Water, Climate, Food, and Environment in the Volta Basin

Contribution to the project ADAPT

Adaptation strategies to changing environments

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TABLE OF CONTENTS

1. INTRODUCTION

The Volta Basin is located in West Africa and lies within latitudes $5^{o}.30$ N and 14^{o} 30 N and longitudes $2^{o}.00$ E and $5^{o}.30$W. The main channel is 1400km and it drains 400,000km^2 of the semi-arid and sub –humid savanna area. The basin lies mainly in Ghana (42%) and Burkina Faso (43%) with minor parts in Togo, Cote d´Ivoire, Mali and Benin. Ghana occupies the downstream part of the basin. A dominating feature of the basin is Lake Volta, which is the largest man-made in the world in terms of surface area (4% of total area of Ghana). The lake was created to generate hydropower at Akosombo and Kpong (1060MW), which is 100km north of its estuary.

Water Resources plays a vital role in the promotion of economic growth and reduction of poverty in Ghana. There is rapidly increasing demand for water in industries (particularly hydropower generation, agriculture, mining, recreation domestic and industrial consumption and environmental enhancement). With these demands, water supplies will be severely stretched and pollution problems and environmental degradation are likely to increase. The situation will worsen as the population continues to grow, urbanisation increases, standard of living rises, mining becomes widespread and human activities are diversified. Lower rainfall amounts over the years due to longer dry seasons have led to more and more tributaries as well as main rivers drying up quickly, leading to lesser amounts of surface and ground waters available for the increasing population.

Climate change is a global phenomenon associated with emission of greenhouse gases into the atmosphere with the resultant effect of raising the global mean temperatures. The emissions, to a large extent, are associated with human activities such as burning of fossil fuels. The levels of emission depend on the degree of industrialisation of the country and available technology among other factors. However, the impacts of the climate change on the natural resources of the region depend on the changes or modifications in the atmospheric circulation over the area induced by the changes in global atmospheric chemistry. Climate change can have very serious negative effects on the socio-economic development of the country if the potential impacts are not identified for appropriate adaptive measures to be put in place. A number of sectors can be impacted by climate change and these include water resources, coastal zone resources, agriculture, human health, energy, industry, forestry, fisheries and wildlife. Agriculture in Ghana is mainly practiced under rain-fed conditions. Irrigation practice in the country is on a very small scale. However, with increase in population and the need to meet food security under Ghana's poverty alleviation strategy, more lands are envisaged to be put under irrigation

This study is part of a larger program called ADAPT. The objective of the ADAPT project is to assess the impacts of climate change and climate variability on global food production and security, environment and livelihoods, link these impacts to similar effects on a basin level and finally develop and promote adaptation strategies for food and environment to alleviate the negative impacts, on a basin scale. This study looks at the impacts of climate change on water resources, food security and the environment and consequently the socio-economic situation of the people with the view to develop adaptation strategies to reduce its vulnerability or alleviate the negative impacts on people and the environment.

2. NATURAL RESOURCES

2.1. Climate

The climate of Ghana, as the rest of tropical West Africa is dominated by the movement of the Inter Tropical Convergence Zone (ITCZ) which is the region where the hot, dry and dust harmattan air mass from the Sahara in the North meets the cool, moist monsoon air from the South Atlantic. The ITCZ is characterised by vigorous frontal activity and its movement controls the amount and duration of rainfall.

Normally from December to February, the front lies across the Gulf of Guinea and the dry harmattan prevails over the whole country. Between March and November, the ITCZ moves across Ghana in a complex fashion crossing some areas twice, which results in a distinctly bimodal rainfall pattern. At higher latitudes the interval between the two peaks decreases until at the limit only a single peak is evident. In the bimodal area in the South, the peak rainfall periods are June July and September October. In the North, the maximum rainfall month is normally September. The rainfall reduces eastwards and northwards to about 800mm and 1000mm respectively.

Generally, the mean temperature never falls below 25^{o}C in the country. This is explained by the fact that no part of the country is really far from the equator. The hottest month of the year is March-April and the coolest is August. There is a variation of 5-6^{o}C in the south and 7/9^{o}C in the north.

The southern section of the country is more humid than the north. In the coastal area of Ghana the relative humidity are 95-100% in the morning and about 75% in the afternoon. In the north values can be as low as 20-30% during the Harmatan period and 70-80% during the rainfall period.

2.2. Topography

The Volta basins comprise the White, the Black Volta, the Daka and the Oti basins. The local relief of the White Volta is about 400m with the maximum altitude of around 600m in the Gambaga hills in the northeast. There is considerable variation in local relief of the Black Volta, varying from 150m – 300m and increasing from the south to the north. The main Volta is generally below 150m with a few areas around the rim of the basin attaining altitudes of more than 300m above sea level. The Daka is not much more than about 150m above sea level.

2.3. Land use

Predominant land use of the White Volta is extensive land rotation cultivation two to six miles away from the village with widespread grazing of large numbers of cattle and other livestock (up to 100 cattle/km2 (FAO, 1991); and compound cropping (home gardening) around the house (Wills, 1962; Adu, 1967; USAID/ADB, 1979; FAO, 1963). Estimates of land use and land cover in 1989 showed that about 50% of the land in the north-east and northern parts of the basin were in the compound and bush fallow cultivation cycle (IFAD, 1990). Farm sizes are usually less than 3 acres. Grazing lands are poor and are those obtainable under natural conditions and annual bush burning. The major land use of the Black Volta is agriculture with extensive bush fallow cultivation under food crops. The major food crops include yams, cassava, maize, sorghum, millet, groundnuts and beans. Animal grazing on the free range is an important activity. Animal numbers are large in the northern and middle parts of the basin in Ghana. Mining for gold in the Birimian rocks in the northern parts of the basin in the 17^{th} and 18^{th} centuries has been reactivated as a growing small scale surface mining activity. Urban land use is most intensive in Lawra, Wa, Bole, Damango, and Wenchi.

The main Volta land use is short bush fallow cultivation along he immediate banks of the river, and less intensive bush fallow cultivation elsewhere. Animal grazing is common while the lake shore is extensively settled by fishing families. Charcoal burning involving the cutting of wood becomes an extensive economic activity in the southern dry forest and transitional environments e.g. the various part of the Afram sub-basin on the West shores of Lake Volta. The Afram plains and other areas in the south have been the focus of increasing settlement and agricultural development since the 1960s, having been generally thinly populated in the past as part of the empty "middle belt" (Dickson and Benneh, 1987). The forested and transitional areas are intensively farmed with cocoa, coffee, plantain, cocoyam, cassava, oil palm and maize on small bush fallow plots. Some timber extraction takes place in these areas. Recent developments, particularly below the Akosombo dam include irrigated rice, sugar and vegetable cultivation in the areas immediately adjoining the Volta river.

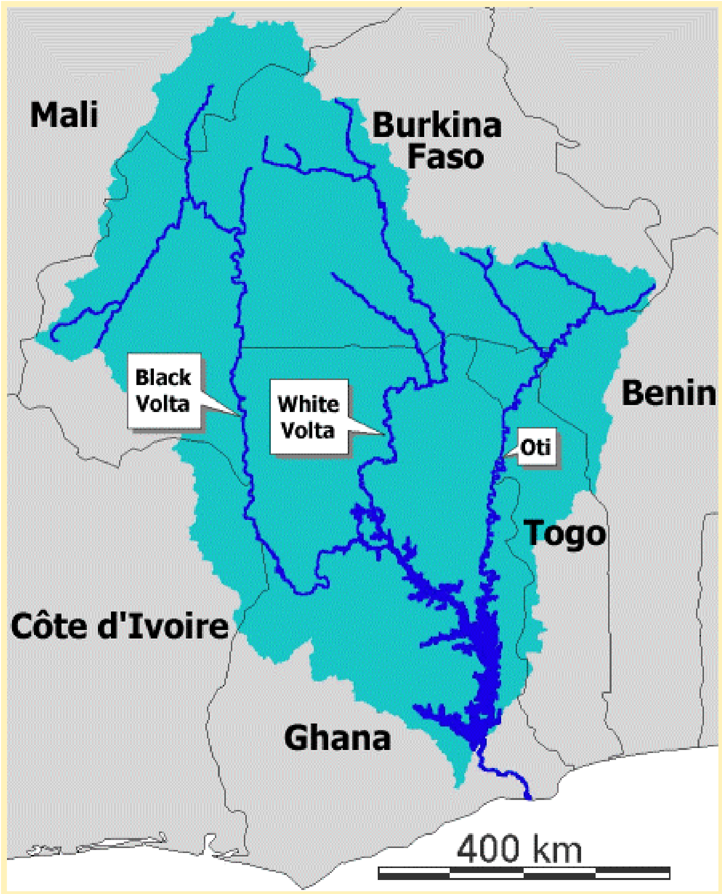
2.4. Water Resources of Ghana

2.4.1 Surface Water Resources

Ghana is drained by 3 main river systems. These are the Volta, South-Western and Coastal River Systems. They cover 70%, 22% and 8% respectively of the total area of Ghana. The Volta system consists of the Black and White Volta rivers and the Oti River.

The total annual runoff from all rivers is 56.4 billion m^3 of which 41.6 billion m^3 is accounted for by the Volta River. The mean annual runoff from Ghana alone is 38.7 billion m^3 which is 68.6% of the total annual runoff. The Volta, South-western and Coastal system contribute 64.7, 29.2 and 6.1% respectively of the annual runoff from Ghana.

Runoffs are marked by wide variability between wet season and dry season flows. Table 2.1 below gives a summary of surface water availability within and beyond the country. The Table shows that 50.2 % of the combined catchment areas of the river basins in Ghana lie outside the boundaries of Ghana. The country however receives 69.7 % of waters generated by these catchments.



The Volta River basin; shared by Ghana Ivory Coast, Upper Volta, Togo, Benin and Mali.

River Basin	Area (km^2)				Mean Annual Runoff ($x10^6$ m^3)			
	Within Ghana	**Outside Ghana**	**Total**	**% Within Ghana**	**Within Ghana**	**Outside Ghana**	**Total**	**% Within Ghana**
Volta Basin System								
Black	35 107	113 908	149 015	23.6	4 401	3 272	7 673	57.4
White	45 804	58 948	104 752	43.7	6 073	3 492	9 565	63.5
Oti	16 213	56 565	72 778	22.3	2 498	8 717	11 215	22.3
Lower	59 414	3 237	62 651	94.8	9 114		9 842	92.6
Total	**16 5712**	**232 658**	**39 8370**	**41.6**	**24 175**	**16 209**	**40 384**	**59.9**

Table 2.1 Water Resources Availability in Volta Basin

2.4.2 Groundwater Resources

The country is underlain by 3 main geological formations. These are the basement complex comprising crystalline igneous and metamorphic rocks; the consolidated sedimentary formations underlying the Volta basin (including the limestone horizon) and the Mesozoic and Cenozoic sedimentary rocks. The basement complex and the Voltain formation cover 54% and 45% of the country respectively. The remaining 1% consists of Mesozoic and Cenozoic sediments.

Groundwater occurrence in the basement complex is associated with the development of secondary porosity as a result of jointing, shearing, fracturing and weathering. Depth of aquifers are normally between 10 m to 60 m; and yields rarely exceed 6 m^3h^{-1}

In the Mesozoic and Cenozoic formations occurring in the extreme south eastern and western part of the country the aquifer depths vary from 6m to 120m. There are also limestone aquifers some 120m to 300m in depth. The average yield in the limestone aquifers is about 184 m^3h^{-1}.

2.4.3. Water Quality

Though some historical data was available for all the rivers, these varied greatly in terms of period and time when they were studied. The mean results of the physico-chemical analysis of samples collected from several stations give an indication of the quality of the river systems. Since each of the stations lie on a tributary of the Volta, the data is also fairly representative of the quality of inflows to the Volta Lake. The period of sampling ranged from 1976 to 1978. To assess the area changes the mean and the standard deviations were calculated. It was observed that some parameters did not change with respect to location in the basin while others did. It is also deduced that for example, the pH and dissolved oxygen were generally the same through the river system.

Unfortunately, the data did not cover the entire water year thus inferences could not be made regarding seasonality of water quality changes. An assessment has been made of the suitability of the water in relation to potable water supply and agricultural use (Nerquaye-Tetteh et al, 1984). WHO surface water standards and Scofield's classification for potable water supply and agricultural supplies were respectively employed. The assessments confirmed the waters to be suitable for both purposes.

An intensive limnological investigation of the physio-chemical conditions of the Volta Lake with a view to developing fishery resource was part of project undertaken by the Government of Ghana with assistance from the United Nations Development Programme and the FAO and reported in 1971. The distribution of temperature and dissolved oxygen were studied over a period of two years. It was observed that, for a tropical lake the temperature is still high averaging between 27^{o}C near the surface to 29^{o}C at the surface, the northern part being warmer than the southern. Themocline depth varied with season and was found to have increased from 15m to 35m since the filling of the lake. The main lake is generally stratified except during the wet seasons (June to September) and during the period of the hot Harmattan wind (between December and March).

Local differences from the pattern occur in tributaries and arms of the lake. Oxygen distribution is similar in that is generally stratified except for the mixing periods. Although the hypolimnion is deoxygenated from, or just below, the thermocline 79% of the total water mass is almost always suitable for fish life. Very low oxygen concentrations can be found in shallow water and within weed mats.

Table 2.2 Summary of Water Quality at some Stations on the Oti, White, Black and Lower Volta

Parameter	Oti River at Sabra (Nov 76 to Feb 78)		White Volta at Daboya (Aug 77 to Feb 78)		Black Volta at Bamboi (Aug 77 to Feb 78)		Lower Volta at Amedeka (Apr 77 to Mar 78)	
	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev
PH	6.9	0.5	6.9	0.4	7.0	0.5	7.1	0.3
Conductivity	280	213	194	156	201	154	520	245
Dissolved Oxygen	9.9	2.4	10.6	3.8	11.2	3.1	8.0	2.0
BOD	2.7	1.3	105	0.5	3.8	2.3	2.8	2.2
Alkalinity	35.3	11.5	42.6	16.5	53.8	23.6	44.8	6.4
Chloride	5.4	2.8	13.6	8.6	7.0	0.8	4.6	2.5
Calcium	4.8	2.0	6.8	2.0	10.1	2.9	5.3	1.4
T Hardness	22.9	10.8	30.4	2.8	44.1	18.6	17.4	7.3
Magnesium	4.3	2.2	5.8	0.8	8.3	4.1	2.5	1.9
Ammonia-N	1.0	1.5	1.6	2.9	1.5	2.4	0.4	0.5
Phosphate	0.9	0.4	0.7	1.0	0.6	1.9	0.2	0.3
Nitrate	0.2	0.1	0.5	0.6	0.2	0.1	6.6	10.9
Nitrite	0.08	0.02	0.06	0.08	0.1	0.1	0.6	1.3
Sulphate	5.7	6.6	8.9	10.7	7.0	8.4	1.2	0.8

Other physico-chemical measurements included transparency (which varied from 400cm in the main lake to 30cm in the north during the flood period); pH, alkalinity, phosphate, nitrate, ammonia, iron, silica, calcium, magnesium, potassium, sodium and hydrogen sulphide. Nutrient content of the Volta Lake is low compared to other tropical lakes but high concentrations occurred during flood conditions of strong mixing. Nutrients so released are quickly taken up by plant growth so that a dynamic study is more important than the situation at a particular instant. Areas of high plankton production are evident. The pH ranged in the northern sections of the lake between 6.8 and 7.4 at the surface and stabilised at 6.7 at the bottom. In the south, the pH on the surface ranged from 7.8 to 8.5. The inflowing tributaries were observed to sometimes have higher pH values. Free carbon dioxide followed the normal pattern, mostly increasing towards the bottom following the decrease of oxygen. In the thermocline or whenever the DO content drops to zero, an increase in free carbon dioxide followed.

Marked differences in total alkalinity of water were found between the upper and lower reaches of the Volta River before the Dam was built (Biswas, 1967). This applied also to the smaller and larger tributaries. After the Dam was built the differences were nearly equalised and there was hardly any change from north to south. The content ranged between 19 and 41mg/$CaCo_3$ in the open lake and was up to 50mg/l in the Sene River. In general, the alkalinity of the Volta Lake is very low. Iron was mostly detected in the surface water layers in the north. In the south it was only found in the hypolimnion, but in higher concentrations. The distribution of orthophosphates in the lake was similar to iron. Phosphates were recorded at all depths in relatively high concentrations (up to 0.5mg/l) in the north, where it is possibly brought in by the Black and White Voltas. In all other parts of the lake, orthophosphate was sometimes not detectable in the epilimnion, especially after long periods of stagnation. In all probability the lack of phosphorus prevents an improvement of primary production in the main lake.

The same pattern exists for nitrate-nitrogen. In the northern regions as well as the upper parts of the tributaries, the amount is quite high and has the tendency to decrease towards the south. But as soon as a water bloom of phytoplankton appears, this nutrient depletes almost entirely in the surface layers. Nitarte-nitrogen is not necessarily a limiting factor in phytoplankton production in the lake, as it might be in other lakes.

Ammonia was mostly present in the hypolimnion where it accumulates during stagnation period like iron and phosphates. However, in the Obosum and in other areas near the shoreline, it was also found in quite high concentration, up to 1.2mg/l on the surface. Silica was always available in sufficient quantities between 12mg/l and 25mg/l SiO_3 in the main lake, and up to 27mg/l in the Upper Afram for diatom production. Calcium and magnesium were inform in vertical as well as in horizontal distribution and ranged mostly under 10mg/l Ca and 5mg/l Mg. The same can be said for potassium and sodium which had low values. Conductivity ranged from 63uS/cm in the north up to 172uS/cm at Kete Krachi. The differences between surface and bottom were very little.

2.5 Soils

The soils of the country are derived from rocks of the mid Palaeozoic age or older, comprising mainly Siluro-Devonian sandstone and shales and some igneous and granitic material. The annual rainfall in the southern forest zone is between 1000 mm and 2000 mm. They are characterised by an accumulation of organic matter in the surface horizon. Forest ochrosols are the most extensive and important of these soils. The rest, mainly in the wetter areas, are Forest Oxysol intergrades. The northern savannah contain much less organic matter and are lower in nutrient than the forest soils. The soils consist mainly of savannah ochrosols and groundwater laterites formed over granite and Voltain shales. In the coastal savannah, soils are younger and closely related to the underlying rocks. They are mainly a mixture of savannah ochrosols, regosolic groundwater laterites, tropical black earths, sodium vleisols, tropical grey earths and acid gleisols and are generally poor largely because of inadequate moisture.

3. SOCIO-ECONOMIC CHARACTERISTICS

The overall population with access to safe drinking water supply was estimated at 57% in a 1992 survey. This survey was conducted by the Community Water and Sanitation Divison (CWSD) of the Ghana Water and Sewerage Corporation (GWSC) with the assistance of UNICEF. In the rural areas, the population served was 46% while the urban population served was 76%. In 1998, data collected by CWSA and GWCL as part of their strategic investment plans indicated that 30% of the population in rural areas and 70% in urban communities currently have access to safe drinking water. However these figures excluded water supplied by vendors and trucks. Surveys carried out under the Core Welfare Indicators Questionnaire (CWIQ, 1997) and Ghana Living Standards Surveys (GLSS, 1998/99) indicated that the national access to safe water supplies was between 66% and 73% for the period between 1997 and 1998/99. Table 3.1 gives a breakdown of the latest access situation.

The GDP per capita in 1996 was $375 at current prices (Statistical Services and Bank of Ghana: see *ISSER, 1999*). Overall real GDP rose by 4.6% in 1998 with an average annual rate of inflation of 19.3% in 1998 down from 27.9 in 1997 (see table 3.2).

	Source	**Inside Plumbing 1**	**Water Vendor /Truck 2**	**Others (Incl. wells and b/holes) 3**	**Natural Sources 4**	**Overall Access (1+2+3)**
Ghana	CWIQ (1997)	14	4	48[a]	34[a]	66[a]
	GLSS (1998/99)	38	35		27	73
Rural	CWIQ (1997)	2	2	48[a]	48[a]	52[a]
	GLSS (1998/99)	17	47		35	73
	CWSA (1998)					30[b]
Urban	CWIQ (1997)	37	7	48[a]	8[a]	92[a]
	GLSS (1998/99)	78	11	?	?	89
	GWCL (1998/99)					70

Table 3.1 Household Coverage of Different Water Supply Sources *Excludes unprotected wells in (3) and includes them in (4) CWSA definition of rural changed between 1992 and 1998 to include small towns with population up to 15,000 in the 1998 estimates.*

Indicator	**1994**	**1995**	**1996**	**1997**	**1998**
Per Capita GDP at current Prices (US$)	320	370	375	NA	NA
Growth Rate of Real GDP	3.7	4.5	5.2	5.1	4.6
Inflation Rate (%)	24.87	59.47	46.56	27.9	19.3

Table 3.2 GDP and inflation rate trends *Source: Institute of Statistical, Social and Economic Research (1999):*

Population figures for Ghana based on census data are available for 1960, 1974, and 1984. The last population census of the country taken in 1984 gave a total of 12,205,574 people with an average population density of 51.6 persons / km^2. The distribution of the 1984 population also showed that 30 % of the population lived in urban areas of 5000 inhabitants and above in all the ten regional capitals. It is estimated that the country had a total population of about 18.9 people in 1998 with an annual growth rate of about 3% per annum. About 65% of the total population was estimated in 1995 to be rural. Projections of the population and other population-related statistics up 2020 are given in Tables 3.3 and 3.4.

Indicator	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	***2025***[a]
Total Pop. (x1000)	15028	17608	20564	23845	26931	29884	32708	*35943*
Density (pop/km^2)	63	74	86	100	113	125	137	*151*
Urbanisation (% of Total Pop.)	33.0	35.1	37.9	41.3	45.3	49.2	52.9	*57.5*

Table 3.3 Population Statistics (1990 - 2020). *Source: UN (1991) World Population Prospects 1990; Population Studies No. 120. Projected from the data up to 2020*

From these projections, it is expected that the population of the country by 2020 will be more than double the population in 1990, with a projected average density of 137 persons / km^2. with 53 % of the population in urban areas of 5,000 inhabitants and above.

	1985 - 1990	1990 - 1995	1995 - 2000	2000 - 2005	2005 - 2010	2010 - 2015	2015 - 2020
Ann. Pop. Growth Rate (%)	3,15	3,17	3,1	2,96	2,43	2,08	1,8
Total Fertility Rate Per Woman	6,39	6,29	5,99	5,48	4,28	3,43	2,8
Infant Mortality Rate (Per 1000 Births)	90	81	73	65	57	50	43
Life Expectancy at Birth (yrs.) - Male	52,2	54,2	56,2	58,2	60,2	62,2	64,2
Female	55,8	57,8	59,9	61,9	63,9	65,9	67,8
Male & Female	54	56	58	60	62	64	66

Table 3.4 Population Statistics 5 Year Intervals 1985/1990 - 2015/2020. Source: UN (1991) World Population Prospects 1990; Population Studies No. 120.

3.1 Agriculture Development, Urbanisation and hydropower

Figures from the 1984 census showed that there were 189 settlements with population sizes greater than 5,000 inhabitants (classified as urban). The frequency distribution of these settlements are given in the table 1.5 below:

The national capital, Accra, with the adjoining sea port town of Tema had a total population of 1.2 million in 1984. Out of the 189 settlements, classified as urban, 110 are district capitals, out of which 10 are regional capitals. Three of the regional capitals, Accra, Kumasi and Takoradi are statutorily declared cities.

Table 4.5 Distribution of Urban Settlements

Population Size	**No. of Urban Areas**
5,000 – 10,000	120
10,000 – 20,000	42

20,000 – 50,000	19
50,000 – 100,000	3
100,000 – 500,000	4
Above 500,000	1
Total	**189**

At the end of 1988, 12% of the total land area of Ghana was taken by cropland, 15% by permanent meadows and pastures, 36% by forest and woodland while other land accounted for 37%. As at 1998 the total area cultivated under the four major starchy crops of the country (Cassava, yam, cocoyam and plantain) increased from 1.21 to 1.31 million hectares while the total area cultivated for the major cereal crops increased from 1.28 to 1.34 million hectares. The land under irrigation formed only a negligible part of the arable and permanent cropland. Presently, only 10,000 ha out of a potential 346,000 ha are under irrigation.

4. INSTITUTIONAL ARRANGEMENTS

Institutional analysis conducted by GLOWA Volta research team after several rounds of interviews with regional experts from the water sector revealed major policy reforms have deeply affected the institutional set-up since the end of the nineties. Basically four types of institutions were defined: national, regional, district, and local. Many national institutions tend to delegate responsibility to the regional and district level, which in turn have to cooperate with the local level. First results of the analysis of the local institutions and the national institutions indicate that many implementation problems occur at the district level, as these institutions are neither sufficiently financed nor trained for the tasks they have to fulfill in water management. The interviews with experts at the national level as well as recent literature underlined high priority for the electric power sector in Ghana. It is likely that this sector will develop various projects (hydropower, thermal plants, West African Gas Pipeline) in order to reduce the regular power shortages regularly in the country. To supply the population with sufficient electricity is at the top of the political agenda.

Decision-makers in various Ghanaian institutions agreed that competing water use between hydropower and irrigated agriculture should be avoided. If irrigated agriculture is to be expanded, this should be in places where there is no competition between agricultural and hydropower use as the area below the Akosombo dam. On the other hand, riparian countries also aim at expanding irrigated agriculture and developing hydropower. Burkina Faso for example is planning a hydropower dam for the supply of Ouagadougou. Togo and Ghana had an exchange agreement on electricity. It is the basis for importing energy from Ghana in the rainy season and exporting it to Togo in the dry season. Togo furthermore exported energy to Ghana in the peak time of the daily power consumption. Togo has recently developed its own thermal plants and does no longer depend on Ghana for power production. Close cooperation is thus needed for the riparian countries in the Volta basin to make an optimal use of the available water resources.

Interviews conducted with different stakeholders by the GLOWA Volta team in the national water related institutions indicated that there are four types of institutions

i Institutions that are still in place but of minor relevance in the institutional landscape and are poorly financed (e.g. Irrigation Development Authority, IDA

ii Mature, "bloated", institutions employing a huge staff but which are asked to perform such a variety of tasks they are unable to focus on any of them. For example, EPA is responsible for environmental protection ranging from noise reduction to air pollution and also water quality. This agenda requires a range of capacities that one institution finds difficult to develop.

iii New institutions established during the process of water sector reforms which have clearly defined tasks and are relatively small number of staff (e.g. Water Resources Commission, Public Utilities Regulatory Commission)

iv Institution that are being considered to be privitised (e.g. Ghana Water Company, Electricity Company of Ghana.

5. PROJECTIONS

5.1. Population

Present population increase in Ghana is just less than 2.5% per year. In Burkina Faso the increase lies just over 3.0%. Projections by the United Nations (Table 3.3) show a general decline in population growth rates. The FAO studies used in the ADAPT project (Revised UN projections) foresee for 2030 a population in Ghana of 32 million and of 29 million for Burkina Faso.

At basin level, we assumed an average population increase of 2.5% per year over the whole 21st century. For the first projected period (2020-2039), this is in concordance with both the revised UN projections and the SRES scenarios. For the second period (2070-2099), the rate of 2.5% per year is a relatively high estimate and the model projections for household water are, therefore, pessimistic. As will be shown later, domestic water consumption is still small compared to total available water resources, even though the population projections for the second period may be unrealistically high. Table 5.1 shows the population projections for the different sub-basins used in this study.

	1961	2020	2070
Black GH	1.03	4.42	15.19
Black BF	3.4	14.59	50.16
White GH	1.6	6.86	23.60
White BF	3.23	13.86	47.65
Oti GH	0.19	0.81	2.80
Oti TG	1.43	6.13	21.09
Lower	2.15	9.22	31.72
Total	13.03	55.93	192.24

Table 5.1 Population projections for Volta sub-basins

5.2 Climate

Four different climate change projections were used based on the A2 and B2 SRES forcing scenarios. The following description of the models and scenarios is taken from Droogers and van Dam (2003) as it provides the standard used throughout the ADAPT Project. For the hydrological projections at basin scale, it was necessary to adjust slightly the data pre-processing, as described in Chapter 6.

The Intergovernmental Panel on Climate Change (IPCC) provides on its data distribution center results from seven General Circulation Models (GCM) (IPCC, 2003). Somewhat arbitrary we have selected to use the model from the Hadley Centre for Climate Prediction and Research, referred to as HADCM3, and the one from the Max Planck Institute für Meteorologie, referred to as ECHAM4.

Resolution of the two models differs substantially. The atmospheric component of HADCM3 has 19 levels with a horizontal resolution of 2.5 degrees of latitude by 3.75 degrees of longitude, which produces a global grid of 96 x 73 grid cells. This is equivalent to a surface resolution of about 417 km x 278 km at the Equator, reducing to 295 km x 278 km at 45 degrees of latitude. ECHAM4 uses also a vertical resolution of 19 layers, but the spatial resolution is horizontal resolution of 128 x 64 grid points. **Error! Reference source not found.** shows the grids for HADCM3 and ECHAM4.

HADCM3 was run for the period 1950-2099, while ECHAM4 from 1990-2100. This means that for ECHAM4 no real reference period is available to downscale to local conditions, and we therefore assumed that the period 1990-1999 was similar to the reference period in the CRU dataset from 1961-1990. Further details and additional links to the specification of the GCMs can be found at the IPCC website (IPCC, 2003).

A summary of downscaling of GCM results is described here. For the historical data series, the East Anglia Climate Research Unit (CRU) database was used to provide data on temperature and precipitation for all seven basins over the 1961-1990 time slice (New et al., 2000). This database provides a consistently interpolated global land surface dataset, with for each month between 1901 and 1996 an average value on a 0.5°x0.5° grid.

Different statistical transformations exist that ensure that GCM and historical data have similar statistical properties. Here, it was decided to use the method developed by the group Alcamo/Doell at the University of Kassel because it is generally accepted within the global change research community (Alcamo et al., 1997). This method is briefly described here whereby it should be noted that the approach for temperature is not the same as for precipitation. For temperature, absolute changes between historical and future GCM time slices are added to measured values:

$$T'_{GCM,fut} = T_{meas} + (\overline{T}_{GCM,fut} - \overline{T}_{GCM,his}) \qquad (6)$$

in which $T'_{GCM,fut}$ is the transformed future temperature, T_{meas} the measured temperature for the 30 years reference period, $\overline{T}_{GCM,fut}$ the average future GCM temperature and $\overline{T}_{GCM,his}$ the average historical GCM temperature. The average of the transformed GCM temperature for historical times is thus the same as for measured historical temperatures. For precipitation, relative changes between historical and future GCM output are applied to measured historical values:

$$P'_{GCM,fut} = P_{meas} * (\overline{P}_{GCM,fut} / \overline{P}_{GCM,his}) \quad (7)$$

in which $P'_{GCM,fut}$ is the transformed future precipitation, P_{meas} the measured precipitation, $\overline{P}_{GCM,fut}$ the average future GCM precipitation and $\overline{P}_{GCM,his}$ the average historical GCM precipitation.

We have selected A2 and B2 IPCC emissions scenarios projections, or the so-called SRES (Special Report on Emissions Scenarios). Within the SRES projections a set of four "scenario families" exists, referred to as "storylines". The storylines of each of these scenario families describes a demographic, politico-economic, societal and technological future. Within each family one or more scenarios explore global energy, industry and other developments and their implications for greenhouse gas emissions and other pollutants.

The four marker scenarios combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization. From the four marker scenarios we have selected the A2 and B2 ones as there seems to be a kind of consensus that these, although less positive than A1 and B1, are more realistic. A more practical reason is also that since the A2 and B2 are seen as more realistic, GCM results are not always available for the A1 and B1 scenarios. The storylines for A2 and B2 are summarized as follows:

> A2: A differentiated world. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.
>
> B2: A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a heterogeneous world with less rapid, and more diverse technological change but a strong emphasis on community initiative and social innovation to find local, rather than global solutions.

The following pages show the temperature and rainfall results for the four different combinations of GCM (Hadley and ECHAM4) and SRES A2 and B2 for the Volta Basin as found in Droogers and van Dam (2003) with descriptive comments added. In each figure, the values shown to the left of the dotted line are historical data for CRU and GCM. These GCM data have not yet been normalized. To the right of the dotted line, the normalized GCM projections are given for the simulation periods 1961-1990, 2010-2039, and 2070-2099. The data are summarized by so-called "whisker boxes". The horizontal line through the boxes gives the average value. The lower and upper sides of the boxes represent the average minus and plus one standard deviation, respectively. The "whiskers" give the minimum and maximum values found in the set, unless real outliers (points that do not fit the general distribution) were present which are marked by diamonds.

Basin	**Volta**
Climate	**Hadley A2**

Period	1961-1990	2010-2039	2070-2099
Temperature (^oC)	27.3	28.5	31.8
Std (^oC)	0.5	0.5	0.8
CV (%)	1.7	1.7	2.5
Precip. (mm y^{-1})	1079	1161	1147
Std (mm y^{-1})	115	105	123
CV (%)	10.7	9.0	10.7

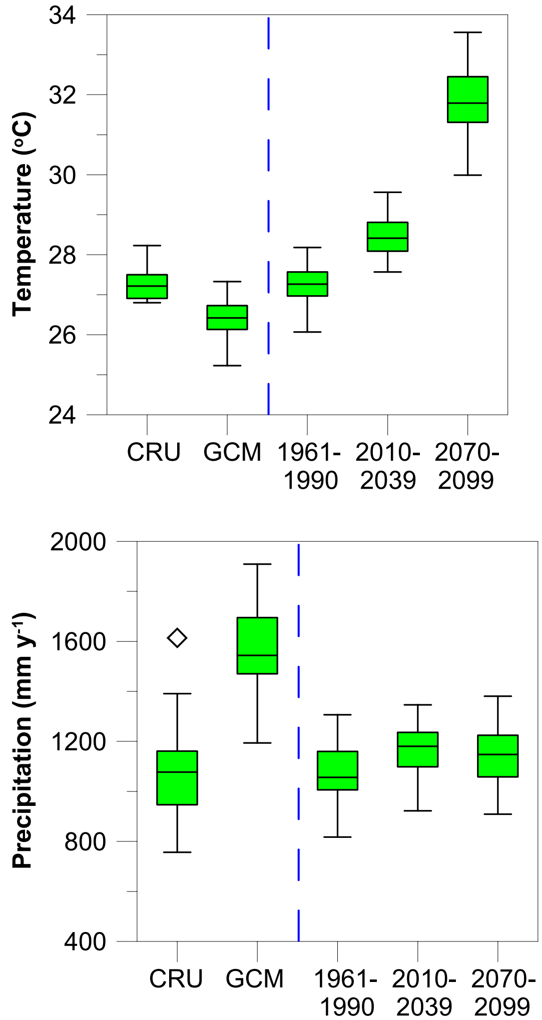
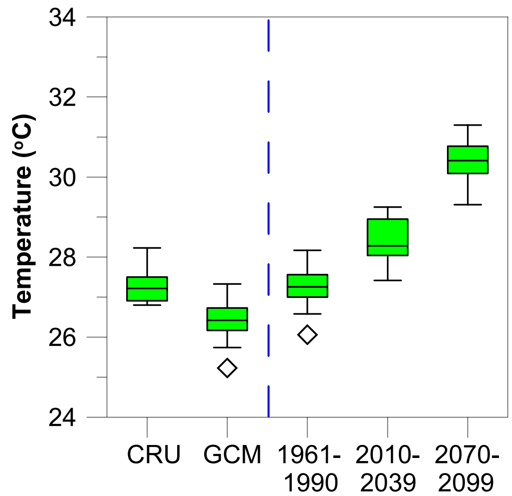


Fig. 5.1 Climate and Climate Change

The temperature projections of the Hadley A2 GCM for the historical period compare well with the historical CRU data. Also for the other projections, this good comparison holds. An upward trend of 4.5° C per hundred years can be seen with an increase in variability for the long-term prediction period. Precipitation was overestimated by the GCM with 40% over the historical period. The normalized precipitation data show a small but very relevant increase of just less than 10% with and important increase in variability over the long-term projection period.

Basin	**Volta**
Climate	**Hadley B2**

Period	*1961-1990*	*2010-2039*	*2070-2099*
Temperature (°C)	27.3	28.4	30.4
Std (°C)	0.5	0.5	0.5
CV (%)	1.7	1.9	1.7
Precip. (mm y^{-1})	1079	1181	1173
Std (mm y^{-1})	117	144	118
CV (%)	10.8	12.2	10.1



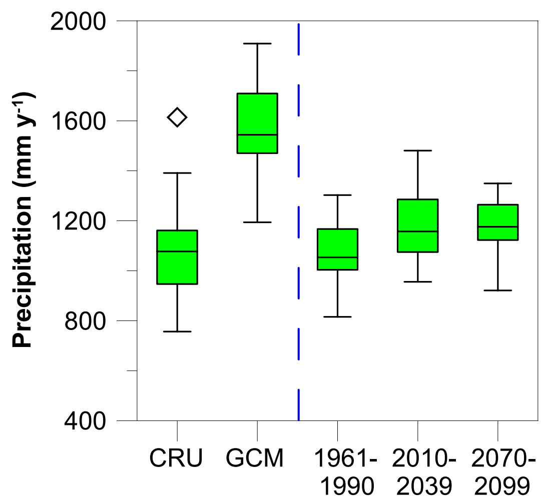


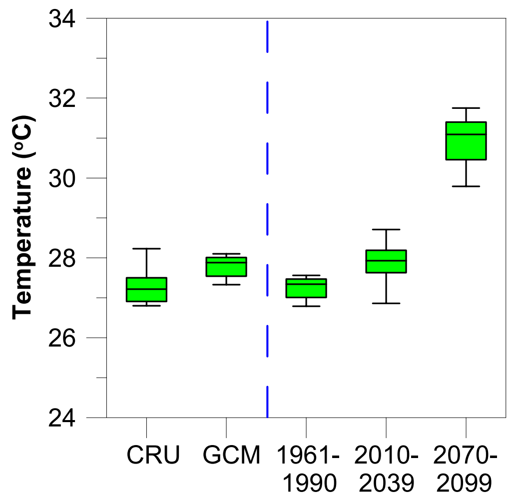
Fig. 5.2 Climate and Climate Change

The temperature projections of the Hadley B2 GCM for the historical period compare again well with the historical CRU data. An upward trend of 3.1° C per hundred years can be seen with no major increase in variability. As one may expect, this temperature increase was less than under the A2 scenario. Precipitation was overestimated by the GCM with 40% over the historical period. The normalized precipitation data show a small but very relevant increase of about 10% with and important increase in variability over the mid-term projection period. The average precipitation trends for Hadley A2 and Hadley B2 are comparable.

The temperature projections of the ECHAM4 A2 GCM for the historical period compare again well with the historical CRU data. An upward trend of 3.6° C per hundred years can be seen with an important increase in variability for the long-term projection period. The shape of this upward curve is less linear, or more exponential, than for the Hadley model; suggesting ECHAM4 predicts a larger long-term and smaller mid-term change than the Hadley model. Precipitation was overestimated by the GCM with over 50% over the historical period.

Basin	**Volta**
Climate	**ECHAM4 A2**

Period	*1961-1990*	*2010-2039*	*2070-2099*
Temperature (^oC)	27.3	27.9	30.9
Std (^oC)	0.3	0.4	0.5
CV (%)	1.0	1.6	1.7
Precip. (mm y^{-1})	1079	1035	1118
Std (mm y^{-1})	109	99	104
CV (%)	10.1	9.6	9.3



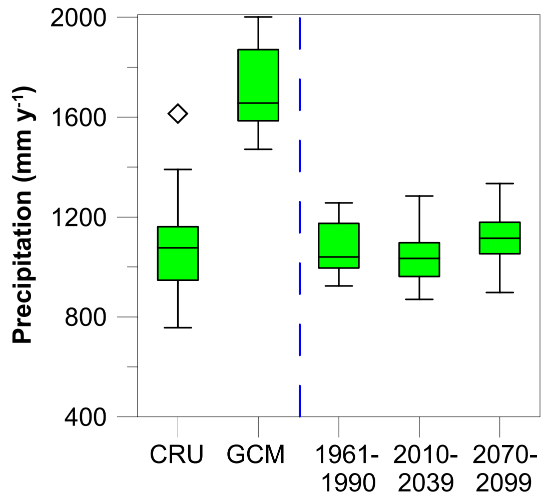


Fig. 5.3 Climate and Climate Change

The normalized precipitation data show no increase for the mid-term and a small increase of about 8% for the long-term. Interestingly, the model predicts a decrease in variability over the mid-term projection period.

The temperature projections of the ECHAM4 B2 GCM for the historical period compare again well with the historical CRU data. An upward trend of 2.5° C per hundred years can be seen which, as expected, is lower than under the A2 scenario. Under the B2 scenario we do not see the increase in variability that we saw under the ECHAM4 A2 scenario. Also for B2, the shape of this upward curve is less linear, or more exponential, than for the Hadley model, suggesting the ECHAM4 predicts a larger long-term and smaller mid-term change than the Hadley model. Precipitation was overestimated by the GCM with over 50% over the historical period. The normalized precipitation data show only minimal increase for the mid-term and long-term prediction periods. The model predicts a slight increase in standard deviation with more extreme minimum and maximum values. The average precipitation trends for ECHAM4 A2 and ECHAM4 B2 are comparable but different from the Hadley projections.

Basin	**Volta**
Climate	**ECHAM4 B2**

Period	*1961-1990*	*2010-2039*	*2070-2099*
Temperature (^oC)	27.3	28.0	29.8
Std (^oC)	0.4	0.4	0.4
CV (%)	1.3	1.5	1.3
Precip. (mm y^{-1})	1079	1122	1110
Std (mm y^{-1})	67	89	90
CV (%)	6.2	7.9	8.1

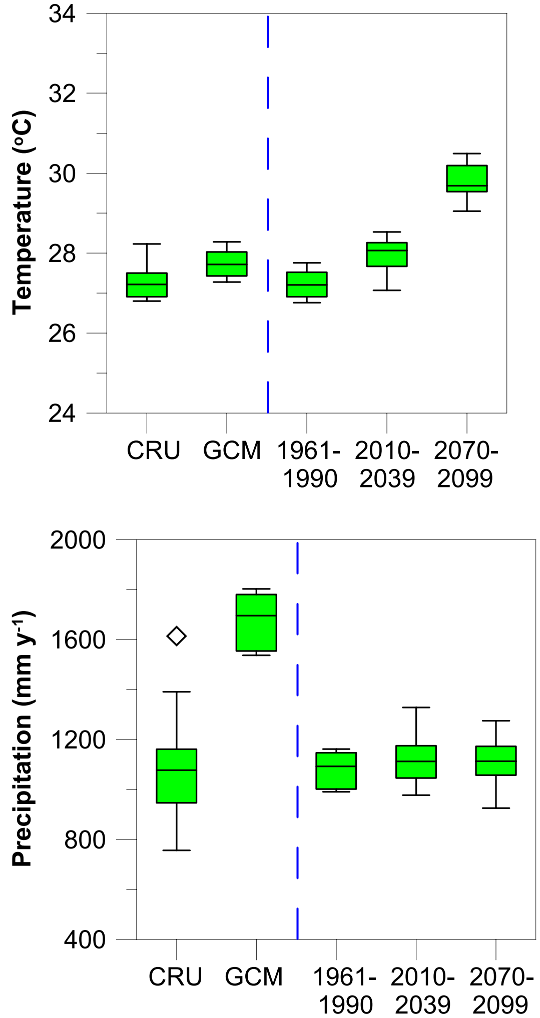


Fig. 5.4 Climate and Climate Change

6. MODELING ACTIVITIES

The field scale model SWAP (Van Dam et al., 1997) and the basin scale model WEAP developed by the Stockholm Environment Institute (WEAP, 2002) were used for the Volta basin to analyze and understand the impact of climate change on water resources, agriculture and environment and to evaluate adaptation strategies

6.1 Field Scale SWAP model

6.1.1 Model description

The agro-hydrological analysis at field scale is performed using the SWAP 2.0 model (Van Dam et al., 1997). SWAP is a one-dimensional physically based model for water, heat and solute transport in the saturated and unsaturated zones, and also includes modules for simulating irrigation practices and crop growth. For this specific case, only the water transport and crop growth modules were used. The water transport module in SWAP is based on the well-known Richards' equation, which is a combination of Darcy's law and the continuity equation. A finite difference solution scheme is used to solve Richards' equation. Crop yields can be computed using a simple crop growth algorithm based on Doorenbos and Kassam (1979) or by using a detailed crop growth simulation module that partitions the carbohydrates produced between the different parts of the plant, as a function of the different phenological stages of the plant (Van Diepen et al., 1989). Potential evapotranspiration is partitioned into potential soil evaporation and crop transpiration using the leaf area index. Actual transpiration and evaporation are obtained as a function of the available soil water in the top layer or the root zone for, evaporation and transpiration respectively, Finally irrigation can be prescribed at fixed times, scheduled according to different criteria, or by using a combination of both. A detailed description of the model and all its components is beyond the scope of this paper, but can be found in Van Dam et al. (1997). The climate scenarios used are described in Chapter 5: Projections.

6.1.2. Data

Soils

The representative soil chosen for the study is the … (see Figure 6.1). The storage capacity of this soil lies between 13.2 and 19.8 cm and is as such also representative for soil physical properties found in the Volta basin.

Crops

The two selected crops for the Volta basin are rice and maize. Although rice consumption is at a relatively low level, with, for example, less than 10 kg milled rice per person in Ghana, it is considered as an important crop. Average yield levels are low, as a result of many factors such as inadequate expertise, low investment options, poor maintenance of irrigation, and unsuitable rice varieties (Maclean, 2002). Maize was selected as the other crop included in the analysis as it is the major rainfed crop in the basin.

Crop production is affected by the air's CO2 level. Photosynthetically Active Radiation (PAR) is used by the plant as energy in the photosynthesis process to convert CO2 into biomass. Important in this process is to make a distinction between C3 and C4 plants. Examples of C3 plants are potato, sugar beet, wheat, barley, rice, and most trees except Mangrove. C4 plants are mainly found in the tropical regions and some examples are millet, maize, and sugarcane. The difference between C3 and C4 plants is the way the carbon fixation takes place. C4 plants are more efficient in this and especially the loss of carbon during the photorespiration process is negligible for C4 plants. C3 plant may lose up to 50 % of their recently-fixed carbon through photorespiration. This difference has suggested that C4 plants will not respond positively to rising levels of atmospheric CO2. However, it has been shown that atmospheric CO2 enrichment can, and does, elicit substantial photosynthetic enhancements in C4 species (Wand et al., 1999).

In addition to these theoretical approaches, experimental data has been collected to assess the impact of CO2 enriched air on crop growth. A vast amount of experiments have been carried out over the last decades, where the impact of increased CO2 levels on crop growth has been quantified. The Center for the Study of Carbon Dioxide and Global Change in Tempe, Arizona, has collected and combined results from these kind of experiments. Table 6.1 shows the impact of increased CO2 levels for the two crops used in the Volta Basin.

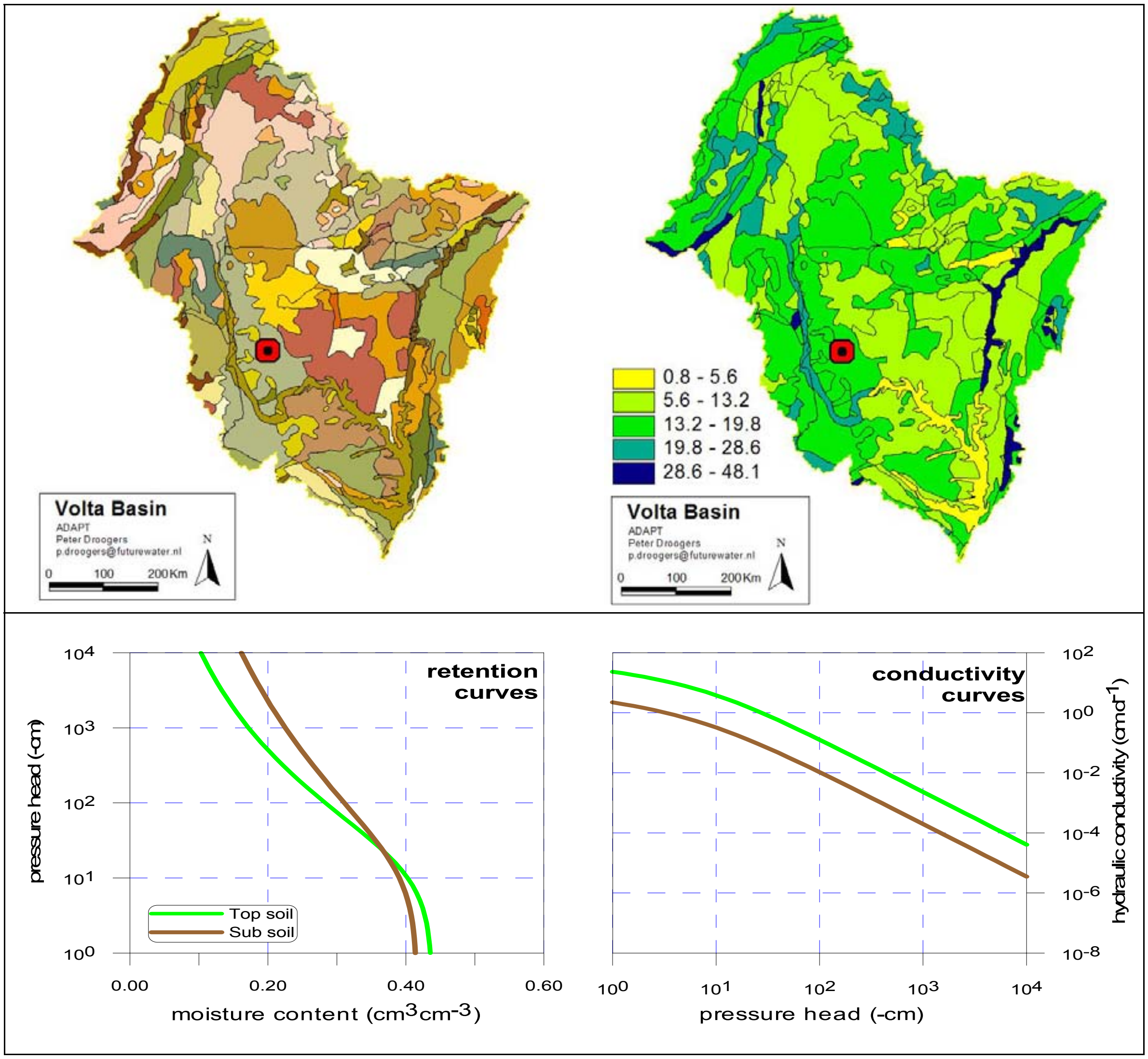


Fig 6.1: Volta Basin: major soil groups (top, left) and soil water holding capacity (top, right) in cm, and soil hydraulic properties for the soil type selected (bottom). (Droogers, 2003).

Crop	Period	A2 (%)	B2 (%)
Rice	2010-2030	20	10
	2070-2100	40	20
Maize	2010-2030	10	5
	2070-2100	20	10

Table 6.1: Increase on potential crop growth as a result of enhance CO_2 levels in percentages. A2 and B2 are the IPCC climate forcings. (*Source: CSCDGC. 2002. Plant growth data. Center for the Study of Carbon Dioxide and Global Change in Tempe, Arizona. http://www.co2science.org*)

6.2 Basin scale WEAP Model

6.2.1 Model description

To assess the impact of climate change on the availability of water resources in the Volta Basin, WEAP software developed by the Stockholm Environment Institute was used. First, two node-link networks were put in place. Fig 1 shows the more detailed of the two designs. Fig 6.3 is a simplified version that was used for the actual simulations. The main difference between the two is that the higher level of aggregation made it easier to assign total water flowing into each link.

The basin is divided over four sub-basins: Black Volta, White Volta, Oti, and Lower Volta. Three sub-basins are divided over Ghana and Burkina Faso (Black and White) or Ghana and Togo (Oti). This gives seven sub-basins or links in the WEAP scheme:

i. Black BF (also includes a small part of Mali.)
ii. White BF
iii. Oti TG (also includes parts of Burkina Faso and Benin)
iv. Black GH (also includes part of Côte d'Ivoire)
v. White GH
vi. Oti GH
vii. Lower (also drains a tiny part of Togo)

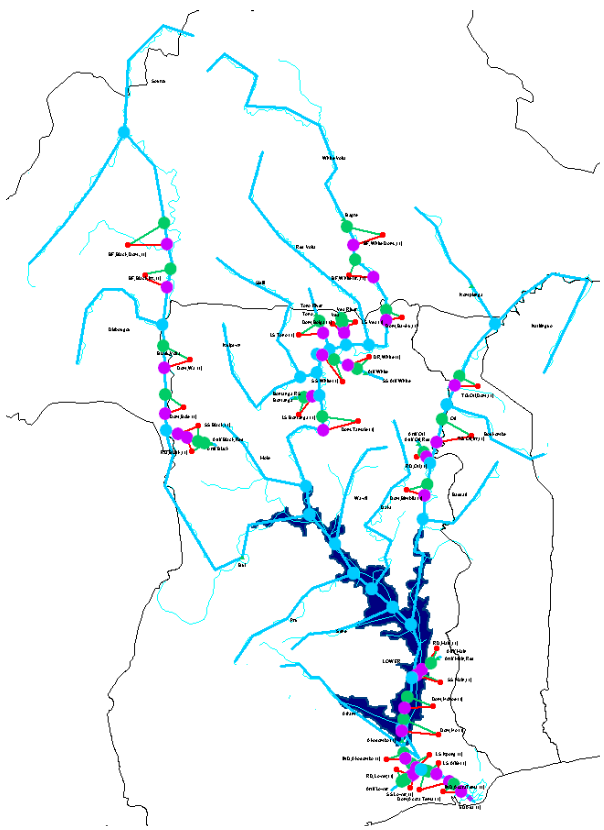


Fig 6.2: Detailed WEAP node-link network of the Volta Basin

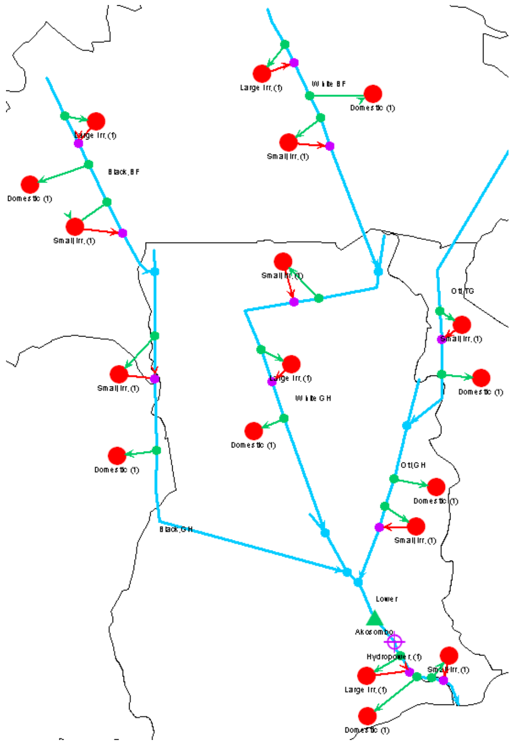


Fig. 6.3 Simplified node-link network used in WEAP for simulation of water use scenarios in the Volta Basin

Inflow into each link was based on a hydrological model described under 6.2.2 Data, which is also where the demand sites are described. Delineation of the sub-basins was calculated with the "*watershed*" command in the Idrisi GIS package on the basis of the USGS GTOPO 30 Digital Elevation Model, which was first resampled to match the resolution of the CRU dataset.

The present scheme gives good insight in the main issues and the relative importance of the different water sectors. Some suggested additions for the near future are the inclusion of a dam at Bui (both a small dam and a large dam), inclusion of the characteristics of the reservoirs used for irrigation and the Bagré and Kompienga dams in Burkina Faso, and inclusion of field measurement based crop and irrigation water demands in the Volta Basin. A complete WEAP data report can be found in the Appendix.

6.2.2 Input data

For the current accounts and historical scenario (1961-1990), the CRU database was used as input. The CRU database was also used to normalize the GCM inputs used. The normalization method used for the Volta, slightly differed from the standard procedure. The idea was to normalize the GCM in such a way that when used as input into our hydrological model, the simulated annual runoff had similar statistical properties (mean and variance) as the measured annual runoff. It turned out that in order to achieve this; the following procedure had to be used. For each month of the year, averages and standard deviations were calculated for each data set (CRU, Hadley A2, and Hadley B2). The GCM monthly data were then transformed using:

$$\hat{P}'_{GCM} = \frac{\sigma_{CRUhis}}{\sigma_{GCMhis}}\left(\hat{P}_{GCMhis} - \mu_{GCMhis}\right) + \mu_{CRUhis}$$

In which P'_{GCM} is the transformed GCM rainfall, the subscript *his* denotes data over the 1961-1990 period, σ is standard deviation and μ is the mean. The historical mean runoff was 32.8 km^3/yr with σ=4.7. For both the A2 and B2 scenarios, the Hadley model gave an average runoff of 32.5 km^3/yr with σ=4.5.

Interestingly, when, instead, monthly data were normalized by normalizing the annual rainfall amounts, the GCM output of the hydrological model showed a standard deviation that was much larger than the standard deviation of the measured runoff. Normalizing with annual rainfall means in this case that for a dry year, the "dryness" is distributed over all months, weighted by average monthly rainfall. Please note that also in this case, the stochastic distribution of monthly and annual rainfall is comparable to that of the historical series. Apparently, monthly rainfall series within years are relatively independent or have a dependency that is properly described by the GCM.

The hydrological model used was a simple bucket model combined with a factor that accounted for the fact that not the complete watershed contributes fully to the surface runoff. For each month, the rainfall was added to the storage in the "bucket". When the storage exceeded a threshold of 52.3 km^3, the amount of water above this threshold runoff. The actual evapotranspiration was equal to the actual storage divided by the maximum storage multiplied with the potential evapotranspiration of about 48 km^3 per month. The monthly actual evapotranspiration was removed from the storage. The calculated runoff was multiplied with a factor of 0.123 to give the monthly runoff at basin level. The monthly runoff that summed obtained was added to give total yearly runoff. Both maximum storage and the multiplication factor were fitted to give the best match between simulated and measured yearly runoff. The resulting model had an r^2=0.91 and showed a very good general agreement.

To obtain hydrographs with monthly time steps, the original runoff could be entered into a hydraulic routing model to give the correct distribution over time (there is a delay before the runoff actually reaches the watershed outlet). Instead, we used the shape of the historical average yearly hydrographs to distribute the yearly runoff totals over the individual months. Spatial disaggregation was also obtained in a rather straightforward fashion. Historically, the Black Volta contributes 23% of the total runoff, White Volta 25%, Oti 27% and the Lower Volta the remaining 25%. This was how the calculated annual runoff was distributed between the four main watersheds. As described above, White, Black and Oti were further sub-divided into a Ghanaian and a Burkina Faso or Togo part. Runoff for these sub-basins was calculated proportional to surface area. Following this method, we arrive at the average yearly runoff amounts given in Table 6.2 below together with some other key variables:

The input data that were used to run the model were CRU data for the 1961-1990 basic scenario, and Hadley A2 and Hadley B2 for the time slices 2010-2039 and 2070-2099 giving a total of five input data sets.

On the demand side, we distinguish domestic use, small scale irrigation, large scale irrigation, and hydropower use at Akosombo. Domestic use was calculated on the basis of 1990 population data from the Deichman database (Deichman, 1994?).

Sub-basin	Area $10^3 km^2$	Rainfall km^3	Runoff km^3	Runoff Fraction	Urban Million	Rural million	Irrigation ha
1 Black BF	102.4	99.8	5.0	0.16	0.4	3.00	2000
2 White BF	57.3	55.8	3.9	0.13	2	1.23	8000
3 Oti TG	51.5	50.2	6.5	0.21		1.43	400
4 Black GH	45.7	44.5	2.2	0.07		1.03	800
5 White GH	54.7	53.3	3.7	0.12	0.7	0.90	3200
6 Oti GH	15.2	14.8	1.9	0.06		0.19	400
7 Lower	74.3	72.4	8.0	0.25	0.7	1.45	2700

Table 6.2 Average yearly runoff and other key variables

The population for each sub-basin was extracted with Idrisi GIS software. For the rural population, a daily consumption of 30 l per person was assumed, for Accra, 95 l per person per day is used, while for the remaining urban areas a consumption of 50 l pppd was used. All these consumption levels are based on the Ghanaian WARM report (Ghana Government, 1998?). One third of the population of Accra (total population of about 2 million) receives drinking water through a long pipeline from the Lower Volta. Therefore, 700,000 urban inhabitants were added to this sub-basin. A general population increase of 2.5% per year was assumed, based on the 2000 census data for Ghana.

Large scale irrigation was based on reported surfaces of the Vea, Tono and Bontanga schemes for the White Volta, and the Kpong and Afife schemes for the Lower Volta. Small scale irrigation is more difficult to estimate. The only available hard data are those for reservoir surfaces in the Upper East in Ghana (Liebe, 2003) and the White Volta part of Burkina Faso. Based on field observations of about five reservoirs, it was estimated that the maximum irrigated area equals about 200% of the reservoir area. This may sound like a very small area, but this is not uncommon throughout the region that simply has a very flat topography. Finally, for the remaining areas where in general less irrigation takes place (Oti, Lower, Black) coarse estimates were made based on general occurrence of irrigation in comparison with the two White Volta sub-basins. Total irrigated areas are given in the table above. Clearly, irrigated areas are still very modest. Probably four to five percent of the total area is readily irrigable. For the irrigation future scenario, an irrigated area of a modest 1% of the total area was assumed which still implies a twenty-fold increase. Water use in the irrigated areas was calculated with the CROPWAT software. For the dry season, a horticultural crop was used (tomato), and for the wet season we used rice. The main difference between small and large scale irrigation was expressed in terms of efficiency with a loss rate of 30% for small scale irrigation and a loss rate of 50% for large scale irrigation. The difference is caused by the fact that small scale irrigation typically takes place in wetland areas that also without irrigation would have lost water through evapotranspiration. Reservoir losses were assumed to be equal to the effective evaporation of around 3mm/d (see below).

The final demand node was the Akosombo dam. The level/volume curve used was provided by the Volta River Authority, which operates the dam. Effective evaporation was taken at 3 mm per day based on the idea that the lake evaporates at potential rate (2100 mm/yr) while rain is about 1000 mm/yr. There are actually good surface/level curves for Akosombo but WEAP does not allow using such surface data but instead assumes a certain (unknown) relation between level and surface area which is used to transform the effective evaporation rate into volumes. Operation of the dam was set at the actual average outflow for the period 1961-1990. Actually, the dam is operated slightly differently but this could not be implemented. The simulation results gave good results at a yearly basis so no further refinement was deemed necessary. The water that flows through Akosombo also flows through a lower, zero-storage dam at Kpong, about twenty kilometers downstream. Unfortunately, no head and tail water data are available for Kpong. Instead, a lower tail end elevation of 1m was used for Akosombo which, together with a calibrated generating efficiency of 89.1% gives the correct amount of electricity generated in historical times. For the future energy scenario, the extra water that is predicted to be available under the A2 and B2 scenarios was simply allowed to be completely used at Akosombo.

7. INDICATORS AND IMPACTS

7.1 Hydrology

The main tributaries of the Volta are Black Volta, White Volta and Oti. The total annual runoff is on average 41.6 billion m^3. This runoff is characterized by wide variability between wet and dry seasons and also from year to year. As indicators of the impact of climate change on the hydrology of the basin we use average annual runoff into Lake Volta and the variability in runoff as expressed by the coefficient of variation (=standard deviation/mean). A dry year is defined as a year with less than 75% of the average runoff during the period under consideration.

7.1.1 Impact of climate change on hydrology

Table 7.1 shows the inflow into Lake Volta for the historical and future periods as predicted by the Hadley GCM A2 and B2 scenarios. Each scenario shows an important increase in runoff. The underlying relative increases in rainfall were much less but the non-linear response to slight absolute increases in rainfall causes the dramatic rise in runoff into the lake. The Hadley A2 simulation for 2070-2099 shows less increase and even a slight increase in the coefficient of variation. Interestingly, the other simulations show an important decrease in the coefficient of variation. The B2 scenarios show in general a more important increase than the A2 scenarios, something that does not concur with the general idea that increase in temperature (which is higher under A2 than under B2) accelerates the hydrological cycle.

		Average	StDev	CoeffVar
Historical		32.8	17.1	0.52
HA2	2020-2039	41.6	14.0	0.34
HB2	2020-2039	43.8	15.4	0.35
HA2	2070-2099	37.2	19.9	0.54
HB2	2070-2099	44.0	17.6	0.40

Table 7.1: Average yearly inflow into Lake Volta [km^3] together with standard deviation and coefficient of variation of the respective simulation periods for Hadley A2 and Hadley B2.

Figure 7.1 and Figure 7.2 show for completeness the time series as produced by the different scenarios in comparison with the inflow simulated for period 1961-1990.

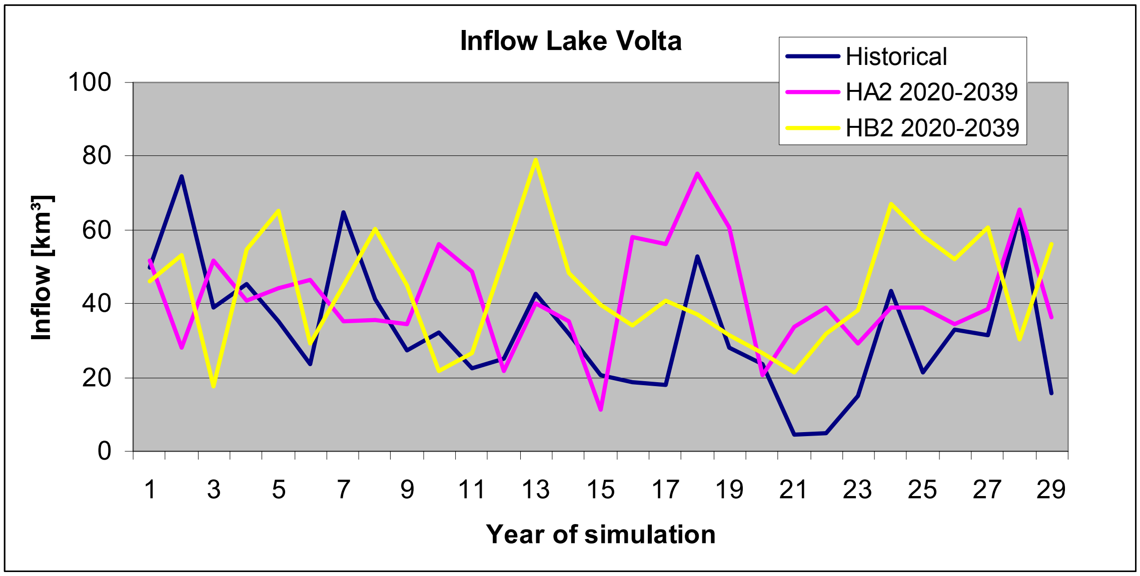


Figure 7.1: Comparison of modeled flows for mid-term (2020-2039) and historical (1961-1990) periods, using output from the Hadley A2 and B2 models.

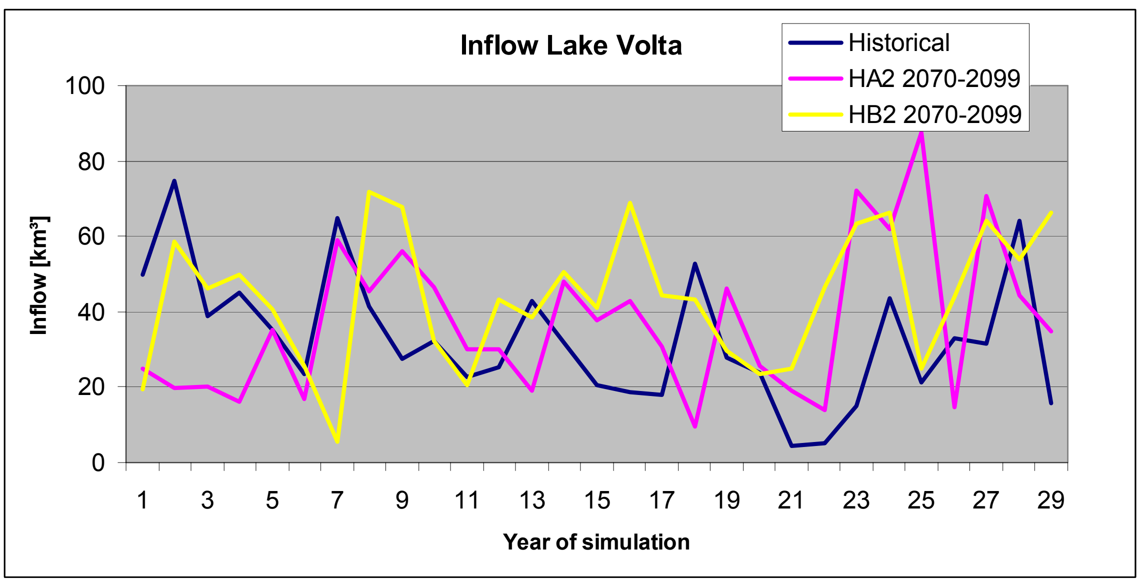


Figure 7.2: Comparison of modeled flows for long-term (2070-2079) and historical (1961-1990) periods, using output from the Hadley A2 and B2 models.

7.2 Environment

7.2.1 Human Health

Irrigation development creates a wide range of conditions that allow the growth and spread of disease like malaria, schistosomiasis, etc. The construction of the Akosombo dam eliminated the regular annual flooding of the Lower Volta River. This resulted in the development of sandbars that virtually blocked the estuary and prevented the upstream flow of sea water such that the estuarine salt wedge reduced from 30 to less than 5 km. Without the influence of saline waters, the clear waters of the Lower Volta became an ideal habitat for aquatic weeds and vectors of water-related diseases, particularly, schistosomiasis. However, the impact of these activities on the human health is difficult to estimate so we have not defined a disease related indicator.

Safe drinking water is also difficult to model as a function of climate change and adaptation strategies. An obvious indicator, such as percentage of households with safe drinking water, would be simply predicted by definition of the adaptation strategy ("increase of households with safe drinking water from 40% to 70 %") and would, thereby, be meaningless.

7.2.2. Bio-physical

Increase in irrigation and hydropower facilities for food production and cheap power generation could impact negatively on the environment. These impacts include loss of the actual wetlands as they are modified to suit particular irrigation practices and associated losses in biodiversity. These impacts can eventually lead to socio-economic hardships as local people are deprived of useful wetlands. If, for example, the Bui dam is constructed in the future, positive impacts will include increased availability of water for food production and for industry. The major negative impacts will be those associated with loss of the forest reserves, particularly the rich biodiversity especially the wide range of animals. After the construction of the Akosombo Dam for hydropower which drastically the annual flooding downstream also resulted in the loss of several lagoons and creeks in the estuary which served as important fishing grounds. Associated with the shift in the estuarine salt wedge was the loss of the clam and prawn fisheries in the main channel that were a major source of livelihood.

As indicator for the biophysical impact of climate change, or associated adaptation strategies, we choose the number of **hectares of wetland lost**. The total number of hectares of wetland in the basin now is estimated at 2,000,000 ha.

Impact of climate change
The climate predictions show generally wetter conditions in the Volta Basin which implies there will be no loss of wetlands under projected climate change. The wetland indicator is still relevant for measuring the impact of adaptation strategies.

7.3. Food

Ghana depends on agriculture for about 60% of gross national product and also provides work for about 80% of the population. Meanwhile, agriculture is almost wholly on rain fed basis. With increasing population and growing demand for food, the economy can no longer depend on rain fed agriculture. For the past twenty years Ghana has experienced drought periods and erratic rainfall. Irrigation is therefore the way forward in agriculture if the country is to solve the food security problem. This is especially so in Northern Ghana and Burkina Faso where rainy season last for only four to five months. The formal irrigation projects in Ghana (about 22 of them) which are sometimes referred to as large scale irrigation are almost overwhelmed with problems of finance, operation, management etc and therefore their impact are not well felt in the economy. Small scale irrigation development in the inland valleys, where unlike the large scale ones does not need huge initial capital seems to have good potential in the short term. Irrigation development therefore will be very important in the economies of the countries in the basin.

As indicators for the food production sector, we use the **total tonnage produced** for two important crops, rice and maize. Rice is taken as representative or irrigated crop and maize for rainfed crops.

Period	*1961-1990*	*2010-2039*	*2070-2099*
Average (kg ha^{-1})	3249	3903	4688
Std (kg ha^{-1})	306	322	447
CV (%)	9.4	8.2	9.5
Tot. Cons. (mm)	737	761	894
Prod. Cons. (mm)	403	424	531
WP (\$ m^{-3})	0.10	0.12	0.12

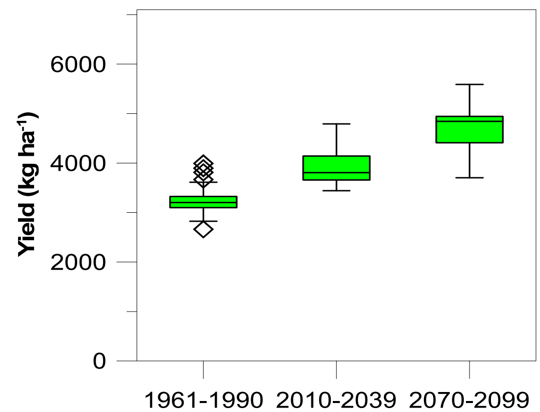


Fig.7.3: Baseline prediction for Rice under Hadley A2 *Impacts*

The SWAT field model predicts increases in yields for rice with respect to the baseline year under future climate. For example, under the Hadley A2 scenario, the years 1961-90, 2010-39, 2070-99 showed an increase in average yield from 3249 kg/ha to 3903 kg/ha and to 4688 kg/ha, respectively (Fig. 7.2). The trend is similar for Hardley B2

Maize on the other hand did not show much increase in the medium term (2010 to 2039) and rather a decrease in the long term. In the case of Hadley B2 there was virtually no change in yield.

Period	*1961-1990*	*2010-2039*	*2070-2099*
Average (kg ha^{-1})	927	1064	490
Std (kg ha^{-1})	387	339	267
CV (%)	41.7	31.8	54.6
Tot. Cons. (mm)	790	824	885
Prod. Cons. (mm)	421	459	502
WP (\$ m^{-3})	0.03	0.03	0.01

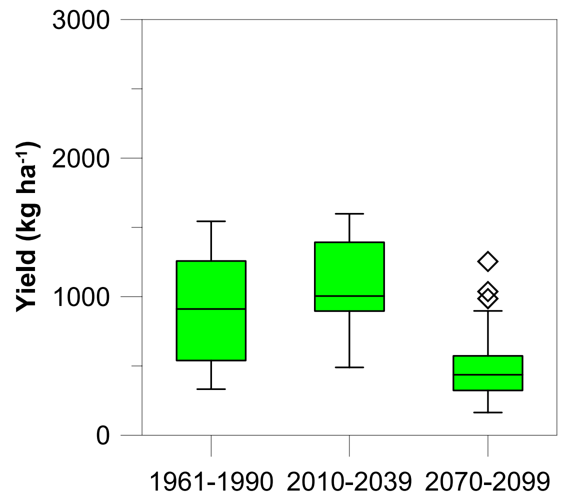


Fig 7.3. Baseline prediction for Maize under Hadley A2

As an input into the basin modeling, the yields in the SWAP field level predictions in kg/ ha were converted into production values by multiplying by the area under cultivation using the FAOadaptcrop values both for rainfed and irrigation conditions(Table 7.2).

	1961-1990	2010-2039	2070-2099
Rice	71478	85866	103136
Maize	833373	956536	440510

Table 7.2 Baseline Crop Production in tons

7.4 Industry (Energy)

Hydropower equals industry for about 90%. One could talk about mining and water quality issues but there are no data. There is a continuously increasing demand for energy. The pressure to produce more energy is so high that the Volta River Authority (the energy producing institution) lets too much water through the dam with the hope that next year's rains will replenish the reservoir. When the rains are not so good for a single year, such as happened in 1982/83 and1997/1998, there is no buffer and hydropower production comes to a halt. At present, hydropower generation is not very sustainable. The withdrawal rates are higher than the average inflow, leading to periodic shortages

The average annual generation is about 20300GJ and a graph of major users is presented in Fig. 4

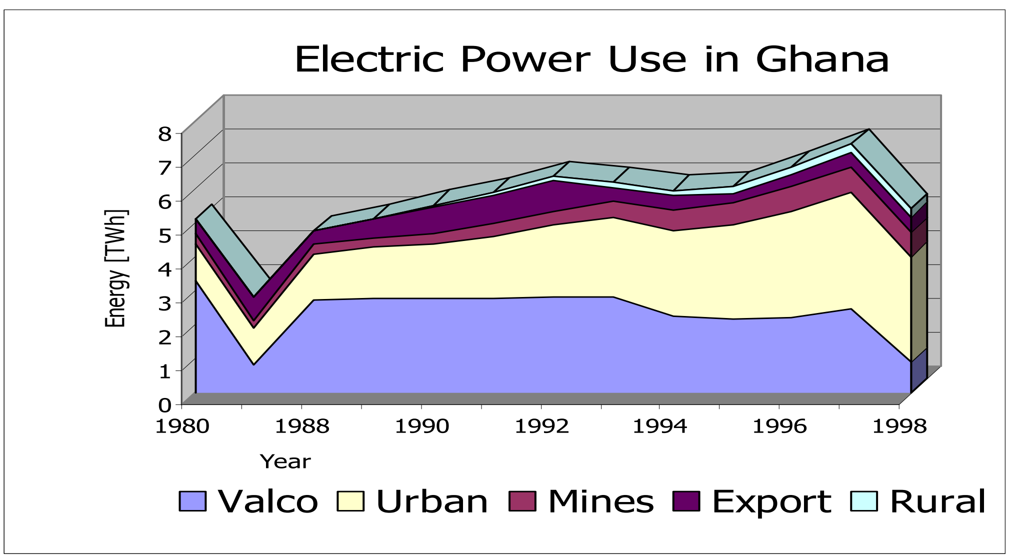


Fig. 7.4 Electric power use in Ghana. (Source: GLOWA Volta Project.)

The Akosombo reservoir experienced two drought spells during the last two decades 1983/84 and 1997/98 resulting in levels reducing below the minimum operating level (Fig. 7.5).

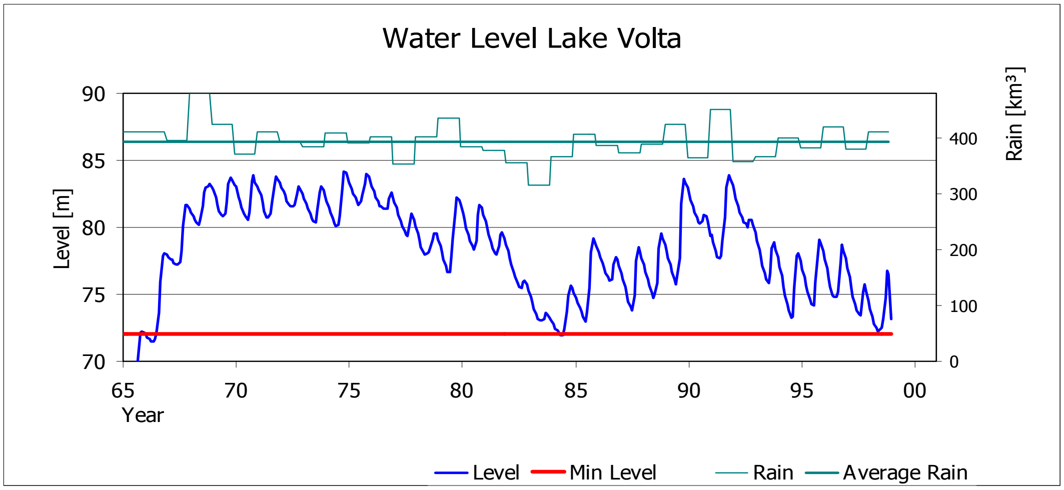


Fig.7.5 Water Level of the Volta Lake. (Source: GLOWA Volta Project.)

As indicators for energy production we used the **average energy production** and the **frequency of years in which the Lake Volta has water levels below minimum operation level**. The latter result in lack of power, at least during parts of the year.

7.3.1 Impact of climate change

Future climate predictions show increased rainfall. This is good for the Akosombo dam since extra rainfall means more water in the reservoir and therefore more energy for people and the economy. However in addition to the increased rainfall there is also the increased variability, because the standard deviation also increases.

The WEAP simulations shown in Table 7.1 show that in general average energy production increases due to the increase in runoff. The only exception is the Hadley A2 long-term scenario (2070-2099) which gives result similar to that under historical conditions.

BAU HA2 10-39	21,595
BAU HA2 70-99	18,742
BAU HB2 10-39	22,177
BAU HB2 70-99	21,809
Historical 1961-1990	18,116

Table 7.1: Projected average energy production at Akosombo using the Hadley models and scenarios A2 and B2 under climate change only (Business as Usual).

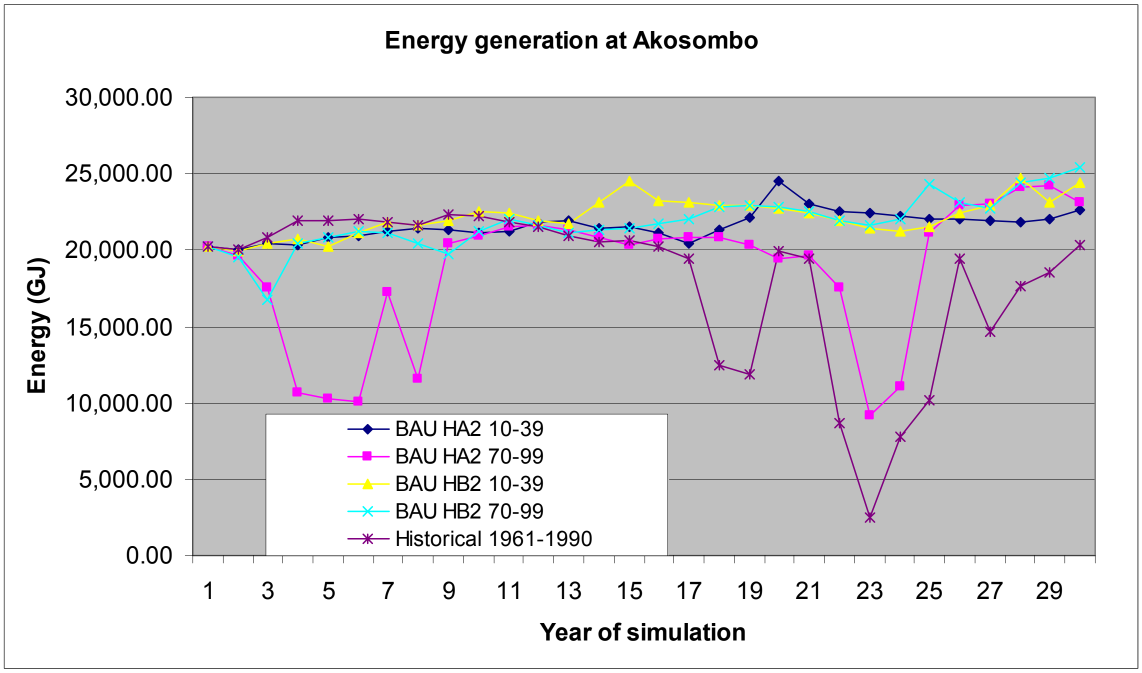


Figure 7.1: Energy production at Akosombo for the different simulation periods using the Hadley model and A2 and B2 scenarios.

Figure 7.1 shows the impact of climate change for the individual years. The figure shows that there is an definite decrease in years of failure. With the exception of Hadley A2 2070-2099, there are no years with power failures anymore. Under Hadley A2 2070-2099, there are still six years with lake levels below the minimum level of operation for part of the year, comparable to the seven found under the historical simulations.

8. ADAPTATION STRATEGIES

8.1 Basin level

8.1.1 Strategy description

Three adaptation strategies were developed at basin level: Business-as-usual, irrigation and energy. In business-as-usual, the present water use levels were maintained to assess what the isolated impact of climate change would be. Both future climate scenarios (Hadley A2 and B2) predict higher rainfall for the Volta Basin. It is not realistic to assume that existing infrastructure will be removed to favor environmental water flows. One could, therefore, see the business-as-usual adaptation strategy also as the best possible environmental adaptation strategy. The general impact of the business-as-usual “strategy” on the indicators is described in section 7.

The second adaptation strategy is the irrigation strategy. Food production is mainly rainfed in the Volta Basin but irrigated agriculture is growing quickly. It is difficult to increase the productivity of rainfed agriculture mainly because investments in labor or agro-chemicals do not pay off when the rains fail. Irrigation is therefore definitely an important means by which local food production can be increased. The present level of irrigation is very low. When Asian-type land use pressures would exist in the Volta, probably more than four percent of the total area would be under irrigation. This would correspond with a hundred-fold increase with respect to present levels, which is not realistic under present institutional arrangements. Instead, an irrigated area of one percent of the total area is put forward as the irrigation scenario, still an enormous relative increase from the present situation. We expect that most irrigation expansion will take place as small scale, village-level irrigation.

The third adaptation strategy is the energy strategy. At present, the dam at Akosombo is used at unsustainable rates. The pressure to produce more energy is so high that the Volta River Authority (the energy producing institution) lets too much water through the dam in the hope that next year's rains will replenish the reservoir. When the rains are not so good for a single year, such as happened in 1997/1998, there is no buffer and hydropower production comes to a halt. In the business-as-usual scenario, we used a thru-flow of 983 CMS, which is equal to the average flow over the past decades. In that case, flow demands were only not met in 1983/1984 under the historical scenario, which corresponds with true disaster years in Ghana in which many forests burned down due to the drought (1983 also was the strongest el Nino year on record). In recent years, outflow levels of 1350 CMS were reached which are not sustainable. For the energy scenario, it was assumed that the operation engineers will continue to push the envelope but in a more sustainable manner. In practice, this translated into letting all extra runoff water that becomes available under projected future climates run through the Akosombo turbines.

The three adaptation strategies are relatively simple but we can with confidence state that they span most of the realistic "management space". The business-as-usual adaptation strategy is definitely the minimum level of water resource development. The one-percent irrigation adaptation strategy implies a very large extension of present irrigated areas and, as such, a maximum in irrigated area to be expected. Perhaps the only somewhat conservative strategy is the energy strategy because it assumes actually a reduction of the flows through Akosombo. It is, however, the only sustainable energy adaptation strategy because letting more water out from a reservoir than flows in, clearly means that one runs out off water quickly.

Additional adaptation strategies that may be developed for future use could include one scenario in which the flows through Akosombo are concentrated in a shorter period in the wet season so that salt is allowed to enter the estuary as used to be the case before building the dam. It has been reported that the lack of movement in the salt front over the year has been the main environmental impact of Akosombo, destroying clam fisheries and increasing schistosomiasis. Thermal power could be used to fill in the dry season energy gap, which would most likely come at considerable financial costs. A second scenario that should be tried in the future is building the Bui dam. It has many times been proposed to build a dam in the Bui gorge on the Black Volta, which would flood an almost uninhabited flood forest. This would be associated with unknown environmental damage. At present, it seems that a full-fledged Bui dam would produce electricity at a cost of \$0.09/kWh whereas a thermal plant would produce at \$0.07/kWh. A second alternative would be a smaller Bui dam that would produce at economical costs but may not be interesting from a development-political point of view. Unfortunately, because the Bui dam is presently in a bidding stage, no information concerning the properties of the Bui dam and reservoir are available.

8.1.2 Impact of adaptation strategies at basin level

8.1.2.1 Food adaptation strategy

At basin level, the food adaptation strategy mainly means expansion of irrigated area. The irrigated area for rice would increase from the present 17,500 ha to 400,000 ha. In practice, only wetland areas, be it as small inland valley bottoms or flood plains, are the only technically feasible irrigation options. The impact on the indicator wetland loss is, therefore, 382,500 ha. Using the outputs of the SWAP field model, this gives the following results for impact on the total tonnage produced for rice as caused by increased irrigation area and tons/ha:

		1961-1990	2020-2039	2070-2099
HA2	Standard	56672	1561200	1875200
		(9.4)	(8.2)	(9.5)
HA2	Intensified	69545	2004400	2385200
		(10.4)	(8.6)	(10.1)
HB2	Standard	56341	1431600	1688400
		(9.6)	(9.9)	(7.3)
HB2	Intensified	69231	1760000	2099200
		(10.5)	(10.7)	(7.8)

Table 8.1: Tons of irrigated rice produced under the food adaptation strategy. The numbers between brackets are the coefficients of variation.

In general, we see an enormous increase in rice production, mainly due to the increase in irrigated surface but also through the increase in rice production per hectare as predicted by the SWAP model. Irrigation expansion and CO2 induced yield increases seem to be the dominant factors. Climate scenario differences have minimal impacts. There is no obvious pattern in terms of the coefficient of variation.

According to the SWAP model, irrigating maize does not have a positive impact so irrigated maize will not be part of the food adaptation strategy. Similarly, there seems to be no advantage to grow rice under rainfed conditions and this adaptation is, therefore, also left out off the basin scale analysis.

The WEAP simulations show the impacts of the food adaptation strategy on the hydrological indicators as shown in Table 8.2

		Mean	StDev	CoeffVar
Historical		32.8	17.1	0.52
HA2	2020-2039	39.9	13.8	0.34
HB2	2020-2039	42.2	15.2	0.36
HA2	2070-2099	35.9	19.6	0.54
HB2	2070-2099	42.5	17.3	0.40

Table 8. 2. Impact of food adaptation strategy on hydrology indicators **inflow into lake Volta** [km^3/year] and its **coefficient of variation** under different climate scenarios.

In general, we see that the increase in runoff as induced by the increased rainfall under the climate scenarios used here more than compensates for the extra water consumed by the irrigation development. The Hadley A2 scenario for 2070-2099 shows again the lowest increase in runoff.

The changes in Lake inflow translate into the impacts on hydropower generation as shown in Table 8.3

		Mean	StDev	CoeffVar
Historical		18044	5237	0.29
HB	2070-2099	21353	1797	0.08
HA	2070-2099	18095	4786	0.26
HB	2020-2039	21752	979	0.04
HA	2020-2039	21121	738	0.03

Table 8.3: Impact of food adaptation scenario on energy production.

Except for the Hadley A2 2070-2099 simulation, all other scenarios still show an increase in hydropower production despite increased

The number of years with insufficient lake levels increased for Hadley A2 2070-2099 from six to seven years. Also Hadley B2 2070-2099 showed two years during which the lake level was insufficient for part of the year.

As an example, the full time series for the historical and 2020-2039 time slice is given in Fig.8.1

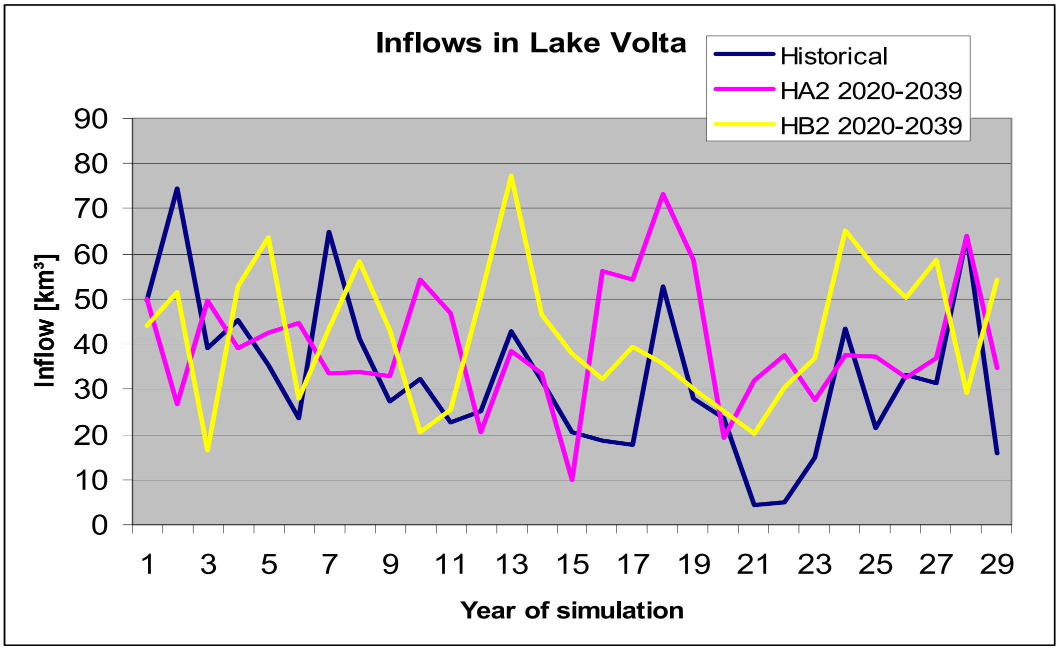


Figure 8.1: Inflows into Lake Volta for the historical and 2020-2039 time slices under the food adaptation strategy using the Hadley A2 and B2 scenarios.

8.1.2.2 Energy adaptation strategy

The impact of the energy adaptation strategy on its target indicators, **total energy produced** and **years with less-than-minimal lake levels**, were simulated with the WEAP model. The total energy produced and associated statistics is given in Table 8.4.

			Mean	StDev	CoeffVar
Historical			18044	5237	0.29
Energy	HA	2020-2039	23232	3821	0.16
Energy	HB	2020-2039	24300	5117	0.21
Energy	HA	2070-2099	19467	5939	0.30
Energy	HB	2070-2099	24153	5824	0.24

Table 8.4: Impact of different scenarios and energy adaptation strategy on power production (TJoule).

There is an important increase in power production caused by the fact that this strategy translates each increase in runoff into extra power. The coefficient of variation actually increases pointing towards increased risks. This is also clear from Figure 8.2 that shows that years with insufficient lake levels are very regular (Table 8.5)

HA2	2020-2039	8
HB2	2020-2039	6
HA2	2070-2099	10
HB2	2070-2099	5

Table 8.5: Number of years in which the lake level drops under the minimum operation level for part of the year under different scenarios and time slices.

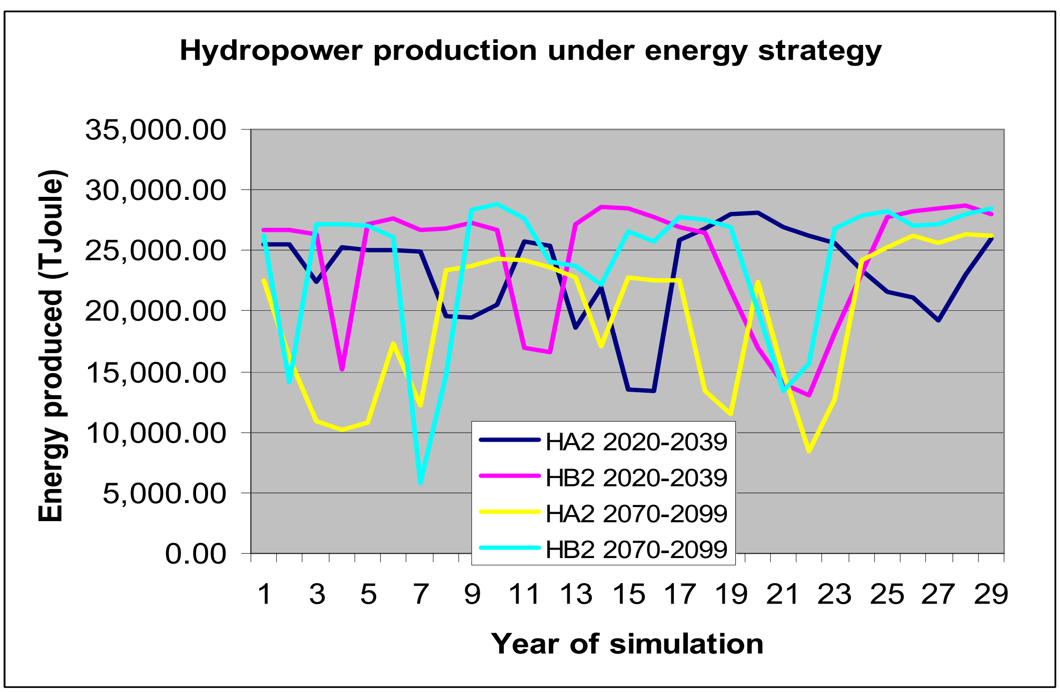


Figure 8.2: Energy production under the energy adaptation strategy.

At basin level, the energy adaptation strategy maximizes hydropower production by using the increased runoff for hydropower production. Because Lake Volta is in the downstream part of the basin, there is no appreciable impact on our environmental impact indicator **wetland loss**.

There is no real impact on inflow into Lake Volta either as can be seen by comparing Table 7.1 with Table 8.6.

		Mean	StDev	CoeffVar
historical		32.7	17.1	0.52
HA	2020-2039	41.5	13.9	0.33
HB	2020-2039	43.8	15.4	0.35
HA	2070-2099	37.2	19.8	0.53
HB	2070-2099	44.0	17.5	0.39

Table 8.6: Inflow into Lake Volta under the energy adaptation strategy.

8.2 Field level

8.1.2 Description of adaptation strategies

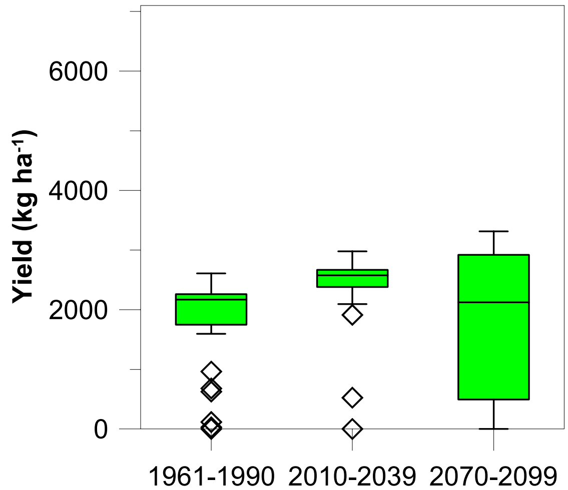
For the two crops used, rice and maize, the adaptation strategies explored are growing crops under rainfed, irrigated, and intensified conditions. The adaptation strategy mentioned here as intensification consists of a package of cultivation practices which in general will increase crop yields such as improved crop variety, denser planting, chemical inputs and shorter season. Since rice is grown in the wet period it was explored what the result of growing rice only under rainfed conditions would be. Irrigated rice was, therefore, the baseline. Rainfed rice was one adaptation strategy and intensified rice production was the second strategy. Maize production during the wet season is normally done under rainfed conditions and this practice is used here as the base line. The adaptation strategies for maize were growing irrigated maize and growing maize with intensified cultivation practices.

8.2.2 Impact of adaptation strategies at field level

Under no irrigation, rice yield increase slightly for the medium term (2010-2039) under Hardley A2. However in the long term the yield experienced not only a decrease but also high variability. Under intensification in its cultivation there is a dramatic increase in the yield both in the medium and long terms (Table 8.7). Intensification here means; using improved seeds, good agronomic practices, good soil fertility and pest and diseases management but without irrigation.

Basin	**Volta**
Crop	**Rice**
Climate	**Hadley A2**
Scenario	**No irrigation**

Period	*1961-1990*	*2010-2039*	*2070-2099*
Average (kg ha^{-1})	1828	2418	1790
Std (kg ha^{-1})	773	631	1222
CV (%)	42.3	26.1	68.3
Tot. Cons. (mm)	604	643	702
Prod. Cons. (mm)	326	356	389
WP ($ m^{-3})	0.07	0.09	0.06



Basin	**Volta**
Crop	**Rice**
Climate	**Hadley A2**
Scenario	**Intensification**

Period	*1961-1990*	*2010-2039*	*2070-2099*
Average (kg ha^{-1})	3987	5011	5963
Std (kg ha^{-1})	413	433	600
CV (%)	10.4	8.6	10.1
Tot. Cons. (mm)	575	597	716
Prod. Cons. (mm)	404	424	533
WP ($ m^{-3})	0.16	0.19	0.19

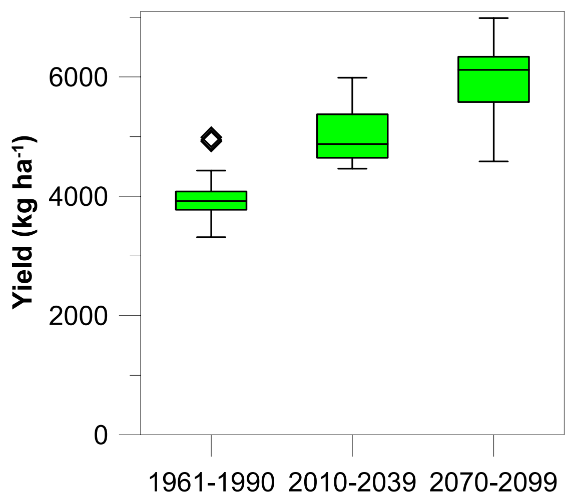
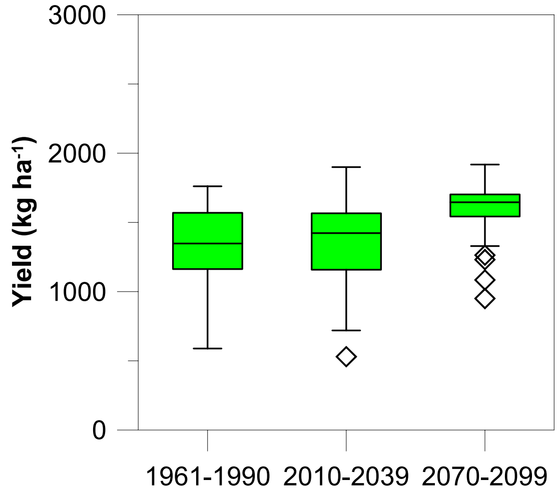


Table 8.7 Rice yield prediction under Hadley A2 for no Irrigation and Intensification

Maize yield prediction under Hadley A2 showed modest increase with decrease in viability in the long term under irrigation. Under intensification of its production however there was a high variability in the yield, which slightly increases in the medium term and unexpectedly decrease in the long term.

Basin	**Volta**
Crop	**Maize**
Climate	**Hadley A2**
Scenario	**Irrigation**

Period	*1961-1990*	*2010-2039*	*2070-2099*
Average (kg ha^{-1})	1320	1327	1585
Std (kg ha^{-1})	311	349	216
CV (%)	23.6	26.3	13.7
Tot. Cons. (mm)	844	873	1120
Prod. Cons. (mm)	465	495	715
WP (\$ m^{-3})	0.04	0.03	0.03



Basin	**Volta**
Crop	**Maize**
Climate	**Hadley A2**
Scenario	**Intensification**

Period	*1961-1990*	*2010-2039*	*2070-2099*
Average (kg ha^{-1})	1642	1864	1210
Std (kg ha^{-1})	431	509	585
CV (%)	26.2	27.3	48.3
Tot. Cons. (mm)	497	520	573
Prod. Cons. (mm)	297	321	365
WP (\$ m^{-3})	0.08	0.08	0.05

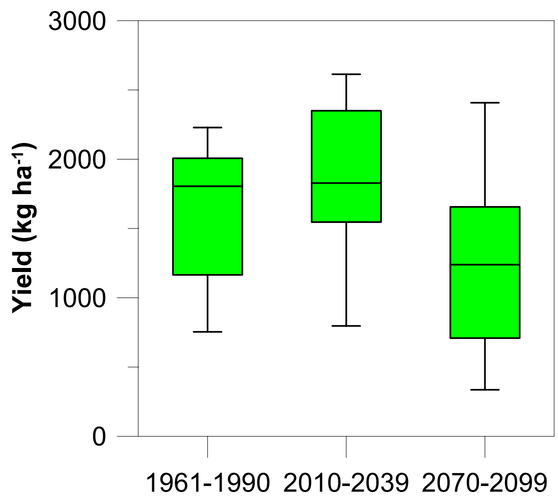


Table 8.8 Maize yield prediction under Hadley A2 for Irrigation and crop Intensification

		1961-1990	2010-2039	2070-2099
Rice	No Irrigation	40216	53196	39830
	Intensification	8734	110242	131186
Maize	Irrigation	1186680	1192973	131186
	Intensification	1476158	1675736	1087790

Table 8.9 Crop Production in Tons

8.3 Impact matrix

Table 8 shows the impact matrix for the different adaptation scenarios. If the wetland loss is acceptable, the food adaptation strategy seems relatively optimal. Remarkable is also the fact that even under increased runoff, it is not wise to rely on hydropower for 100% because there will still be regular periods where the water level is too low.

Volta	Indicator	Measured in	Current	Future no adaptation	Future no adaptation	Adaptation			
			1990	2030 A2	2070 A2	2030 Food	2070 Food	2030 Energy	2070 Energy
Environment	Wetland loss	ha	0	0	0	382,500	382,500	0	0
Food	Rice	tons	71,478	85,866	103,136	2,004,400	2,385,200	85,866	103,136
	Maize	tons	833,373	956,536	440,510	1,476,158	1,675,736	956,536	440,510
Energy	Energy/year	TJoule	18,116	21,595	18,742	21,121	18,095	23,232	19,467
	Low level	Years/30 yrs	7	0	6	0	7	8	10

green	good
yellow	stable
orange	bad

Table 8.10: Impact matrix for the main adaptation strategies and the Hadley A2 scenarios. The individual results are described in 8.1 and 8.2.

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