Pre-water audit for the Volta River Basin, West Africa

(River bank restoration along White Volta in northern Ghana)

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Abbreviations

AGRYMET	a specialized institute of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), it includes Burkina Faso and not Ghana (Niamey, Niger)
CERSGIS	Centre for Remote Sensing and Geographical Information Services, University of Ghana, Legon
CIDA	Canadian International Development Agency
CSIR	Council for Scientific and Industrial Research (Accra, same as WRI)
CGIAR	Consultative Group on International Agricultural Research (Washington)
CWSA	Community Water and Sanitation Agency responsible for rural water supply (Accra, represented in the Board of WRC)
DGIRH	Directorate General for the Inventory of Hydraulic Resources (Burkina Faso, part of MAHR, key institutional beneficiary and partner of the PAGEV Project)
DRAHRH-HB	Direction Régionale de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques de Hauts-Bassin (Bobo Dioulasso, hydrological data collected by this governmental organisation is sent to DGRIH)
DSS	Decision Support System
EC	Electrical Conductivity of water
EIER	L'Ecole Inter-Etats d'Ingénieurs de l'Equipment Rural (Burkina Faso)
FFEM	Le Fonds Français pour l'Environment Mondial (France)
GCM	Global Climate Model
GeEau	a project focussed on irrigation in the upstream part of the Black Volta, bassin du Kou (Bobo Dioulasso, funded by Belgium)
GEF-Volta	Global Environmental Facility Volta Project (part of UNEP)
GIS	Geographical Information System
GLOWA-Volta	Global Change and the Water Cycle Project for the Volta Basin (funded by the German Ministry of Research and Education and lead by ZEF)
GWCL	Ghana Water Company Limited, responsible for domestic and industrial water supply (Accra, represented in the Board of WRC)
GWP-WAWP	West African Water Partnership of the Global Water Partnership
GRDC	Global Runoff Data Centre (Koblenz, Germany)
HSD	Hydrological Services Division, Ministry of Works and Housing (Accra, represented in the Board of WRC)
IDA	Irrigation Development Authority responsible for agriculture (Accra, represented in the Board of WRC)
IRD	Institut de Recherche pour le Dévelopment (Ouagadougou & Montpellier, France)
IUCN-BRAO	The West Africa Office of the World Conservation Union (Ouagadougou)
IWMI	International Water Management Institute (Accra)
MAHRH	Ministère de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques (Ouagadougou)
MMCE	Ministère des Mines, des Carrières et de l'Energie (Ouagadougou)
MOB	Maîtrise d'Ouvrage de Bagré, responsible for the management of the Bagré Dam (Ouagadougou)
MSD	Meteorological Services Department (Accra, represented in the Board of WRC)
OCP	Onchocercosis (river blindness) Control Project (Ghana), a former project ran by the WHO
ONEA	Office National de l'Eau et de l'Assainissement, responsible for providing water to urban centres in Burkina Faso (Ouagadougou)
PAGEN	Projet de Partenariat l'Amélioration de la Gestion des Ecosystèmes Naturels (Burkina Faso)
PAGEV	Volta Water Governance Project (Ouagadougou, IUCN-BRAO and GWP-WAWP are the project facilitators)
RESO	Programme Ressources en Eau du Sud-Ouest
SONABEL	Société Nationale d'électricité du Burkina, responsible for electrical power production in Burkina Faso (Ouagadougou)
TOR	Terms Of References
UNEP	United Nations Environmental Programme
Volta-HYCOS	Hydrological Cycle Observing System in the Volta a project launched by the WMO at EIER

VRA	Volta River Authority responsible for electrical power production in Ghana (Accra, represented in the Board of WRC)
VREO	Programme de Valorisation des Ressources en Eau de l'Ouest, an EU sponsored project that focuses on the water management in the Burkinabe part of the Black Volta sub-basin
WEAP	Water Evaluation And Planning, water management software developed by the Stockholm Environment Institute
WHYCOS	World Hydrological Cycle Observing System a project launched by the WMO
WHO	World Health Organization
WMO	World Meteorological Organisation
WRC	Water Resources Commission, an umbrella institution for national water policy in Ghana (Accra, key institutional beneficiary and partner of the PAGEV Project)
WRCU	Water Research Coordination Unit of ECOWAS, set up in 2004 to coordinate water management related initiatives in West Africa (Ouagadougou)
WRI	Water Research Institute (Accra, represented in the Board of WRC)
ZEF	Centre for Development Research (Bonn, Germany)

1 Introduction

1.1 The Volta River Basin

The Volta River Basin in West Africa has a surface of approximately 400,000 km^2 and covers five countries, namely, Burkina Faso, Ghana, Togo, Côte d'Ivoire, Benin and Mali. The largest part of the basin lies in Burkina Faso and Ghana. The basin is divided into four sub-basins: the Black Volta, the White Volta, the Oti and the Lower Volta. The sub-basins and hydropower plants (Figure 1), as well as river flow stations (Appendix 1) are shown on a GIS map prepared by the Consultant for this report. The climate in the Volta Basin ranges from arid in the far north of Burkina Faso (mean precipitation <500 mm/y), semi-arid in the middle part of Burkina Faso (~700 mm/y) to sub-humid in southern Ghana (~1600 mm/y).

There has been increasing pressure on the surface water resources of the basin during the past two decades. There are two principal factors responsible for this - the first is an increase in water uses. In 1964 the closure of the Akosombo Dam in southern Ghana (hydropower plant 6, Figure 1) created one of the largest man-made lakes in the world, the Volta Lake. The dam was built to generate hydropower. In order to increase the hydropower production, a second dam (the Kpong Dam, hydropower plant 5), was completed in 1982 just downstream of the Akosombo Dam. Still, plans exist to build more hydropower dams in Ghana; for example at Bui and Pwalagu (proposed hydropower plants 1 and 4). Similarly, Burkina Faso constructed two smaller (<2% of the capacity behind Akosombo Dam) hydropower/irrigation dams on the upstream part of the basin in the late 1980s and 1990s (hydropower plants 2 and 3). Furthermore, Giesen, et al. (2002) stated that the number of small dams constructed in northern Ghana and especially in Burkina Faso for irrigation, cattle and domestic uses has been rising since the 1980s. In 1998, the water level in Volta Lake fell below the operating level of the power plants resulting in severe power shortages (IUCN-BRAO, 2004). There are therefore some concerns in Ghana that increased water uses upstream of Lake Volta would threaten the operation of hydropower plants downstream of the lake. The second factor leading to an increasing pressure on water resources is a decrease in annual rainfall, especially in the 1970s and 1980s, which caused a reduction in river flow in the middle and lower part of the basin (e.g. Gyau-Boakye and Tumbulto, 2000). A decrease in and a less reliable timing of annual rainfall make rain-fed agriculture much more difficult (especially in the northern semi-arid part of the basin), thus, the demand for new small agricultural reservoirs increases.

Other hydrological issues of concern in the Volta River Basin (IUCN-BRAO, 2004) are:

- A suspected degradation of river water quality.
- An increase in the growth of aquatic weeds, especially in the lower reaches of the basin.
- Floods in the northern part of Ghana are sometimes related to alleged water releases from dams in Burkina Faso. The floods resulted in the loss of human lives in 1994/5. Presently, flood releases from the larger dam in Burkina Faso (Bagré) only affects farmland because there is a warning system in place between Burkina Faso and Ghana on flood releases.

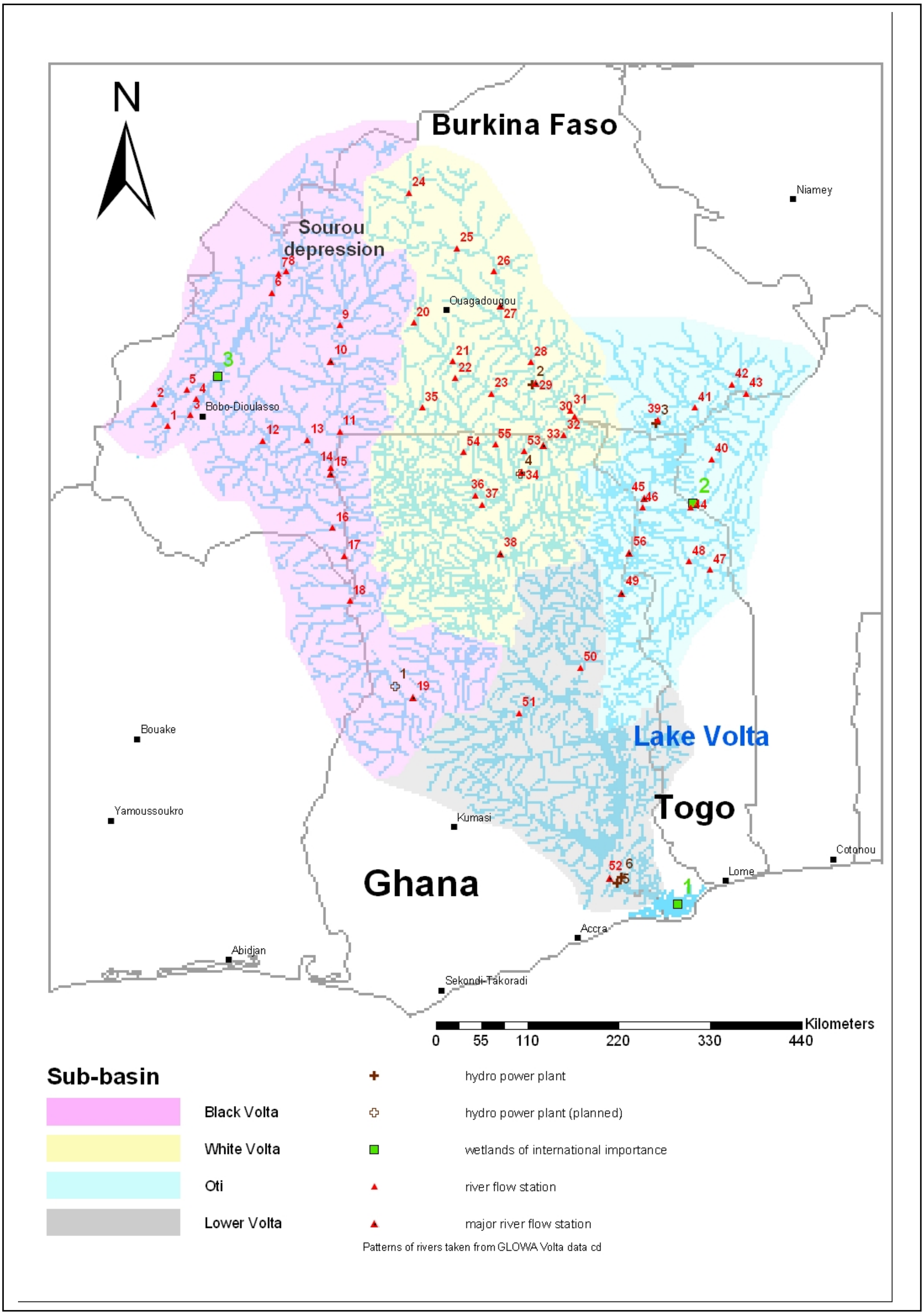

Figure 1 **GIS map of the Volta River Basin (see Appendix 1c for river flow stations).**

1.2 The PAGEV Project

The Project for Improving Water Governance in the Volta River Basin (French acronym "PAGEV") is a joint initiative of the IUCN-GWP/WAWP (The World Conservation Union and the West African Water Partnership of the Global Water Partnership) that supports Burkina Faso and Ghana in their joint management of trans-boundary water resources (see IUCN-BRAO, 2004 for a complete outline of the project). The project has a time-span of 3 years (mid 2004 to mid 2007). The key governmental institutions in Ghana and Burkina Faso are, respectively, the WRC (Water Resources Commission) of Ghana and the DGIRH (Department of Water Resources Assessment) of Burkina Faso. A major component of the PAGEV Project is the building of a Decision-Support Knowledge Base. The key objectives of this component are to:

- join together and share scientific knowledge available on the statute and the dynamics of the quantity and the quality of water in the Volta Rivers Systems;
- develop water management options on the basis of scenarios on water availability and water demand in the Volta Basin.

1.3 Objectives and terms of reference

A Water Audit is an assessment of current, and anticipated water availability and demand. This report is a pre-water audit that is defined as the preparation for the water audit by determining the available and missing data for the work and a proposed step-by-step work plan on how the water audit can be executed. The PAGEV Project gave an assignment with the objective to: conduct a pre-water audit study of the Volta River Basin, as a basis for defining the scope of a water audit of the basin, and in assessing the impacts of existing and planned water developments, climate variability, and also to fill identified information gaps. In practical terms, this exercise (pre-water audit) will provide a format for compiling and improving on existing information on water availability, quality and demand, with emphasis on water resources in the basin that are shared by Ghana and Burkina Faso. The itinerary can be found in Appendix 3. The scope of this study is modest in terms of time (10 working days) and budget, and will rely substantially on existing sources of data, articles and discussions with experts working in the basin.

The focus is on surface water and activities for the assignment consist of:

1. Carrying out a first order inventory of the available surface water resources data (quantity and quality) and collection networks at the sub-basins of the Volta River from available literature.
2. Compiling (from accessible reports and published papers) the hydrological information on prevailing water availability and demand with respect to the sub-basins.
3. Visiting the basin and assessing the status of the hydrometric network in the basin as a whole and more specifically in the portion of the basin shared by Burkina Faso and Ghana.
4. Assessing the adequacy of the existing data and data collection network for carrying out a water audit, and to develop water management scenarios to cope with trends in water demand and availability, and water resources planning in general.
5. Conducting interviews with appropriate key persons and institutions in Burkina-Faso and Ghana, including the water resources and environmental agencies in order to identify research institutions, consulting firms and experts, especially in Ghana and Burkina Faso or in the West Africa sub-region that could be considered to carry out the water audit.
6. Preparing the scope of the water audit and the TOR for consultancy to conduct the water audit.
7. Proposing an estimate of the cost to carry out the water audit
8. If necessary advise on requirements in terms of additional investments aimed at improving the quality of hydrometric data, and harmonising the data collection systems in riparian countries.

1.4 Outline of report

Chapter 2 presents information on the water availability; the current and predicted river flows. The hydrological characteristics of the rivers in the basin and the hydrometric network are also discussed. Chapter 2 continues with the demand side of the water audit; the present and potential future water uses. The final section of the chapter is on surface water quality. Chapters 3 and 4 provide a short overview on groundwater and rainfall in the Volta Basin. Chapter 5 proposes a work method for the water audit. Furthermore, consultants who may be considered to participate in the water audit are presented. The last section of chapter 5 proposes a work method for a surface water quality study in the basin. Chapter 6 comprises the conclusions and recommendations. A data cd is also submitted with this report. The cd includes: the GIS map that was prepared for this assignment (Figure 1), reports and papers that were obtained in a digital format, all the digital information from the GLOWA Volta Project, river flow data from the GRDC and meta-data files on river flow, rainfall and evaporation.

2 Surface water

2.1 River flow

2.1.1 River flow data

An overview of the river flow stations in the Volta basin and information on the availability of data are presented in Appendix 1. Whilst Figure 1 is a map indicating the river flow stations. In the basin, the responsibility for monitoring river flow lies with a number of governmental organisations. However, a number of research institutions have also monitored (or plan to monitor) river flows while others have a database for river flows. Furthermore, it is also worth mentioning that the GLOWA-Volta Project has a GIS map on the rivers and its tributaries (on enclosed cd).

The following governmental organisations have responsibility for monitoring river flow in the basin:

- The Directorate General for the Inventory of Hydraulic Resources or National Hydrological Services of Burkina Faso (DGIRH) collected in 2004 daily river flow data for 43 river flow stations (MAHRH, 2004). The river flow data is available in a digital database (HYDROM 3.2, works under DOS). For this report we received a metadata file on available data in the HYDROM database (on enclosed cd). Unfortunately not all the older (<1995) river flow data is captured in the HYDROM database (e.g. for Wayen). This was also observed by Kam (2002). The metadata table (Appendix 1a) on river flow stations in Burkina Faso is therefore based on Kam (2002). The HYDROM data can be exported into ASCI format and are therefore easily accessible for use in Excel. The data can be bought for fixed rates (e.g. 1 year of monthly data costs ~500 CFA). There is no agreement between DGRIH and WRC or HSD (Ghana) to share the data but DGIRH is very open to do so (probably at some costs). The data can also be me made available to PAGEV for the Water Audit (free of charge because DGIRH is a partner of the project).
- Hydrological Services Division (HSD) that is part of the Ministry of Works and Housing. This division collects daily river flow data for ~60 stations (see Appendix 1b). All the river flow data are digital. A quality control check of the data is ongoing. About 60% of the data has been checked; it may be difficult to obtain the other 40% of the data that has not yet undergone the quality check. The WRC has obtained part of the White Volta River flow data from HSD. The metadata are available in Access and the river flow data itself is stored in a digital database (HYDATA 4.2, 2001). The data can be exported into ASCI format. Generally one has to pay for the data, the rates are not yet exactly fixed. The HSD also said that they currently do not share their data with DGIRH but expressed their interest in doing so (probably at some costs).
- SONABEL (Société Nationale d'électricité du Burkina) registers for Bagré and Kompienga reservoirs: the inflow, the outflow, the evaporation and the inflow into the Bagré irrigation project. Since the construction of the dams the monthly data have been published in their annual reports. The data can easily be obtained from SONABEL (for this assignment data was obtained for 2003 and 2004, on enclosed cd).
- SONABEL has a satellite (Immarsat-C) warning system in place at five sites along rivers in the White Volta sub-basin upstream of Bagré Reservoir (Wayen, Komtoega, Sanogo, Niaggo, Kaïbo Sud). The system transmits an automatic warning to the operators of Bagré Dam when the water level exceeds a threshold that may lead to flood flows. The system is very expensive and therefore not used for regular water level monitoring.
- The Volta River Authority (VRA, Ghana) has information on the water releases from the Akosombo Dam.

Research institutions and projects that have monitored (or plan to monitor) river flow in the basin are:

- The Onchocercosis Control Project (OCP, Ghana) ran by the WHO, collected a lot of river flow data in Ghana from 1975 to 1995 (Giesen et al, 2001). The OPC river flow data are included in the database of the HSD (HSD).
- The Volta-HYCOS project (WMO) plans to collect near real time hydrological (such as river flow) information in the Volta Basin. The project will be executed by the EIER (L'Ecole Inter-Etats d'Ingénieurs de l'Equipment Rural) and the IRD in Burkina Faso (contacts: Michel Gautier, gautier@hydro.ird.bf and Emmanuel Patruel). Test measurements are currently being executed and the first stations are expected to be (re)installed in 2005. The sites for river flow monitoring are not yet

known. According to ZEF (2002) the total number of Volta-HYCOS hydrometric station sites in the whole basin will be 25.

Research institutions that have a database on river flow data are:

- The Global Runoff Data Centre (GRDC) has monthly and sometimes daily river flow data for 52 stations in the Volta basin. For most stations, the period for which the data is available does not extend beyond the 1980s. A summary of the GRDC data is presented in Appendix 1c. The complete dataset is available on the enclosed cd (please follow the GRDC the users conditions that are enclosed on the cd).
- AGRYMET (Niamey, Niger) has a regional hydrological database for West Africa. The database stores river flow data for 522 stations. It is not clear whether or not they also have river flow data on the Volta basin (I enquired by email but they did not respond).
- L'institut de Recherche pour le Dévelopment (IRD) has a database on daily river flow data for Burkina Faso. The content of their database is not exactly known but it contains at least daily river flow data (1965-1998) for Wayen on the White Volta (station 27, Figure 1) for the period 1965 to 1998 (Mahe et al., 2005). A lot of the older IRD river flow data and rating curves for many stations in the whole basin can be found in Ostrom (1977, book in IUCN-BRAO library).

2.1.2 Observations on the river flow data and the hydrometric network

The following observations are made on the river flow stations and their data in the basin:

- There is an enormous amount of river flow stations in the basin (over 200) but quite a number of stations: are no longer functioning, are situated on relatively small tributaries, only have water level data (no reliable rating curves), only have data for a couple of years or have large data gaps. This a forest in which one can easily be lost. For the water audit it is therefore recommended to focus on a limited number of key river flow stations (20 to 30) in the basin.
- At this moment most directly accessible river flow data is in monthly form (GRDC, Ostrom, 1977).
- The DGIRH has spent quite some effort and time on reorganising, including the revision of rating curves, their hydrological database (Kam, 2002). The metadata for Burkina Faso (Appendix 1a), which is taken from this report, is very elaborate (including coordinates, years for which data are available, etc.). The available information in the metadata file for Ghana (Appendix 1c) is limited.
- The hydrometric network in Burkina Faso has two main weaknesses (MAHRH, 2004): 1) a number of stations only have only water-level data since no reliable rating curves are available; 2) an increasing number of stations are menaced by modifications in the river (e.g. reservoirs) that disturb the measurements.
- Up-to-date time series of discharge will not be available for any, or only few, stations in the Ghanaian part of the White Volta. However water level data have been collected. The process of making new discharge measurements, constructing rating curves and calculating the discharge is ongoing (NIRAS, 2004).
- During a field trip 14 hydrometric stations in the White Volta sub-basin in Ghana were visited. It was concluded that many of the stations suffer frequent visits, proper maintenance and timely repair. For example most automatic water level recorders were not functioning during the visit (NIRAS, 2004).
- It is encouraging that most river flow stations with automatic water level recorders, that malfunction regularly, have a backup in the form of a stageboard reader. Still, it is recommended that the relevant organisations spend more effort on enhancing the commitment of the readers to the work by, for example, paying the readers in time, providing them a bicycle if they live far from the stageboard and letting them have annual results of their work (river flow graph for the site).
- Recently there are lots of donor-supported activities (FFEM through Volta-Hycos in the whole basin, DANIDA in Ghana, the French through IRD in Burkina Faso) going on in Burkina Faso and Ghana to reinstate the hydrometric network. So the Pre-Water Audit recommends not to do field measurements on river flow, but to rely on the existing river flow databases.
- In order to make the best use of the limited resources for the maintenance of the hydrometric network it is recommended that key river flow stations in the basin (at the most 20) that need to be monitored be identified for getting a good overview of the available surface water resources in the basin. This can be done by comparing river flow data from various stations along the same river. For example if there is a strong relation between an up- and downstream station than, in the case of limited resources, the flow measurements at one of the stations can be temporarily halted. This process is called optimisation of the hydrometric network. Optimisation of the network does not imply that measurements at 'second class' stations should be stopped completely because river flow relations can change in time due to, for example, land use change or the construction of a dam. Burkina Faso already proposed priority river flow

stations in their part of the Volta Basin (MAHRH, 2004; Tables 4 and 5). For the White Volta in Ghana also a list of priority stations has been prepared (NIRAS, 2004).

- River flow data sharing is not taking place between Burkina Faso (DGIRH) and Ghana (HSD). The databases from both institutions can export the data into ASCI format, which can be manipulated within Ms-Excel into any desired format. Furthermore, the interviewed people from both organisations showed a positive attitude towards data sharing (negotiations are required on the finances). So there are good opportunities for the PAGEV Project to assume the role of facilitator for data sharing.

2.1.2 Current river flow

2.1.2.1 Basin Characteristics

An overview of surface water resources in the basin is presented in Table 1. The table is based on the river flow data that was obtained from the GRDC (Appendix 1c). The table shows that there are strongly varying annual runoffs (water availability) in the Volta Basin. The runoff is on average (1936-96) 9% of the annual rainfall (Andreini et al., 2002). The discharge in the Volta Basin upstream of Lake Volta has distinct wet (mid-May to early November) and dry (mid-November to early May) seasons. The mean historical (1937-63, prior to the closure of Akosombo Dam) water availability at Senchi, just before the Volta River flows into the Atlantic Ocean, was ~40 10^9 m^3/y.

Table 1 Overview of the annual surface water resources in the Volta River Basin

Sub-basin	River flow station	No.#	Catchm. area** $10^3 km^2$	Period	No. years	Mean annual flow $[10^6 m^3]$	[mm]	Stand. dev. $[10^6 m^3]$	Minimum discharge (year) $[10^6 m^3]$	Maximum discharge (year) $[10^6 m^3]$	Period of predominant flow
Black Volta	Nwokuy (BF)	6	15	1957-88	31	814	55	358	157 (1984)	1,616 (1970)	perennial: peak
	Boromo (BF)	10	48	1956-90	32	1,036	22	413	145 (1984)	1,727 (1958)	Sept/Oct
	Dapola (BF)	15	67	1952-90	36	3,133	47	1,375	854 (1984)	6,307 (1952)	
	Bamboi (Gh)	19	134	1951-73	23	8,402	63	3,686	3,361 (1972)	16,853 (1963)	
Red Volta	Nangodi (Gh)	33	12	1958-73	16	727	63	320	205 (1972)	1,348 (1964)	ephemeral: June to Oct.
White Volta	Wayen (BF)	27	21	1955-87	24	230	11	151	66 (1966)	602 (1974)	
	Bagré (BF)	31	33	1974-90	13	995	30	573	279 (1984)	2,087 (1974)	
	Pwalagu (Gh)	34	63	1951-73	23	3,948	62	1,472	1,495 (1972)	6,481 (1957)	ephemeral: May to Nov.
	Nawuni (Gh)	38	93	1954-73	20	7,694	83	2,269	2,200 (1972)	11,881 (1963)	perennial: peak Sept.
Oti	Tagou/Kom-pienga (BF)	39	6	1980-87	8	290	51	131	108 (1984)	523 (1985)	ephemeral: Jun.-Sept.
	Mango (Tg)	45	36	1954-73	19	4,330	121	1,805	1,790 (1953)	7,776 (1956)	ephemeral: Jun. -Dec.
	Sabari (Gh)	49	59	1960-73	14	11,247	192	4,229	5,934 (1972)	18,115 (1963)	perennial: peak Sept.
Lower Volta	Senchi (Gh)	52	394	1937-63*	24	40,010	102	18,965	11,308 (1958)	94,453 (1963)	perennial: peak Oct.

* period prior to closure of Akosombo Dam
# locations of river flow stations on Figure 1
** average at Boromo from GRDC (37 $10^3 km^2$) and Shanin, 2002 (58 $10^3 km^2$)
based on river flow data from GRDC

The four sub-basins (Figure 1) are discussed below.

<u>The White Volta or the Nakambé River</u>. The White Volta sub-basin contributes about 23% of the annual flow into Volta Lake (Andreini et al., 2000). The landscape in the largest part of the White Volta is relatively flat with some gently sloping hills (<100 m) in the upstream part and a very broad floodplain area surrounded by hills (up to 500 m) in the downstream part of the sub-basin. In the upstream part the river only carries water in the wet season (July to mid-October). Downstream of Bagré the river flow is influenced by releases from the Bagré Dam in Burkina Faso (hydropower plant 2, Figure 1).

<u>The Black Volta or the Mouhoun River</u>. The Black Volta sub-basin contributes about 23% of the annual flow into Volta Lake (Andreini et al., 2000; Shanin, 2002). The Black Volta is the only sub-basin that does not have large dams and hardly any small dams. The river carries water all year round. In the slightly hilly upstream part of the Black Volta, near Bobo Dioulassou (Burkina Faso, Figure 1), the river flows roughly north, opposite to the general flow direction in the basin. The river makes a 180° turn where it meets the Sourou River situated in a

north-south depression. This depression routes the flood wave of the river and retains much of its sediment (Shanin, 2002). The low runoff at Boromo (22 mm, station 10, Figure 1) compared to the upstream station (Nwokuy, 55 mm) can be attributed to the flood routing in the depression and the low slope of the area (Shanin, 2002). On the border between Ghana and Ivory Coast the river flows from north to south through a valley that is surrounded by hills (up to 500 m high). At Bui in Ghana, the Black Volta passes through a gorge. A dam (the Bui Dam) construction has started at this site and has reached an advanced development stage (planned power plant 1, Figure 1) but the construction is currently stalled (IUCN-BRAO, 2004).

The Oti. The Oti sub-basin (though only about 18% of the total basin), contributes between 35 and 40% of the annual flow into Volta Lake (Gyau-Boakye and Tumbulto, 2000; Andreini et al., 2000). This is because the catchment of the Oti River is the most hilly and mountainous (>900 m) in the whole Volta Basin. The Oti River carries water all year round as a result of regular releases from the Kompienga Dam in Burkina Faso (hydro power plant 3, Figure 1).

The Lower Volta. The Lower Volta consists of the smaller tributaries to Lake Volta and the Volta River downstream of the lake. The smaller tributaries contribute about 17% of the annual flow into Volta Lake (Andreini et al., 2000). Some of the hills surrounding the lake, from which the tributaries originate, are over 800 m high. The Volta River passes through a narrow gorge roughly 100 km before it flows into the Atlantic Ocean. The Akosombo Dam was constructed on this site in 1964. The dam reduced the seasonal and inter-annual variation in discharge at the downstream end of the Volta River (Senchi, station no. 52). And it reduced the sediment load.

2.1.2.2 Influences on river flow

Three important factors influence river flow in the basin, namely rainfall, change in landuse and water uses.

Rainfall. Water balance studies for the Volta Basin as a whole indicate a non-linear response of annual river flow to rainfall. The non-linear response indicates that until the mean annual rainfall reaches a threshold (~343 mm) most rainwater wets the soil and recharges the groundwater. After this threshold has been reached, more than half of the rainwater becomes river flow (Andreini, 2000; Giesen et al. 2001; Friesen et al. 2005). The non-linear relationship also means that the river flow is very sensitive to climatic variations. Between 1950-70 and 1971-90, for instance, due to a decrease in rainfall, the mean annual runoff in the White Volta and the Oti decreased by 23.1% and 32.5%, respectively (Gyau-Boakye and Tumblutu, 2000).

Change in Landuse. Between 1955/65-70 and 1972-98, in the upstream part of the White Volta in Burkina Faso (Nakambé River) at Wayen (station 27), the mean river flow increased by 108% despite a reduction in rainfall and an increase in the number of dams. The increase was the highest during the first part of the rainy seasons (July and August). The increase was due to a reduction in the Water Holding Capacity of the soil as a result of changes in land use. The changes in land use were: increase in cultivated area, increase in area with bare soil and a decrease in area with natural vegetation (Mahe et al., 2003 and 2005a). An amplified runoff despite a reduction in rainfall can only be found in the Sahelian part of West Africa north of the 700 mm annual precipitation line. South of the 700 mm isohyet the river flow variations follow the rainfall (Mahe et al., 2003 and 2005b). Outside the Volta Basin, in neighbouring Niger, a similar change in land use is linked to a long-term rise in the groundwater table due to an increase in groundwater recharge (Leduc et al., 2001).

Water uses. It is expected that an increase in the number of dams and storage of surface water would lead to an increase in evaporation and a decrease in river flow. But, between the periods 1966-80 and 1981-95 for the mean river flow at a basin wide level no change in hydrological behaviour (excluding rainfall variations) was found. This is partially explained by the fact that the change in landuse and increased surface water uses are human impacts with contrary effects on the river flow (Friesen et al, 2005).

Two issues that are worth investigating are:

- How the discharge in the upstream part of the Black Volta River (north of ~700 mm isohyet) responded to changes in land use.
- How the floods in northern Ghana (IUCN-BRAO, 2004) are related to unanticipated high inflows in the reservoir of the upstream Bagré Dam in Burkina Faso (hydropower station 2, Figure 1) as a result of land use changes in the upstream part of the White Volta (Nakambé River)

2.1.3 Predicted river flow

Kunstmann and Jung (2005) investigated the impact of downscaled global climate scenarios on the water resources in the Volta Basin. The principal climate scenario in the paper assumes an annual increase of 1% in atmospheric CO_2-content commencing in 1990. The predicted impact of this scenario is an increase of 5%, in annual precipitation but also a significant decrease of precipitation at the transition from the dry to the rainy season. Consequently, there will be a reduction in the duration of the rainy season and a predicted increase in mean annual surface runoff of 18%. Such a high increase after a slight increase in rainfall is related to the described (Section 2.1.2.2) non-linear response of the river flow to variations in rainfall. In addition, an increase in temperature is predicted, especially in the northern part of the basin. An increase in temperature would lead to an increase in evaporation from reservoirs. Also, Andah et al. (2003) predicted the impact of four different down scaled global climate change scenarios on river flow. For all the used climate scenarios, average yearly inflow into Volta Lake is predicted to increase (ranging from 13 to 34%). Variability in river flow is predicted to increase as well. According to the report, the predicted increase in runoff more than compensates for the extra water used by the irrigation development. The report concludes that it is not wise to rely entirely on hydropower because there will still be regular periods during which the water level in the reservoir would be too low to generate hydropower. It is suggested that the above predictions not be taken at face value; as an earlier calculation (Opoku-Ankomah, 2000 quoted in GEF 2002) predicts a 16% and 37% reduction in runoff in the White Volta River (on the basis of a Global Climate Model - GCM) by 2020 and 2050 respectively.

The GLOWA Volta Project (Phase 2, Sub-project A1) is trying to provide estimates on how precipitation behaviour will change in the Volta Basin due to global climate change and regional land use. There is also a plan to predict the effect of this possible change on surface and groundwater balance (ZEF, 2002). The EIER is currently working on the impact of climate change on the river flow in the White Volta in Burkina Faso (contacts: Hamma Yacouba and Harouna Karambiri).

2.2 Surface water uses

2.2.1 Data on Surface water uses

The following governmental organisations have responsibility for estimating surface water uses:

- The WRC for Ghana (VRA for hydropower, IDA for irrigation, GWCL for urban water supply and industrial uses, CWSA for rural water supply).
- Ministry of Agriculture in Burkina Faso for irrigation.
- Maîtrise d'Ouvrage de Bagré (MOB) for agricultural water uses by the Bagré Dam in Burkina Faso.
- Société Nationale d'électricité du Burkina (SONABEL) for hydropower uses in Burkina Faso.
- Office National de l'Eau et de l'Assainissement (ONEA) for industrial and domestic water uses in Burkina Faso.
- Ministry of Agriculture in Ghana and le Ministère d'Elevage in Burkina Faso have data on livestock populations.
- DGIRH has information on the surface area of all the major reservoirs in Burkina Faso.

The following research institutions and projects have a database on surface water use:

- GLOWA-Volta Project (Liebe, 2002) localised reservoirs in northern Ghana and southern Burkina Faso. The project has also information on the surface of the reservoirs.
- The EIER has an inventory of small dams with their characteristics (volume, level and sometimes flow and abstractions) in Burkina Faso. The data can be made available for the Water Audit (there is a link between EIER and the GLOWA-Volta Project through Bruno Barbier based at EIER). This is probably the same database as at DGIRH.
- The GEF (2002) report (pages 41-42) present tables on present and future water demands in the basin, per riparian country and water use sector,
- L'institut de Recherche pour le Dévelopment (IRD) has calculated evapotranspiration for a large part of Burkina Faso for the period 1950-97 for a grid 0.5° x 0.5° (Ouedraogo et al., 2001). These data are useful for estimating evaporation from reservoirs in the region.
- The Volta Challenge Project may contribute by providing estimates on water uses per crop type in the basin.

2.2.2 Analysis of surface water uses

2.2.2.1 Current surface water uses

Table 2, Table 3, Table 4 and Table 5 present an overview of all the major surface water uses in the White Volta, Black Volta, Oti and Lower Volta, respectively. The most prominent anthropogenic water uses in the Volta Basin are: water uses by small-scale reservoirs in the upstream part of the basin and hydropower in the downstream part of the basin.

Table 2 Overview of the major surface water uses in the White Volta sub-basin.

Sites	Country	Type of use*	References with information on quantities
small dams and reservoirs	BF, GH	agriculture, cattle, domestic	Vescovi et. al. (2002); Giesen at al. (2002); Mahe et al. (2005); GLOWA-Volta, IRD
Goinré Reservoir	BF	urban water supply to Ouahigouya, 0.07 10^6 m^3/y (2002)	ONEA
Ouagadougou reservoirs 1,2 & 3 (tributary to White Volta)	BF	urban water supply (Ouagadougou), 5.2 10^6 m^3/y (2004)	ONEA
Ziga dam	BF	urban water supply (Ouagadougou), completed in November 2004, surface 72 km^2	ONEA
Loumbila dam (Massilli River, a tributary)	BF	urban water supply (Ouagadougou), 13.9 10^6 m^3/y (2004)	ONEA
Itengué Reservoir (tributary to White Volta)	BF	urban water supply (Koupela & Pouytenga), 0.59 10^6 m^3/y (2004)	ONEA
Bagré dam	BF	hydropower: 16 MW, surface 255 km^2; irrigation: 600 ha (1999) and expanding to 2,100 ha (June 2006, mainly rice)	Berger et al. (2001); MOB (irrigation); SONABEL & DANIDA (2001) (hydropower)
Vea dam (tributary to White Volta)	GH	irrigation 1000 ha; urban water supply **; regular water shortage (CSIR, 2000)	IDA
Tono dam (tributary to White Volta)	GH	irrigation 2,500 ha; regular water shortage (CSIR, 2000)	IDA
Tiogo Yarugu	GH	irrigation, 138 ha, 2.4 10^6 m^3/y	IDA
Dinga (Diare)	GH	irrigation, 115 ha, 1.5 10^6 m^3/y	IDA
Sogo	GH	irrigation, 151 ha, 1.5 10^6 m^3/y	IDA
Dipali	GH	irrigation, 148 ha, 1.5 10^6 m^3/y	IDA
Yapei	GH	irrigation, 194 ha, 1.8 10^6 m^3/y	IDA
Yendi dam (Daka River, a tributary)	GH	abstraction for urban water supply, 0.40 (WRC) to 0.95 (GWCL) 10^6 m^3/y; no water in dry-season (CSIR, 2000)	GWCL, WRC
Saboba dam	GH	small urban water supply abstraction	GWCL
Bolgatanga dam (Yaregantanga River, a tributary)	GH	abstraction for urban water supply, 1.8 to 2.7 10^6 m^3/y and irrigation 450 ha (rice and vegetables)	GWCL, WRC, IDA
Tamala dam	GH	abstraction for urban water supply 7.1 10^6 m^3/y	GWCL, WRC

* hydropower capacities based on the GLOWA-Volta data cd and GEF (2002)

** there is an agreement that the water intake for irrigation stops when the water level drops below a threshold level (IDA)

Table 3 Overview of the major surface water uses in the Black Volta sub-basin.

Sites	Country	Type of use*	References with information on quantities
small dams and reservoirs (much less than in White Volta)	Mali, BF, CI, GH	agriculture, cattle, domestic	Vescovi et. al. (2002); Giesen at al. (2002); GLOWA-Volta, IRD
Bobo Dioulasso (water taken from sources)	BF	urban water supply to Bobo Dioulasso, ~0.8 10^6 m^3/y (2004)	ONEA
Bobo Dioulasso area	BF	small scale irrigation (e.g. cotton) that uses surface water from rivers and sources (hardly any reservoirs), vallé du Kou: 1,260 ha (potential 2,300 ha)	GeEau, VREO
La Mare aux Hippopotames	BF	ecological, wetland of international importance (~19 km^2)	PAGEN?
Sourou Dam	BF	irrigation, 5,000 ha (rice, maize, vegetables)	DGHA
Salbisbogo Reservoir	BF	urban water supply to Koudougou, ~0.5 10^6 m^3/y (2004)	ONEA
Tiogo (Ténado, water taken direct from river)	BF	urban water supply to Koudougou, ~0.8 10^6 m^3/y (2004)	ONEA
Poura (water taken direct from river)	BF	urban water supply to Poura, ~0.07 10^6 m^3/y (2004)	ONEA
Bui National Park	GH	ecological	
Bagri	GH	irrigation, 100 ha	IDA

* 'wetland of international importance' from Wetlands International

Table 4 Overview of the major surface water uses in the Oti sub-basin.

Sites	Country	Type of use*	References with information on quantities
small dams and reservoirs (much less than in White Volta)	BF, GH Togo, Benin	agriculture, cattle, domestic	Vescovi et. al. (2002); Giesen at al. (2002); GLOWA-Volta, IRD
Kompienga dam	BF	hydropower: 14 MW; urban water supply to Kompienga 0.06 10^6 m^3/y (2004)	SONABEL; ONEA; DANIDA (2001)
? (name unknown)	Benin	hydropower: 15 MW	GEF (2002)
Parc National de la Keran	Togo	ecological, wetland of international importance (~163 km^2)	

* hydropower capacities based on the GLOWA-Volta data cd and GEF (2002)
'wetland of international importance' from Wetlands International

Table 5 Overview of the major surface water uses in Lower Volta sub-basin.

Sites	Country	Type of use*	References with information on quantities
Hohoe (Dayi River)	GH	water abstraction for urban water supply, 0.8 10^6 m^3/y	GWCL, WRC
Kpeve (Volta Lake)	GH	water abstraction for urban water supply, 3.3 10^6 m^3/y	GWCL, WRC
Tsito (Wuve River)	GH	water abstraction for urban water supply, 0.08 10^6 m^3/y	GWCL, WRC
Volta Lake	GH	net-evaporation 7.7 km^3/y*, surface at full supply level: 8,500 km^2	Andreini et al. (2000); Friesen et al. (2005); WRI, GLOWA-Volta, VRA
Akosombo dam	GH	hydropower: 912 MW	Obeng-Asiedo (2004); VRA
Kpong	GH	abstraction for urban water supply (eastern Accra), 62 (GWCL) to 77.5 (WRC) 10^6 m^3/y	GWCL, WRC
Kpong dam	GH	hydropower (160 MW), irrigation on right bank 4,000 ha, ~44 10^6 m^3/y	Obeng-Asiedo (2004); IDA; VRA
Anum Boso	GH	water abstraction for urban water supply, 0.08 10^6 m^3/y	GWCL, WRC
Bosuso (Yaya River)	GH	water abstraction for urban water supply, 0.08 10^6 m^3/y	GWCL, WRC
Sege	GH	water abstraction for urban water supply, 0.58 10^6 m^3/y	GWCL, WRC
Ada	GH	small urban water supply abstraction	GWCL, WRC
Anlo-Keta lagoon complex	GH	ecological, wetland of international importance (~128 km^2), RAMSAR site	Dorm-Adzobu et al. (2004)

* evapotranspiration from Lake - part of rainfall falling on Lake that would have returned to the atmosphere (Friesen et al. 2005)
'wetland of international importance' from Wetlands International

Hydropower generation requires a fairly full reservoir behind the dam. The creation of such large body of water results in water loss due to evapo(transpi)ration. By far, the largest hydropower dam in the basin (the Kpong dam below Lake Volta), is presently used at unsustainable rates. The pressure to produce more energy is so high that the Volta River Authority lets too much water through the dam in the hope that next year's rains will replenish the reservoirs. When the rains are not so good for a single year, such as happened in 1997/98, there is no buffer and hydropower production comes to a halt (Andah, et al. 2003).

Most irrigation that depends on reservoirs takes place in the White Volta sub-basin (Andah et al., 2003). The GLOWA-Volta Project (contacts: Marc Andreini, Jens Liebe, www.smallreservoirs.org) is doing a lot of work on estimating water uses by the small dams in northern Ghana and southern Burkina Faso. Using satellite images, they identified reservoirs and their surfaces in the area (Vescovi et. al. (2002). Based on an extensive field survey of 61reservoirs, a relation was established between the surface area of reservoirs and its depth and volume. Total evaporative losses from the reservoirs' surfaces have also been estimated (Liebe, 2002). Water use from these reservoirs (mainly irrigation) has not yet been estimated. However, GLOWA Volta Project Phase 2 (sub-project W1) is working on this (ZEF 2002) and their interpretation of satellite images are being extended to the whole Volta Basin. It should be confirmed that the water use by livestock is clearly represented in the ongoing study on water abstractions from small reservoirs. Surface water uses by livestock is probably relatively small. Still, this should be quantified since it is seen as a very important water use by many people in the upstream part of the basin. DANIDA (2002) provides estimates for the water use per animal and the water use by livestock for Burkina Faso as a whole (ground- and surface water lumped together). The report also provides estimates for the water use per ha irrigated area for Burkina Faso.

The water uses by the formal irrigation projects (evaporation from reservoirs and irrigation) are mostly not monitored in Ghana. Still, figures for the surface of the area under irrigation and the crop type are often available. These data, together with the surface area of the reservoirs and the evaporation rates, can be used to estimate the water uses by the larger irrigation projects.

In the upstream part of the Black Volta (near Bobo Dioulasso) a lot of irrigation is taking place that depends on surface and groundwater. There are hardly any reservoirs in the area, which is partly related to the fact that the

Black Volta generally carries water throughout the year. The GeEau Project knows the size of the cultivated area in a small part of the Black Volta sub-basin (Kou). The VREO Project wants to assess the water uses in the Black Volta sub-basin that lies within Burkina Faso, but this phase of the project will only start in May 2006.

The most prominent surface water abstractions for urban water supply are: Ouagadougou and the eastern part of Accra. The water supply of Ouagadougou depends on reservoirs at three sites: Ouagadougou (3 small reservoirs), Loumbilla and Ziga. Because of the recent construction of Ziga Reservoir (November 2004), the intake of surface water from the three small reservoirs in Ouagadougou for urban water supply will stop within the coming two or three years (ONEA).

There are no significant direct surface water abstractions by industries in Ghana (GWCL) and Burkina Faso (ONEA).

The most prominent ecological surface water uses are wetlands. The total surface area of wetlands in the basin is estimated at 20,000 km^2 (Andah et al., 2003; the source for this estimate is not given in the report). The most important wetlands are listed in the tables above. Locations of 'wetlands of international importance' are shown in Figure 1. Ecological flow requirements for wetlands are generally defined in the form of hydrographs that are as close as possible to the natural situation before human interventions took place. The ecological flow requirements (seasonal floods) are almost always in conflict with the relatively constant releases from hydropower dams. Majority of the wetlands are in the upstream part of the Volta Basin and therefore not affected by the large hydropower dams downstream of Lake Volta (Akosombo and Kpong dams). However, in the Anlo-Keta lagoon complex (wetland 1, Figure 1) downstream of the two large dams the seasonal floods have become erratic due to hydropower releases from the dams. And, the length of the estuarine salt wedge has reduced from 30 to less than 5 km (Andah et al. 2003). Together with the decreased sediment load these factors created favourable circumstances for the growth of aquatic weeds (Grove, 1985; Andah et al., 2003). The VRA is taking measures (mainly dredging) to stimulate the return of the salt wedge (Kalitsi, 1999). What is notable from the reviewed literature is that river flow requirements for ecological uses are seldom mentioned. Even the existence of wetlands and Ramsar sites are easily overlooked in papers on the Volta Basin. No concrete figures have been found in the reviewed literature on required environmental river flows (quantity and timing) in the basin. There are also no available water balance studies for the wetlands.

2.2.2.2 Potential future water uses

The potentially irrigable area in Ghana is enormous, over 1 million hectares (FAO 1997 quoted in Obeng-Asiedo, 2004). However, irrigation development in northern Ghana, although spoken of frequently, has thus far been given low priority. In Ghana, water is most often seen as a source of hydropower (Andreini, et al. 2002). Still, the Irrigation Development Authority (IDA) perceives hydropower dams as a benefit because they provide energy and a part of the required infrastructure for irrigation projects. Furthermore, the general opinion in Ghana (based on discussions with IDA, WRC and WRI) is that the expansion of large irrigation projects is rather limited by available funds, lack of infrastructure and the fact that some of the potential areas are thinly populated than by lack of political will. If the Ghanaian government decides to reduce the import of rice then the expansion of the number and size of large irrigation projects may come high on the political agenda. So the planned expansions of existing and new irrigation projects in Ghana should be included in the development of scenarios for the water audit (Table 6). The need for the development of large-scale irrigation projects in southern Ghana (Lower Volta) does not seem to be very appropriate since there is abundant rainfall in this area.

Concerning large-scale irrigation the focus in Burkina Faso is on the expansion of the Bagré irrigation project. The total potentially irrigable area for Burkina Faso is estimated at 160.000 ha. Giesen et al. (2002), indicates that if this area were to be completely developed and if it is assumed that irrigated areas evaporate at full potential rate throughout two growing seasons, the total evapotranspiration from reservoirs and irrigation schemes will amount to 2.6 km^3 or about 7% of the outflow of Volta Lake before the construction of Akosombo Dam.

Large-scale irrigation projects in the basin are not profitable while small-scale schemes do extremely well in every part of the basin (Obeng-Asiedu, 2004). So the continued expansion of small-scale irrigation projects in the relatively dry northern part of the basin (northern Ghana and Burkina Faso) is, from an economical perspective, more likely than the expansion of large-scale irrigation projects.

Compared to the height of the energy crisis in Ghana during the late 1990s, the pressure on the hydropower dams downstream of Volta Lake has temporarily decreased. The Valco Aluminium factory, that uses the largest part of the hydropower, has new owners with new (less tight) power delivery conditions. Furthermore, the gas pipeline from Nigeria will provide additional energy to Ghana. In the long-term, depending on the population growth, the economic development and the gas price; the pressure to construct more hydropower dams may increase again. In Burkina Faso only one new large hydropower site has been identified.

The demand for water in Ouagadougou is at the moment much higher than the water availability. After the completion of Ziga Reservoir (November 2004, capacity 200 10^6 m^3) the urban water supply is limited by the capacity of the water treatment plants. For now it is expected that the urban water use will rise by 30 to 50% in the coming two years. When funds are obtained for the expansion of the capacity of the treatment plant the urban water use for Ouagadougou is expected to experience another significant rise. The urban surface water abstractions in Ghana will also continue to rise if Ghana's Vision 2020 is realised (safe water supply for all).

The above-identified differences in capabilities, requirements and focus between Ghana and Burkina Faso underscore the need for a basin-wide water management.

In order to develop water management scenarios for the basin the possible future water uses need to be identified and quantified. The following possible future uses are identified and in some cases quantified (Table 6):

- Increase in the number of small dams and reservoirs in the basin. Based on satellite images, the GLOWA-Volta project monitored increments in the number and surface of dams for southern Burkina Faso and northern Ghana (Vescovi et al., 2002; Giesen et al. 2002). These data may help in determining a trend.
- Significant expansion of the area under irrigation downstream of the Bagré Dam (Burkina Faso, Table 6). The number of fishponds in the area (small scale at present) may also increase. An irrigation project at the Kompienga Dam (Burkina Faso) is not likely because the local soil conditions are not so good and the space is limited since the dam is very close to the border with Togo.
- Expansion of large-scale irrigation at the identified sites in Ghana and Burkina Faso.
- The construction of large hydropower dams at several sites in Ghana (the planning for Bui Dam is the most advanced), at one site in Burkina Faso and at one site in Benin.
- Expansion of urban water uses (notably Ouagadougou and Accra).
- Figures on the population growth in the basin (about 2.5 to 3% per year), the level of development and the mean domestic water uses are required to estimate future domestic water uses. These figures are generally available for both countries (e.g. Gleick, 2002, UN Population Study Reports, Ministry of Works and Housing, Accra, etc.).
- Increased evapo(transpi)ration from reservoirs if the predicted temperature rise in the basin (Section 2.1.3) will materialize.

Table 6 Overview of possible expansions of currents water uses and possible new future water uses

Sites	**Country**	**Sub-basin**	**Type of use***	**References with information on quantities**
expansion of small dams and reservoirs in northern part of Volta Basin	BF, GH	White Volta, Black Volta, Oti	agriculture, cattle, domestic	Vescovi et. al. (2002); Giesen at al. (2002); Mahe et al. (2005); GLOWA-Volta, IRD
Pouya (Natitingou), suggested dam site	Benin	Oti	hydropower	
Juale, suggested dam site	GH	Oti	hydropower (90 MW, originally 300 MW)	VRA
Ouahigouya dam, suggested dam site	BF	White Volta	urban water supply to Ouahigouya	ONEA
Ziga dam	BF	White Volta	~5 (replacement for Ouagadougou res.) + ~8 (extra within 3 years) 10^6 m^3/y; more growth when treatment plant is expanded	ONEA

Bagré dam	BF	White Volta	expansion of irrigation from 2,100 ha (2006) to 4,200 ha (rice and vegetables) and in long-term to 30,000 ha; urban water supply to Tenkodogo, Koupéla & Fada	MOB; ONEA; Obeng-Asiedo (2004)
Tamili (Bawku area, tributary to White Volta)	GH	White Volta	irrigation, 1,500 ha (rice and onions), 80 10^6 m^3/y	IDA
Pwalagu, suggested dam site	GH	White Volta	hydropower (36 MW) and irrigation 110,000 ha (rice and vegetables)	VRA, IDA
Kulpawn, suggested dam site (tributary to White Volta)	GH	White Volta	hydropower (40 MW)	VRA
Daboya	GH	White Volta	hydropower (40 MW) and irrigation 10,000 ha, 180 10^6 m^3/y (phase 1: sugar cane) expanding to 25,000 ha	VRA, IDA
Tamale(expansion)	GH	White Volta	urban water supply expansion in phases from 7 to 16.1 and 25.2 10^6 m^3/y	GWCL
Samendeni, suggested dam site (relatively advanced)	BF	Black Volta	small scale hydropower and irrigation 20,000 ha	DGHA
Sourou Dam	BF	Black Volta	expansion of irrigated area from 5,000 to 30,000 ha	DGHA
Ouessa, suggested dam site	BF	Black Volta	irrigation ~20,000 ha	DGHA
Noumbiel, suggested dam site	BF	Black Volta	hydropower 48 MW (initially 62 MW) and irrigation >20,000 ha; reservoir volume: 11.3 km^3 (total), 8.3 km^3 (active), surface: 1,430 km^2	MMCE (2001); SONABEL; DGHA; Obeng-Asiedo (2004)
Koulbi, suggested dam site	GH	Black Volta	hydropower (68 MW)	VRA
Ntereso, suggested dam site	GH	Black Volta	hydropower (64 MW)	VRA
Lanka, suggested dam site	GH	Black Volta	hydropower (95 MW)	VRA
Kamba, suggested dam site	GH	Black Volta	irrigation 29,400 ha (rice) 35 10^6 m^3/y	IDA
Bui, suggested dam site (relatively advanced)	GH	Black Volta	hydropower (260 MW, originally 400 MW) and irrigation 64,000 ha	VRA; IDA; Obeng-Asiedo (2004)
Buipé, suggested dam site	GH	Black Volta	95 ha	IDA
Mpaha, suggested dam site	GH	Black Volta	5,400 ha	IDA
Jambito, suggested dam site	GH	Black Volta	hydropower (55 MW)	VRA
Yendi dam	GH	Lower Volta, tributary to Volta Lake	urban water supply expansion from ~0.7 to ~2.4 10^6 m^3/y	GWCL
Afram Plains	GH	Lower Volta	110,000 ha	IDA
Accra Plains	GH	Lower Volta	200,000 ha, 2,700 10^6 m^3/y	IDA
Kpong	GH	Lower Volta	urban water supply Accra, expansion from ~70 to 183 10^6 m^3/y; irrigation left bank 10,000 ha, right bank extension from 4,000 to 10,000 ha (total irrigation use ~220 10^6 m^3/y)	GWCL, IDA
Aveyime	GH	Lower Volta	6,000 ha	IDA
Sogakope	GH	Lower Volta	urban water supply for Lomé, 116 10^6 m^3/y	GWCL

2.3 Surface water quality

2.3.1 Data on Surface water quality

The following governmental organisations have responsibility for monitoring the quality of the surface water in the basin:

- The Environmental Protection Agency (EPA, Ghana) monitors the water quality of industries releasing water in the rivers.
- Ghana Water Company Limited (GWCL) monitors the water quality at intake points for urban water supply.
- The Water Research Institute (WRI, Accra) has water quality data from some ad-hoc studies.
- The National office of Water and Housing monitors the water quality at surface water abstraction sites (ONEA, Burkina Faso). The surface water quality network in the basin consists of nine sites (MAHRH, 2004: maps 3 & 4, Table 8; Kam, 2002). ONEA also does occasional water quality tests for private clients.
- The DGIRH runs a ground- and surface water quality-monitoring network in Burkina Faso. The surface water quality network consists of 18 sites (MAHRH, 2004: maps 3 & 4, Table 8; Kam 2002). The sampling of the network is irregular; it depends on the available resources. For example, the most recent samples for the Black Volta were taken in 2000 (Appendix 2).

The following research institutions and projects have analysed the quality of the surface water in the basin:
- Onchocercosis Control Project (OCP, ran by WHO) during the 1980s up to 1995 in Ghana.
- EIER is within the framework of a project called 'Eutrophication and sedimentation in small dams' monitoring the surface water quality in 10 small reservoirs in Burkina Faso (contact: Prof. Amadou Maïga).
- The RESO programme also has a water quality-monitoring network that includes six sites along the Black Volta River. Unfortunately the network was not functioning in 2004 (MAHRH, 2004).

2.3.2 Surface water quality field survey

For this assignment, a number of field water quality tests (Appendix 2) were carried out on 15 surface water samples from various locations in the White and Black Volta sub-basins. An overview of the water quality tests is presented in Table 7. It should be noted that the survey is a one-time measurement and therefore not conclusive as the water quality is, amongst other things, a function of human activities upstream of the sampling sites which change with time.

Table 7 Water quality parameters tested for this assignment.

Water quality parameter***	Explanation	Results of field tests	Accepted limits
Electrical Conductivity (EC)**	indication for the amount of ions in the water	21 tot 114 µS/cm	750 to 1500 µS/cm*
pH	acidity of the water, 7 is neutral	6.4 to 6.6	6.5-8.5 (WHO)
Nitrite (NO_2)	indicates the presence of biological waste such as manure, nitrite is broken down by bacteria into nitrate	<0.5 mg/l	0 mg/l (WHO) 0.5 mg/l (EU)
Nitrate (NO_3)	indicates the presence of biological waste such as manure	<5 mg/l	10 mg/l (WHO) 50 mg/l (EU)
Total hardness	sum of ions which can precipitate as 'hard particles'; calcium, magnesium and sometimes iron	<107 mg/l	
Carbonate ($CaCO_3$) hardness	sum of calcium ions which can precipitate as 'hard particles'; influences pH and CO_2	<53 to 107 mg/l	500 mg/l (WHO)

* or roughly 500 to 1000 mg/l Total Dissolved Solids
** measured with an EC meter from Hanna Instruments (USA)
*** measured with test strips from eSHA (The Netherlands)

All the results from the water quality test (including some unpublished data from DGIRH) are presented in Appendix 2. In some of the samples the Ph is a bit low (slightly acidic), but besides that all water samples show, for the tested parameters, values that indicate a very low mineral content. Furthermore, no indication for the presence of biological waste (nitrite, nitrate) was found. Special attention was paid to the Bagré irrigation project on the White Volta River in Burkina Faso since there are some concerns in Ghana that drainage water from the irrigation project may pollute the White Volta River. The EC just downstream of the irrigation project was slightly higher (90 µS/cm, sample 11) than just upstream of the irrigation project (77 µS/cm, sample 12). Still, both samples indicate a low mineral content and variation like these are not uncommon between sites along the same river.

2.3.3 Analysis of surface water quality

There is very little information in the available literatures on surface water quality for the basin. The only fairly elaborate dataset found is presented in a summary table and covers one site per each of the four sub-basins during the period 1976-78 (GEF 2002; Andah et al., 2003). GEF (2002) provides a more recent (1995) summary table for one site on the Lower Volta. The report identified (potential) surface water pollution sources in all the riparian countries in the Volta Basin. According to the report, the surface water quality is deteriorating due to an increase in development and population pressure. Iron and phosphate are the components with the most elevated values. Still, outside the developed areas the water is generally of good quality, such that, mineral content of the water is suitable for potable drinking water and agriculture (Andah et al., 2003). A notable parameter is the relatively high mean Biological Oxygen Demand (BOD)[1] in the White Volta (105 mg/l) compared to the other rivers (<5 mg/l). A high BOD results in a reduction of available oxygen in the water for plant and animal life. Most datasets on which these conclusions are based are almost 30 years old so there is an urgent need for more recent water quality measurements. Furthermore microbiological contaminants raise concern; Faecal Coliforms (16-18 / 100 ml) have been found in the White Volta (Dalon) and Lower Volta rivers (Sogakope; Amoah, 1999; GEF, 2002).

For a water quality study in Burkina Faso (2001) nine surface- and groundwater samples from various sites at which an agricultural pollution was suspected were taken for analyses on nutrients and pesticides. The conclusion was that in general no the water did not contain pesticides (a very slight pollution was found at two sites) and that at a number of sites an elevated nutrient content was found (MAHRH, 2004).

Theoretically, potential sources that may lead to a degradation of surface water quality are:

- Waste releasing industries (e.g. textile and tanning factories, slaughterhouses, etc.).
- Gold mines may introduce chemical like cyanide into the river.
- Human waste in densely populated areas.
- Agriculture may introduce fertilizers and pesticides (relatively low in Burkina Faso because of the traditional agricultural production system, see Section 2.2.2.1 for sites of large irrigation projects).

The possible consequences of increased surface water pollution in the basin are:

- The introduction of phosphates and nitrates creates a favourable circumstance (eutrophication) for the development of weeds such as the water hyacinth. A map of the location of aquatic weeds can be found in GEF (2002, Appendix D-11).
- Water pollutants have a negative effect on all the uses (ecological, domestic, etc.) along the river.

Surface water quality can be improved by reducing the discharge of waste on the surface waters. It can also be improved by introducing artificial wetlands downstream of developed areas.

[1] *The BOD is defined as the amount of oxygen needed for the bacterial decomposition of rotting organic material to reach a stable stage [to compare, a crude sewage has a BOD of 600 and unpolluted water of <5 mg/l; (Jones, 1997).*

3 Groundwater

3.1 Groundwater data

Organisations and projects that have groundwater data are:

- The DGIRH runs a monitoring network of observation wells in Burkina Faso. About 38 wells from the network are situated in the Volta Basin. In most wells the monitoring started in the 1980s. The metadata on all wells in the network, including a quality label, can be found in MAHRH (2004; Table 1). The piezometers are also listed in KAM (2002).
- There is no monitoring network of observation wells in Ghana. Some ad-hoc water level measurements have been made. The WRC/WRI is currently setting up a by CIDA (Canadian International Development Agency) assisted well monitoring programme in the White-Volta sub-basin (~20 wells, contact: Enock B. Asare).
- The GLOWA-Volta Project has a database on urban and rural boreholes and wells in Burkina Faso and Ghana. It contains hydrogeological information but the quality is questionable and differs, depending on the drilling agent, very much per drilling, (contact: Nicola Martin, N.Martin@bgr.de; see also Martin and Giesen, 2005).
- DANIDA (2002) estimated the groundwater uses and availability for Burkina Faso.

3.2 Analysis of the aquifer in the Volta Basin

The underlying rocks of the basin (basement complex and consolidated sedimentary formations) have no primary porosity. The aquifer can be conceptualised as a two components system; the weathered mantle and the fractured bedrock. The weathered mantle consists of a more or less homogeneous cover ranging from clay to clayey sand with a generally high porosity and a low permeability. The fractured bedrock has a low porosity and a high permeability. The amount of weathering and the intensity of fracturing depend on the nature of the bedrock. A hydraulic contact is present between both components. The depth to the water table decreases from 13 to 14 m in the central region of Burkina Faso to about 6 m in northern Ghana (Sommen and Geirnaert, 1988). According to local reports the water level in boreholes along the White Volta in northern Ghana is currently declining, there are no water level measurements available to proof this. The observation is based on the fact that many of the over 1000 boreholes drilled by CIDA in the 1970s and 1980s in northern Ghana stopped, especially in the dry season, producing water. Some of the boreholes had to be rehabilitated by drilling a little deeper and reinstalling the pumps (PAGEV, 2005 and pers.com. PAGEV staff). This is the basis for CIDA sponsoring a groundwater monitoring system in the northern Ghana (see above).

The thickness of the aquifer varies from several metres up to roughly 100 m, while the mean thickness is approximately 20 m. The mean yield from the boreholes in the basin is relatively low, between 2 and 9 m^3/h (Sommen and Geirnaert, 1988; Dapaah-Siakwan and Gyau-Boakye, 2002; GEF, 2002; Glowa-Volta data cd). Generally, high yield wells are at locations where both components of the aquifer system (weathered mantle and fractured bedrock) are well developed (Sommen and Geirnaert, 1988). The groundwater potential varies over the basin. For example, the region that contains the headwaters of the Black Volta has a good groundwater potential while, at the other end, the Middle Voltaian Obosum Sediments in Ghana have generally a low groundwater potential (Martin and Giesen, 2005).

A local groundwater recharge study near Lake Volta based on isotopes concluded that modern recharge is taking place and that the studied groundwater system does not derive significant recharge from Lake Volta (Acheampong and Hess, 2000). Based on: water balance calculations, water table fluctuations and isotope analysis, Sommen and Geirnaert (1988) provide a rough estimate of an annual recharge in the range of 2 to 16% of the annual precipitation (i.e. 17 to 136 mm/y). Based on a literature study Martin and Giesen (2005) present annual recharge rates that vary with the rainfall; up to 13% in sandstone and up to 8% in weathered rock.

The GLOWA-Volta Project is currently studying the groundwater contribution over time to stream flow in representative river catchments in the basin.

3.3 Groundwater uses

To assess the development of groundwater use, an inventory of drilled wells and data on existing pipe-borne systems based on groundwater has been compiled by the GLOWA-Volta Project for the part of the Volta Basin that is located in Ghana and Burkina Faso. Since 1970 the number of drilled wells equipped with hand pumps have increased from several hundreds to almost 20,000. A summary of the rural and urban groundwater uses by drilled wells in the Volta Basin (Burkina Faso and Ghana) estimated by the GLOWA-Volta Project is presented in Table 8. Groundwater abstraction for irrigation is not included in this estimate. In the Ghanaian part of the basin groundwater abstraction for irrigation is expected to be small because it is based on hand-dug shallow wells near riverbeds (pers.com. N.C. van de Giesen). In the headwaters of the Black Volta in Burkina Faso significant groundwater abstraction for irrigation is taking place. The mean urban and rural groundwater extraction by drilled wells (2001) from the part of the Volta Basin that is located in Ghana and Burkina Faso is much less (<1 mm) than the estimated mean annual recharge (≥17 mm, see above). This is a basin-wide perspective and does not rule out the possibility of local over-abstractions from the aquifer. Martin and Giesen (2005) concluded that groundwater production is still less than 5% of the average annual groundwater recharge in most of the Volta Basin and that the present groundwater production should not be expected to have any significant impact on the regional groundwater balance. They attribute a decline of the water table in wells as local problems caused by low transmissivities unable to sustain a yield large enough to match the pumping rate.

Table 8 Summary of groundwater production for rural and urban water supply (excluding irrigation) in the Volta Basin in Ghana and Burkina Faso

Uses in 2001	**Quantity [10^6 m^3/y]***	**Quantity in [mm/y]****
Borehole with hand pump	61.2	
Modern hand dug well	1.7	
Boreholes with a piped system	15.4	
Total	88.3	0.26

* source: GLOWA-Volta Project data cd, and Martin and Giesen (2005)

** surface area of Volta Basin shared by Burkina Faso and Ghana ~346,000 km^2 (GEF, 2002)

3.4 Further analysis of groundwater data

The above information and analysis of groundwater resources in the basin is far from complete, given the limited time available for this assignment, and for the fact that the focus of this assignment was skewed towards surface water rather than on groundwater and because surface water is more of a shared trans-boundary resource than groundwater. However, there is a need to pay attention to groundwater during the water audit exercise because surface water and groundwater are closely linked, and the fact that, at this stage, it is already possible to draw the conclusion that the information on groundwater resources is too scarce and too dispersed for the development of a groundwater flow model for the basin.

For further analysis of the groundwater in the basin the following is recommended:

1. Expand the GLOWA database on boreholes for rural and urban water supply with information on boreholes for agricultural groundwater abstractions.
2. Link the current (Burkina Faso) and coming (Ghana) groundwater level and quality monitoring networks to the database(s) and map (Martin and Giesen, 2005) on groundwater production. This can serve as a primary indicator to areas where over-abstraction occurs and/or areas that should be included in the groundwater-monitoring network.
3. Start with the building up of a database that may in the future serve as the basis for groundwater model(s) for the basin. The database should at least include:
    - information on location and direction of faults (these are potential preferential groundwater flow paths);
    - information on boreholes (abstraction rate, diameter, depth of screens, water level, description of lithology, well logs, etc.);
    - pumping test information (for permeability of aquifer);
    - geophysical measurements (for determination of thickness of aquifer);
    - groundwater recharge studies;
    - groundwater levels (levelled piezometers to determine groundwater gradient);
    - reports and papers on groundwater studies in the basin.

4 Rainfall

4.1 Rainfall data

The following governmental organisations have responsibility for monitoring meteorological parameters in the basin:

- The Direction de la Météorologie collects rainfall (~180 stations, first station started ~1900) and evaporation data (~20 stations, first station started ~1970) for Burkina Faso. The data are digitally available and can be bought for a fixed price. A map with the locations of stations is available (see enclosed cd).
- The Meteorological Services Department (MSD) collects rainfall (~100 for the whole of Ghana, digital) and evaporation data (~15 for the whole of Ghana, digital and analogue). The data can be bought for a fixed price. A map with the locations of stations is available (see enclosed cd). The MSD has no bilateral cooperation with Burkina Faso, but the MSD receives the data for the synoptic stations in Burkina Faso through the WMO. MSD knows that the VRA is very interested in receiving rainfall data from Burkina Faso.

The following research institutions have monitored or plan to monitor rainfall in the basin:

- The WHYCOS Project collects rainfall data for various sites in Burkina Faso.

The following research institutions and projects have a database on meteorological data:

- The GLOWA Volta has a meteorological database for Burkina Faso and Ghana for the period 1960-2002, the data comes from the meteorological departments of both countries.
- The Institut de Recherche pour le Dévelopment (IRD) has meteorological data (potential evapotranspiration and rainfall) for the White Volta sub-basin in Burkina Faso for the period 1950-1995 (Mahe et al, 2005a).
- AGRYMET has long-term rainfall data for at least five stations in Burkina Faso (Hubert, 1989; Hôte et al. 2002; Mahe et al., 2002).

4.2 Analysis of rainfall data

As described above (Section 2.1.2.2), the non-linear relation between rainfall and river flow makes the runoff in the Volta Basin very sensitive to climatic variations. There have been many publications that analyse rainfall in the Sahel (Hôte et al., 2002; Ozer et al., 2003; Dai et al., 2004) and West Africa from the Sahel down to the Atlantic coast (Mahe et al. 2002; Ardoin et al., 2003). All these publications agree that there has been rainfall deficit in the Sahel and the coastal parts of western Africa (west of the Togo-Benin boundary) during the 1970s, 1980s and the first half of the 1990s. In the literature, there is some discussion on whether or not the rainfall deficit continued in the Sahel during the second half of the 1990s and beyond. It can be summarised as: 1) there are signs of recovery of rainfall since the late 1990s but that longer time series are required before it can be confirmed statistically; 2) another interesting observation is the fact that large multi-year oscillations appear to be more frequent and extreme after the late 1980s (Dai et al., 2004). This is likely to result in large inter-annual variations in river flow.

5 Water audit

5.1 Introduction

A water audit consists of an assessment of current and anticipated water availability and demand. There are two important choices to be made before doing a water audit:

- The time scale of the audit (annually or monthly or weekly or daily),
- The spatial scale or the size of river sections for which the water audit is executed (whole basin, four sub-basins, four sub-basins each divided into 3 to 4 sections, all first order tributaries to the river, all second order tributaries, etc.).

The factors that influence the choice of time and spatial scales are:

1) The aim for the water audit, in other words, what PAGEV plans to do with the information. For example, a detailed time and spatial scale are required when the outcome of the water audit is going to be used for the management of dams and reservoirs in the basin. Based on discussions with the PAGEV project and the project proposal (IUCN-BRAO, 2004) it can be stated that the outcome of the audit will be used to help policy makers in the basin to take informed decisions on water management planning. Generally, supporting decision makers requires a less detailed scale than advising on day-by-day water management of the dams.

2) The available data for the water audit. An important attribute of the presently available data is that there is more monthly than daily river flow data.

3) The timeframe of the water audit. For example, it should be noted that the ongoing study on the water uses of all the small reservoirs in the basin (GLOWA-Volta) will become fully available after the related PhD study is finished (June 2007). The PAGEV plans to have the bulk of the water audit executed in 2005 and 2006.

4) The available financial budget for the water audit. The smaller the budget, the less detailed the water audit will be. For example, a water audit based on an annual time scale for the basin as a whole requires a relatively small budget, while a water audit on a daily time and detailed spatial scale would require a larger budget.

Basin wide annual water audits mask intra-annual and local variations on water availability and water uses. An audit at a detailed time (days or weeks) and spatial (2nd order tributaries) scale probably goes beyond the available budget and requires a lot of detailed data in order to make it reliable at the presented scale. Furthermore, this scale is more important for day-by-day management than providing decision support to policy makers. So it is recommended to do a water audit for a monthly time scale in which the four sub-basins have been divided into three or four larger sections.

A water audit generally focuses on water quantity. Still, the water quality is important to determine if the available water is good enough for all the uses. This is particularly so, considering the fact that the only elaborate water quality data set that is quoted in the accessible literature is almost 30 years old and covers only four sites. For several reasons such as the facts that: 1) doing a water quality study requires a different discipline than a water quantity study, 2) there is much less information available on water quality than on water quantity, and 3) the focus of the water quality study will be more location specific (mainly downstream of potentially polluting activities) than the quantitative water audit (basin wide); it is recommended that the water quality study be separated from the water audit. Still, the predicted impact of water management scenarios on the water quality should be included in the water audit.

5.2 Candidates for the water audit

In order to ensure acceptance of the outcome of the surface water quantity audit by all stakeholders in the basin, it is recommended that the study be executed as collaboration between parties from both the riparian countries with the largest landmass in the Volta Basin; Burkina Faso and Ghana. An independent consultant from outside the basin can also generate an output that will be accepted as non-biased by all stakeholders, but for a long-term water management in the basin it would be better if relatively young local experts do the bulk of the water audit work. It would also be useful if the candidates have good contacts with the two organisations in the basin that have relevant information and the most published papers in international hydrological journals on the basin

(GLOWA-Volta Project and IRD). In the TOR for the consultants special attention should be given to the facilitation of the close cooperation between the experts from both countries. Another aspect that should be monitored, especially if people with recently obtained PhD's are hired, is that the work remains practical and does not go too deep into academic details that do not have a large impact on the outcome of the scenarios that are going to be developed within the water audit.

Identified people/organisations who may participate in the surface water audit:

Graduated PhD. students from the GLOWA-Volta Project:

- Barnabas Amisigo (barnyy2002@yahoo.co.uk; Ghanaian, Phd. Student on groundwater-surface water interaction with Prof. N. van de Giesen in Delft who will finish his PhD. in 2005, recent publication on filling data gaps in river flow data in the basin).
- Dr. Patrick Obeng-Asiedu (pobenga@uni-bonn.de; Ghanaian, University of Bonn, PhD. in 2004 on an hydrologic-agronomic-economic model for the basin).

It is recommended that information be obtained from Prof. van de Giesen (Technical University Delft, former team leader of GLOWA-Volta Project, at email: n.c.vandegiesen@citg.tudelft.nl) on which graduated Ghanaian PhD. students from the GLOWA-Volta Project are most suited for the work.

IRD has, as far I know, only French hydrologists working at their office in Ouagadougou. So they are not suitable candidates to do the bulk of the water audit work, assuming that local capacity building is an important goal for PAGEV.

Experts at EIER:

- Dr. Harouna Karambi (assistant researcher, Burkinabe).
- Dr. Bacabar Dieng (Professor in hydrology, Senegalese).
- Dr. Christophe Laroche (Professor in surface water hydrology, French).

It should be noted that many experts at EIER come from outside the Volta Basin and that they may not be available fulltime for longer periods due to their work at EIER.

Consultants who have worked for DGRIH (ranked in order of recommendation from DGIRH):

- Kam Sié Ludovic (surface water expert, very experienced on hydrometric network in Burkina Faso but quite mature so no long-term capacity building if he is chosen).
- Savadogo Kandaogo (expert on hydrometric networks).
- Abel Tigassé.

Mr. Innocent Ouédraogo (Burkinabe, former director at DGRIH, worked for IWACO and the FEM-Volta Project, works currently for WRCU and as an independent hydrological consultant).

People who work(ed) at/for the WRI (number of people working in the surface water department has decreased during the past few years) are:

- Dr Philip Gyau-Boyake (Current Head of Surface Water at WRI, scientific publications on the filling of data gaps in river flow data and surface water flow in the Volta Basin),
- Nii Boi Ayibotele (Ghanaian, former director of WRI, very experienced but very busy, ayibotele@niiconsult.com.gh),
- Dr Yaw Opoku-Ankouah (Deputy Director of WRI and head of GEF-Volta project, scientific publication on surface water resources in south-western Ghana).

Dr Kwabena Obeng Nyarko (Ghanaian, hydrological consultant, currently working in Botswana).

Prof. Chris Gordon from the university of Ghana is an expert on wetlands in the Volta Basin that may be able to assist with the filling of the information gap on required environmental flows in the basin (cgordon@ug.edu.gh). Furthermore, IUCN has in-house experts on environmental flows (e.g. Dr. G. Bergkamp).

It should also be noted that the PAGEV Project employs two experienced hydrologists (Burkinabe and Ghanaian) from the basin who can, provided that they have the time, execute parts of the Water Audit.

5.3 Proposed TOR for the water audit

5.3.1 Relevance of current activities in the basin

As shown above (Chapters 2 and 3), there is already a lot of work being done on water resources in the basin. The situation is a big advantage, as existing work can be used as building blocks, thereby releasing more energy that can be channelled into filling the information gaps. Hopefully this will produce a better outcome. Close cooperation with other organisations is also important in order to prevent policy makers from being fed with competing DSS (Decision-Support systems) for the management of water resources. The research institutions that do work that are most relevant to the water audit are the GLOWA-Volta Project, IRD and the recently started GEF-Volta Project. The VREO Project also plans to start working on the improvement of the water management in a part of the basin (the Black Volta in Burkina Faso) by May 2006. The overall objective of the GLOWA-Volta Project: 'the implementation of a Decision Support System for the assessment, sustainable use and development of water resources in the Volta Basin' is congruent to the objectives of the water audit. So close cooperation with this organisation is specially recommended (GLOWA contact for DSS at basin level: Charles Rodgers, crodgers@uni-bonn.de). Close collaboration with the relevant governmental organisations in Burkina Faso (DGIRH) and Ghana (WRC) is also essential in order to pave the ground for acceptance of the outcome of the work.

5.3.2 Relevant experiences and studies for the water audit

A crucial factor for the acceptance of the water audit is that the outcome be not a water management 'plan' but water management 'options' for the basin. The options and their consequences for water availability for the uses in the basin will assist policy makers to make decisions based on sound scientific knowledge.

Some studies that may help in executing the water audit are: the impact of five water management scenarios on the Volta River Basin developed by the GLOWA-Volta Project (Amisigo et al. 2003) and an hydrologic-agronomic-economic model on the water uses and resources in the basin developed by Obeng-Asiedu (2004). Another important study is DANIDA (2001), which estimated the surface and groundwater availability and demand for the year 2000 per sub-basin in Burkina Faso. The report also used rainfall-runoff models to fill data gaps in the river flow data. Although old, Ostrom (1977, available in the IUCN-BRAO library) can help with the river flow data quality analyses because it provides many rating curves and monthly river flow data for the whole basin. Water management experiences in Botswana can also provide technical inspiration for the water audit. In eastern Botswana the increasing water demand of small-scale upstream farm reservoirs has been known to have an impact on the availability of water from the major reservoirs. A daily model has been developed to quantify the effects of the existing small reservoirs and the possible impacts of future proposed ones on the water resources of the major downstream reservoirs (Meigh, 1995). Also the water management options prepared for the Komadugu-Yobe Basin in Nigeria may serve as a useful example (IUCN-HNWCP, 1999; Goes 2002). Dyson et al. (2003) provides a guideline on determining environmental flow requirements.

5.3.3 Exclusion from water audit

The development of new future water uses in the Lower Volta (the smaller tributaries to Volta Lake and the river downstream of Akosombo Dam) will not be included in the scenarios. This is done to limit the amount of work for the water audit and because the development of these uses is considered to be a national Ghanaian issue and not a trans-boundary issue. The impact of present and future uses in the three other sub-basins on water availability and water uses in the Lower Volta will still be an important part of the water audit.

The other three sub-basins (Black Volta, White Volta and Oti) should all be covered completely in the water audit. Still, the most detailed analysis should be done on the sub-basin with the largest pressure on its water resources; the White Volta. Thus initially, for the Black Volta and the Oti, fewer river flow stations and only major water uses need to be considered for the development of scenarios.

5.3.4 Strategy for minimizing delays during water audit

Obtaining river flow data may, especially in Ghana, take some time. In order to prevent large delays during the water audit it is therefore recommended to obtain all available river flow data (including gaugings and rating curves) before the Water Audit officially starts. In the event that it is decided to hire experts from Burkina Faso and Ghana, it is recommended that TOR explicitly reflect and facilitate that the experts physically share an office for at least two thirds of the time.

5.3.5 Water audit components

The proposed water audit should comprise the following components:

1) Collect and compile monthly data on present and future water uses (see Section 2.2) from all identified sources. Collect water level data from the well monitoring network in Burkina Faso and available studies in Ghana.

2) Select stations that are candidates to be qualified as key river flow station for the water audit based on location and length of period for which data are available. Execute quality checks on the river flow data for these stations (including rating curves) and determine which data are reliable enough to be used in the water audit. Make a final selection of key river flow stations for the water audit (20 to 30 in total; the stations presented in Table 1 should be included). If only water level data are available for certain periods for the key stations than the discharge should be estimated using available river gaugings and rating curves. When data gaps in runoff series for key station are limited and/or other data (e.g. rainfall or discharge at neighbouring stations) are available, the missing data should be estimated. This can for example be done by using a procedure that was especially developed for rivers in West Africa (Gyau-Boyake and Schultz, 1994) or by using a method that have recently been applied on flow data from various rivers in the Volta Basin (Amisigo and Giesen, 2005).

3) Collect relevant rainfall (to fill data gaps in runoff series) and evaporation data (to estimate losses from reservoirs).

4) Fill the data gaps. The identified data gaps are:
- Quality control and filling of gaps in the river flow data (see above).
- Information on environmental river flow requirements.
- Information on direct abstractions from the river and springs for irrigation in the Burkinabe part of the Black Volta Basin.
- Information on groundwater abstractions for irrigation.
- Information on flow requirements/releases by the existing and planned dams in Ghana (VRA).
- Because the focus of most projects in the basin is on Burkina Faso and Ghana the data on water uses and water availability in the other riparian countries is scarce (Oti River in Togo and Benin, Black Volta River in Côte d'Ivoire and Mali). A visit to, at least, the relevant institutions in Togo is required.

5) Divide, on the basis of the available data and number of surface water uses, the four sub-basins into at least four sub-sections that will form the basis for the water audit. The proposed subdivision should be presented in the form of a schematic diagram with motivation and overview of data availability per element of the diagram.

6).Determine the monthly water availability (very-dry year, dry year, normal year, wet year, very-wet year, standard deviation, etc.) for all the water audit sections in the basin on the basis of statistical analyses of river flow data.

7) Determine the future water availability for all the water audit sections for at least three different (sometimes conflicting) climate change scenarios. The scenarios should be based on existing work (e.g. impact of on river flow down-scaled global climate scenarios) as identified above (Section 2.1.3). Rank the future water availability scenarios on the basis of their likelihood.

8) Quantify, on a monthly basis, the present surface water uses for all water audit sections in the basin. Estimate future water uses for the water audit sections for three future years (e.g. 2010, 2020 and 2030) for at least five different development scenarios. Rank the future water uses scenarios on the basis of their likelihood. For the development of the scenarios the rainfall distribution over the basin should be taken into account. For example areas that have a low potential for rain-fed agriculture are more dependant on river flow than areas with a high potential for rain-fed agriculture. Also the millennium development goals ('reduce by half the proportion of people without sustainable access to safe drinking water by 2015') should be reflected in at least one of the scenarios (www.un.org/millenniumgoals).

9) Build a Decision Support System (DSS) that calculates water balances on a monthly and annual basis for all the water audit sections in the basin and all the combinations of the above mentioned present and future water uses and water availabilities. Create the possibility in the DSS for a non-technical user to prepare his/her own scenarios. It is recommended to build the DSS in a format that is easily accessible to all the relevant organisations in the basin, notably WRC and DGIRH. At least the following software formats (in order of prevalence) should be evaluated for its suitability to develop water management scenarios:

- WEAP (Water Evaluation And Planning, software from the Stockholm Environment Institute). The software is based on monthly data, available free of charge and communicates well with GIS. The software is being used by the WRC. WEAP will also be used by the GLOWA-Volta Project for the current study on small reservoirs. The study will also modify WEAP to allow entry of reservoir clusters (www.smallreservoirs.org).
- MS-Excel. The advantage is that almost everybody with a computer has MS-Excel and that it is very flexible. The disadvantage is that it does not have a nice graphical interface and that it requires quite a lot of programming.
- MIKE Basin (software from Danish Hydraulic Institute). The software is quite expensive (~7000 Euro) and requires a lot of daily data. The software is being used by DGIRH.

The chosen software for the DSS should be approved by the PAGEV Project.

10) Write a report that should at least contain:

- An executive summary for policy makers.
- Description of the work done.
- An overview table with river flow and water uses data used to build the DSS (including an indication of their reliability, in an appendix).
- A manual on how to use the DSS (in an appendix).
- The limitations of the DSS.
- The outcome of the all the scenarios in tables and graphs (the scenarios should be ranked on likelihood).
- Discuss the expected impact on downstream uses, water quality, human health (notably, Onchocerciasis and Schistosomiasis) and the prevalence of invasive aquatic weeds of all the scenarios.
- A technical description on how the DSS has been built (in an appendix).
- A list of hydrometric stations in the Volta Basin for which river flow monitoring is essential from the perspective of the water audit. It should also be indicated if, from the water audit perspective, the monitoring of the by GLOWA established stations should be continued when the project is ended. The possibility (practical and costs) for expanding the SONABEL satellite warning system for high water levels in the White Volta to hydrometric stations that monitor the water level at regular intervals should be investigated. Its relevance for a basin wide warning system should also be discussed.
- Areas where over abstraction from the aquifers is likely to occur and areas that should be included in the groundwater monitoring network. The identification of these areas should at least be based on: data from the current groundwater level monitoring network in Burkina Faso, accessible ad-hoc groundwater studies in Ghana, the existing GLOWA database on rural and urban groundwater abstractions and the for the water audit gathered information on groundwater abstractions for irrigation.
- Recommendations on what is required to fully include groundwater in the water audit.

11) Compile a cd that at least contains:

- a database on all the data (notably river flows and water uses) that have been used for the assignment,
- the report,
- the scenarios
- the DSS.

12) Organise, in cooperation with PAGEV, a workshop for the relevant organisations in the basin in which the DSS is presented and the outcome debated.

Note it is recommended to build in regular evaluation moments during which the work up to that point is evaluated by PAGEV or a by PAGEV appointed expert(s) before the water audit is continued. This can be done after steps 3, 4, 5, 8, 9 and 11.

5.4 Estimated time to carry out the water audit

It is envisaged that two local water resources experts (Burkinabe and Ghanaian), an ecologist and two juniors will carry out the water audit. Table 9 presents a rough estimate of the time required to carry out the water audit components. The estimate does not include data related delays such as obtaining difficult accessible data or transferring analogue data into a readable digital format. Furthermore, the water audit team needs an office space for a period of ~7 months and access to a vehicle for a period of approximately 6 weeks.

Table 9 Estimated time required to carry out the Water Audit (working days)

Water audit component	**Water Res. Expert 1**	**Water Res. Expert 2**	**Ecological flows expert**	**Assistant 1**	**Assistant 2**
1	3	3	-	5	5
2	10	10	-	-	-
3	-	-	-	2	2
4	10	10	10	6	6
5	2	2	1	-	-
6	2	2	-	2	2
7	4	4	-	2	2
8	3	3	1	2	2
9	10	10	2	-	-
10, 11	15	15	2	5	5
12	2	2	2	-	-
unforeseen delays	9	9	3	6	6
Total	**70**	**70**	**21**	**30**	**30**

5.5 Surface water quality study

First it is recommended is to try to obtain the water quality data from the relevant organisations (Section 2.3.1) and to put them in a database. Than, together with these organisations, the most critical sites can be determined for additional water quality measurements. It should be taken into account that for Burkina Faso a water quality network, that is partly based on the existing networks (Section 2.3.1), has already been proposed (MAHRH, 2004: Table 17).

The surface water quality study can possibly be executed by PAGEV staff in collaboration with the governmental organisations responsible for the water quality monitoring in Burkina Faso and Ghana. As described in Section 2.3.2 simple and cheap field tests can easily give a rough indication of the water quality. At sites where the field tests show elevated values and other sites that raise concern (e.g. the Bagré irrigation project) additional samples can be taken and send to laboratories for a more elaborate analyses. Prior to the submission of samples information should be obtained on how the selected laboratories ensure quality of their work. It is also recommended that some of the samples be analysed at two different laboratories in order to ensure reliability of the result. The focus of the water quality study should be on densely populated areas and just downstream of potentially polluting activities. For locations of potentially polluting activities that should receive attention in the water quality study the reader is referred to Section 2.2.2.1 of this report for sites of large irrigation projects and GEF (2002, p. 93-95) for sites of other potentially polluting activities such as industries. The survey should at least contain one wet and one dry season survey. It is recommended to also include the four sites for which the water quality had been monitored in the late 1970s in order to monitor changes in time (Sabra on Oti River, Daboya on White Volta, Bamboi on Black Volta and Ameda on Lower Volta). Parameters that require special attention are: Faecal Coliforms (downstream of urban areas), Biological Oxygen Demand (notably White Volta), nitrate, pesticides (drainage water from irrigation projects), iron and phosphate.

In order to examine the cause for the slight EC difference between up- and downstream of Bagré irrigation project in more detail (Section 2.3.2) it is recommended to do more elaborate laboratory tests (including pesticides) on water samples from both sites at various moments in the year. If possible drainage water from the irrigation plots, before the water enters the river, should be sampled as well.

The possible relation between the nutrients and salt content of the surface water and the prevalence of aquatic weeds is worth examining within the water quality study, knowing that other possible causes for aquatic weed development are: flow regulation and a change in sediment load.

In the event of non-availability of qualified personnel, a water quality expert may be hired to assist with the planning of the survey and the reporting. The following people/organisations may be considered for this task:

- A member of the group in the EIER who do the water quality study in small reservoirs in Burkina Faso (contact: Prof. Amadou Maïga),
- Silga Matias (no further details, name mentioned by DGRIH),
- Dr. Enoch B. Asane (Ghanaian, WRC),
- Dr. Bisque Hamilton (WRC).

The following laboratories for analysing water samples have been identified:

- EIER (Ouagadougou),
- ONEA (Ouagadougou),
- Bureau des Mines et de la Géologie du Burkina, Service Laboratoire et Pétrographie (Bobo Dioulasso and Ouagadougou),
- WRI (Accra and Tamale),
- GWCL (Accra).

6 Summary, conclusions and recommendations

6.1 Summary

A pre-water audit study was executed for the Volta Basin in Burkina Faso and Ghana. The study (ten working days) relied substantially on existing sources of data, articles, short field trips and discussions with experts working in the basin. The study: 1) determined the available and missing data on present and future water resources and uses, 2) assessed the hydrometric network, 3) proposed a step-by-step work plan on how the water audit can be executed , 4) identified a number of consultants who can contribute to the water audit, 5) made an inventory of water quality studies and monitoring networks, 6) executed surface water quality tests, 7) prepared a work plan for a surface water quality study, 8) assessed briefly the groundwater resources and the rainfall in the basin.

6.2 Conclusions

The identified information gaps for the surface water audit are:

- Quality control and filling of gaps in the river flow data.
- Information on environmental river flow requirements.
- Information on direct abstractions from the river and springs for irrigation in the Burkinabe part of the Black Volta Basin.
- Information on flow requirements/releases by the existing and planned dams in Ghana.
- Information on groundwater abstractions for irrigation.
- Because the focus of most projects in the basin is on Burkina Faso and Ghana the data on water uses and water availability in the other riparian countries is scarce (Oti River in Togo and Benin, Black Volta River in Côte d'Ivoire and Mali).

Getting access to information on present and future surface water uses in the Volta Basin is relatively easy. All governmental organisations visited in Burkina Faso and Ghana that are responsible for the use of surface water in the basin are very open to sharing information. Furthermore, there is also a lot of information on water uses in the basin in accessible literature and reports.

A fairly large but incomplete, especially for the period before 1980, river flow data set on the whole basin have been obtained for this assignment from the Global Runoff Data Centre. Monthly release data on the two hydropower dams in Burkina Faso are easily obtainable from SONABEL (data for the last two years have already been obtained).

The relevant governmental institutions in Ghana (HSD) and Burkina Faso (DGIRH) provided an overview of the available river flow data (metadata). A number of observations were made on the metadata: 1) the metadata file for Ghana does not provide details on data gaps, 2) possibly more river flow data are available at other institutions than presented in the metadata files (notably at IRD), 3) the accessibility to the rating curves and the gaugings, that are required for the quality control, is unclear, and 4) the relevant governmental organisations may be reluctant to give out data that have not yet undergone a quality check (roughly 40% of the data for Ghana). So obtaining the river flow data may take some time.

There is an enormous amount of river flow stations in the basin (over 200) but quite a number of stations: are no longer functioning, are situated on relatively small tributaries, only have water level data (no reliable rating curves), only have data for a couple of years or have large data gaps. This is a forest in which one can easily be lost.

A number of potential consultants in Burkina Faso and Ghana exist who can participate in the water audit. Most people have a long experience in executing consultancies in the basin, but at the same time their available time for the work is probably limited.

There are some ad-hoc surface water quality data for the basin. Still, it is not so easy to obtain the data because they are dispersed over many different organisations in the basin. The scarce accessible data and the field survey executed for this assignment revealed that the river water has generally a very low mineral content, and has thus a good quality (EC is generally < 100 µS/cm). But, the presence of microbiological contaminants (Faecal Coliforms), especially in the White and Lower Volta, raise the most concern.

Conclusions on water resources and uses in the basin:

- There is an enormous amount of suggested future surface water uses in the basin in Ghana and, to a lesser extend, also in Burkina Faso. This underlines the need for a water audit in the basin.
- The non-linear relation between the rainfall and the river flow (Andreini, 2000) makes the runoff in the Volta Basin very sensitive to climatic variations.
- Large multi-year oscillations appear to be more frequent and extreme after the late 1980s (Dai et al., 2004). This may result in large inter-annual variations in river flow.
- Two studies that investigated the impact of downscaled global climate scenarios on the water resources in the Volta Basin predict an increase in river flow, while a third study predicts a decrease in river flow.
- Between 1955/65-70 and 1972-98, in the upstream part of the White Volta in Burkina Faso the mean river flow increased despite a reduction in rainfall and an increase in the number of dams. The increase was due to the following changes in land use; increase in cultivated area, increase in area with bare soil and a decrease in area with natural vegetation (Mahe et al., 2003 and 2005a).
- The estimated quantity of used groundwater by drilled wells for rural and urban water supply in 2001 (GLOWA Volta) is less than 5% of the mean annual groundwater recharge.
- At this stage the information on groundwater resources is too scarce and too dispersed for the development of a groundwater flow model for the basin.

6.3 Recommendations

6.3.1 Technical recommendations

The following recommendations are made for improving the quality of the water audit:

1. Obtain all available river flow data (including gaugings and rating curves) before the water audit officially starts as this will prevent large delays during the water audit.
2. A visit to the VRA is recommended to get more information on water requirements by existing and planned large dams in Ghana (no VRA staff was available in Accra during the assignment).
3. Focus on a limited number of key river flow stations (20 to 30) in the basin.
4. The starting point for the determination of environmental flows can be historical (before human induced changes in the river) daily hydrographs for sites upstream of the ecological sites. Collaboration should be sought with an hydro-ecologist to examine the impact of flow removal from the hydrographs on the ecosystem.

Recommendations on a surface water quality study in the basin:

1. Obtain water quality data from relevant organisations and put them in a central database so as to ensure their accessibility to researchers, policy makers and program managers.
2. Use relatively cheap field tests for rough indication of the water quality and send additional samples for sites that show elevated values and other sites that raise concern to laboratories for a more elaborate analyses.
3. Focus water quality studies on densely populated areas and just downstream of potentially polluting activities and contain at least one wet and one dry season survey. It is recommended to also include the four sites for which the water quality had been monitored in the late 1970s in order to monitor changes in time.
4. Parameters that require special attention are: Faecal Coliforms (downstream of urban areas), Biological Oxygen Demand (notably White Volta), nitrate, pesticides (drainage water from irrigation projects), iron and phosphate.

Recommendations on the functioning of the hydrometric network in the Volta Basin:

1. Identify key river flow stations in the basin (at the most 20) that need to be monitored in order to give a good overview of the available surface water resources in the basin (optimisation of the hydrometric network). This will allow optimal use of limited resources for the maintenance of the hydrometric network. An optimisation should, however, not be done at the expense of ‘second class’ stations because river flow relations can change in time due to, for example, the construction of a dam.
2. Spend more effort on enhancing the commitment of the readers to do their work by for instance providing them a bicycle if they live far from the stageboard and giving them annually the results of their work (river flow graph for the site).

3. The possibility (practical and costs) for expanding the SONABEL satellite warning system for high water levels in the White Volta to hydrometric stations that monitor the water level at regular intervals and its relevance for a basin wide warning system should be investigated.

Other surface water related topics that may be worth investigating:

1. How the discharge in the upstream part of the Black Volta River (north of ~700 mm isohyet) responded to changes in land use.
2. How the floods in northern Ghana are related to unanticipated high inflows in the reservoir of the upstream Bagré Dam in Burkina Faso as a result of land use changes in the upstream part of the White Volta.
3. The introduction of artificial wetlands downstream of developed areas to capture surface water pollution is a topic that may be examined.

For further analysis of the groundwater in the basin the following are recommended:

1. Link the current (Burkina Faso) and coming (Ghana) groundwater level and quality monitoring networks to the database(s) on groundwater abstractions. This can serve as a primary indicator to areas where over abstraction occurs and/or areas that should be included in the groundwater-monitoring network.
2. Start with the building up of a database that may in the future serve as the basis for a groundwater model for the basin.

6.3.2 Collaboration and networking related recommendations

To improve the outcome and acceptance of the water audit study, the following recommendations are made:

1. Harmonize the coming work for the water audit with water management related activities from other projects in the basin. The most relevant projects to cooperate with are: GLOWA-Volta, IRD, GEF-Volta and VREO for the Black Volta. Possibly the WRCU of ECOWAS and/or the IWMI can assist with the facilitation of this process. The cooperation can be done by defining a common goal, for example the establishment of a Volta River Basin Authority that takes informed decisions, and an organogram with a timeframe that defines what each project will contribute to achieve the common goal.
2. The PAGEV Project can start on improving the water governance in the basin by facilitating the sharing of river flow data between Burkina Faso (DGRIH) and Ghana (HSD). The interviewed people from both organisations showed a positive attitude towards data sharing (negotiations are required on the finances).
3. PAGEV and its consultants should offer their assistance, especially to HSD (Ghana), with the quality control study. The consultants should be aware of the sensibilities of organisations in providing data that are of poor quality.
4. In order to ensure that the water audit will be a common work between Burkina Faso and Ghana it is recommended to pay special attention to consultants from both countries physically working together in one office for the majority of the time. For capacity building purposes and availability it may be worth to focus on recruiting relatively young consultants who are keen on establishing their name.
5. In order to ensure a good cooperation with the for the Water Audit most relevant project in the basin (GLOWA-Volta) and also to get a high scientific standard it is recommended to recruit at least one graduated Ghanaian PhD student that worked for GLOWA-Volta Project.
6. Since a significant part of the main channel of the Oti River flows though Togo a visit to the relevant institutions in that country is recommended.

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Appendix 1a: Metadata for river flow stations in Burkina Faso, White Volta & Oti (Kam, 2002)

IDENTIFICATION DES STATIONS HYDROMETRIQUES

BASSIN VERSANT DU NAKANBE

N°	Superficie Bassin Versant Km² (2)	Cours d'eau (3)	Nom de la station (4)	Coordonnées (5)	Ancien Code (précédent) (6)	Code OMM Proposé p/c 2001 (7)	Année création (ouverture) (8)	Equipement station E/LG (9)	Nature station N/D (10)	Objectif (11)	Observations (12)
1	16965	Nakanbé	Bissiga	12°46' N 01°09' W		19315140	03/1975	LG	D		S
2	2375	Nakanbé	Rambo	13°36' N 02°04 N	1931420	19315010	1983	LG	D		S
3	20800	Nakanbé	Wayen	12°23' N 01°05' W	1931725	19315160	1955	LG	D	Stat témoin Ressces en eau	S
4	33120	Nakanbé	Bagré	11°27' N 00°33' W	1931830	19315300	05/1974	LG	D	Etudes Barrage hydroélectrique	F
5	………..	Nakanbé	Ziga	12°33'20" N 01°04'W		19315150	1984	LG	D	Etudes site barrage	F
6	3960	Nakanbé	Tampelga	13°07'54" N 01°17' W		19315135	1997	LG	D		corrélation avec Bissiga
7	8000	Nakanbé	Dourou	13°01' N 02°0 W		19315021	1996	E	N		?
8	34		Petit Bagré	11°28'40''N 0°32'W	1931760	19315310	~1984			Hydraulique agricole	S
9	30200	Nazinon	Niaogho	11°46' N 00°45' W	1931770	19315260	06/1963	LG	D		S
10	3400	Nakanbé	Ramsa	13°29'35" N 02°06'53" W		19315020	1983	LG	D		F
11	4540	Nazinon	Dakaye	11°46' N 01°36' W	1931565	19316020	04/1975	LG	D		S
12	7600	Nazinon	Nobéré	11°26' N 01°11' W	1931695	19316030	1965	LG	D		S
13	1210	Nazinon	Sakoinsé	12°12'N 02°01' W	1931535	19316010	1963/1975	LG	D		F
14	2100	Massili	Gonsé	12°29' N 01°24' W	1931590	19315200	1975	LG	D		S
15	2120	Massili	Loumbila	12°29' N 01°24' W	1931650	19315190	1956	E	N	Stat. témoin AEP Ouaga	S
16	4050	Nouhao	Bittou	11°11' N	1931845	19315330	1973	LG	D		S

IDENTIFICATION DES STATIONS HYDROMETRIQUES *BASSIN VERSANT DU NAKANBE*											
N°	***Superficie Bassin Versant Km² (2)***	***Cours d'eau (3)***	***Nom de la station (4)***	***Coordonnées (5)***	***Ancien Code (précédent) (6)***	***Code OMM Proposé p/c 2001 (7)***	***Année création (ouverture) (8)***	***Equipement station E/LG (9)***	***Nature station N/D (10)***	***Objectif (11)***	***Observations (12)***
				00°17' W							
17	***3240***	***Sissili***	***Nebbou***	***11°17' W 01°56' WD***	***1931550***	***19317010***	***1974***	***LG***	***D***		***S***
18	***9180***	***Nakanbé***	***Kampala (Amont)***	***11°13'N 00°56' W***		***19316040***	***1955***	***LG***	***D***		***F***
19	***10260***	***Pendjari***	***Arly***	***11°26' N 01°34' E***	***1931830***	***19318040***	***1976***	***LG***	***D***		***S***
20	***350***	***Affl. Massili***	***Barrage Ouaga III***	***12°23' N 01°33' W***	***1931493***	***19315230***	***1955***	***E***	***N***	***AEP Ouaga***	***S***
21	***368***		***Barrage Mogtédo***	***12°18'22" N 00°49'25" W***	***1931690***	***19315210***	***1965***	***E***	***N***		***F***
22	***151***		***Barrage Ouahigouya***	***13°35' N 02°26' W***	***1931370***	***19315040***	***07/1984***	***E***	***N***		***S***
23	***2560***	***Lac***	***Bam***	***13°20' N 01°31' W***	***1931595***	***19315060***	***1966***	***E/LG***	***N/D***		***S***
24	***5640***	***Kompienga***	***Tagou***	***11°09' N 00°37' E***		***19318010***	***1970***	***E***	***N***		***F***
25	***198***	***Lac***	***Sian***	***13°05'42" N 01°13'11 W***	***1931600***	***19315090***	***1984***	***LG***	***N***		***S***
26	***402***	***Lac***	***Dem***	***13°10'20" N 01°10' W***	***1931620***	***19315080***	***1984***	***LG***	***N***		***S***
27	***468***		***Barrage Louda***	***13°01'14" N 01°01'21" W***	***1931670***	***19315130***	***1984***	***E***	***N***	***Hydraulique agricole***	***F***
28	***4560***	***Singou***	***Samboali***	***11°16' N 01°01' W***		***19318030***	***1976***	***LG***	***D***		***S***
29	***6120***	***Sissili***	***Kounou***	***11°05' N 01°29' W***		***19317020***	***03/1979***	***LG***	***D***		***S***
30	***10100***	***Nakanbé***	***Yilou***	***13°00' N 01°33' W***	***1931580***	***19315100***	***04/1973***	***LG***	***D***		***F***
31	***31680 (33000)***	***Nakanbé***	***Yakala***	***11°31' N 00°42' W***	***1931785***	***19315290***	***05/1954***	***LG***	***D***		***F***
32	***6050***	***Doudodo***	***Arly***	***11°32' N 01°34' E***	***1931820***	***19318050***	***1969***	***LG***	***D***		***S***

IDENTIFICATION DES STATIONS HYDROMETRIQUES BASSIN VERSANT DU NAKANBE											
N°	***Superficie Bassin Versant Km² (2)***	***Cours d'eau (3)***	***Nom de la station (4)***	***Coordonnées (5)***	***Ancien Code (précédent) (6)***	***Code OMM Proposé p/c 2001 (7)***	***Année création (ouverture) (8)***	***Equipement station E/LG (9)***	***Nature station N/D (10)***	***Objectif (11)***	***Observations (12)***
33	10700	Nazinon	Ziou	11°05'46"N 00°42'12"	1931681	19316050	1990	LG	D		S
34	11360	Nakanbé	Yabo	12°59' N 01°28' W	1931530	19315110	1984	E	D		F
35	972	Tcherbo	Bagré	11°36' N 01°34' W	1931816	19315320	1976	LG	D		S
36	6984		Barrage de Kompienga	11°05'N 0°43'E		19318020	1988	LG	N		S
37	28		Barrage Napagtenga	12°13'31" N 01°21'14" W	19315570	19315250	1966	E	N		F
38	470	(Massili)	Barrage Nagbangré	12°11'32" N 01°24'14" W	1931560	19315240	1983	E	N		F
39	66,3		Bge Koubri II	12°12'16" N 01°21'07" N		19315241	1995	E	N		F
40	148		Bge Wedbila	12°08' N 01°25' W	19311815	19315242	1986	LG	N		F
41	11800		Mané	12°58' N 01°20' W		19315120	06/1955	E	D		F
42	2536	Dougoulamon di	Komtoega nouvelle	11°54' 34''N 00°41' W	1931720	19315270	1994	LG	D		S
43	100		Bge Tensobentenga	11°59' N 00°16' W		19315271	1989	E	N		F
44	102		Bge Itengué	12°12' N 00°23' W		19315272	1989	E	N		S
45	272	Tcherbo	Sanogho	11°43' N 00°33' 35" W		19315340	1994	LG	D		S
46	(94)		Barrage Manga (Louré)	11°40' N 01°02'33" W		19315295	1989	E	N		S
47	44		Bge Pibaoré	12°54' N 00°49' W		19315122	1995	E	N		S
48	1000		Bge Korsimoro	12°49' N 01°02' W		19315121	1989	E	N		F
49	1110	Kourigui	Niessega	13°07' N		19315025	1995	E	D		S

IDENTIFICATION DES STATIONS HYDROMETRIQUES BASSIN VERSANT DU NAKANBE											
N°	Superficie Bassin Versant Km² (2)	Cours d'eau (3)	Nom de la station (4)	Coordonnées (5)	Ancien Code (précédent) (6)	Code OMM Proposé p/c 2001 (7)	Année création (ouverture) (8)	Equipement station E/LG (9)	Nature station N/D (10)	Objectif (11)	Observations (12)
				02°21' W							
50	660		Barrage Seguénega	13°28' N 01°57' W		19315026	1995	E	N		F
51	400		Bge Titao	13°46'37" N 02°04' W		19315011	1989	E	N		F
52	70		Bge Sylia	13°44'14" N 02°10' W		19315012	1989	E	N		F
53	450		Bge Tougou	13°40' 47" N 02°12'47" W		19315050	1982	E	N		F
54	151		Bge Goinré	13°37'28" N 02°26'34"		19315030	1985	E	N		S
55	245		Bge Koulniéré	13°14'26" N 01°42'03"W		19315053	08/1989	E	N	Agricole	F
56	192		Barrage de Donsé	12°34'47" N 01°24'27" W		19315180	1983	E	N		F
57	72		Bge Nagréongo	12°29'36" N 01°10'21" W		19315155	1995	E	N		F
58	175		Bge Tamasgo	13°15' N 01°16' W	1931640	19315070	07/1984	E	N		F
59	22		Bge Gha	13°12'38" N 01°17' W		19315065	1995?	E	N		F
60	450		Bourzanga	13°40' N 01°33' W		19315051	1990	E	N		F
61	33120		Barrage de Bagré	11°28'38" N 00°32'44" W		19315310	1994	E	N		S
62			Bagré aval	11°28'38" N 00°32'44" W		19315311	1996	E	D	Débit turbiné	S
63		Koulpélé	Niarba	11°41' N 00°52' W		19315280	?		D	Etude de barrage	S
64	198		Bge Pabré	12°30'20" N 01°35' W		19315170	1983	E	N		F
65		Koulpélégo	Gonaba Amont	11°29'17''N		19318017	4/1984	LG	D		S

IDENTIFICATION DES STATIONS HYDROMETRIQUES *BASSIN VERSANT DU NAKANBE*											
N°	***Superficie Bassin Versant Km² (2)***	***Cours d'eau (3)***	***Nom de la station (4)***	***Coordonnées (5)***	***Ancien Code (précédent) (6)***	***Code OMM Proposé p/c 2001 (7)***	***Année création (ouverture) (8)***	***Equipement station E/LG (9)***	***Nature station N/D (10)***	***Objectif (11)***	***Observations (12)***
				0°21'23''E							
66		***''***	***Gonaba aval***	***11°28'N 0°23'39''E***		***19318018***	***1984***		***D***		***S***
67	***150***		***Bge Kamboinsé***	***12°27'23''N 1°33'09''W***		***19315176***	***?***	***E***	***N***		***F***
68	***434?/125?***		***Bge Boulbi***	***12°14'11''N 1°02'22''W***		***19315237***	***?***	***E***	***N***		***F***
69		***Kompienga***	***Kompienga aval***	***11°05'N 0°43'E***		***19318021***		***E***			***S***

Legend: D=Discharge (Débits); N=Water Level (Niveau); LG=Water Level Recorder (Liminigraphe);
S=active in 2000 (Suivi en 2000); F=closed (Fermée); E=stageboard (Echelle limnimétrique)

PARCOURS CHRONOLOGIQUE DES STATIONS HYDROMETRIQUES DU BASSIN VERSANT DU NAKANBE

Années

N°	Station/BR	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	Bissiga																						--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--
2	Rambo																												--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--	--
3	Ramsa																													--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
4	Wayen	--										--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	Bagré																							--	--	--	--	--	--	--	--	--	--	--	--	--					--							
6	Ziga																														--							--	--	--	--							
7	Tampelga																																											--	--	--	--	--
8	Dourou																																										--	--			--	--
9	Petit Bagré																														--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
10	Niaogho									--	--	--	--	--	--				--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--				--	--	--				--
11	Gonsé																				--	--			--	--				--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	Loumbila		--	--	--	--	--	--	--	--	--	--	--	--	--	--											--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
13	Bge Ouaga 1		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--									--	--	--	--	--	--	--	--	--	--	--	--	--	--				--		--			
14	Bge Ouaga 2		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--								--	--	--	--	--	--	--	--	--	--			--	--				--	--	--	--	--	--
15	Bge Ouaga3		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--								--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	Mogtédo											--	--	--	--															--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17	Ouahigouya																															--	--	--	--	--	--	--				--	--	--	--	--	--	--
18	Goinré																											--		--	--	--	--	--	--	--	--	--	--				--	--	--	--	--	--
19	Lac Sian																															--	--	--	--	--	--	--	--				--	--	--	--	--	--
20	Lac Dem																															--	--	--	--	--	--	--	--	--	--					--	--	--
21	Lac Bam												--	--	--	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
22	Louda																														--	--	--	--	--	--	--	--	--			--	--					
23	Yilou																			--	--	--	--	--	--	--	--	--	--	--	--	--	--															
24	Yabo																														--	--	--		--							--						
25	Yakala											--	--	--	--								--	--	--	--	--			--	--		--	--	--				--									
26	Tcherbo/Bagré																										--	--	--	--	--	--	--	--	--													
27	Npagatenga													--	--						--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--				
28	Nagbangré		--	--																										--		--	--	--		--		--	--			--	--					
29	Koubri II																																										--	--	--			

PARCOURS CHRONOLOGIQUE DES STATIONS HYDROMETRIQUES DU BASSIN VERSANT DU NAKANBE																																																
		Années																																														
N°	Station/BR	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
30	Ouédbila																																	--			--	--				--	--			--		
31	Mané	--	--	--	--			--	--	--	--	--	--		--																																	
32	Komtoèga																																								--	--	--	--	--	--	--	--
33	Donsé												--	--	--																			--			--											
34	Kampala Amont	--	--								--	--																																				
35	Sakoinsé											--	--						--				--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--						
36	Dakaye																					--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			--	--	--	--	--	--	--	--
37	Nobéré											--	--	--	--	--				--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			--	--	--	--	--
38	Ziou																																				--		--		--		--	--	--	--	--	--
39	Bittou																			--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
40	Nebbou																				--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--	--	--		--			--	--
41	Kounou																									--	--	--	--	--	--	--	--	--	--	--	--	--			--	--		--				
42	Samboali																								--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--				
43	Doudodod/Arly																		--			--		--		--	--	--	--	--	--	--	--	--	--	--	--			--	--	--	--	--		--	--	--
44	Pendjari/Arly																								--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			--	--	--			--	--
45	Tagou																												--	--	--	--	--															
46	Sanogho																																								--	--	--	--	--	--	--	--
47	Séguénega																																									--	--	--	--			
48	Titao																																			--	--	--	--			--	--	--	--			
49	Silia																																			--	--	--	--			--	--	--	--			
50	Tougou								--	--			--	--															--	--	--	--	--	--	--	--	--	--	--					--	--	--	--	--
51	Koulniéré																																			--	--	--	--	--	--	--	--	--			--	--
52	Nagréongo																																									--	--	--				
53	Tamasgo																														--	--	--	--	--	--	--	--	--									
54	Gah																																				--											
55	Bourzanga																																				--	--	--	--								
56	Gonaba Amont																														--	--	--	--	--	--	--											
57	Gonaba Aval																														--	--	--	--		--	--	--										
58	Bge Bagré																																							--	--	--	--	--	--	--	--	--
59	Bagré Aval																																										--		--	--	--	--

PARCOURS CHRONOLOGIQUE DES STATIONS HYDROMETRIQUES DU BASSIN VERSANT DU NAKANBE

N°	Station/BR	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
		Années																																														
60	Tensobentenga																																									--	--	--	--			
61	Itengué																																								--	--	--	--	--	--	--	--
62	Gonaba Aval																														--	--	--	--		--	--	--										
63	Manga (Louré)																																			--						--	--	--	--	--	--	--
64	Bge Korsimoro																																									--	--	--	--			
65	Niésséga																																									--	--	--		--	--	--
66	Moro Naba				--	--		--	--	--	--	--	--																																			
67	Bge Pibaoré																																										--	--	--	--		
68	Bge Boulbi																															--	--	--	--			--	--									
69	Bge Kamboinsé																														--	--	--	--	--	--	--											
70	Bge Kompienga																																									--	--	--	--	--	--	--
71	Kompienga Aval																																														--	--
72	Kompienga site																													--	--	--	--	--	--													
73	Pont Université																																		--													
74	Canal Université																																		--													
	Total	3	7	6	6	5	4	6	7	8	8	13	15	13	13	7	5	3	5	6	9	11	12	11	17	19	22	22	25	31	39	42	43	42	39	39	40	39	33	22	26	39	44	43	35	32	35	36

Appendix 1a: Metadata for river flow stations in Burkina Faso, Black Volta (Kam, 2002)

IDENTIFICATION DES STATIONS HYDROMETRIQUES

BASSIN VERSANT DU MOUHOUN

N°	Superficie Bassin Versant (2)	Cours d'eau (3)	Nom de la station (4)	Coordonnées (5)	Ancien Code (précédent) (6)	Code OMM Proposé (7)	Année création (ouverture) (8)	Equipement station E/LG (9)	Nature station N/D (10)	Objectif (11)	Observations (12)
1	1100	Plandi	Lanviéra	11°16'N 04°56'W		19311020	1961	LG	D		S
2	780	Dienkoa	Guéna	11°05'N 04°41'N		19311040	1962	LG	D		S
3	2816	Mouhoun	Banzo	11°19'N 04°49'W		19311050	1959	LG	D		S
4	4580	Mouhoun	Samandéni	11°28'N 04°28'W		19311100	1955	LG	D		S
5	405	Kou	Nasso (Amont)	11°12'N' 04°26'W		19311200	1961	LG	D		S
6	412	Kou	Dindéresso	11°13' N 04°31' W		19311230	1975	LG	D		S
7	632	Kou	Diaradougou	11°18' N 04°31'W		19311240	1959	LG	D		S
8			Canal porcherie	11°21'20'' N 04°24' W		19311250	1982 (83?)	E	D		S
9	971	Kou	Badara	11°22'N 04°22'W		19311260	1955	LG	D		S
10	14800	Mouhoun	Nwokuy PT	12°31'N 03°33'W		19311500	1955	LG	D		S
11		Mouhoun	Nwokuy Aval	12°31'29'' N 03°32'43'' W		19311510	1986	LG	D	Calcul hydraulique / Manning S.	S
12		Sourou	Barrage Léry	12°45'N 03°26'W		19312050	1976	E	N		S
13		Sourou	Pt Léry Nord	12°45'N' 03°26'W		19312060	09/1952	E	D		F
14		Sourou	Yaran	12°58'N' 03°27'W		19312040	1955	E	N	Agriculture + AEP	S
15	47000	Sourou	Confluent Sourou/Mouhou n	12°45'N 03°25' W		19312070	1955	E	D		F

IDENTIFICATION DES STATIONS HYDROMETRIQUES

BASSIN VERSANT DU MOUHOUN

N°	Superficie Bassin Versant (2)	Cours d'eau (3)	Nom de la station (4)	Coordonnées (5)	Ancien Code (précédent) (6)	Code OMM Proposé (7)	Année création (ouverture) (8)	Equipement station E/LG (9)	Nature station N/D (10)	Objectif (11)	Observations (12)
16		Sourou	Di	13°11'N 03°25'W		19312020	1955	E	N		F
17	(47000)	Mouhoun	Manimenso	12°44'32'' N 03°24'W		19313030	1955	E	D	St. témoin AEP Kdgou	S
18	1890	Vranso	Ninion	12°31'N 02°23'W		19313120	1971	LG	D		S
19	32700	Mouhoun	Ténado	12°13'N 02°50'W		19313200	1975	LG	D	St. témoin AEP Kdgou	S
20	37140	Mouhoun	Boromo	11°47'N 02°55'W		19313300	1955	LG	D		S
21	1720	Bolo	Poura	11°42'53'' N 02°44'6'' W		19313320	1984	LG	D		S
22	3510 (3780 ird)	Grand Balé	Pa	11°36'N 03°11'W		19313400	1966	LG	D		S
23	50820	Mouhoun	Ouessa	11°01'N 02°49'W	1931310	19313600	05/1969	LG	D		S
24	6345	Bougouriba	Dan	10°55'N 03°39'W	1931130	19314100	1970	LG	D		S
25	12200	Bougouriba	Diébougou	10°56'N 03°10'W	1931250	19314200	1955	LG	D		S
26	66540 (sans Sourou)	Mouhoun	Dapola	10°34'N 02°55'W	1931270	19314750	1955	LG	D		S
27	5630	Bambassou	Batié	09°59'N 02°54'W	1931280	19314800	06/1971	LG	D		S
28	87100	Mouhoun	Noumbiel	09°41'N 02°49' W	1931330	19314900	07/1975	LG	D		S
29	?		Mare aux Hypopotames	11°33'50'' N 04°09'10'' W		19311390		E	N	Stat témoin Zone humid	S
30	1600		Confuent Kou/Niamé	11°21'10'' N 04°20'10'' W		19311330	9/1980	LG	D	Assain. vallée du Kou	S
31	?	Niamé	Pesso	11°19'15'' N 04°15'26'' W		19311310				Zone humide	S

IDENTIFICATION DES STATIONS HYDROMETRIQUES *BASSIN VERSANT DU MOUHOUN*											
N°	***Superficie Bassin Versant (2)***	***Cours d'eau (3)***	***Nom de la station (4)***	***Coordonnées (5)***	***Ancien Code (précédent) (6)***	***Code OMM Proposé (7)***	***Année création (ouverture) (8)***	***Equipement station E/LG (9)***	***Nature station N/D (10)***	***Objectif (11)***	***Observations (12)***
32	***?***	***Niamé***	***Desso***	***11°21'10 N 04°17'15'' W***		***19311320***			***D***	***Zone humide***	***S***
33	***?***	***Kou***	***Guinguette***	***11°11' N 04°26'25'' W***		***19311190***			***D***	***Source***	***S***
34	***13600***	***Mouhoun***	***Tourouba***	***12°22'N 03°43'W***		***19311450***	***1954***		***D***		***F***
35	***49500***	***Mouhoun***	***Niompourou Douroula***	***12°36' N 03°15' W***		***19313050***	***09/1952***	***E***	***D***		***F***
36	***6700***	***Vounhou***	***Bourasso***	***12°37' N 03°41' W***		***19311440***	***8/1962***	***E***	***D***		***F***
37	***?***	***Mouhoun***	***Poura***			***19313750***	***1984***		***D***	***AEP Mine***	***F***
38	***2500***	***Vranso***	***Poun***	***12°26'N 02°35'W***		***19313140***	***1977***	***LG***	***D***		***F***
39	***2500***	***Sourou***	***Pont de Léry Sud***	***12°45'N' 03°26'W***		***19312060***	***09/1952***	***E***	***D***		***S***
40		***Sourou***	***Toumani***	***12°47'N 03°27'W***		***19312050***	***10/1952***	***E***			***F***
41	***405***	***Kou***	***Nasso milieu***	***11°12'N' 04°26'W***		***19311201***	***1961***	***LG***	***D***		***S***
42	***405***	***Kou***	***Nasso aval***	***11°12'N' 04°26'W***		***19311202***	***1961***	***LG***	***D***		***S***
43	***166***		***Barrage Sambisgo***	***12°09' N 02°21' W***		***19313210***	***?***	***E***	***N***	***AEP Kdgou***	***S par ONEA***
44		***Poni***	***Gaoua***	***10°19'45''N 03°11'50''W***		***19314600***	***?***		***D***		***F***
45	***?***	***Pouéné***	***Batié***	***10°20'N 03' 12'W***		***19314950***	***?***		***D***		***F***
46	***?***	***Kou***	***Kodala***	***11°03'N 04°26'15''W***		***19311170***			***D***		***F***
47	***162***	***Yengué***	***Moami***	***11°03'N 20''N 04°26'30'' W***		***19311210***			***D***		***S***
48	***260***	***Yengué***	***Nasso***	***11°12'N'***		***19311220***		***E***	***D***		***S***

IDENTIFICATION DES STATIONS HYDROMETRIQUES *BASSIN VERSANT DU MOUHOUN*											
N°	***Superficie Bassin Versant (2)***	***Cours d'eau (3)***	***Nom de la station (4)***	***Coordonnées (5)***	***Ancien Code (précédent) (6)***	***Code OMM Proposé (7)***	***Année création (ouverture) (8)***	***Equipement station E/LG (9)***	***Nature station N/D (10)***	***Objectif (11)***	***Observations (12)***
				04°26'W							
49		***Mouhoun***	***Lahirasso***	***11°52'N 04°05'N***		***19311420***			***N***		***F***
50	***38***	***Farako***	***Pt de Farakoba***	***11°05'N 04°21'W***		***19311160***	***1961***	***E***	***D***		***F***
51		***Kou***	***Koumi***	***11°08' N 04°25'N***		***19311180***					***S***

Legend: D=Discharge (Débits); N=Water Level (Niveau); LG=Water Level Recorder (Liminigraphe);
S=active in 2000 (Suivi en 2000); F=closed (Fermée); E=stageboard (Echelle limnimétrique)

PARCOURS CHRONOLOGIQUE DES STATIONS HYDROMETRIQUES DU BASSIN VERSANT DU MOUHOUN

Années

N°	Station/BR	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	Sambisgo										--	--	--																																			
2	Guéna								--	--											--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--		
3	Lanviéra								--												--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			
4	Banzo					--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	Samandéni	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	Koumi																																--	--	--	--	--	--	--	--					--	--	--	--
7	Dindérésso																														--	--	--	--	--	--	--	--	--	--	--	--	--	--				
8	Nasso Amont							--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																						
9	Bana																																						--									
10	Badara	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--														--	--	--	--	--	--	--	--	--	--	--		--	--	--	--	--	--
11	Confl Niamé Baoulé																										--	--				--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	Nwokuy Amont	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			--	--		--					--	--	--
13	Bourasso								--																																							
14	Nwokuy Aval																																				--		--		--		--	--	--	--	--	--
15	Bge Léry																										--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	Yaran	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17	Diaradougou					--	--	--	--	--	--	--	--	--																									--	--								
18	Léry Nord	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	Manimenso	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	Confluent S/Mhn	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		--	--		--	--	--	--	--	--	--	--	--
21	Niampourou		--		--	--	--	--	--	--	--	--	--	--	--	--	--																															
22	Tourouba	--	--	--	--	--	--		--	--	--	--		--	--	--																																
23	Baï	--	--	--	--	--	--	--																																								
24	Di		--	--	--	--	--																																									
25	Tenado																						--	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--	--	--
26	Ninion																	--	--	--	--	--									--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	Boromo	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	Bolo/Poura																														--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	Ouessa															--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

PARCOURS CHRONOLOGIQUE DES STATIONS HYDROMETRIQUES DU BASSIN VERSANT DU MOUHOUN

		Années																																														
N°	Station/BR	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
30	Dapola	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	Dan																--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--												
32	Diébougou	--	--	--	--				--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
33	Batié																	--	--	--	--	--	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--	--	--			--	--	--	--	--	--
34	Kodara																																					--	--									
35	Noumbiel																							--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
38	Pa																						--			--	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
39	Poun																							--	--																							
40	Kouri/52	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--							--	--	--	--	--	--	--	--	--														
41	Sakabi									--	--																																					
42	Bourasso								--																																							
43	Lahirasso								--	--	--																																					
44	Farakoba							--		--	--	--																																				
45	Pont Léry sud	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
46	Mouhoun à Poura																														--	--	--	--	--	--	--			--								
47	Desso																																					--	--	--								
48	Guiédougou																															--	--	--	--													
49	Lawra (GH)	--	--	--	--	--	--																																									
50	Bama				--	--	--	--	--	--																		--	--																			
51	Toumani		--	--	--	--	--	--																								--	--	--	--													
53	Yengué/ Nasso																																						--									
54	Mare aux hypo																																						--	--	--	--	--	--	--	--	--	--
	TOTAL	15	18	17	19	19	20	19	23	22	21	19	17	17	16	17	17	17	17	16	18	18	19	20	20	21	22	23	21	21	27	30	31	31	30	25	27	28	32	29	26	23	26	25	26	26	25	25

Appendix 1b: Metadata for river flow stations in the Volta Basin in Ghana (source: HSD)

Sub Basins	River	Type	Station Name	StationID	Area	Gauge	Zero	Region	Project	Established	Closed
Afram	Kyeremfa	Tributary	Kyeremfaso U/S	1014005	466.00	1038.	ft	Ashanti	GoG	01-Dec-71	
Afram	Afram	Tributary	Aframso	1014002	493.00	83.54	ft	Ashanti	WRIS	1-Jan-67	
Afram	Kowire	Tributary	Agogo	1014009	139.00	885.4	ft	Ashanti	GoG	1-Jan-67	1-Mar-90
Afram	Awura	Tributary	Awuraso	1014004	2.00		ft	Ashanti	GoG	10-Jan-69	1-Oct-93
Afram	Chirade	Tributary	Chiradeso	1014003	116.00	973.0	ft	Ashanti	GoG	1-Jan-67	31-Dec-81
Afram	Afram	Tributary	Drabonso	1014010				Ashanti	GoG	17-Dec-75	31-Dec-79
Afram	Drobon	Tributary	Drobonso	1014011	703.00	92.34	ft	Ashanti	GoG	01-Feb-80	30-Jun-84
Afram	Ongwam	Tributary	Kumawu	1014006		83.63	ft	Ashanti	GoG	15-Oct-71	
Afram	Kyeremfa	Tributary	Kyeremfaso D/S	1014008	133.00	90.97	ft	Ashanti	GoG	22-Jun-72	
Afram	Sumampa	Tributary	Mampong (Ash)	1014007	173.00	981.1	ft	Ashanti	GoG	22-Jun-72	
Afram	Afram	Tributary	Mankrong	1014001	101.00	113.0	ft	Ashanti	GoG	10-Jan-63	01-Feb-78
Aklakpa	Aklakpa	River	Aflavenu	1000023	1648.00			Volta	GoG	24-Feb-76	1-Jul-78
Alabo	Alabo	Tributary	Podoe	1015001	4037.00	43.36	m	Volta	WRIS	25-Apr-62	
Asukawkaw	Asukawkaw	Tributary	Dodo Tamale	1011006	153.00	189.3	m	Volta	WRIS	13-Mar-78	
Asukawkaw	Asukawkaw	Tributary	Breniasi	10111002	0.00			Volta	GoG	1-Jan-63	04-Aug-64
Asukawkaw	Asukawkaw	Tributary	Asukawkaw	1011003	262.00	83.02	m	Volta	WRIS	10-Aug-65	
Asukawkaw	Wawa	Tributary	Ahamansu	1011004	228.00	311.5	ft	Volta	GoG	13-Mar-78	
Asukawkaw	Menu	Tributary	Menuso	1011005	43.00	515.2	ft	Volta	GoG	13-Mar-78	
Asukawkaw	Asukawkaw	Tributary	Worawora	10110001	1622.00			Volta	GoG	27-Jul-62	28-Feb-66
Black Volta	Kuon	Tributary	Kunyukuon	1006011	43.00	772.4	ft	Upper	GoG	12-Jul-68	
Black Volta	Sorri	Tributary	Kalbuipe	1006008	51.00	94.13	m	Northen	WRIS	10-Apr-63	
Black Volta	Pale	Tributary	Pise	1006013	141.00	759.9	ft	Upper	GoG	17-May-70	
Black Volta	Dagare	Tributary	Mahatanga	1006012		88.16	ft	Upper	GoG	23-Oct-71	
Black Volta	Black Volta	Tributary	Buipe	1006004	52283.0	235.2	ft	Northen	GoG	26-May-58	
Black Volta	Sorri	Tributary	Damongo	1006019	387.00			Northen	GoG	01-Apr-76	01-Feb-77
Black Volta	Kamba	Tributary	Panyani	1006017	37.00	82.41	ft	Upper	GoG	5-Jun-75	
Black Volta	Pale	Tributary	Pisi	1006016	104.00	83.34	ft	Upper	GoG	1-Oct-71	
Black Volta	Black Volta	Tributary	Lawra	1006002	49714.0	224.1	m	Upper	WRIS	01-May-51	
Black Volta	Black Volta	Tributary	Dab	1006006	46728.0	721.3	ft	Upper	GoG	03-Apr-63	01-Feb-79
Black Volta	Black Volta	Tributary	Chache	1006007	43460.0	202.5	m	Northen	WRIS	06-Apr-63	
Black Volta	Dagare	Tributary	Jingu	1006015		93.36	ft	Upper	GoG	01-0ct-71	31-Aug-77
Black Volta	Black Volta	Tributary	Bui D/S	1006009	461.00	101.9	m	Northen	WRIS	17-Feb-65	
Black Volta	Black Volta	Tributary	Bamboi	1006001		34.75	m	Northen	WRIS	8-Mar-50	
Black Volta	Kamba	Tributary	Tampoe	1006014	101.00	851.1	ft	Upper	GoG	5-Jun-75	
Black Volta	Tain	Tributary	Tainso U/S	1006005	42115.0	40.76	m	Ashanti	WRIS	03-May-62	
Black Volta	Tain	Tributary	Tainso D/S	1006010	289.00	540.6	ft	Ashanti	GoG	1-Jul-67	
Black Volta	Subin	Tributary	Subinso	1006018		528.4	ft	Ashanti	GoG	03-Aug-76	
Black Volta	Black Volta	Tributary	Bui U/S	1006003	48300.0	330.1	ft	Northen	GoG	10-Mar-54	31-Jul-66
Daka	Daka	Tributary	Grube	1008001	3433.00	210.3	ft	Northen	GoG	1-Jun-57	31-Jan-66
Daka	Daka	Tributary	Sabongida	1008003	352.00	68.45	ft	Northen	GoG	06-Feb-61	30-Jun-01
Daka	Daka	Tributary	Yendi	1008002	352.00	505.4	ft	Northen	GoG	01-Apr-58	
Daka	Tanfi	Tributary	Tanfiano	1008006	821.00			Ashanti	GoG	15-Sep-86	31-Dec-86
Daka	Daka	Tributary	Ekumdipe	1008004	597.00	307.9	ft	Northen	GoG	15-May-63	
Daka	Daka	Tributary	New Sabongida	1008005		20.86	m	Northen	WRIS	01-May-97	
Dayi	Dayi	Tributary	Vakpo (Afeyi)	1013001	55.00	260.9	ft	Volta	GoG	06-Feb-62	
Dayi	Dayi	Tributary	Hohoe	1013002	26.00	512.1	ft	Volta	GoG	21-Feb-62	
Dayi	Tsi	Tributary	Soba	1013003				Volta	GoG	15-Jul-72	28-Feb-79

Dayi	Dayi	Tributary	Gbefi	1013006		113.6	m	Volta	WRIS	16-Apr-02	
Dayi	Dayi	Tributary	New Ayoma	1013004	136..00	850.3	ft	Volta	GoG	1-Jun-87	
Dayi	Tsatsadu	Tributary	Alavanyo	1013005	136.00	432.0	ft	Volta	GoG	01-May-86	
Kulpawn	Kulpawn	Tributary	Kulum	1003003		60.81	ft	Upper	GoG	7-Jun-65	22-Jul-66
Kulpawn	Sissili	Tributary	Wiase	1003002	36864.0	125.5	m	Upper	WRIS	08-May-61	
Kulpawn	Kulpawn	Tributary	Yagaba	1003001	35003.0	126.3	m	Upper	WRIS	20-Feb-58	
Kulpawn	Sissili	Tributary	Nakong	1003004	2359.00	696.2	ft	Upper	WRIS	25-Jun-65	
Kulpawn	Kulpawn	Tributary	Wahabu	1003005	1254.00		ft	Upper	GoG	1-Jun-76	01-Feb-78
Mole	Mole	Tributary	Lankatere	1005001		98.20	m	Northen	WRIS	12-Oct-58	
Niasia	Dindebuo	Tributary	Gbensi (Walewale)	1004002	58.00	318.3	ft	Upper	GoG	1-Sep-69	1-Mar-76
Niasia	Nasia	Tributary	Nasia	1004001	853.00	106.8	m	Northen	WRIS	01-May-51	
Oti	Kpassa	River	Kpassa	1010009		105.9	m	Volta	WRIS	11-Mar-78	
Oti	Oti	Tributary	Kpandai	1010005				Northen	GoG	30-Jun-65	31-Aug-65
Oti	Oti	Tributary	Damanko	1010011		226.2	ft	Northen	GoG	08-May-79	01-Feb-95
Oti	Kulaw	River	Benja	1010007	566.00	77.59	ft	Northen	GoG	5-Oct-66	01-Feb-81
Oti	Oti	Tributary	Kpetchu	1010001	969.00			Northen	GoG	27-Jul-52	1-Nov-72
Oti	Bonakye	Tributary	Bonakye	1010010	136.00	464.7	ft	Volta	GoG	17-May-78	
Oti	Oti	Tributary	Sabari	1010003		82.55	m	Northen	WRIS	6-Jun-59	
Oti	Kulaw	River	Zegbeli	1010012	0.00	22.75	m	Northen	WRIS	23-Feb-99	
Oti	Oti	Tributary	Saboba	1010002		310.6	ft	Northen	GoG	20-Mar-53	
Oti	Oti	Tributary	Paliba	1010004		296.2	ft	Northen	GoG	1-Jul-62	30-Nov-66
Oti	Pembik	River	Nabosng	1010008	257.00	25.91	m	Upper	WRIS	5-Oct-66	
Pru	Pru	Tributary	Asauoso	1007004	696.00	82.07	ft	Ashanti	GoG	16-Dec-71	
Pru	Pru	Tributary	Banafour	1007005	184.00	568.0	ft	Ashanti	GoG	01-Aug-76	30-Jun-82
Pru	Pru	Tributary	Pruso	1007001	2711.00	500.5	ft	Ashanti	WRIS	01-May-57	
Pru	Pru	Tributary	Prang	1007002	2543.00	41.43	m	Ashanti	WRIS	01-May-57	
Pru	Fia	Tributary	Nkoranza	1007003		670.7	ft	Ashanti	GoG	1-Nov-68	
Red Volta	Red Volta	Tributary	Nangoli	1002001		184.1	m	Upper	WRIS	1-Jul-58	
Sene	Sene	Tributary	Seneso	1009001		149.0	ft	Ashanti	WRIS	9-Mar-00	
Volta	Volta	River	Anyanui	1000017				Volta		24-Oct-62	01-Aug-76
Volta	Volta	River	Senchi Ferry	1000001	152161.	18.21	ft	Eastern	GoG	8-Nov-30	31-Dec-48
Volta	Volta	River	Senchi-Halcrow	1000009				Volta	GoG	5-Jul-54	31-Dec-82
Volta	Volta	River	Volta Bridge	1000011	3102.00	42.68	ft	Volta	GoG	17-Feb-55	31-Dec-82
Volta	Volta	River	Aveyime	1000013		-2.44	ft	Volta	GoG	01-Aug-60	1-Nov-79
Volta	Volta	River	Sogakope	1000016		38.12	ft	Volta	GoG	18-Oct-62	
Volta	Volta	River	Ada	1000020		18.22	ft	Volta	GoG	12-Sep-63	
Volta	Volta	River	Accra Tefle Rd. Gd.	1000024	0.00			Volta	GoG	18-Oct-68	15-Oct-70
Volta	Volta	River	Misikrom	1000007	152068.			Eastern	GoG	23-Jul-51	3-Jun-64
Volta	Volta	River	Adidome	1000019	0.00			Volta	GoG	1-Jan-63	30-Apr-66
Volta	Volta	River	Senchi New Gauge	1000003	152161.			Eastern	GoG	01-Apr-48	07-Feb-55
Volta	Volta	River	Amedica	1000018	177.00	0.79	ft	Volta	GoG	1-Jan-63	30-Apr-82
Volta	Volta	River	Akwamu West	1000002	152130.			Eastern	GoG	01-May-47	31-Dec-52
Volta	Volta	River	Akosombo U/S	1000012	119.00			Eastern	GoG	23-Sep-56	
Volta	Volta	River	Akosombo D/S	1000015	12.00	30.84	ft	Eastern	GoG	30-Jun-62	
Volta	Volta	River	Ajena Lower	1000010	152085			Eastern	GoG	01-Feb-55	30-Jun-64
Volta	Volta	River	Ajena Halcrow	1000004	152085			Eastern	GoG	01-Aug-50	30-Jun-64
Volta	Volta	River	Yeji	1000006	125.00	30.32	m	Ashanti	WRIS	13-May-51	
Volta	Volta	River	Accra Tefle Rd. Gd II	1000025	0.00			Volta	GoG	18-Oct-68	15-Oct-70
Volta	Volta	River	Kpandu	1000022				Volta	GoG	26-May-64	31-Dec-80
Volta	Volta	River	Kpong	1000005	152175.	-0.04	ft	Eastern	GoG	01-Apr-51	31-Dec-72
Volta	Volta	River	Dodi	1000021	304.00	753.7	ft	Volta	GoG	06-May-64	01-May-79
Volta	Volta	River	Kete-Krachi	1000014	0.00			Volta	GoG	22-May-62	31-Dec-76

Volta	Volta	River	Obentenya	1000008	125.00	0.01	ft	Volta	GoG	3-Jul-52	31-Dec-80
White Volta	White Volta	Tributary	Sougu	1001020	222.00	78.40	ft	Northen	GoG	6-Jul-77	
White Volta	Tamne	Tributary	Garu	1001011		586.3	ft	Upper	GoG	1-Sep-66	
White Volta	Morgo	Tributary	Nayoko	1001019	594.00	93.86	ft	Upper	GoG	1-Sep-70	31-Oct-80
White Volta	Tono	Tributary	Navrongo	1001010		78.95	ft	Upper	GoG	24-Aug-66	31-Dec-76
White Volta	Diegouro	Tributary	Navio	1001024	0.00	94.27	m	Upper	GLO	26-Apr-04	
White Volta	Yaragatanga	Tributary	Sumbrungu	1001013	272.00	85.70	ft	Upper	GoG	1-Sep-66	
White Volta	Morago	Tributary	Nankpanduri	1001004	47.00	536.6	ft	Upper	GoG	1-Jul-58	
White Volta	Bopare	Tributary	Tugu	1001004	640.00	352.2	ft	Northen	GoG	2-Sep-66	1-Nov-90
White Volta	Bongtanga	Dam	Voggo	1001015	158.00	379.6	ft	Northen	GoG	9-Sep-69	31-Dec-75
White Volta	Jolo	Tributary	Aduyeli	1001018	341.00	409.3	ft	Northen	GoG	01-Aug-70	31-Dec-97
White Volta	White Volta	Tributary	Nawuni	1001003		311.6	ft	Northen	GoG	08-May-53	
White Volta	Atamore	Tributary	Bolgatanga	1001012	11.00	537.0	ft	Upper	GoG	1-Sep-66	31-Dec-79
White Volta	White Volta	Tributary	Yarugu	1001008	383.00	981.1	ft	Upper	GoG	12-Jul-62	19-Apr-89
White Volta	Goshie	Dam	Diare	1001017	32.00			Northen	GoG	15-Jul-70	31-Dec-75
White Volta	Pasam	Tributary	Pagaza	1001009	73.00	354.2	ft	Northen	GoG	19-Jul-66	1-Mar-91
White Volta	White Volta	Tributary	Yarugu (Kabori)	1001021	317.00	24.69	m	Upper	WRIS	24-Jun-95	
White Volta	White Volta	Tributary	Daboya	1001007	1647.00	86.81	m	Northen	WRIS	18-Apr-62	
White Volta	White Volta	Tributary	Kpasenkpe	1001006	263.00	89.69	m	Upper	GoG	04-Apr-62	01-Feb-81
White Volta	White Volta	Tributary	Pwalugu	1001001	3134.00	123.7	m	Upper	WRIS	01-May-51	
White Volta	White Volta	Tributary	Yarugu (Bazua)	1001022	0.00			Upper	GoG	19-Apr-89	31-Dec-99
White Volta	Atankuidi	Tributary	Kandiga	1001023	0.00	93.98	m	Upper	GLO	27-Apr-04	
White Volta	Sillum	Tributary	Kumbungu	1001016	233.00	394.4	ft	Northen	GoG	10-Jul-70	01-Feb-77
White Volta	Nabogo	Tributary	Nabogo	1001005	845.00	335.5	ft	Northen	GoG	01-Apr-62	
White Volta	White Volta	Tributary	Yapei	1001002	257.00	76.98	m	Northen	GoG	01-May-51	

Appendix 1c: Metadata for river flow stations obtained from GRDC (data available on enclosed cd and locations are plotted on Figure 1)

no.										Daily data				Monthly data				
GIS map	Station	Major station	Country	River	River system	Latitude [degr.]	Longitude [degr.]	Area [km²]	Altitude [m asl]	start	end	years	missing [%]	start	end	years	missing [%]	Source
1	Guena		BF	Black Volta	Black Volta	11.080	-4.680	800	383					1962	1983	22	66.03	GRDC
2	Banzo		BF	Black Volta	Black Volta	11.320	-4.820	2816	323					1956	1986	31	9.19	GRDC
3	Nasso		BF	Kou	Black Volta	11.200	-4.430	406						1961	1974	14	6.25	GRDC
4	Badara		BF	Kou	Black Volta	11.370	-4.370	971						1955	1985	31	56.91	GRDC
5	Samandeni		BF	Black Volta	Black Volta	11.470	-4.470	4580	296	1977	1983	7	6.7	1955	1987	33	1.78	GRDC
6	**Nwokuy**	y	BF	Black Volta	Black Volta	12.520	-3.550	14800						1956	1988	33	0.00	GRDC
7	Kouri		BF	Black Volta	Black Volta	12.730	-3.480	20000	248					1955	1982	28	31.08	GRDC
8	Manimenso		BF	Black Volta	Black Volta	12.750	-3.400	20000	247					1956	1984	29	0.00	GRDC
9	Tenado		BF	Black Volta	Black Volta	12.170	-2.820	23700						1976	1985	10	0.00	GRDC
10	**Boromo**	y	BF	Black Volta	Black Volta	11.780	-2.920	37140	238					1955	1991	37	0.70	GRDC
11	Ouessa		BF	Black Volta	Black Volta	11.020	-2.820	50820						1969	1986	18	16.67	GRDC
12	Dan		BF	Bougouriba	Black Volta	10.920	-3.650	6345	275	1977	1983	7	8.1	1970	1985	16	18.18	GRDC
13	Diebougou		BF	Bougouriba	Black Volta	10.930	-3.170	12200	240					1963	1987	25	9.72	GRDC
14	Lawra		GH	Black Volta	Black Volta	10.633	-2.917	93820	224	1975	1995	21	50.6	1951	1974	24	0.00	GRDC
15	**Dapola**	y	BF	Black Volta	Black Volta	10.570	-2.920	66540	228	1977	1977	1	0.0	1951	1991	41	0.63	GRDC
16	Batie		BF	Bambassou	Black Volta	9.980	-2.900	5630	230					1971	1985	15	2.86	GRDC
17	Noumbiel		BF	Black Volta	Black Volta	9.680	-2.770	79700	214					1975	1985	11	27.20	GRDC
18	Vonkoro		CI	Black Volta	Black Volta	9.190	-2.710	111500		1979	1993	15	80.8	1979	1982	4	50.00	GRDC
19	**Bamboi**	y	GH	Black Volta	Black Volta	8.150	-2.033	134200	35	1975	1995	21	68.2	1950	1974	25	0.00	GRDC
20	Sakoinse		BF	Red Volta	Red Volta	12.200	-2.020	1210	297					1970	1986	17	29.38	GRDC
21	Dakaye		BF	Red Volta	Red Volta	11.780	-1.600	4540	270	1977	1983	7	1.7	1975	1987	13	1.39	GRDC
22	Bagre		BF	Tcherbo	Red Volta	11.600	-1.570	972						1978	1987	10	29.46	GRDC
23	Nobere		BF	Red Volta	Red Volta	11.430	-1.180	7600	254					1965	1991	27	22.48	GRDC
24	Rambo		BF	Nakambé	White Volta	13.600	-2.070	2375						1983	1987	5	0.00	GRDC
25	Yilou		BF	Nakambé	White Volta	13.000	-1.550	10100	280	1977	1982	6	1.2	1973	1983	11	4.24	GRDC
26	Bissiga		BF	White Volta	White Volta	12.750	-1.150	16965						1976	1985	10	5.83	GRDC
27	**Wayen**	y	BF	Nakambé	White Volta	12.380	-1.080	20880						1955	1988	34	27.27	GRDC
28	Niaogho		BF	Nakambé	White Volta	11.770	-0.750	30200						1964	1986	23	18.18	GRDC
29	Yakala		BF	Nakambé	White Volta	11.550	-0.700	33000		1977	1977	1	11.8	1956	1985	30	16.57	GRDC
30	Bittou		BF	Nouhao	White Volta	11.180	-0.280	4050						1974	1986	13	16.22	GRDC
31	**Bagre**	y	BF	White Volta	White Volta	11.250	-0.330	33120	210					1974	1990	17	6.37	GRDC
32	Yarugu		GH	White Volta	White Volta	10.980	-0.400	41550	170	1975	1990	16	83.6	1966	1974	9	0.00	GRDC
33	**Nangodi**	y	GH	White Volta	Red Volta	10.867	-0.617	11570	184	1975	1990	16	92.9	1958	1974	17	0.00	GRDC

34	**Pwalagu**	y	GH	White Volta	White Volta	10.583	-0.850	63350	123	1975	1995	21	73.1	1951	1974	24	0.00	GRDC
35	Nebbou		BF	Sisili	White Volta	11.280	-1.930	3240						1974	1987	14	14.56	GRDC
36	Wiasi		GH	Sisili	White Volta	10.330	-1.350	9500	126	1975	1991	17	77.7	1962	1974	13	0.00	GRDC
37	Yagaba		GH	Kulpawn	White Volta	10.230	-1.283	10600	126	1975	1980	6	41.6	1958	1974	17	3.65	GRDC
38	**Nawuni**	y	GH	White Volta	White Volta	9.700	-1.080	92950	96	1975	1995	21	16.0	1953	1974	22	0.00	GRDC
39	**Tagou**	y	BF	Kompienga	Oti	11.150	0.620	5640						1980	1988	9	0.00	GRDC
40	Tiele		BJ	Magou	Oti	10.720	1.200	836		1961	1992	32	45.7	1961	1992	32	45.24	GRDC
41	Samboali		BF	Singou	Oti	11.280	1.020	4560		1978	1983	6	15.3	1978	1983	6	11.11	GRDC
42	Arly		BF	Doudodo	Oti	11.530	1.420	6050						1978	1987	10	27.36	GRDC
43	Arly		BF	Pendjari	Oti	11.430	1.570	10960						1978	1986	9	35.42	GRDC
44	Porga		BJ	Pendjari	Oti	10.200	0.970	22280		1952	1992	41	29.1	1952	1992	41	23.41	GRDC
45	**Mango**	y	TG	Oti	Oti	10.300	0.470	35650	108					1953	1974	22	0.00	GRDC
46	Koumangou		TG	Koumangou	Oti	10.200	0.450	6730	120					1959	1974	16	0.00	GRDC
47	Lama Kara		TG	Kara	Oti	9.530	1.180	1560	270	1978	1982	5	21.8	1978	1982	5	21.67	GRDC
48	Kpesside		TG	Kara	Oti	9.620	0.950	2787	180					1962	1974	13	0.00	GRDC
49	**Sabari**	y	GH	Oti	Oti	9.280	0.230	58670	83					1959	1974	16	0.00	GRDC
50	Ekumdipe		GH	Daka	Lower Volta	8.470	-0.220	6810		1975	1995	21	68.1	1963	1974	12	0.00	GRDC
51	Prang		GH	Pru	Lower Volta	7.983	-0.883	6355	41					1957	1967	11	0.00	GRDC
52	**Senchi**	y	GH	Volta	Lower Volta	6.200	0.100	394100	5					1936	1984	49	3.24	GRDC
53	Bolgatanga		GH		White Volta	10.806	-0.825			1966	1968							GLOWA
54	Nakong		GH	Sisni	White Volta	10.798	-1.481			1966	1968							GLOWA
55	Navrongo		GH	Belepieni	White Volta	10.876	-1.142			1966	1968							GLOWA
56	Soboba		GH		Oti	9.705	0.313											

Appendix 2: Results of field water quality tests

No.	Site	Sub-basin	Coun-try	x-coordinate	y-coordinate	Date	EC (at 25°C) [uS/cm]	Temp. [°C]	NO_3 [mg/l]	NO_2 [mg/l]	Hardness total [mg/l]	Hardness carbonate [mg/l]	Ph
1	Bupe Bridge	Black Volta	GH	W1°27.255'	N8°45.921'	25-6-05	92	29.5	<5	<0.5	<107	<53	6.6
2	Yapei Bridge	White Volta	GH	W1°09.535'	N9°08.436'	25-6-05	51	28.1	<5	<0.5	<107	<53	6.5
3	Nabogo Bridge	White Volta (small tributary)	GH	W0°49.443'	N9°44.439'	26-6-05	43	27.4	<5	<0.5	<107	<53	~6.4
4	Nasia Bridge	White Volta (Nasia River)	GH	W0°48.224'	N10°09.315'	26-6-05	55	28.3	<5	<0.5	<107	<53	6.5
5	Pwalugu Bridge	White Volta	GH	W0°50.499'	N10°35.140'	26-6-05	57	28.4	<5	<0.5	<107	18-53	~6.4
6	Bolgatanga - Bawku Road (bridge)	White Volta (tributary)	GH	W0°50.295'	N10°47.200'	26-6-05	73	28.2	<5	<0.5	<107	~53	~6.4
7	Nangodi - Tilli road (bridge)	White Volta (Red Volta)	GH	W0°36.422'	N10°52.698'	26-6-05	41	28.4	<5	<0.5	<107	~53	~6.4
8	Kobore Bridge (Zebilla-Bawku road)	White Volta	GH	W0°23.421'	N10°58.989'	26-6-05	55	28	<5	<0.5	<107	~53	~6.4
9	Between Bawku & border (bridge)	White Volta (small tributary to Nouhao)	GH	W0°12.207'	N11°07.998'	26-6-05	114	30.9	<5	<0.5	<107	53-71	~6.4
10	Road to Bitou (bridge)	White Volta (Nouhao River)	BF	W0°15.458'	N11°12.878'	26-6-05	46	30	<5	<0.5	<107	<53	~6.4
11	Bagré Bridge (downstream of turbine)	White Volta	BF	W0°32.601'	N11°28.381'	26-6-05	77	30.6	<5	<0.5	<107	~53	~6.4
12	bridge just downstream of Bagré irrigation project	White Volta	BF	W0°30.963'	N11°24.554'	26-6-05	90	29.9	<5	<0.5	<107	~53	~6.4
13	Wayen Bridge	White Volta	BF	W1°04.814'	N12°22.740'	26-6-05	59	30.4	<5	<0.5	<107	~53	~6.4
14	Boromo Bridge	Black Volta	BF	W2°54.842'	N11°46.848'	28-6-05	50	27.5	<5	<0.5	<107	~53	~6.4
15	Saboinse Bridge	White Volta (Red Volta)	BF	W2°00.355'	N12°11.633'	28-6-05	21	26.5	<5	<0.5	<107	<53	~6.4
16	Ouagadougou (water from tap in hotel Soritel)	White Volta (water from tap)	BF			28-6-05	122	27.1	<5	<0.5	<107	53-107	6.5
17	Bossora	Black Volta	BF			~8-3-2000	156	24.1	<10				7.55
18	Samandeni (RRNS2)	Black Volta	BF			~29-6-1999	41	25.6	2.35	0.44			6.62
19	Samandeni	Black Volta	BF			~2-3-2000	107	21.4	<10				7.06
20	Noumbiel (RRMI3)	Black Volta	BF			~29-6-1999	66	25.7	2.62	0.49			6.85
21	Marc aux Hippos	Black Volta	BF			~14-3-2000	109	25	0	0.21			7.21

Appendix 2: Results of field water quality tests

No.	Source	Observations
1	this study	
2	this study	
3	this study	stageboard
4	this study	automatic water-level recorder, meteo-station
5	this study	old automatic water-level recorder, diver, meteo-station (GLOWA)
6	this study	river coming from urban area
7	this study	
8	this study	old automatic water-level recorder, water level: 73 cm
9	this study	
10	this study	PAGEV want to establish a gauging station at this site to monitor flood flows
11	this study	no water is being released for hydropower because it is Sunday
12	this study	drainage water from the Bagré Irrigation Project passes this site, EC slightly higher than upstream of irrigation project (sample 11)
13	this study	automatic water-level recorder (DGIRH), satellite water-level warning system (SONABEL), water level: 1.21 m
14	this study	automatic water-level recorder
15	this study	
16	this study	
17	DRAHRH-HB	P_2O_5: 1-2.5; O_2:6 [mg/l]
18	DRAHRH-HB	HCO_3^-=21.35; CO_3^{2-}=0; Cl^-=0;PO_4^{3-}=3.24;SO_4^{2-}=0.08;F^-=0;Ca^{2+}=2.9;Mg^{2+}=2.61; FeTot=1.2;Mn^{2+}=0;K^+=7.5;Zn^+=0;NH_4^+=0.45;Na^+=1 [mg/l]
19	DRAHRH-HB	
20	DRAHRH-HB	HCO_3^-=30.5; CO_3^{2-}=0; Cl^-=0;PO_4^{3-}=3.16;SO_4^{2-}=0.16;F^-=0;Ca^{2+}=5.8;Mg^{2+}=3.28; FeTot=1.9;Mn^{2+}=0;K^+=6.8;Zn^+=0;NH_4^+=0.52;Na^+=3.5 [mg/l]
21	DRAHRH-HB	HCO_3^-=87.84; CO_3^{2-}=0; Cl^-=0;PO_4^{3-}=0.04;SO_4^{2-}=0;F^-=0;Ca^{2+}=10.02;Mg^{2+}=6.55; FeTot=0;Mn^{2+}=0;K^+=21.3;Zn^+=0;NH_4^+=0;Na^+=2.1 [mg/l]

Appendix 3: Itinerary

Date	Day	Activities
June 2005		• Literature search in university libraries (the Netherlands) and on the internet. • Prepare a GIS map of the Volta Basin. • Obtain river flow data on the Volta Basin from the Global Runoff Data Centre.
June 15th		• Telephone conversation with Prof. P.Vlek (GLOWA-Volta Project, Bonn, Germany).
June 18th	1	• Literature reading. • Travel from Amsterdam to Ouagadougou.
June 20th	2	• Obtain visa for Burkina Faso and Ghana. • Meeting with staff from IUCN-BRAO (Madiodio Niasse, Olumide Akinsola) and PAGEV (Kwame Odame Ababio, Jacob Tumbulto, Ludovic Tapsoba) on the Water Audit. • Literature reading.
June 21st	3	Meetings with the following organisations in Burkina Faso (together with Jacob Tumbulto & Ludovic Tapsoba from PAGEV): • DGRIH (Mr. Jean Pierre Mihin - Directeur des Etudes et de l'Information sûr de l'Eau, Mrs. Belemlilga Eléonore), • EIER (Mr. Babacar Dieng, Dr. Harouna Karambiri - Chercheur Assistant) • MOB (Mr. Alassoun Sori - Directeur des Etudes et Travaux), • Direction de la Météorologie (Mr. Kouka Dénis Ouedraogo - Ingénieur Agro-météorologiste). A meeting with IRD was also planned but all the relevant staff had travelled.
June 22nd	4	• Travel by car from Ouagadougou to Accra.
June 23rd	5	Meetings with the following organisations in Accra (together with Jacob Tumbulto & Ludovic Tapsoba from PAGEV and Isaac Asamoah from WRC): • GWCL (Mr. Gilbert Quaye - Head of Projects & Construction Management), • HSD (Mr. Harold T. Clottey, Mr. Ebeuezer Allotey), • IDA (Mr. Kwabena Boateng - Director, Mr. Daniel Nyarko Ohemeng - Deputy Chief Executive Agronomy, B.S. Ouwsu, Yaw Yeboah), • MSD (G.A. Wilson - Deputy Director, Kwa Wunodu, Erasmus Mavfui, Andrew Hkansal), • WRC/WRI (Dr. Charles A.. Biney - Director), WRC (Enock B. Asare - Groundwater Specialist), WRI (Ben Nobiya, Dr Philip Gyau-Boyake, Head of Surface Water). A meeting with GEF-Volta was also planned but all the relevant staff had travelled.
June 24th	6	Continued meetings in Accra: • Volta Challenge Programme (Dr. Winston E.I. Andah - Volta Basin Coordinator), • GLOWA-Volta Project (Dr. Boubacar Barry), • IWMI (Dr. Pay Drechsel - Head West Africa Office). A meeting with VRA was also planned but all the relevant staff had travelled. • Report writing.
June 25th	7	• Travel from Accra to Tamale • Water quality checks at 2 sites along Black and White Volta Rivers
June 26th	8	• Travel from Tamale to Ouagadougou • Water quality checks at 11 sites in the White Volta sub-basin • A short coincidental meeting with a field team from the GLOWA-Volta Project working on small reservoirs (Mr. Jens Liebe - PhD Student and Mr. Kofi Nwarko) • Visit Bagré Dam and Bagré irrigation project
June 27th	9	• Meeting (together with Ludovic Tapsoba) with Sonabel in Ouagadougou (Mr. Bouda Ouiraogo) • Travel from Ouagadougou to Bobo Dioulasso Meetings in Bobo Dioulasso (together with Ludovic Tapsoba from PAGEV): • GEeau (Ir. Joost Wellens - Coopérant Scientifique), • VREO (Mr. Denis C. Dakoure - Coordonnateur National & Mr. Y. Nestor Fiarce Compaore - Chef de Composante Appui Institutionnel), • DRAHRH-HB (Mr. Karimou Bicaba).
June 28th	10	• Travel from Bobo Dioulasso to Ouagadougou. • Water quality checks at 2 sites along Black and Red Volta Rivers. • Meeting (together with Ludovic Tapsoba) with ONEA (Mr. Mahamadou Koné - Chef de Service Gestion de la Demande et des Ressources en Eau).
June 29th	11	• Report writing.

		• Short meeting with Innocent Ouédrafo in PAGEV office (WRCU-ECOWAS). • Visit to DGIRH to obtain meta-data on river flow.
June 30th	12	• A meeting (together with Ludovic Tapsoba) with DGHA (Ouermi Zambendé - Directeur de la Coordination des Aménagements Hydro-Agricoles). • Report writing.
July 1st	13	• Report writing.
July 4th		• Submission of: draft report, equipment for water quality tests, cd with collected information and photocopies of reports that are not digital to PAGEV (Kwame Odame Ababio)
July 6th	14	• Discussion on draft report with staff from IUCN-BRAO (Madiodio Niasse, Olumide Akinsola) and PAGEV (Kwame Odame Ababio, Jacob Tumbulto).
July 7th	15	• Travel from Ouagadougou to Amsterdam.
July 19th		• Written comments on draft report from PAGEV.
July 28th		• Revise draft report. • Submission of final report to PAGEV (Kwame Odame Ababio).