and Ghana (e.g., domestic, agriculture, hydroelectricity) and following the work of Andah et al. (2004), the objective of this work is to introduce a pre-parameterised version of a Decision-Support Tool (DST) for water allocation in the Volta basin. The DST is based on the hydrologic model of Kirby et al. (2006) coupled with the software *Water Evaluation And Planning* (WEAP) of the *Stockholm Environment Institute* (Yates et al. 2005a; Yates et al. 2005b). First, the parameterisation of the hydrologic module and WEAP is presented. Next, scenarios of climate changes and of development of upstream small reservoirs are developed and impacts on the downstream Akosombo hydropower scheme (Lake Volta + Akosombo dam) in Ghana are examined as an illustration.

II. Parameterisation and validation of the Decision-Support Tool

The Decision-Support Tool (DST) developed in this work is composed of two modules (Figure 1): the hydrologic module, which is the spreadsheet of Kirby et al. (2006), and the water allocation module, which is the software *Water Evaluation And Planning* (WEAP). This section details these two elements, the input data, the parameterisation of the Volta basin and its validation. Scenarios will be developed in section III.

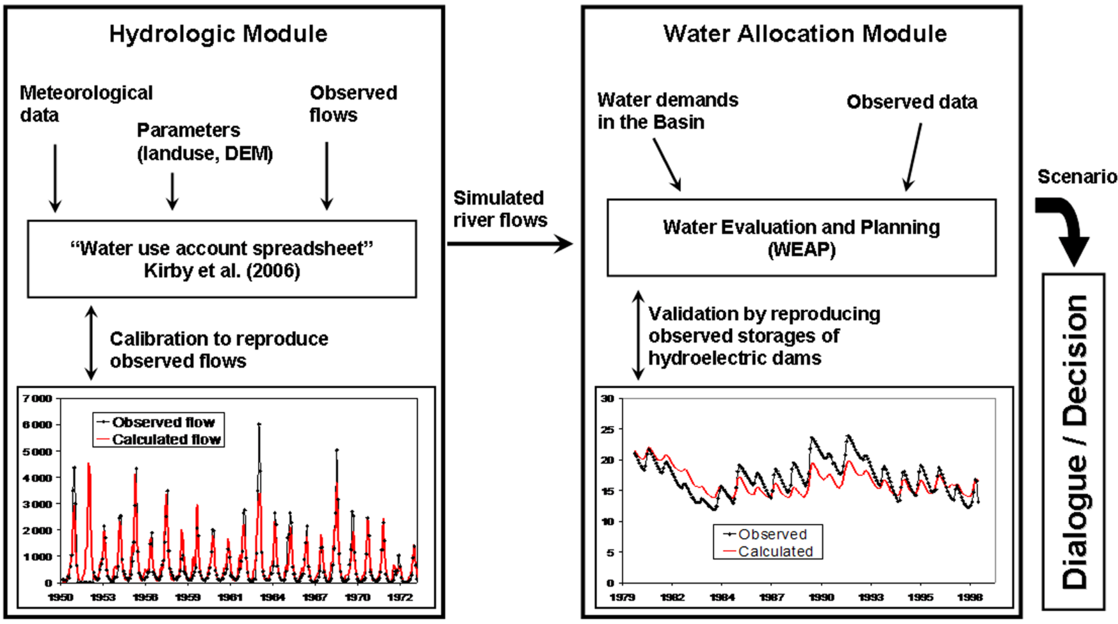


Figure 1:Scheme of the decision-tool and its hydrologic and water allocation modules.

II.1. Parameterisation of the hydrologic module

II.1.1. Input data

The hydrologic module is composed of the "Water use account spreadsheet" developed by Kirby et al. (2006). We will not consider the behaviour of groundwater, due to the lack of data, and we will focus on surface-water terms (runoff, river flows, and evapotranspiration). The spreadsheet requires as inputs the landuse, the DEM and meteorological data. The DEM (SRTM data obtained from the website CGIAR - CSI) is analysed to identify contributing areas to gauged sites (gauge stations), generating 19 sub-basins (Figure 2).

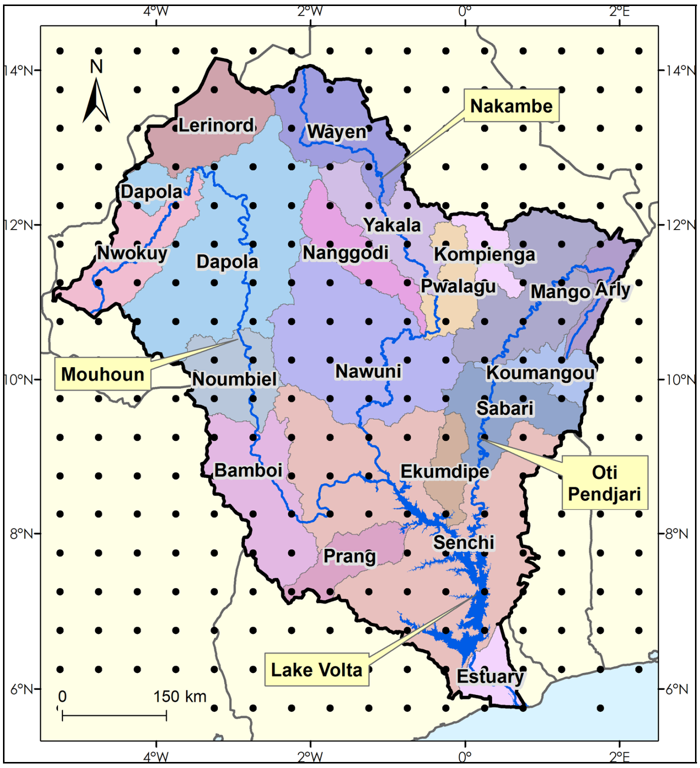


Figure 2: The three main river systems and the sub-basins of the Volta basin, overlaid with the grid of the Climate Research Unit's TS 2.1 data-set (0.5° space).

The spatial and temporal distributions of rainfall are extracted from the TS 2.1 data-set of the Climate Research Unit (http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_2.10/). The reference evapotranspiration (ET0) is calculated using the Hargreaves (1994) method, the minimum and maximum temperatures being extracted from the same TS 2.1 data-set. Figure 2 shows the 0.5° grid of the CRU over the Volta basin. The time period considered in this work is 1951 to 2000. It is assumed that CRU meteorological figures are actual data, although as interpolated data they might smooth natural variability.

The next step is to analyse the landuse of the Basin. We use the AVHRR data from USGS, with a correction of their rain fed cultivated area which appeared largely underestimated when compared with the national statistics of Ghana and Burkina Faso (Ministère de l'Agriculture de l'Hydraulique et des Ressources Halieutiques 2006, Minstry of Food and Agriculture 2006). Meteorological data are regionalised per sub-basin as well and the spreadsheet calculates river flows at the outlet of the 19 sub-basins. Please refer to Kirby et al. (2006) for a detailed description of the calculations steps.

II.1.2. Calibration

The spreadsheet is calibrated with river flows observed between 1951 to 2000, taken partly from Bodo (2001), Obeng-Asiedu (2004) and provided partly by the project Volta HYCOS. The available data set covers a variable part of the whole 1951-2000 period (Table 1). The hydrologic function of the Basin was impacted by the change in rainfall pattern that occurred in the north of the basin in the 70’s, coupled with the continuous development of agriculture and change in natural vegetation. It entailed in particular an important increase of the runoff coefficient in the 90’s (values doubled in average), i.e., a greater proportion of rainfall is transformed into runoff (Mahé et al., 2005). We try to take this change into account by choosing a calibration period starting after mid-1970’s, closest to year 2000 and that contains around 100 monthly observed flows.

We quantify the quality of the calibration with the Nash and Sutcliffe (1970) coefficient defined as follows:

$$1-\frac{\sum_{i=1}^{N}\left(Q_{obs,i}-Q_{est,i}\right)^2}{\sum_{i=1}^{N}\left(Q_{obs,i}-\overline{Q_{obs}}\right)^2} \qquad [1]$$

where Q is the considered variable (here river flows), N is the number of observations, the subscripts ‘obs’ and ‘est’ stand for respectively observation and estimation from the model respectively and $\overline{Q_{obs}}$ is the average of the N observed values for Q. This coefficient compares the sum of squared errors in estimation to the variance of Q. It can takes values from $-\infty$ to 1: the greater its value, the better the model reproduces observations, 1 being exact reproduction. We decide arbitrarily that estimation is satisfactory if: (*i*) the coefficient is greater or equal to 0.70, (*ii*) the chosen period for calibration is recent and (*iii*) N is close to 100.

Calibrations are more or less satisfactory according to data availability, being particularly bad for sub-basins Lerinord and Estuary (no observed river flows), Nwokuy (lowest Nash-Sutcliffe coefficient), Kompienga (lowest number of available flows) and particularly good for Senchi or Koumangou (Table 1 and Figure 3).

For the sake of clarity, all lacking data and assumptions / simplifications taken in this work are summarised in Table 8.

Table 1: Available observed river flows for calibration of the hydrologic module.

Sub-basin	Period of available monthly river flows	Gap	Source	Calibration		
				Chosen period	Number of monthly available river flows	Nash-Sutcliffe coefficient
Arly	1980 – 1997	Yes	Volta HYCOS	1980 - 1997	65	0.65
Bamboi	1951 – 2000	Yes	Volta HYCOS	1980 – 2000	90	0.70
Dapola	1959 – 2000	Yes	Volta HYCOS	1990 – 2000	117	0.61
Ekumdipe	1963 – 1973	No	Bodo (2001)	1963 – 1973	129	0.75
Estuary	None	-	-	None	None	-
Kompienga	1982 – 1987	No	Volta HYCOS	1982 – 1987	59	0.75
Koumangou	1959 – 1991	Yes	Volta HYCOS	1983 – 1991	98	0.82
Lerinord	None	-	-	None	None	-
Mango	1953 – 1991	No	Volta HYCOS	1983 – 1991	107	0.79
Nanggodi	1958 – 1976	Yes	Volta HYCOS	1958 – 1976	110	0.56
Nawuni	1954 – 2000	Yes	Volta HYCOS	1990 – 2000	130	0.74
Noumbiel	1975 – 2000	Yes	Volta HYCOS	1985 – 1996	82	0.82
Nwokuy	1965 – 2000	Yes	Volta HYCOS	1974 – 1983*	116	<0**
Prang	1957 – 1967	No	Bodo (2001)	1957 – 1967	125	0.64
Pwalagu	1951 – 2000	Yes	Volta HYCOS	1971 – 1990	75	0.80
Sabari	1959 – 1974	No	Bodo (2001)	1965 – 1974	110	0.70
Senchi	1985 – 1999	No	Obeng-Asiedu (2004)	1990 – 1999	120	0.86
Yakala	1977 – 1989	Yes	Volta HYCOS	1978 – 1989	124	0.79
Wayen	1965 – 2000	Yes	Volta HYCOS	1990 – 2000	125	0.70

* The construction of the by-channel of the Sourou dam in 1984 affected measured flow afterwards.

** A negative value of the Nash-Sutcliffe criterion would mean that the constant model equal to the average of observed values would give better result.

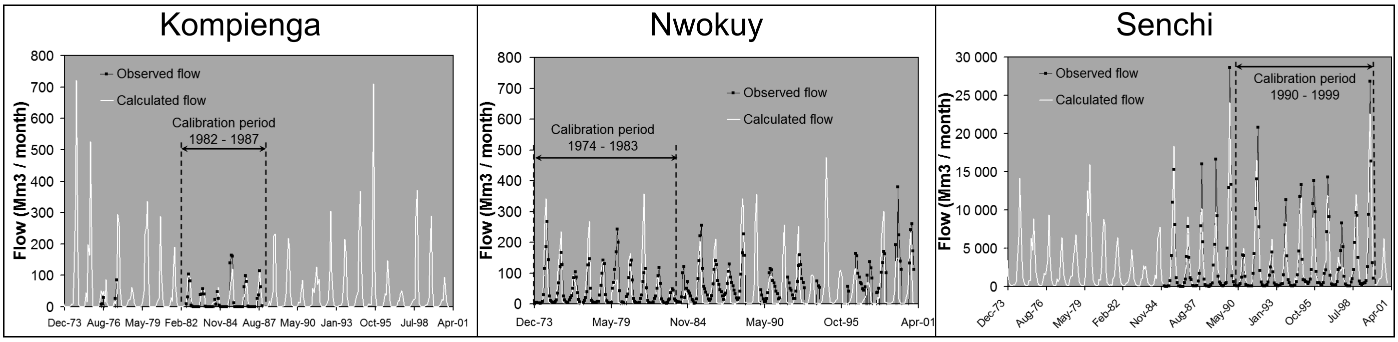


Figure 3: Calibration of the sub-basins Kompienga, Nwokuy and Senchi, according to the data available (source of observed streamflows: the project Volta HYCOS and Obeng-Asiedu (2004)). Note the different vertical scales.

II.2. Parameterisation of the water allocation module

We use the water flows calculated with the hydrologic module as inputs to the water allocation module, i.e., the *Water Evaluation And Planning* (WEAP) software (Figure 1). The 19 sub-basins of Figure 2 are imported into WEAP as spatial modelling entities (Figure 4). Each river of a sub-basin is symbolised as a segment, ending with a tributary outlet (Figure 5). We identify five types of water use in the Basin:

1. small reservoirs, denoted as SRs, which are mostly informal / private arrangements and mainly located in Burkina Faso;
2. large irrigation reservoirs, which are formal / state arrangements;
3. large hydropower schemes;
4. domestic from urban zones;
5. and remaining river-side irrigation schemes and livestock consumptions.

Description of these water uses will be developed below.

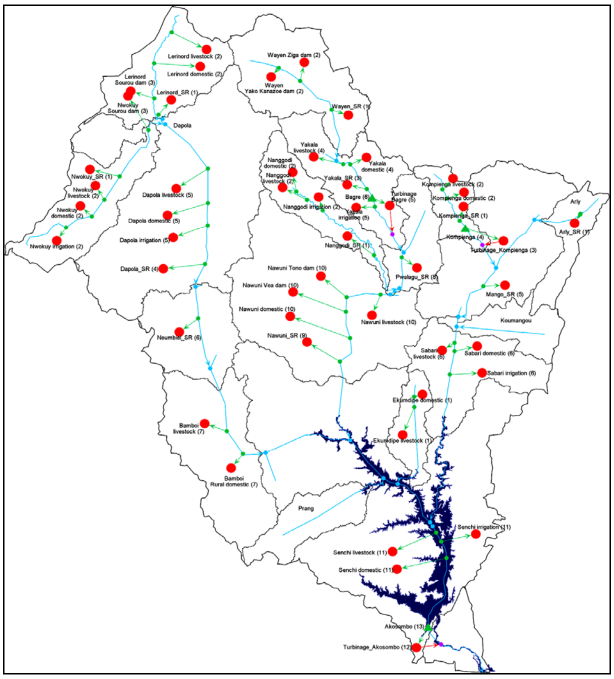


Figure 4: Parameterisation of the Volta basin in WEAP. In background, the hydrologic sub-basins; in blue the river-segments and in red dots the water demands.

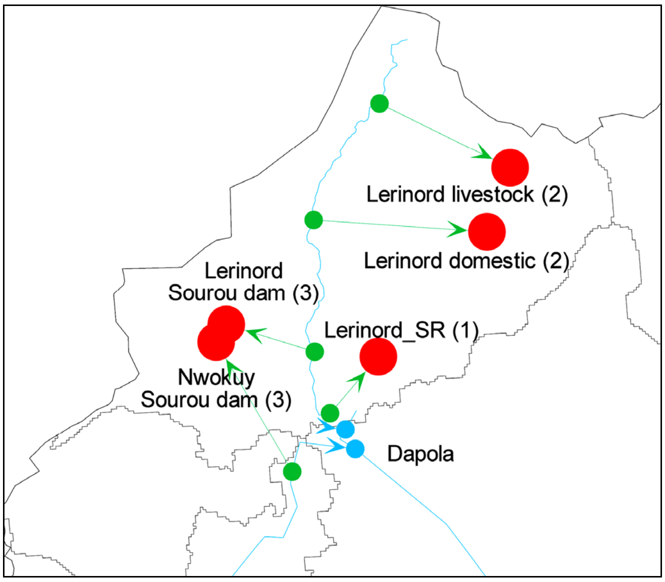


Figure 5: Focus on the Lerinord sub-basin, with its demands. Are visible the tributary outlets of Lerinord and Nwokuy, flowing into Dapola sub-basin.

For the sake of simplicity, the water uses distributed spatially in each sub-basin are lumped into each category of water uses presented above, irrespective of their location in the sub-basin. The runoff calculated by the hydrologic module within a sub-basin is injected into WEAP as the headflow of the sub-basin's river-segment, even though runoff generation is distributed spatially in the sub-basin.

II.2.1. Small reservoirs

Informal / private Small Reservoirs (SRs) are mainly present in Burkina Faso. As for SRs:

- water is used mostly for irrigation and,
- no information on their physical properties (e.g., storage capacity, storage – water elevation relation) nor on their operational rules (e.g., water releases, inactive zone of the reservoir) are available at the time of this work,

it is assumed that:

- arbitrarily, an SR has a storage capacity less or equal to 1 Mm^3;
- water from an SR is consumed totally by (*i*) direct evaporation from the reservoir and (*ii*) evapotranspiration in fields (the part which is percolating to the groundwater is neglected) and,
- as SRs are usually empty just before the onset of the monsoon, they replenish during the wet season but most probably not up to their capacity (due for instance to lack of proper maintenance of the reservoir), hence an SR can be modelled in WEAP as a consumptive water demand which we arbitrarily fix equal to 75% of its storage capacity.

The *Small Reservoir Project* of the CPWF has recorded 1,453 reservoirs in Burkina Faso (Figure 6) and estimated the storage capacity of 1,014 reservoirs (out of the 1,453) (P. Cecchi, personal communication, June 2008). Total storage of SRs in the Burkinabe part of the Basin is calculated as follows (Table 2):

1. reservoirs out of the basin are discarded and 1,140 reservoirs remain (out of the 1,453),
2. since:
   - SRs are assumed to be smaller than 1 Mm^3,
   - and reservoirs with no estimated storage capacity are supposed to be SRs,

   records with an estimated storage capacity greater than 1 Mm^3 are discarded, which lead to the identification of 1,059 SRs in the Burkinabe part of the Basin,
3. these 1,059 SRs are regionalised with respects to the 19 sub-basins (Figure 6),
4. in each sub-basin:
   - are counted the number of SRs for which the storage capacity is known,
   - these storage capacities are summed,
   - and the total storage of all the SRs is estimated by pro-rata.

Finally, the calculated total storage for the 1,059 SRs in the Burkinabe part of the Basin is 212 Mm^3 (Table 2).

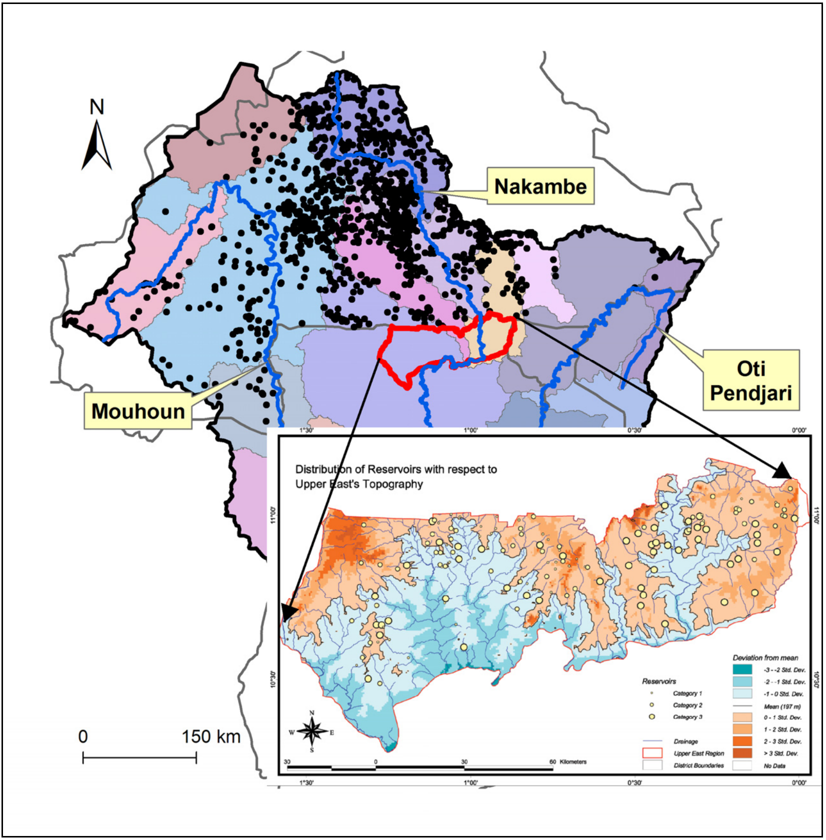


Figure 6: Sub-basins used in the hydrologic modelling of the Volta basin, overlaid with 1,140 SRs identified in the Burkinabe part of the basin (source: the *Small Reservoirs Project* of the CPWF) plus 154 SRs referred by Liebe (2002) in the Upper East Region of Ghana.

Little information is available for informal/private SRs in Ghana. Liebe (2002) and Liebe et al. (2005) identified 504 dugouts and small reservoirs in the Upper East Region of Ghana (Figure 6) and estimated their storage capacity (Table 3). It is assumed that SRs are only present in North of Ghana, hence our estimation will rely solely on these two papers. The calculation procedure is as follows:

- reservoirs with a surface less than 1 ha are discarded as Liebe et al. (2005) judged their characterisation / identification unreliable (limit of remote sensing analysis), making a set of 154 SRs (out of the 504),

- Liebe (2002) gave the logarithmic distribution of the surface *S* in this set, for 1 < *S* < 35 ha, i.e., $\log(S) = 0.0082 \cdot No + 0.0276$, *No* being the number of the SR ($No \in \{1,2,\ldots,154\}$) and *S* being in ha,
- Liebe (2005) derived an equation to estimate the storage of each SR, i.e., $V = 0.00857 \cdot S^{1.4367}$ where the surface *S* is in m² and the storage *V* in m^3,
- former equations are used to calculate the surface and the storage of each SR,
- the total storage of the 154 SRs is estimated, i.e., 12.6 Mm^3 (Table 3),
- from Figure 6, approximately 55 SRs are counted in the Pwalagu sub-basin (out of the 154), making by pro-rata a total storage of 4.5 Mm3, the rest being in the Nawuni sub-basin, i.e., 99 SRs (out of the 154) and totalling 8.1 Mm^3).
- finally, as the Upper East Region covers roughly only half of the northern part of Ghana, the total storage of SRs in the sub-basin Nawuni is doubled, making 198 reservoirs and totalling 16.2 Mm^3 (Table 2).

Finally, the calculated total storage for the 253 SRs (55 in Pwalagu + 198 in Nawuni) in the Ghanaian part of the basin is about 21 Mm^3 (Table 2).

Table 2: Estimated total storage of SRs in the Volta basin.

Sub-basin	**In the Burkinabe part**		**In the Ghanaian part**		**Grand total**	
	Number	**Total storage (Mm3)**	**Number**	**Total storage (Mm3)**	**Number**	**Total storage (Mm3)**
Arly	2	0.6	-	-	2	0.6
Dapola	261	41.6	-	-	261	41.6
Kompienga	29	7.7	-	-	29	7.7
Lerinord	26	5.8	-	-	26	5.8
Mango	9	1.0	-	-	9	1.0
Nanggodi	98	24.3	-	-	98	24.3
Nawuni	59	6.5	198	16.2	257	22.6
Noumbiel	11	2.1	-	-	11	2.1
Nwokuy	23	6.5	-	-	23	6.5
Pwalagu	41	8.4	55	4.5	96	12.9
Wayen	238	42.6	-	-	238	42.6
Yakala	262	64.9	-	-	262	64.9
Total	1 059	211.8	253	20.7	1 312	232.5

Table 3: Distribution of surface and storage of SRs in the Upper East Region of Ghana (adapted from Liebe et al. (2005)).

Surface class (ha)	**Number**	**Total surface (ha)**	**Total storage (Mm^3)**
1 < S < 35	154	999	12.6
0.09 < S < 1	348	79	-

The grand total of SRs storage capacity in the whole basin is 232 Mm^3 (Table 2). The associated water demands (75% of this grand total, giving 174 Mm^3/year) are reported in Table 6 and those along the three main river systems (Mouhoun, Nakambé and Oti Pendjari) are plotted in Figure 8.

II.2.2. Large irrigation reservoirs

Similarly to SRs:

- water is used for irrigation,
- few information on their physical properties (unknown storage – water elevation relation) or on their operational rules (e.g., water releases, possible buffer level in the reservoir) are available at the time of this work,
- and storage in large irrigation reservoirs is usually low just before the onset of the monsoon and they replenish during the wet season

it is assumed that a large irrigation reservoirs can be modelled in WEAP as a consumptive water demand equal to the storage capacity of the reservoir minus the inactive storage or, when inactive storage is unknown, to 75% of the storage capacity.

Five large irrigation reservoirs have been identified and reported in Table 4. The case of the Sourou reservoir is particular: it is located in the Lerinord sub-basin and replenishes from both the Sourou river (Lerinord sub-basin) and the upper Mouhoun (Nwokuy sub-basin) (Figure 5). It is estimated that roughly 188 Mm^3/year are taken from the upper Mouhoun during the rainy season (July to November), the remaining 89 Mm^3/year being supplied by the Sourou river (e.g., Moniod et al. 1977). All the equivalent water demands from large irrigation reservoirs are reported in Table 6 and plotted in Figure 8.

Table 4: Large irrigation reservoirs.

Name	Storage capacity (Mm^3)	Inactive storage (Mm^3)	Demand (Mm^3)	Sub-basin	Source
Sourou	370	Unknown	277	Lerinord and Nwokuy	Direction Générale de l'Hydraulique (2001)
Tono	90	Unknown	67	Nawuni	Liebe et al. (2005)
Vea	20	Unknown	15	Nawuni	Liebe et al. (2005)
Yako Kanazoé	100	50	50	Wayen	http://aochycos.ird.ne/HTMLF/PARTNAT/MEE/GRD_REAL.HTM
Ziga	200	100	100	Wayen	Direction Générale de l'Hydraulique (2001)

II.2.3. Large hydropower schemes

Table 5 contains data gathered from various sources for Akosombo, Bagré and Kompienga hydropower schemes. Additionally, the relation storage – water elevation was obtained from the *Société Nationale d'Electricité du Burkina* (SONABEL) and van de Giesen et al. (2001).

Table 5: Large hydroelectrical reservoirs in the Volta basin.

Dam	Storage capacity (Mm^3)	Inactive storage (Mm^3)	Target for turbined-water		Period of available observed storage	Source
			Period of available observed-flows	Average (Mm^3/year)		
Akosombo	148,000	70,000	1985 – 2000	31,570	1965 – 1998	van de Giesen et al. (2001), Obeng-Asiedu (2004)
Bagré	1,700	400	1995 – 1999	870	1994 – 1999	SONABEL, SIEREM
Kompienga	2,025	500	1995 – 1999	580	1994 – 1999	SONABEL, SIEREM

Evaporation from a reservoir is taken equal to 0.7 x ET0, ET0 being the reference evapotranspiration and the coefficient 0.7 taken as advised by Allen et al. (1998). The net evaporation, i.e., evaporation minus rainfall over the reservoir, is reported in WEAP for each reservoir.

An important parameter is the water released through the hydropower turbines, denoted *turbined-water* hereafter, which is related to the target for hydropower production. This term is modelled in WEAP by a non-consumptive water demand withdrawing from the reservoir, returning the flows to the downstream river. Turbined-water observed at the outlet of the three dams is plotted on

Figure 7. We have however no information on the dams' operational rules, such as the possible buffer level in the reservoir below which releases are restricted.

II.2.4. Remaining water uses

Remaining water uses are river-side irrigations, livestock consumptions and domestic. Associated water demands are estimated from Ministry of Works and Housing (1998), Direction Générale de l'Hydraulique (2001), Barry et al. (2005) and Nii Consult (2007). As data on groundwater utilisation in the Volta basin is lacking, interactions with groundwater are disregarded.

River-side irrigation uses we consider here are small scale irrigation schemes (different from small or large reservoirs), where water is withdrawn directly from rivers. They are labelled as 'River-side' in Table 6 and their demands are calculated from figures of irrigated area and expert knowledge. Domestic and livestock demands are estimated from censuses (population in 2000, livestock in 1996) and per capita consumption (which differs among rural / urban population as well as between poultry / sheep / cattle).

II.2.5. Overview of the considered water uses

All the water demands associated with the water uses considered in this work are reported in Table 6. Demands along the three main river systems (Mouhoun, Nakambé and Oti Pendjari) are plotted in Figure 8.

The targets for turbined-water at the three hydroelectric dams (totally 33,020 Mm^3/year on average), especially at Akosombo, are by far the greatest water demands in the Volta basin. However, on the contrary to all the other demands, these targets are non-consumptive (100% return flow to downstream rivers) and reusable. The greatest consumptive demand is for the Sourou irrigation scheme, along the Mouhoun river system (277 Mm3/year, taken from sub-basins Lerinord and Nwokuy).

II.2.6. Priorities for water allocation

In WEAP, the parameter quantifying the priority of water allocation can range from 1 to 99, with 1 being the highest priority and 99 the lowest. Assuming that there is no upstream – downstream cooperation in management of the basin water resource, demand priorities are fixed per river system (i.e., Mouhoun, Nakambe, Oti Pendjari) as follows (Table 7):

- water allocation is based on a "first come, first served" basis, i.e., water is withdrawn upstream without consideration for downstream requirements,
- hence water allocation priority decreases from upstream to downstream sub-basin, i.e., priority parameter in WEAP increases from upstream to downstream,
- in a given sub-basin, water is allocated first to SRs since they are spatially-distributed in the area of the sub-basin (Figure 6) and capture runoff water before it reaches the main river system.

Values of the priority parameter range from 1 to 13, the lowest water allocation priority, i.e., the greatest value for the priority parameter in WEAP, being given to the downstream Lake Volta (sub-basin Senchi).

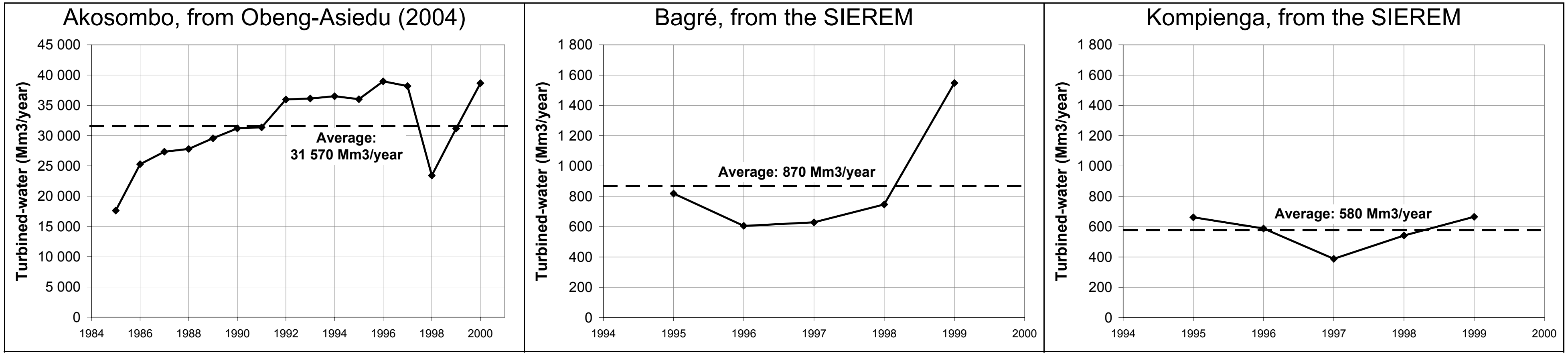


Figure 7: Observed turbined-water. Note the different vertical scales.

Table 6: Water Demands in the sub-basins of the Volta basin.

Sub-basin	**Domestic (Mm3/year)**	**Livestock (Mm3/year)**	**Irrigation (Mm3/year)**			**Hydroelectric (Mm3/year)**
			River-side	**Large reservoirs**	**Small reservoirs**	
Arly	-	-	-	-	0	-
Bamboi	12	4	-	-	-	-
Dapola	17	13	19	-	31	-
Ekumdipe	2	1	-	-	-	-
Kompienga	3	3	-	-	6	580
Lerinord	4	4	-	89	4	-
Mango	-	-	-	-	1	-
Nanggodi	5	4	3	-	18	-
Nawuni	23	13	-	82	17	-
Noumbiel	-	-	-	-	2	-
Nwokuy	13	6	46	188	5	-
Pwalagu	-	-	-	-	10	-
Sabari	7	3	27	-	-	-
Senchi	30	5	81	-	-	31 570
Yakala	38	16	66	-	49	870
Wayen	-	-	-	150	32	-
Total	156	71	242	509	174	33 020

Table 7: Priorities for water allocation in WEAP within the river systems of the Volta basin (Mouhoun, Nakambe and Oti Pendjari, plus the Lake Volta). In WEAP, the allocation priority decreases when the value of the priority parameter increases.

	Demand	Priority parameter	Demand	Priority parameter	Demand	Priority parameter	
	Mouhoun		Nakambé		Oti Pendjari		
Upstream	Nwokuy SRs	1	Wayen SRs	1	Arly SRs	1	Highest
	Nwokuy domestic	2	Wayen Yako Kanazoe dam	2	Kompienga SRs	1	
	Nwokuy irrigation	2	Wayen Ziga dam	2	Kompienga domestic	2	
	Nwokuy livestock	2	Yakala SRs	3	Kompienga livestock	2	
	Nwokuy Sourou dam	3	Yakala domestic	4	Kompienga turbined-water	3	
	Lerinord SRs	1	Yakala livestock	4	Kompienga reservoir	4	
	Lerinord domestic	2	Bagre turbined-water	5	Mango SRs	5	
	Lerinord livestock	2	Bagre irrigation	6	Sabari domestic	6	Allocation priority
	Lerinord Sourou dam	3	Bagre reservoir	7	Sabari irrigation	6	
	Dapola SRs	4	Pwalagu SRs	8	Sabari livestock	6	
	Dapola domestic	5	Nawuni SRs	9			
	Dapola irrigation	5	Nawuni domestic	10			
	Dapola livestock	5	Nawuni Tono dam	10			
	Noumbiel SRs	6	Nawuni Vea dam	10			
	Bamboi livestock	7	Nawuni livestock	10			
	Bamboi Rural domestic	7					
			Lake Volta				
			Senchi domestic	11			
			Senchi irrigation	11			
			Senchi livestock	11			
			Akosombo turbined-water	12			
Downstream			Akosombo reservoir	13			Lowest

II.3. Validation of the Decision-Support Tool

The objective of the validation is to test the parameterisation of the DST, as presented above with its limitations and assumptions (Table 8). We consider the time-variation of observed turbined-water at the three hydroelectric dams (Figure 7) and compare the simulations with observed water storage in the reservoirs Bagre, Kompienga and Lake Volta. Measured storages are taken from the *Système d'Informations Environnementales sur les Ressources en Eaux et leur Modélisation* (SIEREM) and van de Giesen et al. (2001).

We calculated the Nash and Sutcliffe (1970) coefficient using equation [1] and considering the water storage as a variable. Matching is insufficient for Bagre (0.53) and poor for Kompienga (<0) (Figure 9). The cause, especially for Kompienga, is most probably the unsatisfactory calibration of the hydrologic module for the sub-basin where these dams are located (the period of available monthly river flows are not recent for Yakala and Kompienga, compare Table 1 and Figure 3). Conversely, the acceptable calibration of the sub-basin Senchi (0.85) entails a satisfactory simulation of seasonal and inter-annual variations of Lake Volta water level.

III. Scenarios

As a consequence of the foregoing validation step, this section will only consider effects of scenarios on the downstream Akosombo hydropower scheme (Lake Volta + Akosombo dam). Scenarios are developed for 20 years, with the year 2000 as the initial condition (year 0 of the simulations). Three types of scenario are considered:

- a scenario of reference, where no change occurs and where we use meteorological data from the period 1980 – 2000,
- climate change scenarios with a drier and wetter climate,
- a scenario of development of SRs, with a growth in water demand from SRs by 10% per year.

The climate change scenarios are elaborated to answer the question: "Can a climate change impact the hydropower generation at Akosombo?". We consider an additional type of scenario where the number of SRs increases as these informal / private arrangements (mainly in Burkina Faso) are prone to develop in an uncontrolled manner. The consequent question is similarly "How would the development of SRs impact the Akosombo dam?". For scenarios with demographic changes, see Nii Consult (2007).

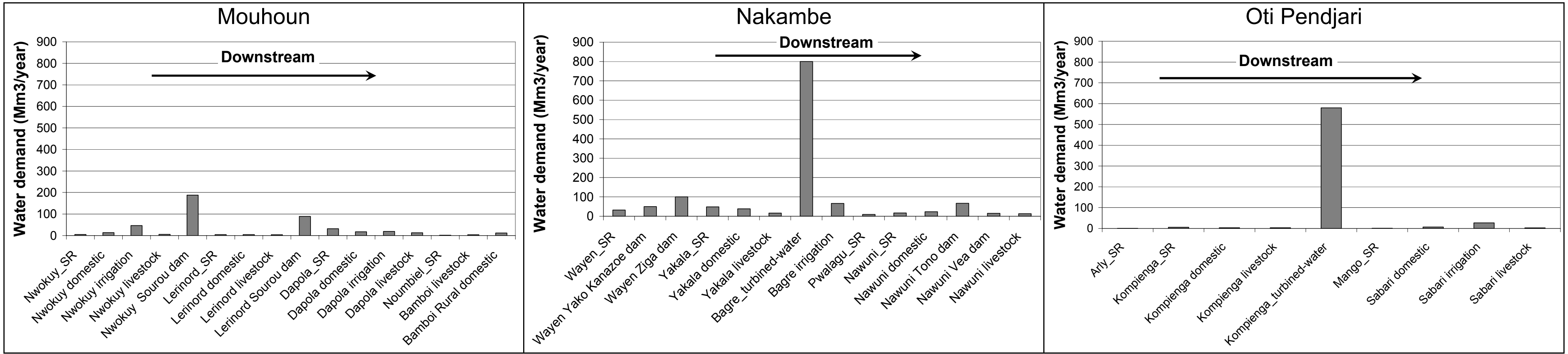


Figure 8: Water demands in the three main river systems (to be compared with the average target of 31,570 Mm^3/year for turbined-water at Akosombo dam).

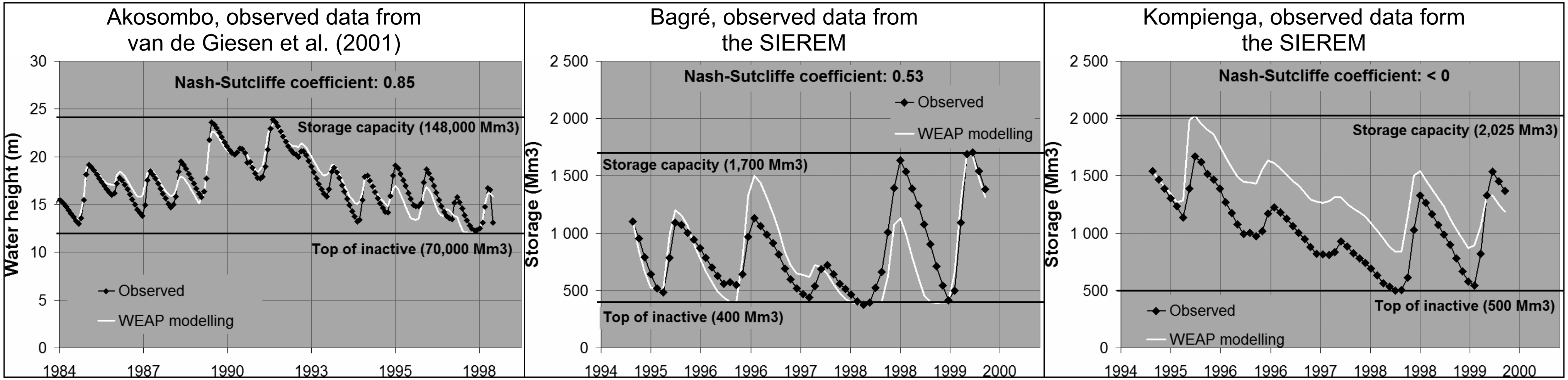


Figure 9: Validation of the Decision-Support Tool: observed storages vs. simulations.

Table 8: Lacking data and assumptions for modelling of the current account (year 2000).

Category	Lacking data	Assumptions
Hydrology	• Gap in observed river flows, especially in the South of the Basin. • No data for sub-basins Lerinord and Estuary.	• Groundwater is neglected. • Calculated runoff is lumped into a headflow point in each sub-basin. • CRU meteorological data are considered as actual data.
Large irrigation reservoirs	• Storage – water elevation relation. • Observed data (storage and water release). • Operational rules (e.g., water releases, possible buffer level in the reservoir).	• Considered as: o a consumptive water demand, o equal to the storage capacity minus the inactive storage, o or equal to 75% of the storage capacity if the inactive storage is unknown.
Large hydroelectric reservoirs	• Precise operational rules (e.g., possible buffer level in the reservoir).	• The target for turbined-water is considered as: o a non-consumptive water demand returning the flows to the downstream river, o which remains constant with time in the scenarios.
Small reservoirs (SRs)	• Physical data (storage capacity and storage – water elevation relation). • Operational rules (e.g., water releases, inactive zone of the reservoir). • Observed data (storage and water release).	• SRs are smaller than 1 Mm3. • No SRs are present in middle and south of Ghana. • All SRs are lumped into a single term in each sub-basin. • This term is considered as: o a consumptive water demand, o equal to 75% of the total storage of SR in the sub-basin.
Other water uses	• Groundwater utilisation. • Most recent figures.	• No population growth. • No interactions with groundwater. • Considered as consumptive water demands. • Irrigated surface is a good proxy for irrigation demand estimation.
Allocation priority		• No upstream – downstream cooperation in management of the Volta basin water resource.

The tendency of turbined-water flows at Akosombo hydropower station was to increase during the period 1985 – 2000 (Figure 7), with decrease in certain years. Having no information on Akosombo's operational rules, we assume that the target for turbined-water at Akosombo hydropower station remains constant in all scenarios, equal to the average value observed during period 1985 to 2000, i.e., 31.6 km3/year (Table 5). This leads to a target which is smaller than turbine flows observed in late 1990's (Figure 7). Assumptions are those mentioned in Table 8 and Table 9 summarises the scenarios as they will be presented below.

Table 9: Scenarios considered for 20 years, with the year 2000 as the initial condition (year 0 of the simulations) and using data from the period 1980-2000.

Scenario for 20 years	Meteorological data	Demands
Reference	CRU grids for the period 1980 to 2000	▪ As in 2000 (year 0 of the simulations). ▪ Target for Akosombo turbine water taken remains constant with time.
Climate Change Drier	CRU grids for the period 1980 to 2000, shifted 1° southwards	As in the Reference Scenario
Climate Change Wetter	CRU grids for the period 1980 to 2000, shifted 1° northwards	As in the Reference Scenario
Small Reservoirs (SRs)	As in the Reference Scenario	SRs water demands increase by 10%/year

III.1. Scenario of reference

In this scenario of reference, WEAP is run for 20 years while all water demands remain as in the year 2000 (year 0 of the simulations), except for the target for turbine water as explained above. So as to account for yearly fluctuations in meteorological data (e.g., rainfall), we use the data for temperature and rainfall of the period 1980 to 2000.

III.1.1. Inflows to the Lake Volta

Figure 10 shows the calculated inflows to the Lake Volta and the contributing rainfall (rain falling in the upstream contributing area) in this reference scenario. Yearly variations in contributing rainfall produce amplified inter-annual variations in inflows, hence the Lake is highly sensitive to fluctuating rainfall. Another consequence is that the proportion of upstream rainfall transformed into inflows to the Lake Volta differs yearly (from 4% to 15%), with an average value of 8%, or about 29.1 km3/year. It is noteworthy that the chosen target for turbined-water at Akosombo (31.6 km3/year) may not be attained every year since it is slightly greater than the average inflow in this scenario of reference.

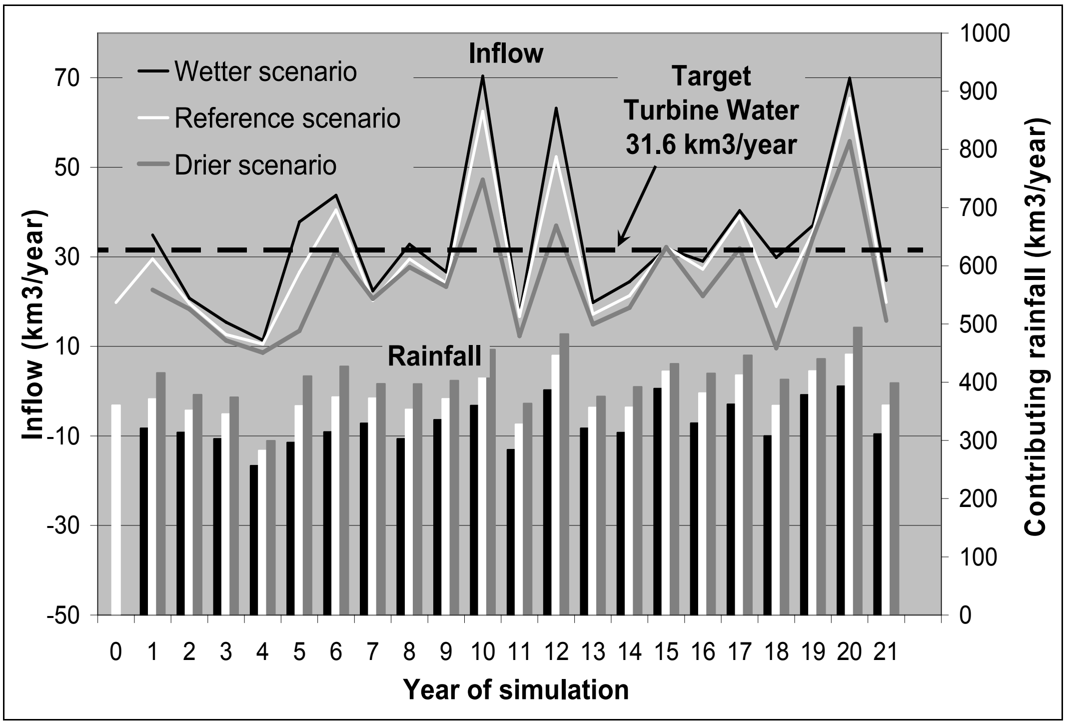


Figure 10: Simulation of annual inflows to the Lake Volta and annual contributing rainfall (falling upstream of the Lake Volta), scenarios of climate change.

III.1.2. Consequences on the Akosombo hydropower scheme

Figure 11 shows the simulated stored volumes in Lake Volta. The high disparity in annual inflows entails an important inter-annual variation of simulated storage. The constant value chosen for the water turbine target (31.6 km^3/year) is not sustainable as storage never reached the maximum capacity and even attained the inactive storage (70 km^3). As foreseen above and even though the constant value of the target is smaller than turbine flows observed in late 1990’s (Figure 7), the goal for hydropower generation is not always attained as turbined water is below the target for certain years (Figure 12). The hydropower capacity of Akosombo is vulnerable in this scenario.

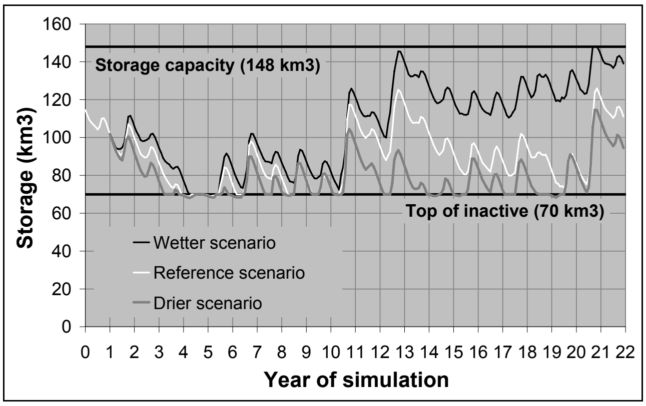


Figure 11: Simulation of the water storage in Lake Volta, scenarios of climate change.

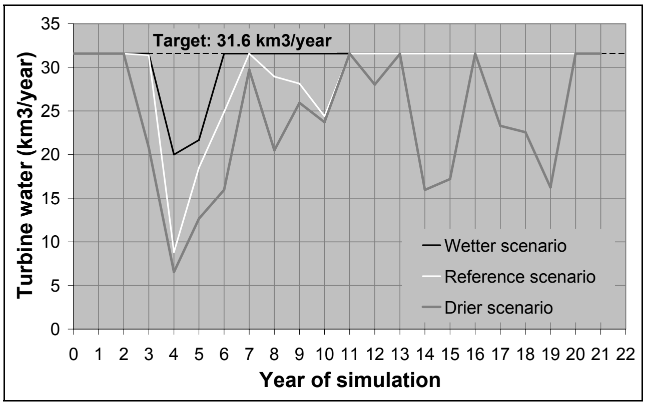


Figure 12: Simulation of annual water release at the Akosombo hydropower station, scenarios of climate change.

III.2. Scenarios of climate change

The report Christensen et al. (2007) from the *Intergovernmental Panel on Climate Change* concludes that there is no consensus on the change in rainfall in West Africa, whether it will increase or decrease. Hence, we simulate a drier and a wetter climate change scenarios by mimicking the reduction in rainfall that occurred in the Basin in the 70’s (Lemoalle, 2007). L’Hôte et al. (2002) estimated that annual rainfall decreased by 150 mm and that the isohyets shifted southwards by about 150 km in the North of the Basin. Consequently, we shift the CRU grids of rainfall and of maximum and minimum temperatures used in the reference scenario (period 1980 to 2000) so as to simulate:

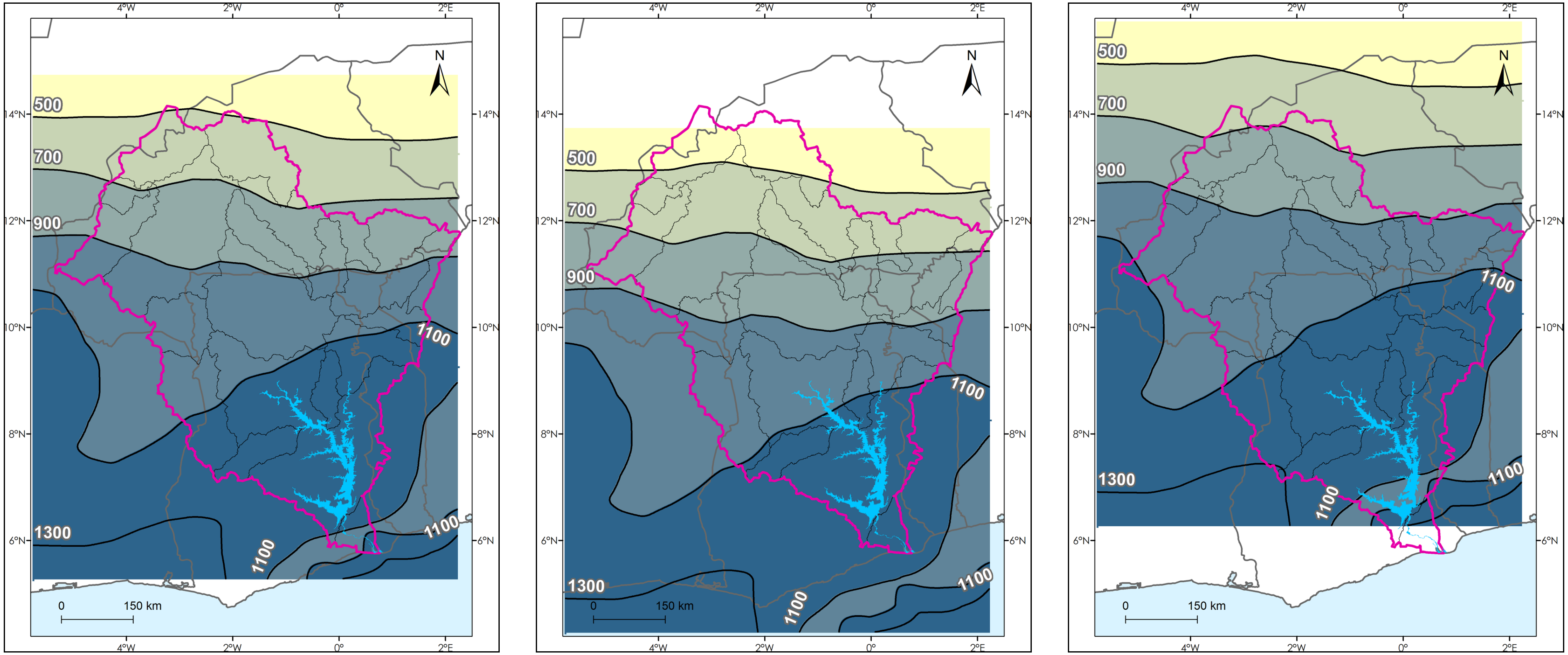
- a drier period, by a shift of 1 degree southwards,
- a wetter period, by a shift of 1 degree northwards.

The two shifts of isohyets are illustrated on Figure 13.

III.2.1. Climatic consequences

Data from the shifted grids were averaged within each sub-basin. For the wetter scenario, a major part of the Estuary sub-basin is not covered by the CRU grid, hence rainfall and temperatures were taken equal to values of the reference scenario. Table 10 shows the consequences of these shifts, expressing the change in temperature with the change in reference evapotranspiration. Since isohyets are approximately along the latitudinal direction in north of the Basin, the northern sub-basins:

- have indeed their annual rainfall and duration of rain season lesser and greater for respectively the drier and wetter scenario,
- and departures from the reference scenario are roughly symmetrical for both scenarios (± 150 mm).



Reference Scenario

Drier Scenario (1° shift southwards)

Wetter Scenario (1° shift northwards)

Figure 13: Spatial distribution of rainfall for the reference scenario (period 1980 – 2000) and the two climatic scenarios (data from the Climate Research Unit's TS 2.1 data-set, cf. Figure 2).

Table 11: Mean annual rainfall and reference evapotranspiration (ET0) in the sub-basins and the whole Volta basin, scenarios of climate change.

		Upstream										**Sub-basin**								**Downstream**	**Volta**
		Lerinord	Nwokuy	Dapola	Noumbiel	Bamboi	Wayen	Yakala	Nangodi	Pwalagu	Nawuni	Arly	Kompienga	Mango	Koumangou	Sabari	Prang	Ekumdipe	Senchi	Estuary	**basin**
Reference scenario	**Rainfall (mm)**	616	890	827	1 007	1 084	626	762	821	867	975	933	844	886	1 072	1 159	1 231	1 209	1 191	1 130	970
	ET0 (mm)	2 064	1 960	1 979	1 865	1 771	2 056	2 004	1 983	1 977	1 916	1 944	1 973	1 968	1 910	1 879	1 706	1 821	1 766	1 578	1 896
	Rainfall / ET0	0.30	0.45	0.42	0.54	0.61	0.30	0.38	0.41	0.44	0.51	0.48	0.43	0.45	0.56	0.62	0.72	0.66	0.67	0.72	0.51
Drier scenario 1° shift southwards	**Rainfall (mm)**	469	723	685	915	1 026	478	622	678	709	847	751	691	726	899	1 002	1 145	1 091	1 130	1 246	854
	ET0 (mm)	2 090	2 015	2 035	1 940	1 835	2 106	2 052	2 037	2 018	1 975	2 005	2 025	2 016	1 954	1 940	1 794	1 891	1 840	1 683	1 956
	Rainfall / ET0	0.22	0.36	0.34	0.47	0.56	0.23	0.30	0.33	0.35	0.43	0.37	0.34	0.36	0.46	0.52	0.64	0.58	0.61	0.74	0.44
Wetter scenario 1° shift northwards	**Rainfall (mm)**	762	1 012	940	1 029	1 173	766	910	959	1 016	1 081	1 100	1 001	1 053	1 201	1 224	1 267	1 254	1 185	1 130	1 057
	ET0 (mm)	2 011	1 908	1 917	1 810	1 712	2 004	1 953	1 931	1 926	1 851	1 884	1 952	1 917	1 856	1 807	1 658	1 751	1 675	1 578	1 832
	Rainfall / ET0	0.38	0.53	0.49	0.57	0.69	0.38	0.47	0.50	0.53	0.58	0.58	0.51	0.55	0.65	0.68	0.76	0.72	0.71	0.72	0.58

Tendencies are not as clear for the southern sub-basins as the isohyets are not along the latitudinal direction, but incurved. For instance, rainfall decreases within the sub-basin Senchi for both the drier and wetter scenario. The reference evapotranspiration increases slightly in the drier scenario and the contrary in the wetter scenario, but not to the same extent as for rainfall.

The ratio of rainfall to reference evapotranspiration gives an indication of the climate: the greater its value, the more humid climate, and vice-versa. This ratio is indeed smaller and greater for all the sub-basins for respectively the drier and wetter scenario (Table 11). It is especially true if the average value for the whole Volta basin is considered: the ratio is 0.51 for the reference scenario, 0.44 for the drier scenario and 0.58 for the wetter scenario.

III.2.2. Inflows to the Lake Volta

Departure of rainfall from the reference scenario is slightly greater for the drier scenario and this deviation is accentuated for the calculated inflows to the Lake Volta (Figure 10). As inflows simulated by the DST are not only function of the hydrologic behaviour of the Basin but are also affected by upstream water allocations, inflows in both scenarios happen to be equal for certain years (as in year 15). The average proportion of upstream rainfall transformed into inflows to the Lake Volta is the same as in the reference scenario, i.e., around 8%., giving an average inflow of about 24.2 km^3/year and 33.5 km^3/year in the drier and wetter scenario respectively. The chosen target for turbined-water at Akosombo (31.6 km^3/year) is definitively not sustainable in the drier scenario while it is suited to the wetter.

III.2.3. Consequences on the Akosombo hydropower scheme

In addition to inter-annual variations of rainfall, effects of climate change become notable after 10 years of simulation (Figure 11). In the drier scenario, the inactive storage limit is reached almost every year while water levels are close to the maximum in the wetter scenario. As for the reference scenario, the water available for hydropower is reduced for both scenarios between the 3rd and the 6th year of simulation after the dry year 4 (Figure 12). Afterwards, the release target is always attained in the wetter scenario while turbined-water is clearly restricted (less than 2/3 of the target) for several years in the drier scenario. In brief, the hydropower capacity of Akosombo is critical in the drier scenario while the situation is comfortable in the wetter scenario.

Taking into account the limitations / assumptions of our work (Table 8), the simulations presented above illustrate clearly that:

- climate changes similar to what have been observed in the recent past would have a critical impact on the Lake Volta; this is in agreement with conclusion of the project GLOWA Volta (Rodgers et al. 2007); and
- hydropower generation up to the level observed in late 1990's would only be sustainable in the wetter scenario, which call for careful management of the Akosombo hydropower scheme.

III.3. Scenario of small reservoirs development

In section II.2.1 we explained that Small Reservoirs (SRs) are mainly located in upstream sub-basins, in Burkina Faso. The objective of this section III.3 is to quantify the impacts that development of upstream SRs could have on the functioning of the downstream Akosombo hydropower scheme, in Ghana.

III.3.1. The growth in water demand

We define a scenario of rapid increase in number of SRs that we express as a growth of 10% per year in water demand from SRs in each upstream sub-basin. Figure 14 shows this increase: starting from 0.17 km^3/year in the year 0 (Table 6), the total water demand reaches 1.29 km^3/year after 20 years, which is more than 7 times greater. Transformed into cropped area, the rate 1.3 km3/year is equivalent in the upstream part of the Basin to an additional irrigated area of about 110,000 hectares. It may appear ambitious but it would be required to improve the resilience of food production to rainfall variability.

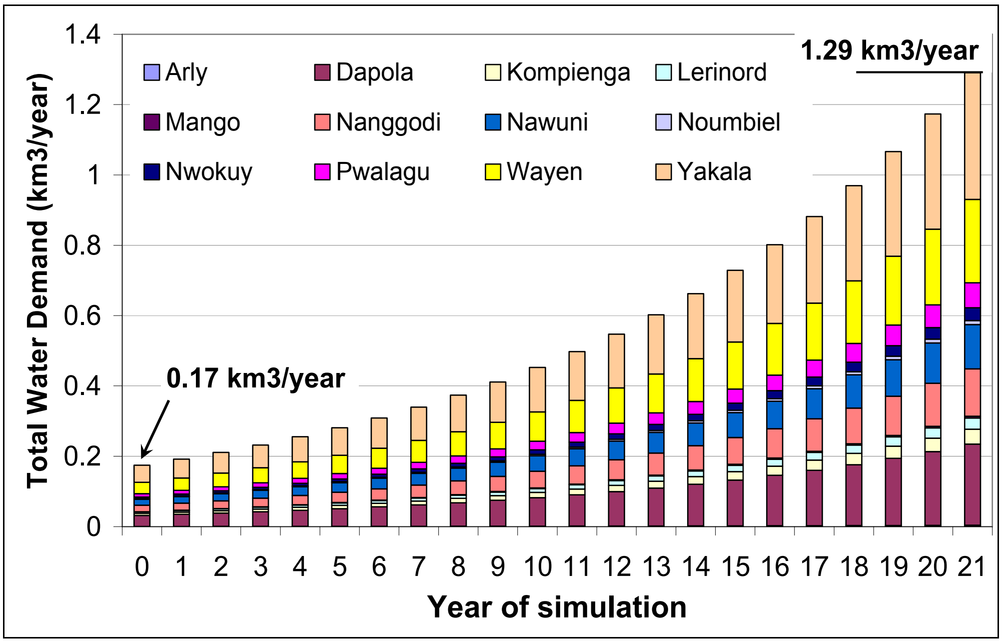


Figure 14: Growth of 10%/year of water demands from SRs in each sub-basin, scenario of small reservoirs development.

III.3.2. Consequences on the Akosombo hydropower scheme

Figure 15 and 16 show that there is a slight impact on the Lake Volta during the span of the scenario as inflow and storage are almost equal to those of the reference scenario – there is no impact on the turbined water as compared to the situation in the reference scenario (Figure 17). The departure from the inflow simulated in the reference scenario increases with time, reaching about 1 km^3/year after 20 years. This is about 3% of the mean inflow simulated in the reference scenario (29.1 km3/year).

The output is that, considering all the limitations / assumptions of this work (Table 8) and provided our estimation of water demands from SRs is realistic (cf. section II.2.1), a growth of 10%/year during 20 years in water demand from SRs:

- to an additional irrigated areas of about 110,000 ha in the upstream part of the Basin, which would be a significant improvement of livelihood;
- a reduction of inflows to the Lake Volta by about 3%, which would be a small but probably noteworthy effect on hydropower production;
- climate variations have a much stronger impact, which is also in agreement with outcome of the project GLOWA Volta (Andreini et al. 2000).

This output calls for a transboundary trade-off: a significant improvement of livelihood upstream of the Basin, in Burkina Faso, vs. a slight negative effect on hydropower downstream of the Basin, in Ghana.

Besides, an extension of our analysis indicates that such a development of SRs may overtake the available water resource and come into competition with other existing demands in the northern part of the Basin. This is especially the case along the Burkinabe section of the Nakambe River where we find downstream the Bagre dam and upstream the greatest density of SRs in the Basin (sub-basins Wayen and Yakala, cf. Figure 6 and 14). The trade-off in the case of the Bagre dam would be a national issue: livelihood of small Burkinabe farmers vs. Burkina Faso's hydropower production.

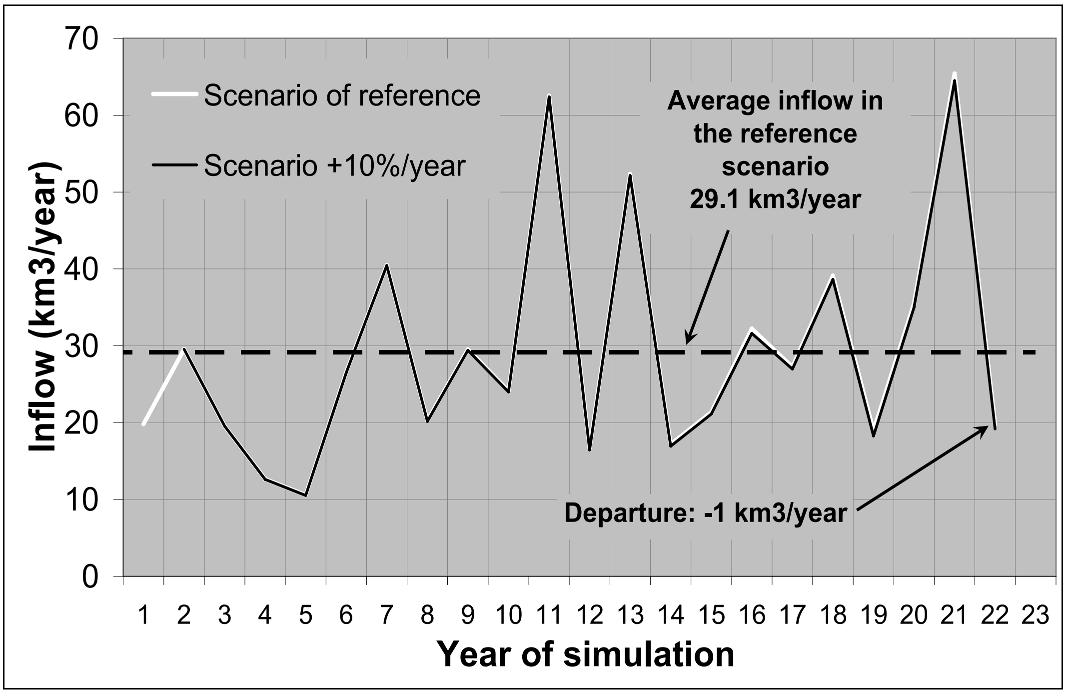


Figure 15: Simulation of annual inflows to the Lake Volta, scenario of small reservoirs development (+10%/year).

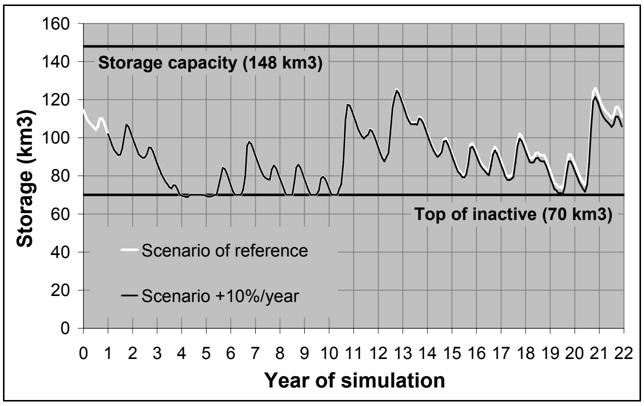


Figure 16: Simulation of water storage in Lake Volta, scenario of small reservoirs development (+10%/year).

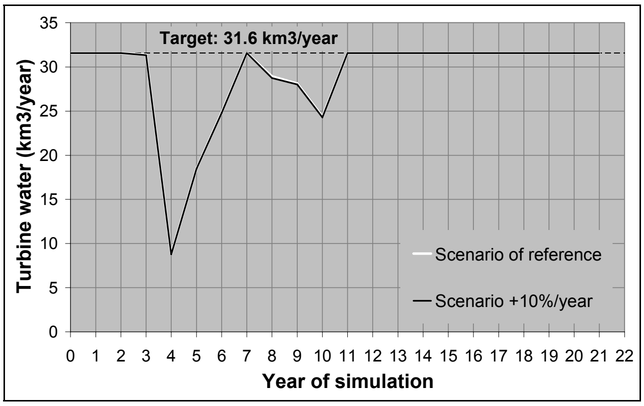


Figure 17: Simulation of annual water release at Akosombo hydropower station, scenario of small reservoirs development (+10%/year).

IV. Conclusion and prospects

The aim of this work was to develop a pre-parameterised Decision-Support Tool (DST) for the management of the transboundary water resource of the Volta basin. To that end, two modelling modules were coupled: the hydrologic spreadsheet of Kirby et al. (2006) and the software WEAP developed by the *Stockholm Environment Institute* (Yates et al. 2005a; Yates et al. 2005b). The first task was to parameterise the DST to describe the Basin, i.e., to fix the parameters of the hydrologic module and to quantify the water demands in the Basin. The hydrologic module was calibrated to reproduce observed river flows and calculation of the Nash and Sutcliffe (1970) coefficient showed that calibrations were more or less satisfactory according to data availability. While quantifying the water uses in the Basin, we estimated in particular the demands from Small Reservoirs (SRs). Afterwards, we tried to validate this parameterisation of the DST by comparing simulated and observed storage of hydroelectric reservoirs. Validation was satisfactory for Akosombo dam but less so for Bagré and Kompienga.

As an illustration at the basin scale, we analysed the possible effects of two types of 20-years scenario on the downstream Akosombo scheme (Lake Volta + Akosombo dam), in Ghana: climate change and development of upstream SRs, in Burkina Faso. In the first type of scenario, we considered three tendencies: a reference period, with no climate change compared to the period 1980 - 2000, and a drier and a wetter climate, simulated by mimicking the change in rainfall that occurred in the Basin around 1970. Water levels in the Lake Volta, hence hydropower operation of the Akosombo dam, were highly sensitive to inter-annual rainfall variations and simulated climate changes. In the reference and drier scenarios, the chosen target for water releases at Akosombo hydropower station (31.6 km^3/year) was not attainable as it was often higher than the simulated available resource, even though we set a target smaller than the turbine flows observed in late 1990's. Only the wet scenario enabled a comfortable operation of the Akosombo dam. Outcome is that, with respect to all the limitations / assumptions of our work (Table 8):

- climate changes similar to what have been observed in the recent past would have a critical impact on the Lake Volta, and
- hydropower generation up to the level observed in late 1990's would only be sustainable in the wetter scenario, which call for careful management of the Akosombo hydropower scheme.

In the second type of scenario, we defined a rapid tendency of further development of upstream SRs that we expressed as a growth of 10% per year in their number. This led after 20 years to a water demand 7 times greater, which is equivalent to an additional irrigated area of about 110,000 ha in Burkina Faso, a significant improvement of livelihood for small farmers. The simulated impacts on the Akosombo scheme were slight during the span of the scenario, although the effects became notable in the last years of simulation. Outcome of this scenario is that, with respect to all the limitations / assumptions of our work (Table 8) and provided our estimation of water demands from SRs was correct (cf. section II.2.1):

- impact on the Akosombo scheme of a continuous growth of 10%/year during 20 years in number of upstream SRs is negligible compared to consequences of the climate changes considered in this paper,
- however, after 20 years of this growth, inflows to the Lake Volta would be reduced by about 1 km^3/year, that is 3% of the mean inflow simulated in the reference scenario (29.1 km^3/year) that would be subtracted to hydropower production.

Such a scenario sets the ground for discussions on a transboundary trade-off: a significant improvement of livelihood upstream of the Basin, in Burkina Faso, versus a slight but probably noteworthy negative effect on hydropower downstream of the Basin, in Ghana. Besides, continuation of this work should focus on the Bagre hydropower scheme, in Burkina Faso, as it is foreseen that this scheme should be more affected by further development of upstream SRs.

To develop further and especially to implement this DST, it will be handed to the *Volta Basin Authority* by providing training and capacity building. The Authority is a platform for consultation at the basin scale and needs this kind of tool for concrete illustration of situations the Basin is very likely to face soon. This DST may foster the transboundary dialogue required for an integrated management of the water resources in the Volta basin. As closing words, our application focused on hydroelectric schemes and proposed continuations are:

- to study more precisely impacts of SRs development on the Bagre and Kompienga schemes,
- development of groundwater exploitation,
- trends for other water demands, such as urban use and population growth.

Acknowledgements

Observed river flows, data on small reservoirs and on hydroelectric dams were provided by the project 'Volta HYCOS', the *Small Reservoir Project* of the CPWF and the *Système d'Informations Environnementales sur les Ressources en Eaux et leur Modélisation* (SIEREM, http://www.hydrosciences.org/sierem/) respectively.

Postface

The work presented in this report has been improved recently by collaborating with the *Project for Improving Water Governance in the Volta River Basin* (PAGEV), implemented by the *International Union for Conservation of Nature* (IUCN). Indeed, PAGEV had also developed a WEAP application to the Volta basin, focusing in particular on trends for main urban water demands. The *Stockholm Environment Institute* organised a two weeks collaborative work session between the PAGEV and the BFP Volta projects so as to:

- to capitalise and make best-use of the work done by both projects in the Volta basin,
- to provide to the *Volta Basin Authority* (VBA) an analytical tool relevant for an integrated water resource management in the Basin.

As a consequence, the DST presented above has been modified. In order to make the tool handy for the VBA, the core change was to model the hydrology with WEAP: as a result, simulation of the hydrology and of the water allocation is operated by the single software WEAP. Inspiration was taken from the parameterisation of the hydrology explained in section II.1, especially by choosing the same 19 hydrologic sub-basins as spatial modelling entities (Figure 2). We used the CRU TS 2.1 meteorological dataset as well, taking additionally from this dataset the mean temperature, the humidity and the cloudiness fraction that WEAP requires. The methodology for calibrating the model was different as we proceeded:

- per river system,
- from upstream to downstream sub-basins, the last basin being the Estuary,
- in a given sub-basin:
    - we placed (*i*) a catchment object, which is the WEAP object simulating the hydrology of the sub-basin, (*ii*) a groundwater object and (*iii*) the water demands sites; the groundwater object receives inflows from the catchment object (groundwater recharge) but is not utilised yet in this current application of WEAP as we still lack groundwater data;
    - and we calibrated the catchment object so as to reproduce observed river-flows at the outlet of the sub-basin.

A significant improvement is that calibration was not based solely on hydrologic data since water uses were considered as well for the adjustment.

The water demands are the same as presented above in section II.2, except the urban water demands and the addition of the Ziga dam on the Nakambe. The project PAGEV has gathered forecast of the main water demand from urban zones (Nii Consult, 2007). As the scope of this work is Basin-wide, we only selected the most demanding urban zones which withdraw from surface water: Bimbila, Koudougou, Ouagadougou and Tamale. Moreover, as PAGEV has data on the

Ziga dam (i.e., the storage – water elevation curve), which was commissioned in 2000 to supply Ouagadougou with domestic water, we added this dam to the identified uses along the Nakambe (sub-basin Wayen).

We considered the same types of scenarios as presented in section III: climate change and development of small reservoirs. Results and outcomes are similar to those presented above, with some additional results for supply to Ouagadougou city (from the Ziga dam).

Next initiative is to continue collaboration with PAGEV so as to hand this tool to the VBA and to provide training in WEAP and capacity building.

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