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Impacts of Irrigation and Hydroelectric Power Developments on the Victoria Nile in Uganda

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Dedication

To my sister Deborah Mutonyi, who passed on during the course of this study and to my children Angel, Lydia, Ivan, Chelsea and Jesse who I so dearly missed.

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I am very grateful to all those who contributed in different ways to the success of this research. I am highly indebted to the Nile Basin Initiative that selected me and sponsored me to undertake the PhD study. Without them this work and the experiences gained would never have been realised.

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Last but not least many thanks to my supervisors Prof. Richard Carter and Dr. David Parsons who guided me through and saw the work evolve from the first word to the last.

Abstract

This research aimed at increasing the understanding of the water resources of the Victoria Nile basin and assessing the impact of irrigation and hydropower developments on the Victoria Nile under different rainfall regimes. A Bayesian Network constructed with the HUGIN expert researcher software version 6.9 was used as the decision tool. The Network used a mixture of data, information from previous studies and consultation with experts/stakeholders. A network consisting of 21 nodes was developed and run to determine the impacts of different development scenarios.

The Victoria Nile basin in Uganda is the first recipient of the river Nile flow as it leaves Lake Victoria. In this basin, there is potential for 5 large hydroelectric power plants and the basin consists of 70% of the irrigation potential in Uganda and yet it is one of the most lacking in hydrological data in the Nile basin. Further downstream of this basin are two riparian states, Egypt and Sudan which according to the prevailing legislation on the use of the Nile share amongst themselves the entire river flow.

The research shows that Irrigation and hydropower developments have modest effects on lake levels and river flows exiting the basin. Rainfall occurrence on the other hand has the largest effect on the lake levels and Victoria Nile river flow exiting the basin. It is shown that in situations of very high water demand, which occurs when annual rainfall is less than 1,200 mm, full irrigation potential is utilized and all 5 hydroelectric power plants are developed, irrigation water need is not more than 7% of the Nile flow from the basin. The effects of hydropower plants are manifested mainly in the socioeconomic impacts in their vicinity, which are found to be large and to increase with the number of plants developed. The current mode of operation of outflows from Lake Victoria which is based on an international agreement between Uganda and Egypt is a satisfactory means of control only during moderate rainfall events and lake levels. However, for extreme conditions of lake levels outside the range of 10.8-11.6 m it is inadequate under increasing demands of hydroelectric power generation.

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List of Abbreviations and Acronyms

AESNP	AES Nile Power
AI	Artificial Intelligence
ARTES	Africa Rainfall and Temperature Evaluation System
BEL	Bujagali Energy Limited
BN	Bayesian Network
CEH	Centre for Ecology and Hydrology
CPT	Conditional Probability Table
DAG	Directed Acyclic Graph
DFID	Department for International Development
DRC	Democratic Republic of Congo
DSS	Decision Support System
DST	Decision Support Tool
DWD	Directorate of Water Development
EdFI	Electricite de France International
EIA	Environmental Impact Assessment
ENSO	El Niño-Southern Oscillation
EU	European Union
FAO	Food and Agricultural Organisation
GDP	Gross Domestic Product
GIS	Geographical Information System
ha	Hectare
HEP	Hydroelectric Power
Hydromet	Hydro-meteorology
ICRAF	International Centre for Research in Agro forestry
IDP	Internally Displaced Person
IMS	Information Management System
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
IWRM	Integrated Water Resources Management
Lidar	Light Detection and Ranging

LVDSS	Lake Victoria Decision Support System
MERIT	Management of the Environment and Resources using Integrated Techniques
MFPED	Ministry of Finance, Planning and Economic Development
MW	Mega Watt
NB-DSS	Nile Basin Decision Support System
NBI	Nile Basin Initiative
NEMA	National Environment Management Authority
NEWATER	New approaches for adaptive water management
NWA	Nile Waters Agreement
NWSC	National Water and Sewerage Corporation
OECD	Organisation for Economic Cooperation and Development
PSR	Pressure, State, Response
RADAR	Radio Detection And Ranging
TMDL	Total Maximum Daily Load
UBOS	Uganda Bureau of Statistics
UN	United Nations Organisation
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WG	Wolf-Gleissberg
WMO	World Meteorological Organisation
WWAP	World Water Assessment Programme

Chapter 1 Introduction

1.1 Background

This study arose as a result of the high emphasis on hydroelectric power developments on the Victoria Nile in Uganda at a time when Lake Victoria levels and outflows were highly variable while at the same time more need for irrigation was anticipated due to high population growth rates in Uganda. During the same period the Victoria Nile basin areas of north eastern Uganda registered a series of extended drought and flooding conditions in the period 2000-2006, which many attributed to climate variability and change. The study set out to review the knowledge of the water resources in the Victoria Nile basin, to guide decision making under these complex interactions and to assess what the likely state of the water resources and environment and the impacts on the socio-economic situation would be under different scenarios of water resources and development pressures.

River and lake systems are important resources in many ways. One important function is to provide humans with potable water and at the same time carry away wastes generated by man and his activities. Unfortunately at the moment there is hardly any region of the earth with a river system whose hydrology and quality has not been disturbed by human activities. These disturbances are normally a result of social and economic activities that man undertakes for his survival and livelihood and may therefore be inevitable. As populations increase the impact of human activity on the available resources will continue to degrade the quantity and quality of the resources. In developing countries there are inadequate financial and other resources to harness and manage the available water in a sustainable manner and exploitation often occurs due to use of rudimentary methods.

Only 7% of Africa's hydropower potential has been developed compared to Europe's 70%, while only 4% of arable land in sub-Saharan Africa is irrigated compared to 40% in South Asia (DFID, 2006). World Bank projections indicate that one third of the world's population is expected to experience severe water scarcity by 2025. There is a worldwide consensus that the need for water and water supply systems is increasing rapidly as a direct result of human population growth, improved standards of living and industrial expansion as well as an escalating need for food in dry regions. At the same time there is a major threat to the relationship between upstream and downstream users in the case of trans-boundary water resources due to conflicting demands for water (Mahmoud Abu-Zeid and Shiklomanov, 2004). It is therefore important that regular assessments be undertaken in order to identify the likely impacts caused by the various water uses and devise means to mitigate them. In addition to guiding decision-making, it is important that predictions be made to give an indication of how the water catchment as a whole may respond to different development scenarios.

In order to obtain a general assessment of the water resources and the water availability for a basin or a region and to determine future needs, it is necessary to assess the changes caused by human activities and developments in the basin concerned. Development projects, notably irrigation, hydroelectric power and industries, provide benefits to society but they may also be accompanied by impacts that can be detrimental to the social and environmental fabric of the areas in which they are implemented. The construction of reservoirs for example can lead to a radical transformation in the space and time distribution of runoff. Reservoirs can also make a considerable contribution to evaporation, particularly in arid and semi-arid regions. This may lead to a decrease in the total water resources of the region concerned. In the Nile river basin seven large dams and barrages were built in Egypt and Sudan in a period of less than fifty years[1] (table 1.1).

The impacts of these dams, and especially the Aswan High dam in Egypt, have been described in the literature (Shiklomanov and Rodda, 2003; Shalash, 1980a; Shalash, 1980b). These include flood control, increasing area of irrigation, electric power generation and flow control among others. The negative impacts have been the complete change of the hydrological

[1] Data of Shiklomanov and Rodda 2003 World Water Series at the Beginning of the 21st Century, Table 6.29 page 206.

regime of the river Nile. The Aswan High dam and the reservoir it created led to a radical change in the distribution of runoff and a reduction in its volume by 43% (Shiklomanov and Rodda, 2003). Other impacts include reduction in sediment loads, increased concentrations of minerals in the water and negative social and economic conditions such as decreased productivity of the soils, spread of infectious diseases and migration of indigenous people.

Table 1.1 Dams and Barrages in the Nile Basin

Dam or Barrage	River	Year of construction	Country
Roseires Dam	Blue Nile	1922	Sudan
Sennar Dam	Blue Nile	1922	Sudan
Khashm el Girba Dam	Atbara	After 1922	Sudan
Nag-Hammadi Barrage	Nile	1930	Egypt
Jebel-Aulia Dam	White Nile	1937	Sudan
Edfina Barrage	Nile Delta	1950	Egypt
Aswan High Dam	Nile	1968	Egypt

The prevailing international legislation for the river Nile was inherited from the colonial governments and does not adequately consider the needs of all riparian states. The 1959 agreement for the full utilization of the Nile waters, for instance, allocated all the Nile flow to Egypt and Sudan without consideration to other riparian states. These colonial laws are seen to be unfair and have caused tension between the riparian states.

Effects of Climate Change

Climate change may cause detrimental effects to water resources and their spatial and temporal distribution. Global mean surface temperature estimates by the Intergovernmental Panel on Climate Change (IPCC) show consistent warming trends with a total temperature increase of about 0.76°C over the last 100 year period 1906-2005 (IPCC, 2007b). Such changes in climate have significant impacts on local and regional hydrological regimes, which in turn affect ecological, social and economic systems. It is estimated that by 2020 up to 250 million people in Africa will be exposed to increased water stress due to climate change (IPCC, 2007a). Furthermore climate variability and change is likely to severely compromise agricultural production including access to food. The IPCC's projection is that by 2020 in some African countries yields from rain-fed agriculture could be reduced by up to 50% of what they were in the climate conditions of 2006 (IPCC, 2007a). Climate change impacts are discussed in detail in section 4.5.

In Uganda there are two dams at Jinja, the outflow of Lake Victoria at Kiira and Nalubaale which are constructed in a parallel stream whose construction is believed to have contributed to 55% of the declining water levels in Lake Victoria, while persistent drought is responsible for 45% (Kull 2006). This lake level decline, estimated to be about 3 m is the largest recorded on Lake Victoria in the last 51 years. Rainfall patterns have been erratic in the past few years with rains coming during unexpected times of the year and with unexpected magnitudes. This has caused low food crop yields and famine in the north eastern parts of Uganda.

In 2005-06 the reduction in water levels of Lake Victoria, the main reservoir for the White Nile, caused a discomfort that resulted into an outcry from communities and organisations in the river Nile basin. In 2006 it was reported that the Minister of Water, Lands and Environment, Maj. Gen. Kahinda Otafiire, said the Government would close down one hydroelectric dam at Jinja due to the falling levels of water in the lake[2]. While this could save the declining level of the lake it would have the effect of reducing the already insufficient electric power generated. As a direct consequence of the declining lake levels the National Water and Sewerage Corporation (NWSC) planned a development of US$ 4 million to avert the water crisis that was being experienced in most parts of Kampala city. The funds were to be used for improving the water intake from Lake Victoria, which according to experts, had dropped drastically. In this Project NWSC planned to build and extend a pipeline 24 m deeper and extend the intake to 2.4 km into the lake at Gaba water treatment works to restore the intake which had been affected by the low water levels. This intake at the Gaba water works was left with only 0.5 m

[2] The New Vision of 21st January 2006

submerged at the time of the crisis. The situation for the water company was even worse for the areas of Jinja and Entebbe where the intakes were left exposed. This situation led to rationing of water in Kampala, a city of an estimated population of 1.5 million.

Hydroelectric Power Demand

The estimated hydroelectric power (HEP) potential of the river Nile in Uganda is about 2,000 MW of which only 300 MW has been exploited. Due to the high rate of industrialization in Uganda it is projected that peak power demand in 2010 will be up to 649 MW (MFPED, 2004) which is more than double the current supply. This high anticipated demand creates a need for further generation of electricity. There is no doubt that the potential of the river Nile will be the first priority given that there are not many alternative energy sources. By 2008 construction of a plant at Bujagali (250 MW) was underway while plans to construct another at Karuma (200 MW) were in advanced stages.

Irrigation Demand

Uganda has over 90,000 ha of economically viable irrigation potential of which only 7,600 ha are formally irrigated and 53,000 ha are irrigated informally, mainly by farmers growing rice in wetlands (MFPED, 2004). It is estimated that 64% and 68% of wetlands in Iganga and Pallisa districts respectively have been reclaimed (NEMA, 2001). This is due to the increasing need for food and it shows that irrigated agriculture is likely to increase in the region. While it is not anticipated that irrigation in Uganda will use water directly from the Nile, increased exploitation of wetlands for cultivation and increased use of water for irrigation may have an effect on the flow pattern of water resources in the basin.

Data Availability

For the river Nile basin, many studies have been undertaken most of which have been led by Egypt and the colonial governments in East Africa and to a lesser extent Sudan. For this reason these studies have concentrated mainly on how much water is available for Egypt and Sudan. This has made data availability rather skewed with much data available in Egypt and very little available in the upper Nile riparian states. The World Meteorological Organisation (WMO) Hydromet projects which started in the 1960s were the first main attempts to collect hydrological data in these countries. As such, most hydrological data in Uganda and other upper Nile countries starts in the 1960s, when gauging stations were expanded by the Hydromet projects. Until 1999, when the Nile Basin Initiative (NBI) was launched, there were few studies carried out jointly by the riparian states for the benefit of the upper riparian states in which the White Nile originates. This has left these equatorial states ill-prepared to make decisions on which developments to undertake; it has also left them with no system of decision-making when it comes to local developments within the Nile system. The already documented impacts caused by the Aswan High dam illustrate the dangers to which this upstream part of the great Nile may be subjected to. The high population growth rates in the region, estimated at an average of 2.5-3.0%/year, and the high rate of industrialisation exert pressure on the region and the individual nations which have to initiate development projects to provide the required energy, water supplies and other services.

1.2 Problem Statement

As populations grow and industrialization expands, there is pressure for countries to accelerate development in order to match and cope with the emerging demands. Governments are therefore often forced to exploit the available natural resources to satisfy the increasing demands. In the case of water resources, the problem of availability of water is exacerbated by climate variability and change, which may affect the spatial and temporal distribution of the already insufficient water. As a result of this complex situation there is a risk of over exploitation of the water resources if programmes are not well planned and the right decisions are not made. For the Victoria Nile Basin, where there is a lack of sufficient data, planning and decision making is made even more difficult. This has consequences for environmental degradation and even regional tension as the water resources are shared between several countries.

The Victoria Nile basin in Uganda is the first recipient of the Nile flow as it leaves its source from Lake Victoria on its long journey to the Mediterranean Sea. Within this catchment, a total of 5 hydroelectric power plants are proposed. It has the largest potential for irrigation in Uganda and it has a lake system characterised by flooding and blockages caused by floating vegetation. Moreover, the prevailing legislation on the use of the river Nile waters requires that developments in the basin should not alter the flow pattern of the Nile significantly. Against the backdrop of these characteristics decision making on which developments to undertake and what likely impacts they may cause to the basin and to downstream riparian states is a challenge.

1.3 Conceptual Framework

The conceptual framework for the study (figure 1.1) is based on the Pressure-State-Response (PSR) framework developed by the Organization for Economic Cooperation and Development (OECD). Economic and social activities generate welfare benefits but simultaneously exert pressures on the environment. The PSR framework links pressures on the environment as a result of natural phenomena and human activities, with changes in the state (condition) of the environment (land, air, water). The pressures on the environment cause a change of the state of the environment which may be undesirable to society. Society then responds to these changes by instituting environmental and economic programmes and policies, which feed back to reduce or mitigate the pressures or repair the natural resource (OECD, 1993).

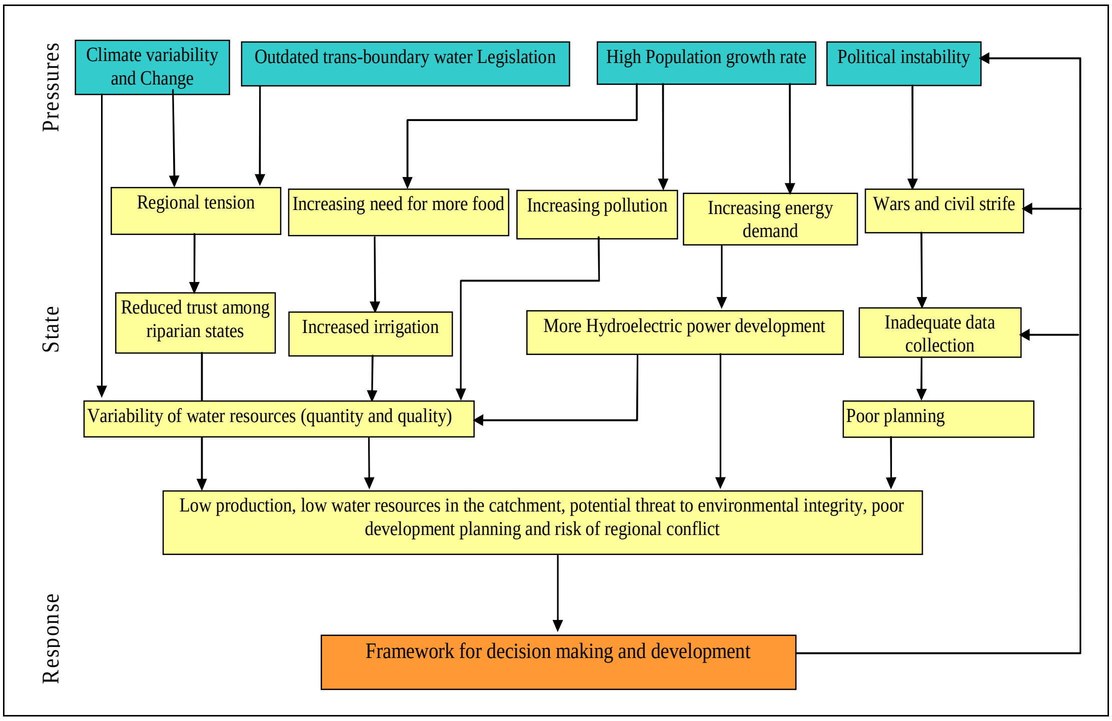


Figure.1.1 Conceptual Framework

Based on the P-S-R framework developed by OECD, 1994

1.3.1 Pressures

Pressures are the variables which directly or indirectly cause (or may cause) environmental or other problems to the system under study. These influence decisions and actions taken by society for their livelihood and as a result the natural resources may be adversely affected. Climate variability and change, high population growth rates, outdated trans-boundary water resources management legislation and political instability are identified as the key pressures in the Victoria Nile basin.

Climate Variability and Change

Climate variability and change create hydrological problems such as droughts and floods which impact on the state of the water resources in a way that can cause regional tension as each riparian state wants to secure a share of the resources in situations of need. Generally, substantial variations in Nile basin precipitation have taken place on long (>1000 years) and short (<10 years) timescales. In central Sudan precipitation has declined by 9% during the twentieth century (Hulme, 1990); these types of variations, especially reductions in precipitation, can trigger regional tension. The lower riparian states, Egypt and the Sudan which happen to be the economically more powerful feel the upper riparian states are not doing what is needed to deal with the effects of climate variability and change. On the other hand, the upper riparian states feel these two are exerting hegemony over the Nile whose water does not originate within their territorial boundaries.

Outdated Trans-boundary Legislation

Trans-boundary legislation can be viewed as a response rather than a pressure. However, given that the current legislation was inherited from colonial times, it is seen here as a pressure on the nations, particularly those that did not participate in developing the laws. In this context, the prevailing trans-boundary water management legislation is perceived to be outdated; it does not reflect the current state of affairs of the riparian states and may be a recipe for regional tension, which in turn causes lack of trust as some states feel the laws are unfair to them. The British imperial regime was party to a series of agreements which constrained the actions of their own colonial authorities in the East African territories to take no measure which would reduce the flow of water to the north (Allan, 1990). For instance the Nile Waters agreement of 1929 in which Britain was to desist from construction of irrigation or power works in Sudan that could reduce or delay the water destined for Egypt, and the 1959 agreement for the full utilization of the Nile waters which allocated all the waters of the Nile to Egypt and Sudan. These agreements have been condemned by most of the upper riparian states. For example the Al-Ahram weekly reported after a meeting of NBI states in Uganda in its bulletin of 11th June 2004 that other countries of the Nile consider the colonial arrangements that govern the Nile waters as invalid. Gamal Nkrumah (2008) further reported in the Al-Ahram Weekly that the other Nile nations are essentially aggrieved because of the 1959 treaty that gave Egypt and the Sudan exclusive rights over the Nile river's use and that they all strongly object to the 1929 treaty that stipulates that no country can undertake any project that would reduce the volume of water reaching Egypt (Nkrumah, 12 November 2008). The NBI is seen as a means of achieving mutual benefit to all riparian states if it succeeds because it is all-inclusive and it is facilitated by international organisations like the UNDP and the World Bank. The main focus of all NBI projects is confidence building showing how critical trust is among the states. The UN Chronicle reports that success for The NBI would mean security and sustainable supply for the downstream states and a chance for development for upstream states. It however considers that its failure would mean more mistrust and suspicion among the riparian states (Lemma, 2008).

High Population Growth Rates

High population growth leads to increased need for food and therefore more demand for irrigation, high domestic water and energy demands and increased pollution of the receiving water bodies. These pressures have the combined effect of reducing the quantity and quality of the available water resources and the need for development of more energy resources. Most of the Nile basin countries share a history of poverty and high population growth. The current average population growth rate in the region is 2.5-3.0%/year, one of the highest in the world, with an average population density of $96/km^2$. Half the population in the basin lives below the poverty line of US$1/day. In the Victoria Nile basin, the most appropriate source of electricity is hydropower. Developing more hydroelectric power plants may have negative social and environmental impacts to the system. In addition the reduced water resources will lead to reduced production.

Political Instability

Political instability has been a common phenomenon in the Nile riparian states for many decades now. Of the ten riparian states that share the Nile, only Egypt and Tanzania have not seen their share of political instability in the recent past (Table 1.2 shows a list of recent political conflicts in the Nile Basin countries).

Table 1.2 Recent conflicts in the Nile Basin Countries from 1970s to-date
Obtained from various sources

Year	Country	Nature of conflict
1974 - 1991	Ethiopia	Civil war that erupted after the Marxist Derg staged a coupe d'état that ousted the Ethiopian emperor, Haile Selassie. During this time the country was hit by terrible drought and famine in the mid 1980s.
1998-1999	Ethiopia and Eritrea	A war over currency and trade issues and a disputed 150 square mile border region of Badame in northern Ethiopia.
1972	Burundi	Tutsi genocide of Hutu is said to have taken the lives of approximately 5 percent of the population and virtually wiped out the stratum of educated Hutu. Anywhere from 100,000 to 150,000 Hutu were killed in the repression triggered by the outbreak of Hutu-instigated uprisings. Besides creating deep and lasting hatred on both sides of the ethnic divide, the events of 1972 became the source of considerable tension within the Tutsi minority to date.
1988	Burundi	Hutu-Tutsi violence of 1988 estimates that about 20,000 people mostly Hutus were massacred as a result of animosity that had built up between these two ethnic groups.
1993-1996	Burundi	Civil war that was a follow on the historic background of decade long ethnic hatred. As a result of power struggle between the Hutu and Tutsi ensued, this climaxed with the shooting down and killing of the Burundian and Rwandese presidents. Later in 1996 government was later overthrown by the Tutsi military.
1973	Rwanda	A bloodless coup that brought Juvenal Habyarimana into a 21 year rule. This followed later in 1980 with an aborted coup that sought to oust the sitting government of Juvenal Habyarimana.
1990 - 1994	Rwanda	Tension between the Hutu and Tutsi flared in 1990 leading to the Tutsi-led invasion of Rwanda from Uganda. This was followed later by the 1994 genocide that left half a million people mostly Tutsis killed precipitated by the shooting down of a plane carrying the Rwandan and Burundian presidents.
1985- 2008	Sudan	A military coup that imposed harsh military rule to the mainly Christian South which intensified the civil war between southerners and northerners. This war became a full fledged guerrilla war accompanied by massive starvation and diseases that to date has led to more than million deaths and many more fled to escape the war.
2003 - 2008	Sudan	The Darfur conflict started in 2003. It is believed that among the causes of the conflict are a combination of decades of drought, desertification and over population. The Baggara nomads who are Arabs moved further south to areas occupied by black African farming communities in search for water for livestock. This caused the conflict which has resulted in over 500,000 deaths and displacement of 2.5 million people. The

Year	Country	Nature of conflict
		Sudanese government in Khartoum has been accused of supporting the Arabs against the Black Africans. This conflict which has been categorised as genocide has spread to Chad and by 2008 was still ongoing.
1971-79	Uganda	A military coup that brought in Idi Amin Dada to 8 years rule that was characterised with terror. This regime was later overthrown by a conventional war by Ugandan exiles assisted by the armed forces of Tanzania.
1981-86	Uganda	After losing an election and allegations of vote rigging Museveni launched a guerrilla war that left the economy of the country on its knees. An estimated 300,000 people lost their lives in the conflict.
1986 - 2008	Uganda	Rebel insurgence in northern Uganda considered one of the longest running conflicts has cost over three hundred lives and many more displaced persons leaving northern Uganda region with barely any productivity. This insurgence was considered the biggest neglected humanitarian emergency in the world by UN Undersecretary for humanitarian affairs, Jan Egeland.
1998 - 2008	DRC*	Also known as the Africa world war or the great war of Africa which directly involved up to 8 African nations and 25 armed groups. The main war ended in 2003 but later started again and by 2008 was still running. By 2008 the war and its aftermath had killed up to 5.4 million mostly from disease and starvation making this war the deadliest after the second world war.
2007	Kenya	After a disputed presidential election in Kenya a near civil war erupted when supporters of rival presidential candidates engaged in fights that left thousands dead.

* Democratic Republic of Congo

Abrupt government changes, civil wars and internal conflict have been prevalent in the region and as such have impeded development and joint action within the states. As a result of these conflicts and other reasons such as lack of skill, remoteness and poor infrastructure, facilities for collecting hydrologic and meteorological data have been run down while many others have been kept non operational for long periods. Little emphasis has been put on data collection as most government resources are directed towards averting internal conflicts. This has led to poor planning that is based on inaccurate information and ultimately poor decision making.

1.3.2 State

Pressures exerted on the environment may cause its state to deteriorate to levels that affect social and economic welfare. These pressures can affect the state of the environment to such an extent that it is unable to provide natural resources, absorb waste or support living systems. For the Nile basin, the undesirable state to which the physical environment can be reduced include declining water resources quantity and quality. Other states that are attributed to the social fabric are increasing regional tension, inadequate data for planning, increasing demand for food and energy, more wars and civil strife.

Under the concept of human security, water resources, their scarcity, distribution and quality have been named as the factors most likely to lead to intense political pressure (Yoffe et al., 2004). The unfolding scenario for water use in the Nile basin is one of increasing concern about access, equity and the response to growing needs. This affects relations within and between nations, between rural and urban populations and between upstream and downstream users. Such tense relations have existed before and are still evident in the Nile basin and are likely to increase given the increasing demands on the available water resources, climate variability and the military might of the downstream nations compared to the upstream ones. It is shown that in a river basin conflict is more likely to emerge when the downstream nation is militarily and politically stronger than the nations upstream and the downstream nation believes its interests in the shared water is threatened by the actions of upstream nations (Kameri-Mbote, 2008). For the river Nile Basin most past conflicts have indeed involved Egypt as evidenced by the major conflicts in the Nile basin summarised by El-Fadel et al. (2003). The Nile basin together with the Indus, Jordan and the Tigris-Euphrates are listed as the most conflictive basins (Yoffe et al., 2004). Lack of trust amongst riparian states undermines the real objective that international water management legislation sets out to achieve. This lack of trust may be a precedent for lack of cooperation and integrated and joint planning which is highly emphasized under the NBI projects. In the Nile basin, lack of trust is clearly manifested in the lack of data sharing amongst the riparian states as was experienced by the researcher of this study.

1.3.3 Response

When the state of the environment and the social fabric deteriorates, society often responds by implementing plans, regulations or deriving frameworks that aim at resisting the pressures or reinstating the environment to the desired state.

Such strategies may be diverse depending on the capacity of the state or organisations involved. One such undertaking being spearheaded by the NBI is the reformulation of the Nile basin legislation so that it is all-embracing and considers the needs of all riparian states. A framework for decision making and development is another such strategy that needs to be developed. Specifically a framework for guiding decision making and assessing the impacts of such decisions for the Victoria Nile basin is discussed in this study.

Improved decision making is seen as one way in which the pressures above and the state of the environment can be dealt with and improved. By developing a framework to guide decision making under the prevailing conditions of climate variability and change, trans-boundary water management legislation, high population growth rates and inadequate data, the cycle may be broken. The available water resources can be equitably used by all riparian states if better development decisions which recognize the state of the environment and the specific future needs of each individual state are made.

1.4 Aim and Objectives of the Research

This research was an attempt to increase the understanding of the water resources of the Victoria Nile basin and to develop a framework for decision support that can assist government and implementing agencies in deciding on which developments to undertake and assess the likely impacts caused by such developments. The research aim was to assess the impact of development projects on the water resources of a catchment within a trans-boundary river system subjected to different development projects against a background of climate variability and change.

The specific objectives of the study were to set out:

1. A review of knowledge of the available water resources in the Victoria Nile basin.
2. An analysis of the potential water resource development projects likely to be implemented in the Victoria Nile basin.
3. A decision support methodology for the Victoria Nile basin.
4. An indication of the likely impacts of key development decisions on the water resources and environment state of the basin.

1.5 Thesis Structure

The thesis is structured into nine chapters. After this introduction, Chapter 2 describes the socioeconomic, geographic and hydrological aspects of the study area. Chapter 3 gives a review of the water resources of the Victoria Nile basin to which objective 1 refers. Chapter 4 outlines the key development projects and challenges facing the Victoria Nile basin and addresses objective 2. Chapter 5 describes the research approach used and gives details of the selection of the decision model. Chapter 6 addresses objective 3 and describes how the Bayesian Network for the Victoria Nile was developed. Chapter 7 gives the key model results and addresses objective 4. Chapter 8 gives discussions of results and Chapter 9 presents the conclusion and recommendations.

Chapter 2 The Study Area

2.1 Introduction

The study area is the Victoria Nile basin, which is a sub-basin of the river Nile basin (figure 2.1). The Victoria Nile basin comprises Lake Kyoga and the Victoria Nile river sub-basins stretching from the river Nile exit from Lake Victoria to its entry into Lake Albert. The River Nile is the longest river in the world stretching for 6,671 km from its source in Lake Victoria to its final destination in the Mediterranean Sea. Along its journey the Nile passes through Uganda, Sudan, Ethiopia and Egypt, however the area draining into the Nile covers a total of ten countries that include Rwanda, Burundi, Tanzania, Kenya, Eritrea and the Democratic Republic of Congo (DRC) in addition to the four above. This drainage basin covers an area of 3,349,000 km^2, approximately a tenth of the size of Africa. This large area of the Nile makes it of interest to many researchers and the Victoria Nile, being the first recipient of the waters of the Nile, is very important for the understanding of the hydrology of the entire Nile catchment.

The climate of the Nile basin is extremely variable, mainly because of the expanse of area it covers extending over 36 degrees of latitude. The rainfall pattern changes from high bimodal rainfall in the East African plateau with an annual average of 1,292 mm reducing northwards to a mere 15 mm in the arid Egyptian desert. Inter-annual variations in rainfall can cause considerable changes to river discharges and lake levels. This seems to be more explicitly the case for the White Nile river system originating from Lake Victoria in Uganda than the Blue Nile that originates from the Ethiopian highlands (Figure 2.1). For this reason, river Nile discharge figures vary greatly depending on the period under consideration (FAO Land and Water Division, 1997). Although the basin is spread over ten countries, the areas which actually contribute significant volumes to the river flow are relatively small and isolated. These include the East African lakes region and the Ethiopian highlands which contribute 20% and 80% respectively of the total Nile flow.

Over most of the basin, the runoff is low and there are high evaporation and channel losses.

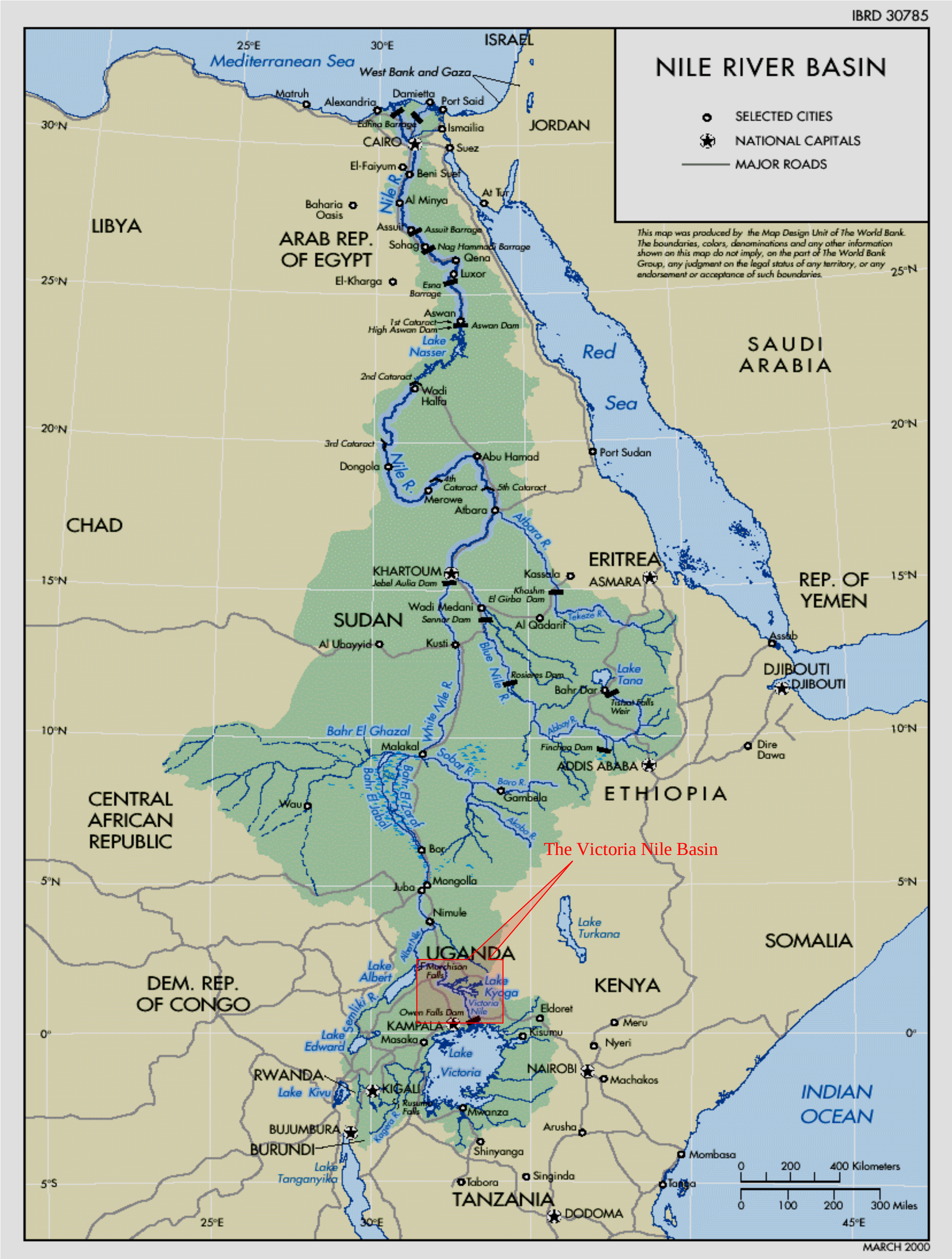


Figure 2.1 The River Nile Basin

Source: World Bank, (2000)

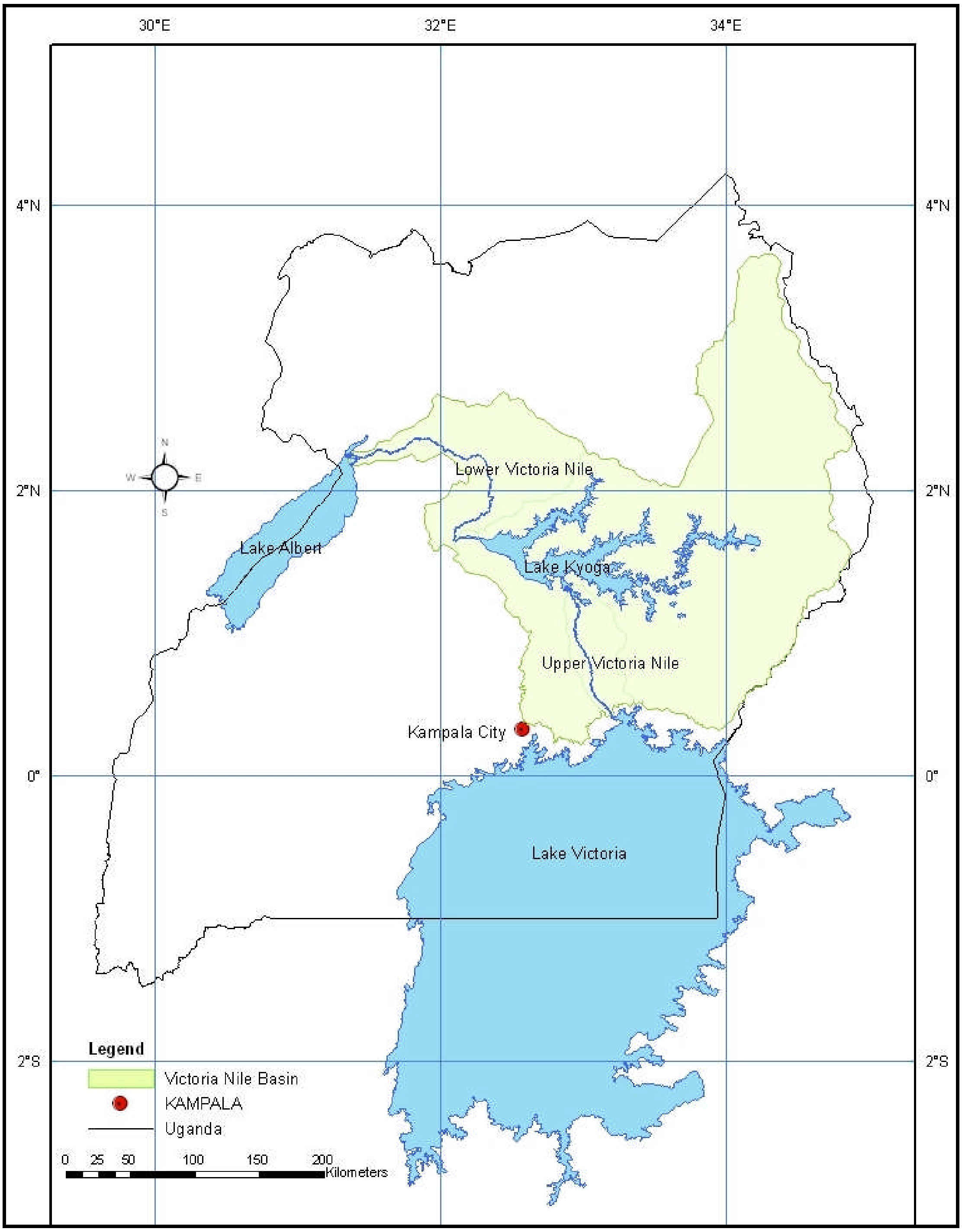


Figure 2.2 The Victoria Nile Basin Location in Uganda

2.2 The Victoria Nile Basin

2.2.1 Location and Geographic Features

The Victoria Nile basin is the area of focus of this research (figure 2.2). The basin is found within the territorial boundary of the Republic of Uganda extending from 31° 24' east to 34° 52' east and 0° 14' north to 3° 39' north.

With a total surface area of 74,713 km^2 (Shahin, 1985) the Victoria Nile basin is the largest drainage basin in Uganda. The Victoria Nile River into which this area drains is the single outflow from Lake Victoria and the first recipient of the waters that make up the great river Nile. It has a total length of 483 km stretching from the outlet from Lake Victoria to its inlet to Lake Albert. Before discharging into Lake Albert it passes through Lake Kyoga. This configuration of the Victoria Nile basin suggests three sub-systems namely; The Upper Victoria Nile basin, lake Kyoga basin and the Lower Victoria Nile or the Kyoga Nile basin. These subsystems are shown in figure 2.3.

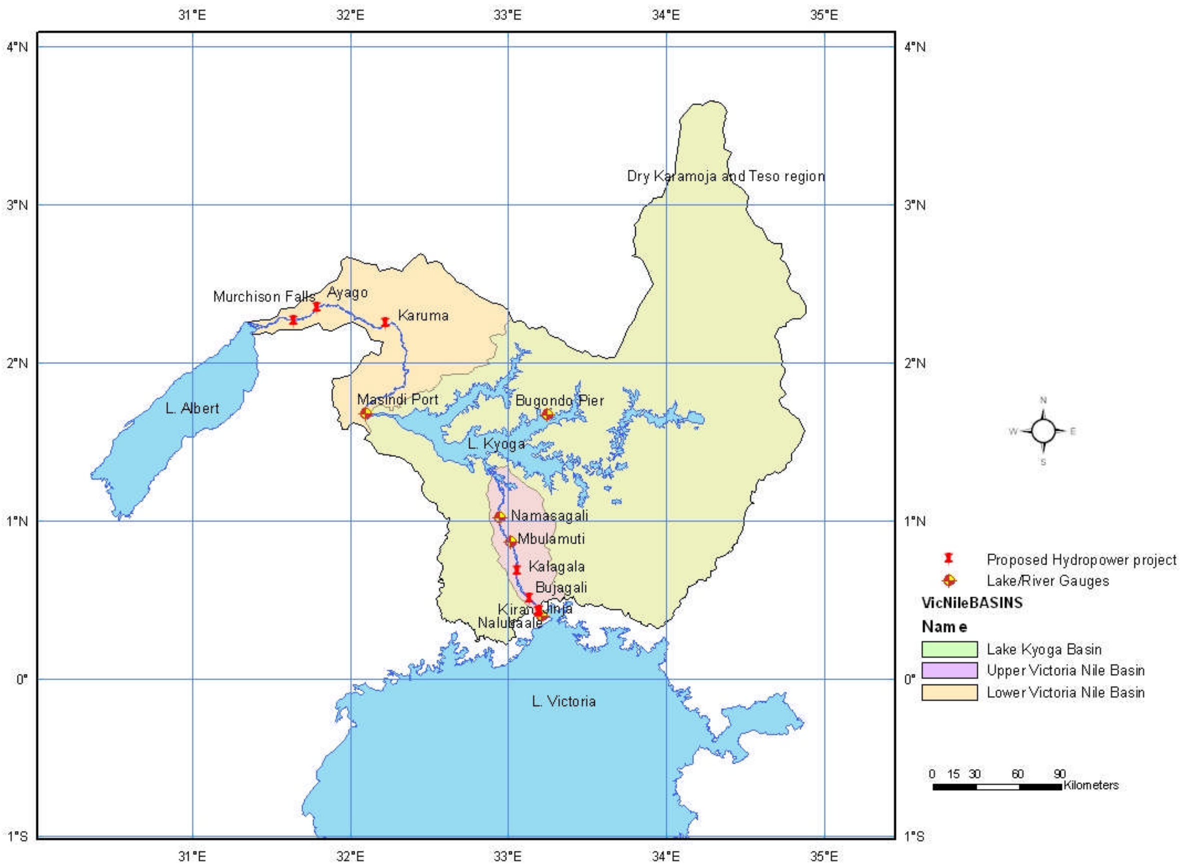


Figure 2.3 Sub drainage systems of the Victoria Nile

2.2.2 The Upper Victoria Nile Sub-Basin

The Upper Victoria Nile sub-basin represents the area drained by the first reach of the Victoria Nile River stretching from its exit from Lake Victoria at Jinja to its entry into Lake Kyoga (figure 2.3). The upper Victoria Nile river flows from the Nalubaale (originally known as Owen) falls dam at the outlet of Lake Victoria into Lake Kyoga.

The Victoria Nile is highly influenced by the hydrology of Lake Victoria. This is mainly due to the fact that the lake is the source of the Nile, but also because its massive size creates a unique climate system that influences its surrounding areas. Along the upper Victoria Nile are three gauging stations located at Jinja, Mbulamuti and Namasagali. These are used to measure the river level and flows. Lake Victoria levels have subsequent impacts on the flows of the Victoria Nile and Lake Kyoga levels. Flow releases from the Nalubaale dam determine the level and area of inundation in the basin. Analysis of a single outflow release from Lake Victoria revealed that over-release of more than 15% from the natural flow as per the operating rule of dam operation causes significant flooding in the basin (Okonga, 2002). Because of the small area of the upper Victoria Nile catchment, local runoff contribution to the flow of the Nile is insignificant, most of the flow being from Lake Victoria.

The upper Victoria Nile sub-system is the smallest of the three subsystems; however it is of great significance. It is the closest to the Ugandan capital city, Kampala, and the north road that traverses Uganda connecting it to Kenya, Rwanda, DRC and the Sudan passes through it. As such this region has a higher population density, it has more commercial activity and is more industrialized than the other two. The main town in this region, Jinja, was the main industrial hub of Uganda until the mid nineties when industrialisation moved to Kampala. Economically this town still plays a significant role in the development of Uganda because of its location and its proximity to the main source of energy in Uganda, the Nalubaale and Kiira hydroelectric power plants. Its hydrology is equally important, firstly because its outflow significantly determines the Nile flows to the lower basins. Thus any developments that affect the flow regime of the river in this section will subsequently affect the flow regime in the other sub-basins. Secondly its proximity to Lake Victoria makes its climate similar to that in the Lake Victoria basin, which is characterised by high tropical rainfall averaging 1,292 mm annually and high temperatures, up to 30° C.

By 2008 there were two hydroelectric power plants constructed in this part of the Nile (Nalubaale hydroelectric power plant and Kiira hydroelectric power plant) and one was under construction (Bujagali hydroelectric power plant) while another with a planned capacity of 350 MW of power (Kalagala) is feasible. It is projected that when the full potential of these plants is exploited they will be able to supply a large proportion of the energy demand in the country plus energy export to the neighbouring countries of Kenya, Tanzania and Rwanda.

Nalubaale (Owen Falls) Plant

The Nalubaale power station (figure 2.3) was the principal source of power in Uganda until 2002 when Kiira, an extension to it was commissioned into service. It is located about 3 km from the exit of the river Nile from Lake Victoria at Jinja and about 80 km east of the capital city Kampala. Its location is 0º 26’ 36.03” N and 33º 11’ 13” E. The power station was originally commissioned as the Owen Falls dam in 1954 with two 15 MW units. It was designed to utilise an average water head of 18.2 m and an average flow of 96 m^3/s per turbine. In 2000 the dam was given a local name: Nalubaale. Over the period 1954 to 1968 a further eight units were progressively brought into service, thereby utilising the full 150 MW design capacity of the original site. Electricity from this station is also exported to Rwanda, Kenya and Tanzania. Between 1989 and 1998 the turbines at the facility were upgraded and their capacities were raised from 15 MW to 18 MW bringing the total installed station capacity to 180 MW. This was in response to increasing energy demand, but even after this upgrading the national demand for power was still higher than the available supply. Following the Acres feasibility study of 1990 for the extension of the Owen Falls dam an extension of the dam called the Kiira dam commenced in 1997 and was commissioned in 2002.

This dam is important to the river Nile because it is here that the river Nile flow is regulated as it exits from its source, Lake Victoria. As such its operation is keenly observed by all riparian states especially Egypt which has permanently stationed its engineers at the dam to monitor lake outflows. For Uganda, its importance lies mainly in its electricity production but also because it is here that the only road between the eastern part of the country connects to the capital and the rest of the country. An additional economic importance is that Uganda being a landlocked country heavily depends on Kenya for ocean transportation of its imports and exports and it is this dam that provides the only road link between the coast in Kenya to Uganda and the neighbouring countries of Rwanda, Burundi and DRC.

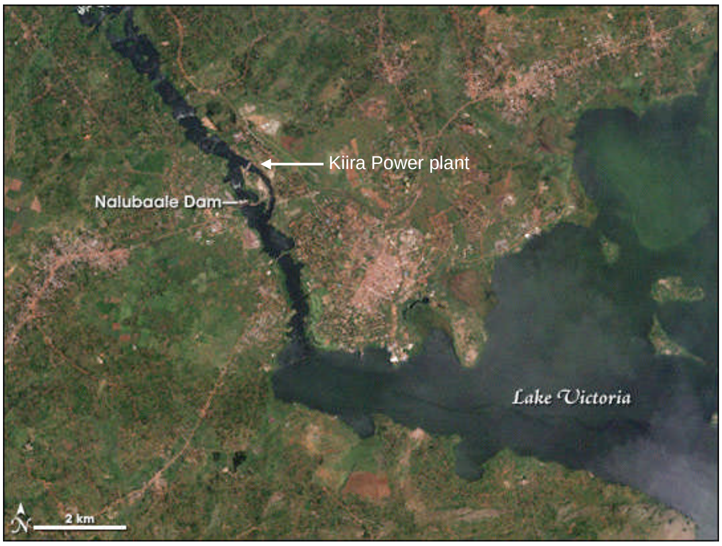


Figure 2.4 Satellite image showing Nalubaale and Kiira hydropower plants
Source: http://earthobservatory.nasa.gov/

Kiira Dam (Owen Falls extension) Plant

The Kiira dam was built as an extension to the Nalubaale dam and was commissioned in 2002. It is located 800 metres downstream of the Nalubaale dam and is built in a parallel stream to it. The facility has a maximum capacity to generate 200 MW from a set of five turbines each rated at 40 MW but currently three units are installed generating 120 MW. It was designed to utilize an average net water head of 21.6 m and average turbine discharge rate of 1,076.4 m^3/s which is higher than that for Nalubaale. This plant was initially conceived to generate electricity power from excess water spilled from the Nalubaale plant sluice gates which was seen as a waste yet there was high demand for electricity. However, after recognizing that Nalubaale was aging, it was upgraded as a plant to take over all the generation from the dilapidated Nalubaale, which was to be taken out of service.

Controversy over operation of this facility built up in 2005 when the water levels of Lake Victoria reached a record low as it was claimed by many that more water was being released through the turbines for generation of electricity (Kull, 2006). The controversy behind this dam did not come in isolation as the dam was built purposely to utilise only excess water that would otherwise be spilled unused over the sluices of the Nalubaale dam. The government saw this as a way of generating additional electricity from excess water that was flowing through the sluice gates unused. Unfortunately following the long droughts of 2003-2006 which coincided with the coming into service of this dam, it seems that more than the anticipated flow was released for power generation.

2.2.3 Lake Kyoga Basin

Lake Kyoga basin has the largest land surface area compared to any other drainage basin in Uganda. The basin has a surface area of 57,233 km^2 (FAO, 1997) although other researchers record an area of 75,000 km^2 (Shahin, 1985). The basin is complex, containing Lake Kyoga, two medium sized minor lakes, Bisina and Nakuwa with open water areas of 130 km^2 and 83 km^2, and about 30 other minor lakes (Twongo, 2001).

Because of its central location in Uganda, the Lake Kyoga basin spans all the key regional ethnic groupings in Uganda, namely Buganda, Busoga, western, northern and eastern Uganda, and covers an area that is exclusively within the territorial boundaries of Uganda. Lake Kyoga is vital to the livelihood of hundreds of thousands of people who live on its shoreline and on its Sudds (floating mass of vegetation). The mainstay of people here is farming, mainly rice cultivation in the swampy areas that surround the lake and also fishing. To the far north east of the basin are the Karimojong pastoralists, who are nomads and move from place to place in search of pasture and water for their livestock. The rest of the basin is inhabited by cultivators and fishermen. The basin has a high irrigation potential of 128,865 ha, that makes 68% of the total irrigation potential in Uganda. By 2006 rice irrigation in the basin accounted for 60,418 ha most of which was informal small scale irrigation.

2.2.4 The Lower Victoria Nile Sub Basin

The lower Victoria Nile basin is located in mid-northern Uganda. It represents a relatively small area that drains into the Kyoga Nile. Within this region are the spectacular Murchison falls and the Murchison falls National Park. This sub basin is sparsely populated, partly because of the presence of the national park. A significant feature of this region is its strategic location as the main divide between the northern and southern parts of the country. Politically this is important as it creates a demarcation between the mainly Bantu ethnic groups in the south and the Nilotics and Luo of the north. Economically this region provides the main entry to the northern region from the south and the capital city of Kampala. Consequently there is a high level of transit population moving north to south and vice versa depending on the prevailing socio-economic and political events in the country.

The outflow from Lake Kyoga is the Kyoga Nile or the lower Victoria Nile, which enters Lake Albert within the western arm of the Great Rift Valley. The difference in water level between the two ends of the Kyoga Nile, Lake Kyoga and Lake Albert, is 410 m (Shahin, 1985). This rapid drop makes this part of the Nile a great tourist attraction and it also provides high potential for hydroelectric power generation. There are three potential sites for hydroelectric power development at Murchison falls, Karuma and Ayago. By 2008, Karuma hydroelectric power plant was in the final stages of design and plans for its development were in advanced stages.

2.3 Socioeconomic Status

2.3.1 Demographic Features

Uganda’s demographic characteristics pose a big challenge to national development and growth. Uganda’s national population growth rate of 3.5%/year (in 2005) is the third highest in the world; it has the world’s highest dependency ratio of 111 dependents per 100 working people and it has a very high fertility of 7 children per woman (World Bank, 2007).

Out of the 77 administrative districts in Uganda (in 2007), 37 wholly or partly lie within the Victoria Nile basin. According to the national population census of 2002, the total population within these districts was 9 million in 2002 making 36% of the total population of Uganda. This is expected to grow to 15 million by 2025. In this catchment, 94% of the population live in rural areas and are directly dependent on renewable natural resources within the basin for their livelihood (Eriksson, 2004). The largest part of the Victoria Nile basin lies within the eastern and northern regions of the country. According to the Uganda national household surveys of 2002 these regions show the highest levels of poverty in the country. The proportion of people living below the poverty line in the eastern and northern regions has been consistently higher than in the other regions since 1992. According to 2002/3 poverty figures, the northern and eastern regions respectively had 63.6% and 46% of people living below the poverty line. This is way above the national figure of 37.7 % (MFPED, 2004). The same regions, especially the north, have been experiencing a civil war since 1986. The displacement of hundreds of thousands of people who have fled their homes to live in Internally Displaced People's Camps (IDPs) has contributed to high poverty levels. This has left vast areas of otherwise cultivatable land unattended for fear of attacks from rebel insurgencies.

The shores of Lake Kyoga are heavily populated with people who depend predominantly on fish resources. Lake Kyoga is second only to Lake Victoria in fish catch levels. Because of the high demand for Ugandan fish in the European and American markets it is envisaged that there will be more Government emphasis to promote the fish industry in Uganda. This boost in demand saw a sharp rise in the export earnings from fish which doubled in the period 2003-2006 (MFPED, 2004). This shift may increase the population engaged in the fish industry and could lead to more activity and migration to the lakeshore and surrounding areas.

2.3.2 Economic performance

The main economic activity in Uganda is agriculture. The sector accounted for 38.7% of GDP in 2002/03 and over 90% of exports, and it employs 80% of the employed household population (MFPED, 2004). The breakdown of the contribution of agriculture to GDP is as follows: food crops 63%, livestock 14%, Cash crops 10%, fisheries 8%, and forestry 5% (WWAP, 2006). These statistics show how important the agriculture sector is to the Ugandan economy. Agriculture is however heavily dependent on rainfall with irrigated land estimated at only 90 km^2 (WWAP, 2006).

Production has been shifting slowly towards services and industry as growth in these sectors outpaced agriculture in the past few years. The contribution of agriculture to GDP fell from 51.1% in 1991/92 to 38.7% in 2002/03 (MFPED, 2004). This shift shows a structural transformation in the economy whereby production is slowly moving away from subsistence-based agriculture to a mix of commercial agriculture, services and industry. This creates an opportunity for boosting commercial agriculture.

The total land area in Uganda is 199,768 km^2, of which 82.7% is arable (suitable for cultivation). However, only 42.4% of this was under cultivation by 1996, most of which was under small-holdings used for subsistence farming. Larger commercial farms accounted for only 0.8% of the cultivated land (WWAP, 2006). Given the increasing population and the declining contribution of agriculture to GDP, it is evident that the government will increase investment in the agriculture sector. Because of the erratic pattern of rainfall in the past years the heavy dependence on rain-fed agriculture is now seen as unsustainable and there will be efforts to increase irrigation in order to cope with the food requirements of the increasing population.

2.4 Hydrology and Water Resources

This section gives a summary of the hydrology of Uganda and the important uses of water in the basin. A detailed review of the water resources in the Victoria Nile basin is dealt with in Chapter three.

With total renewable water resources estimated at 66 km^3/year corresponding to 2,800 m^3/person/year (WWAP, 2006), Uganda is considered to be well endowed in terms of water resources. The world's longest river (the Nile) and the world's second largest lake (Lake Victoria) are both found within Uganda. In addition there are many other rivers whose flows are significant throughout the year. Unfortunately the spatial and temporal distribution of the water resources is rather uneven. While the southern and western parts of the country have much fresh water resources, the eastern and northern parts have sparsely distributed rivers and lakes and are more prone to floods during the rainfall seasons. The north eastern regions of Karamoja and Teso are semi-arid and have frequent drought spells but at the same time these areas experience regular floods. Both these areas are found within the Victoria Nile basin

Lake Victoria and the river Nile are the most significant water resources in Uganda mainly because of their socioeconomic benefits but also because of the strategic location of these water bodies. Lake Victoria is shared amongst three countries; Kenya, Tanzania and Uganda while the river Nile basin lies within the territorial boundaries of ten countries. For the river Nile, Uganda occupies a dual position being a lower riparian with respect to Kenya, Tanzania, Rwanda, DRC and Burundi and an upper riparian with respect to the Sudan and Egypt. This puts Uganda in a unique position in terms of management and use of the river.

2.4.1 Climate

Climate in the equatorial lakes region is highly influenced by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) whose maximum range of movement is between about 15° S and 20° N or from Malawi to Sudan (Sene and Plinston, 1994). In the Victoria Nile basin, as is the case in the rest of Uganda, this ITCZ migration results in a bimodal rainfall distribution with rainy seasons occurring typically between March and May and between August and November. The earlier rains of March to May are more abundant and the later rains of August to November are more variable as can be seen from figure 2.5 which shows the average monthly rainfall for the period 1960 to 2004 for three stations of Serere, Soroti and Masindi (figure 2.5). Average annual rainfall in the basin is estimated at 1300-1400 mm.

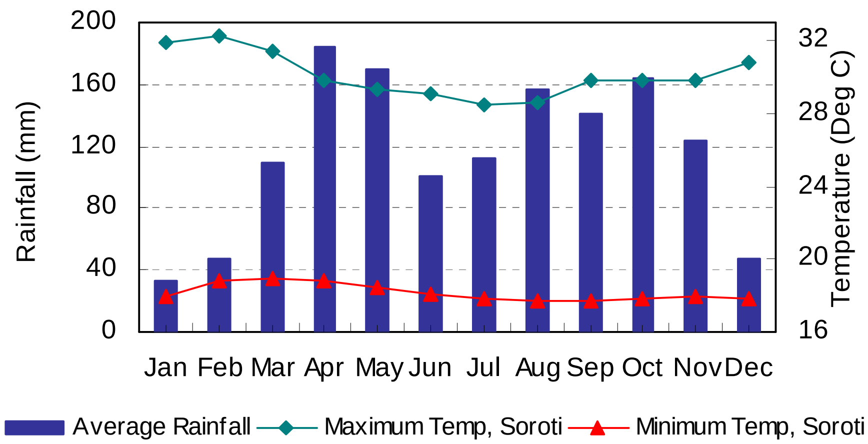


Figure 2.5 Mean monthly rainfall for Soroti, Serere and Masindi

Original data source: Uganda Meteorological Department, 2006.

The Victoria Nile basin is generally a hotter area compared to the rest of Uganda. Maximum temperatures range from 26° C in Masindi and increase north and eastwards to a maximum of 32.2° C in Soroti. High temperatures occur during the period September to March. Minimum temperatures range from 16.2° C in Masindi to 19° C in Soroti. Temperature variations for records of Soroti are shown in figure 2.5. A similar pattern of temperature occurs for the other stations including those in the Lake Victoria basin, although temperatures are lower around Lake Victoria.

2.5 Water Use

The main water uses in the Victoria Nile basin are domestic water consumption, industrial use, agriculture production including livestock, fisheries, recreation, transport and hydroelectric power development.

Domestic Water Supply

As is the case in the rest of Uganda, domestic water supply in the Victoria Nile basin is supplied mainly by groundwater through boreholes. Because the majority of people live in rural areas and also because of the good quality and the ease with which boreholes can be operated and maintained, boreholes are considered appropriate technology for domestic water supplies and whenever possible they are the preferred choice for domestic water supply. This makes groundwater the main source of domestic water in the Victoria Nile basin. For urban areas where population densities are high surface water is used as the source of water. The largest of these is the water supply for Jinja town which uses Lake Victoria as the source of water and supplies an estimated 500,000 people. There are a few other domestic water supplies using surface water, however abstractions from the Victoria Nile are negligible compared to its flow. Domestic water consumption in the basin is therefore low and is not considered to make a significant contribution to water abstractions from the water resources in the basin.

Industrial water use

Industrial water use is limited to a few industries located in the industrial town of Jinja. These industries include textile, paper manufacturing, grain milling and breweries. Most of them use water from Lake Victoria and their abstraction rates are minimal. There is no industrial water abstraction along the Victoria Nile River or Lake Kyoga.

Fisheries

Lake Victoria and Lake Kyoga are the main water bodies on which fishing is undertaken. Lake Victoria contributes 50% of the total annual fish production most of which is exported. The rest of the fish catch is from other rivers and lakes like Kyoga and is consumed in the local market. In the Victoria Nile basin fishing is a mainstay for most people living on the shores of Lake Kyoga. As such any changes in the water quantity and quality that may affect the fish catch will have a detrimental effect to the livelihood of many people. Lake Kyoga levels are therefore watched keenly by the fishing communities that live within the basin.

Agricultural Water Use

Water for agriculture through irrigation and hydropower developments contribute to the highest water uses and are considered separately in the proceeding sections.

Chapter 3 Water Resources Review

3.1 Introduction

This chapter reviews the main water resources available in the Victoria Nile basin, their occurrence and how they affect one another and what contribution they make to the development of the region.

The main water resources in the region are rainfall, the Victoria Nile River-comprising the upper section between Lake Victoria and Lake Kyoga and the Kyoga Nile between Lake Kyoga and Lake Albert, and Lake Kyoga. Lake Victoria is not located within the Victoria Nile basin, however it is the source of the Victoria Nile River and it has a large influence on the levels of Lake Kyoga and therefore an essential water resource. Its key effects on the Victoria Nile water resources will therefore be discussed.

3.2 Rainfall

3.2.1 Lake Victoria Rainfall

Rainfall over Lake Victoria and its surrounding areas has a large influence on the hydrology of the equatorial lakes region in which the Victoria Nile basin lies. It is therefore important to review the Lake Victoria rainfall variation over time in order to translate this variation into impacts on the Victoria Nile basin. Unfortunately in carrying out a water balance of the Lake Victoria region, the term that has been most difficult to estimate in the past has been rainfall (Nicholson et al., 2000). Previous studies by Yin and Nicholson, (1998) and Sutcliffe and Parks, (1999) have shown that the water balance of the lake is dominated by rainfall over the lake (estimated to be 1,791 mm/year) and evaporation (estimated to be 1,532 mm/year). Mean annual rainfall around the lake is however lower at 1,200-1,600 (Yin and Nicholson, 1998).

Lake Victoria rainfall has been monitored since 1903 at the Jinja rain gauge, the closest rain gauge station to the Victoria Nile basin. However, overall there are eight rain gauge stations around the lake with records from 1925 or earlier. These include Jinja (Uganda), Entebbe (Uganda), Kalangala (Uganda), Bukoba (Tanzania), Kagondo (Tanzania), Mwanza (Tanzania), Musoma (Tanzania) and Kisumu (Kenya). All these are located on the shores of the lake and therefore do not give the magnitude of rainfall over the lake itself. Sutcliffe and Parks (1999) report that measurements of rainfall near the centre of the lake show a 30% higher rainfall than that observed at any lakeshore station. Analysis of rainfall in the water balance of the Lake Victoria system therefore needs to take into consideration the high rainfall over the lake. Rainfall at the different stations around the lake shows a similar seasonal pattern, with two seasons of high rainfall: March to May and October to December (figure 3.1). This shows that while the rainfall magnitudes vary from station to station, the pattern of rainfall for the stations is similar for an annual cycle. This rainfall pattern greatly influences the local land use as many socio-economic development activities depend on rainfall.

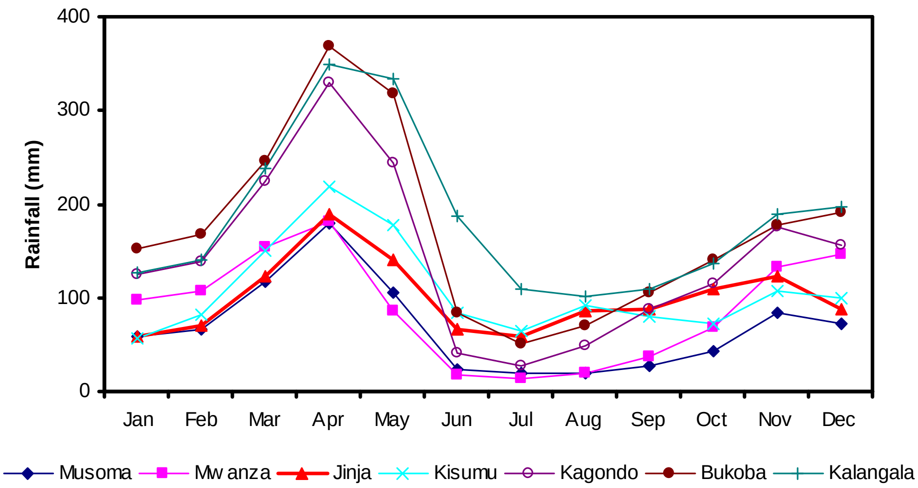


Figure 3.1 Monthly rainfall at selected shoreline stations on lake Victoria (1926-1977)
Data source: Piper et al, 1986 and Uganda Meteorology Department, 2006

Out of the above seven rainfall stations located around Lake Victoria, the Jinja station is the nearest to the Victoria Nile basin and it has the longest continuous rainfall record (1903-2005). Jinja rainfall shows a long term annual average of 1,216 mm (figure 3.2). The years 1961-1964, 1972, 1999 and 2001 show very high rainfall while 1918, 1950-53 show very low annual rainfall. The highest annual rainfall at Jinja was recorded in 1961 (1,730 mm) while the lowest was recorded in 1918 (728 mm). This station alone does not however give a fair representation of rainfall in and around Lake Victoria.

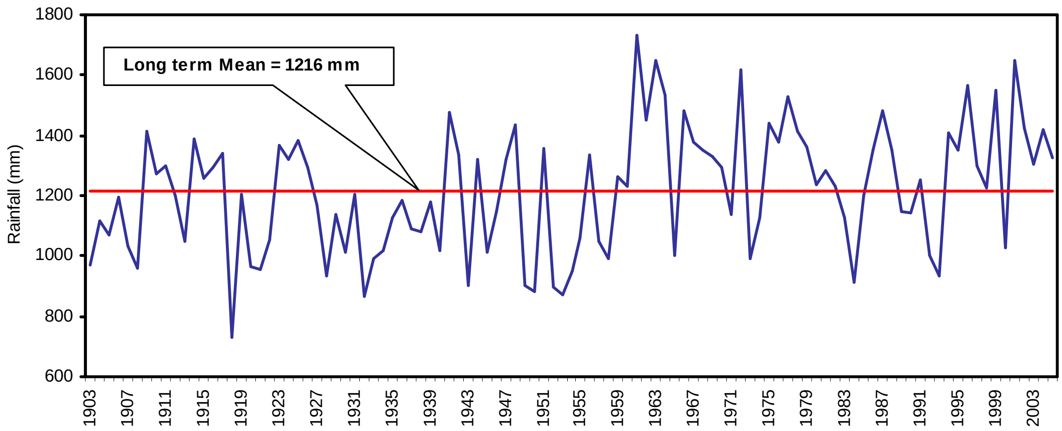


Figure 3.2 Annual rainfall at Jinja station (1903 – 2005)

Data source: Uganda Meteorology Department, 2006

Data obtained from the World Bank's Africa Rainfall and Temperature Evaluation System (ARTES), provides average rainfall and temperature over different regions. Using this data for the period 1948-2001(appendix 1), average rainfall in and around Lake Victoria was found to be 1,292 mm with a minimum of 1,016 mm occurring in 1949 and a maximum of 1,708 mm occurring in 1961.

3.2.2 Victoria Nile Basin Rainfall

Rainfall records for 20 stations in the study area were accessed from the literature, however these were for a period of 30 years only (1938 to 1967). Rainfall measured at the Soroti rain gauge (Gauge registration number 88330060) was used to represent Victoria Nile basin rainfall (Appendix 1). Soroti rainfall was taken to be representative because Soroti has a moderate altitude, is centrally located, it has a long rainfall record of 67 years and it has a rainfall pattern close to that of the average of all the other stations (figure 3.3). At this station rainfall records were available for the period 1938-2004 and were used in the analysis to determine rainfall occurrence and distribution.

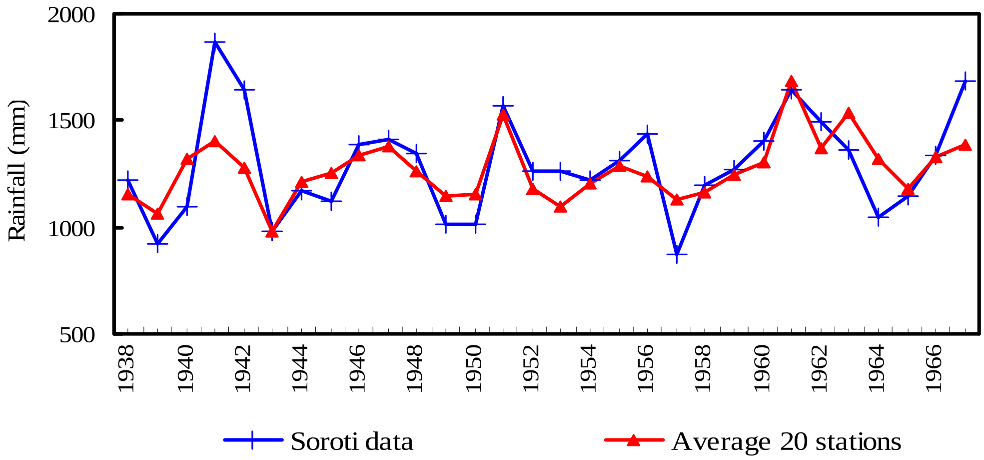


Figure 3.3 Soroti rainfall and average rainfall of 20 other stations in the Victoria Nile basin

The long term annual rainfall record (figure 3.4) shows a long term average annual rainfall of 1,334 mm with maximum and minimum recorded of 1,868 (1941) mm and 873 mm (1957) respectively.

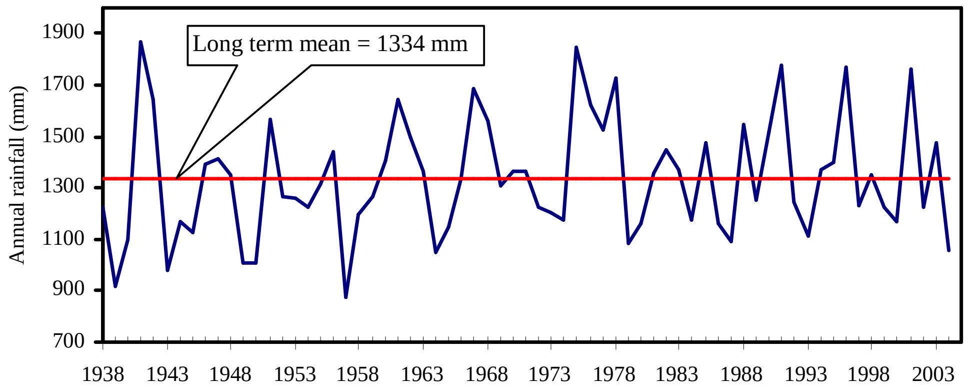


Figure 3.4 Annual rainfall for lake Kyoga basin at Soroti rain gauge (1938-2004)

Data source: Uganda Meteorology Department, 2006

Comparing rainfall distributions of the Lake Kyoga basin to that of the Lake Victoria basin shows a difference in annual rainfall patterns (figure 3.5). While Lake Victoria basin rainfall shows a marked difference between the two rain seasons lake Kyoga rainfall does not show a significant difference between them, making it more difficult to distinguish between the two seasons.

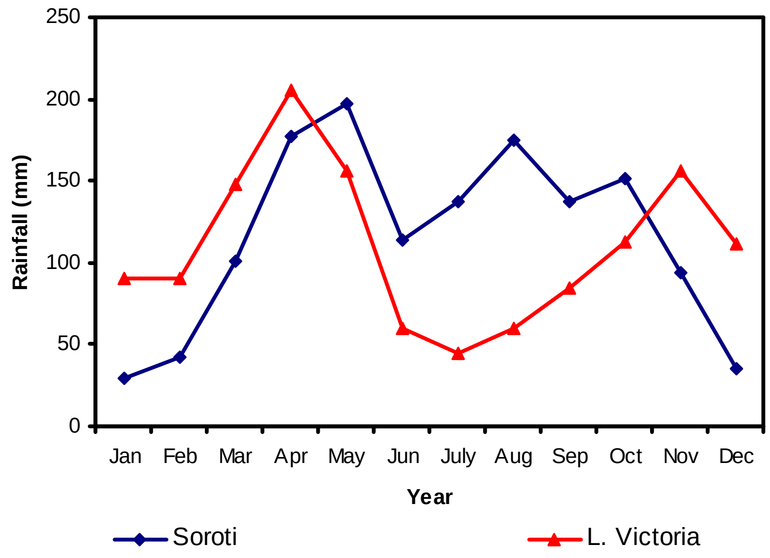


Figure 3.5 Lake Victoria and Victoria Nile basin (Soroti) rainfall compared (1960–2004)

Data source: Uganda Meteorology Department, 2006

Long term rainfall for Jinja and Soroti are similar (figure 3.6). The years of extreme highs and lows follow closely between the two stations. From the figure it is evident that Soroti has higher maxima while Jinja shows lower minima. These large magnitudes of rainfall during high rainfall years could partly explain the extensive floods in the Lake Kyoga region during the rainfall seasons.

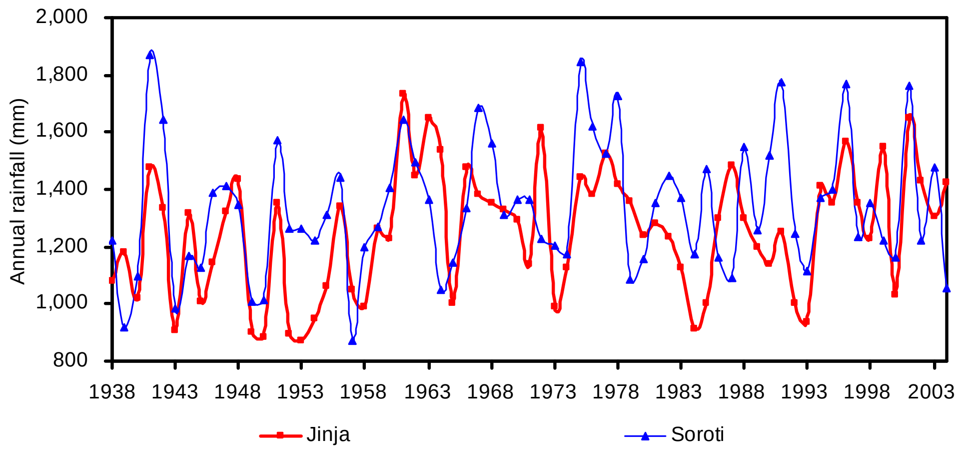


Figure 3.6 Jinja and Soroti annual rainfall for the period 1938-2004

Data Source: Uganda Meteorology Department, 2006

3.3 The Victoria Nile River

3.3.1 General Description

The only outflow from Lake Victoria emerges at Jinja as the Victoria Nile River that flows into the Victoria Nile basin (figure 3.7). It is here that the river Nile starts its long journey through the Victoria Nile basin to its final destination, the Mediterranean Sea. The river descends first through a series of rapids, notably the Bujagali Falls and Kalagala Falls, and then through quiet navigable reaches from Namasagali to Lake Kyoga. It is about 130 km in length between Lake Victoria and Lake Kyoga. This stretch of the Nile has a difference in level between its head and its tail of about 105m and a water surface width variation of between 300 to 600 m (Shahin, 1985).

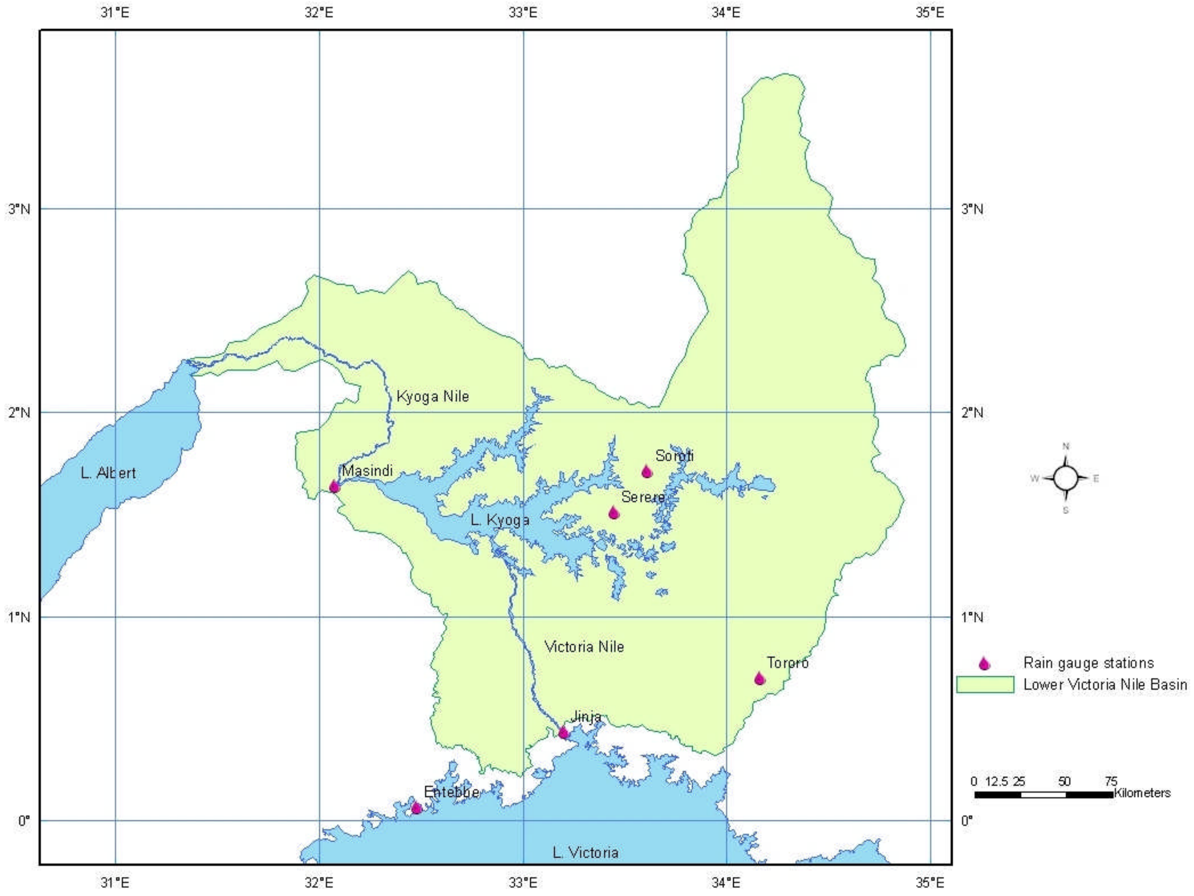


Figure 3.7 Location of rain gauge stations

Because of its rapid drop in level between its mouth and its tail, the Victoria Nile has a high potential for hydropower generation. The many spectacular falls make it a key destination for tourists, mainly for white water rafting at its numerous rapids. There is potential for two hydroelectric power plants at

Bujagali and Kalagala falls capable of generating a total of 700 MW of electricity in addition to the two already running plants of Nalubaale and Kiira. Hydroelectric power development and tourist attraction are considered to be the main contributions that this section of the Nile can make to the Ugandan economy.

3.3.2 River Flow Regime

River flow and level measurements for the Victoria Nile are monitored at three locations; the Nalubaale dam at Jinja, Mbulamuti located about 50 km downstream from Jinja and Namasagali located 64 km downstream from Jinja. Namasagali used to be an inland port for navigation on Lake Kyoga till the floods of the early sixties which submerged and destroyed most of the port infrastructure. Data was accessed from the Jinja gauge and Mbulamuti gauge, no data was available from Namasagali. River flow at Mbulamuti and Jinja show a very similar pattern (figure 3.8).

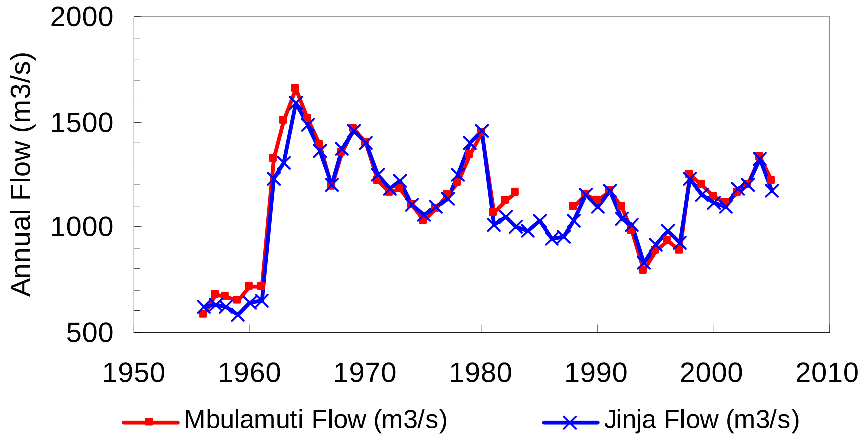


Figure 3.8 River Nile flow at Jinja and Mbulamuti for the period 1956-2006
Data Source: Uganda Ministry of Water and Environment, 2006

This close similarity suggests that the river flow at Mbulamuti could be inferred from the readings at Jinja. This is evident from a graph of Mbulamuti flow plotted against Jinja flow which shows a linear relationship with a correlation coefficient of 0.978 (figure 3.9).

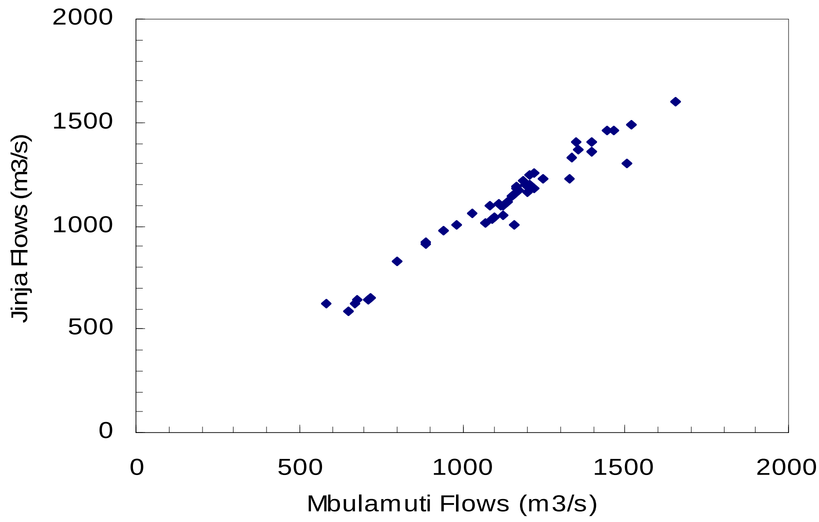


Figure 3.9 Relationship between Victoria Nile annual flows at Jinja and Mbulamuti

The high correlation between the flows measured at Jinja and Mbulamuti implies that the variation in the flow at Mbulamuti is largely due to the variation in the flow at Jinja. This could be because there is no significant runoff to the river or discharge from the river in this section, in which case the flow at Jinja is about the same as at Mbulamuti. Therefore the outflow from Jinja directly determines the flow at Mbulamuti and hence inflow to Lake Kyoga. The linear relationship in figure 3.9 suggests that river Nile flows at Mbulamuti can be taken as the reading from the Jinja outflow. The Victoria Nile flow is therefore deemed to be that measured at Jinja.

The Victoria Nile flow shows two distinct annual flow magnitudes for the available record period of 1896-2005. The period 1896-1961 shows relatively low outflows with an average of 662 m^3/s. Minimum and maximum annual flows for this period were 416 m^3/s (in 1922) and 964m^3/s (in 1917) respectively. On the other hand the period 1962-2005 shows an annual average outflow of 1,165m^3/s almost double the previous period and minimum and maximum recorded flows of 828 m^3/s (in 1994) and 1,596 m^3/s (in 1964) respectively. This dramatic change in flow followed a similarly high rainfall event that occurred from 1961 through 1964 (figure 3.2).

The Victoria Nile flow is very much dependent on the level of Lake Victoria. A time series (figure 3.10) of Victoria Nile river annual flows and Lake Victoria levels shows a close relationship between annual outflows and end of year lake Level. The correlation coefficient (r) for the Victoria Nile flow and end of year lake level for the data series (1896-1995) is 0.938 indicating a high positive correlation. Both rainfall and Lake Victoria levels show a dramatic rise that occurred during the period 1961-1962. This dramatic rise in lake level is widely believed to have been caused by the high rainfall that occurred at the time. However, the fact that the Owen falls dam was commissioned in 1954 just before this rise has made some believe the construction of the dam could have had an influence on the high level rise (Sutcliffe and Parks, 1999); (Sene and Plinston, 1994). There has not been any conclusive study that has confirmed to what extent Owen falls construction caused this dramatic rise. However, since high lake levels were registered during the high rainfall years of 1961-1964 gives sufficient evidence that this rise in lake level was partly due to high rainfall. Sene and Plinston, (1994) presented annual and monthly water balance models which showed that variations in Lake Victoria levels were related primarily to variations in rainfall over the lake and the surrounding basin with a small influence from the Owen falls dam and land use changes. Their models further confirmed that this unusual rise in lake level between 1961 and 1964 was consistent with the observed rainfall variations in that period.

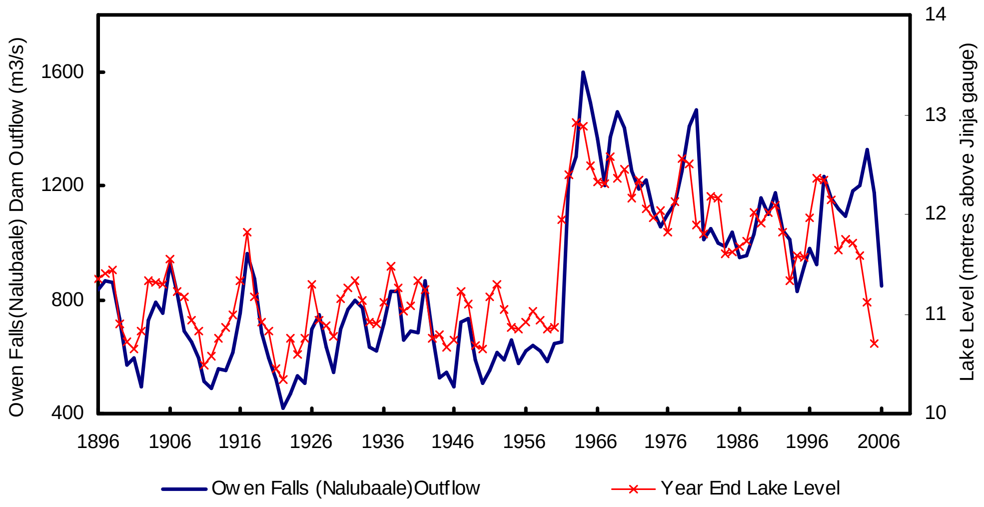


Figure 3.10 Historical lake Victoria outflow and Level

Victoria Nile flows are therefore positively correlated to Lake Victoria levels. The relationship between lake Victoria rainfall and lake level is discussed in chapter 6 in which it is shown that lake level correlates to lake rainfall, albeit with a weak relationship (r = 0.475). This means that a high annual rainfall over the lake leads to high lake level which in turn leads to a high flow of the Victoria Nile. This close dependence on Victoria Nile flow to Lake Victoria levels means that any hydraulic development on the Victoria Nile River should consider the behaviour of Lake Victoria as an essential factor.

Seasonal rainfall variation shows that while the wet season is at its peak in April, river flows do not reach their peak until two months later in June (figure 3.11). Lake levels on the other hand do not show the effect of changes in rainfall until a month later. This reveals that there is a lag of approximately one month before the effect of rainfall on lake level is observed, which in turn can be observed in the river flows a month later. This suggests that the seasonal variation of rainfall, lake level and river flow depict a time lag of one month between them.

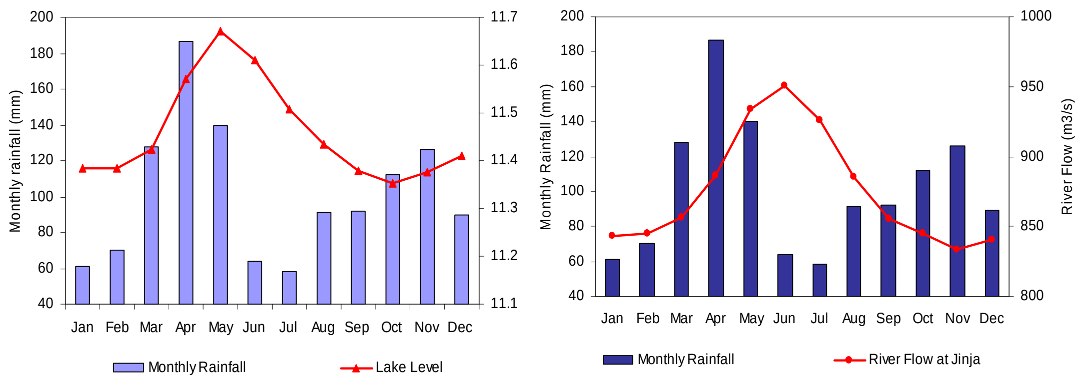


Figure 3.11 Seasonal variation of monthly rainfall, Lake Victoria Level and Victoria Nile flow

3.3.3 Control of the Victoria Nile Flow

The Victoria Nile flow is controlled at Jinja as the river exits Lake Victoria by a model called the “Agreed Curve”. This model was constructed from lake level-discharge observations made by the Hydraulic Research Station on the Ripon falls at Jinja between 1939 and 1950 in order to develop a relationship between lake level and discharge. The level was taken as the water level in

Lake Victoria (observed at the Jinja gauge, half a mile upstream of the falls and the discharge being measured at Namasagali (40 miles downstream). A plot of the level-discharge relationship so obtained was agreed by the concerned countries (Egypt and Britain) and hence the name “Agreed Curve” (Hydraulics Research Station, 1966). In 1961-64 Lake Victoria rose to abnormal levels out of range of the agreed curve which originally covered the levels 10.3 to 12.0 metres on the Jinja gauge. This abnormal rise meant that the agreed curve could not be used to deduce discharges for these high levels since they were not covered by the existing curve. The agreed curve was therefore extended by investigations carried out by the Hydraulics Research Station on behalf of the Ugandan government in 1966 (Hydraulics Research Station, 1966). The purpose of the model investigation was to extend the level-Discharge relationship to include a water level as low as 10.0 metres and as high as 15.0 metres on the Jinja gauge. The Agreed curve was therefore developed as the operating rule for the Owen falls Dam (now renamed Nalubaale Dam since 2000) to dictate how much water should be released from lake Victoria based on the water level in the lake. The purpose of the operating rule was to have the dam operated in such a way as to retain the original natural (pre-dam) relationship between Lake Victoria level and outflow. The agreed curve (figure 3.12) is used to derive Lake Victoria outflows for every level of the lake.

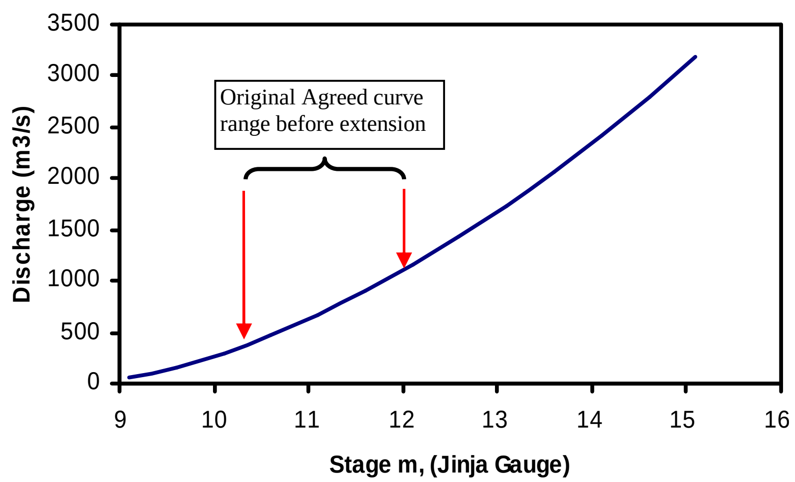
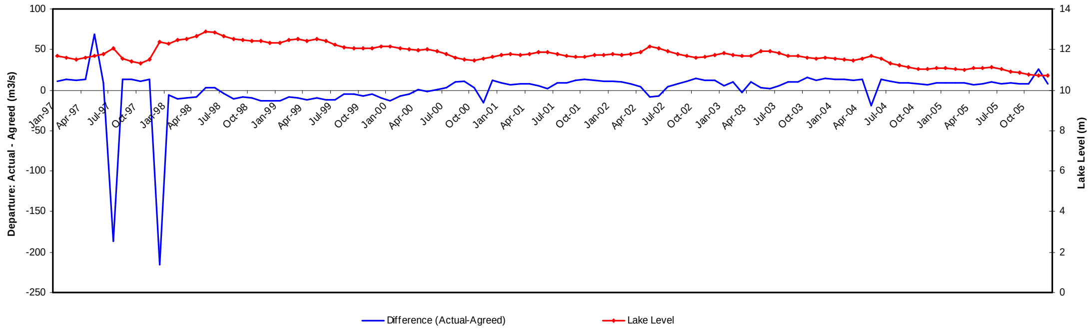


Figure 3.12 Agreed Curve model for operation of Lake Victoria Outflows
Source of data: Hydraulics Research Station, (1966)

The agreed curve has not been strictly adhered to in the past. Some attribute this non-adherence to the need to generate more electricity at the Jinja dam (Kull, 2006). It is claimed that over abstraction of water above the agreed curve outflows commenced around 2001 when an additional hydropower plant (Kiira) adjacent to the Nalubaale plant was commissioned. The claim that there was over-abstraction was confirmed by Sutcliffe and Petersen, (2007) who concluded that the effect of over abstraction was significant over the years 2000-2006. Over abstraction was however refuted by Mubiru (2006) who claimed that the reduced Lake Victoria levels were rather due to persistent drought conditions.

According to data obtained from the electricity power generation house in Jinja for the period 1997-2005 the agreed curve has not been strictly followed (figure 3.13). Over this period there is a deviation between actual discharges and discharges as per the agreed curve requirement. For most of the time the actual discharge is higher than the discharge required by the agreed curve except for the period of November 1997 to June 2000 when the actual discharges were lower than those required by the agreed curve. Departure from the agreed curve outflow is closely related to rainfall occurrence in that whenever there is high rainfall occurrence, this is followed by about a month later with a drop in the level of outflow departure. On the other hand low rainfall occurrence is followed by higher level of departure in most cases higher than agreed curve requirements. This close relationship however changes from June 2004 till end of 2005 when there was consistent over-abstraction irrespective of high rainfall events in September-November 2004, April-May 2005 and July-August 2005. This anomaly coincides with the commissioning of additional units to the Kiira hydroelectric power station at Jinja. The addition of more generation units could have caused the over abstraction which led to reduced lake levels. The findings here suggest that departure from the agreed curve is dictated not only by the rainfall occurrence but also by the need to generate more power. This brings forth the question “Is the agreed curve still sustainable under conditions of changing rainfall regimes and increased demand for electricity generation?” If it is not sustainable then what other option of control of lake discharges is there?



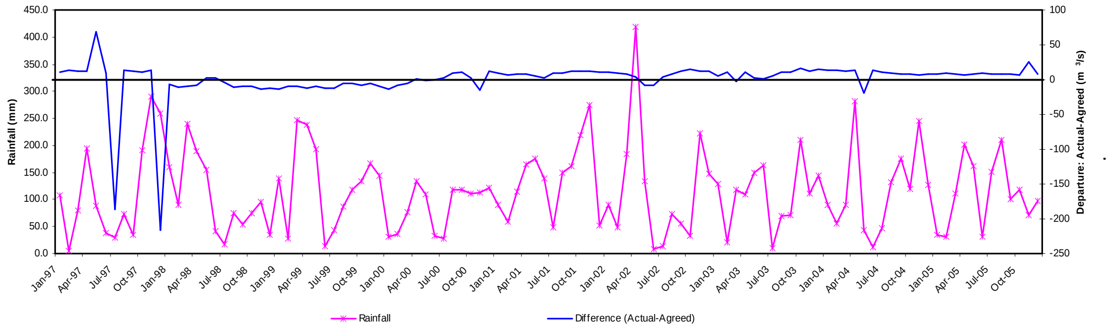


Figure 3.13 Departure of actual discharges from agreed curve discharges compared to lake level and rainfall occurrence for the period 1997-2005

The deviations from the agreed curve shown above give further evidence that the agreed curve as it stands may not be a sufficient operating guide for the lake discharges.

3.4 The Kyoga (Lower Victoria) Nile

The Kyoga Nile (Lower Victoria Nile) makes up the second section of the Victoria Nile which drains into Lake Albert in the western arm of the Rift Valley (figure 3.7). Some tributaries flow into the Kyoga Nile, such as the River Tochi and River Ayago. The largest of these is the Ayago with average annual flow of only 230 million m^3 which is less than 0.1% of the main river flow and therefore increase in the flow of the Nile from these tributaries can reasonably be neglected (Sutcliffe and Parks, 1999).

Records of the Kyoga Nile flow available at the Directorate of Water Development (DWD) at Entebbe show river flow measurements at Masindi (for the period 1947-2005) and Paraa (for the period 1963-2005) but with many gaps between measurements, some gaps being as long as 14 years.

Unlike records at Jinja, there is a lot of irregularity in measurements for this section of the Nile. Lack of records for these long periods are attributed partly to the wars in the country in 1979-1988 which made it difficult for measurements to be done. The literature available (Sutcliffe and Parks, 1999), (Kennedy & Donkin Power Ltd et al., 1997) shows that Kyoga Nile flows were recorded at four main river gauges: Masindi, just below lake Kyoga, Kamdini about 80 km downstream, at Fajao, 1 km below the Murchison falls and Paraa 5 km downstream. Using available data from these stations and Jinja, Kennedy & Donkin Power Ltd et al., (1997) developed extended Kyoga Nile flow data for the period 1896-1995. Using this data and that for the Masindi gauge for the period 1996-2005 obtained from DWD, a long term record of Kyoga Nile flow was obtained (figure 3.14).

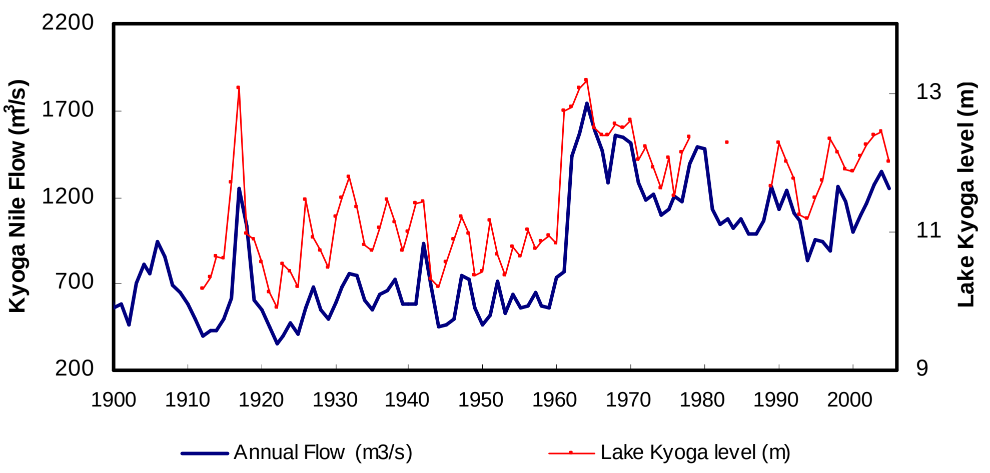


Figure 3.14 Kyoga Nile flow and Lake Kyoga level for the period 1896-2005

Kyoga Nile annual flow is highly dependent on the level of Lake Kyoga (figure 3.14); this is confirmed by the high correlation, with r^2 of 0.789 for Kyoga Nile annual flow and end-of-year Lake Kyoga level. There is also a seasonal dependence as shown in figure 3.15.

Comparing basin rainfall, lake level and Kyoga Nile flows shows that monthly rainfall does not highly affect the lake Kyoga level and monthly outflows(r^2 for monthly rainfall and lake level is only 0.15; and for monthly rainfall and Kyoga Nile flow the r^2 is only 0.12). Lake Kyoga inflow is the other variable that affects lake level and outflows. It is interesting that after June when inflow reaches its peak, the lake level and outflow remain at a high level until December when they start dropping (figure 3.16).

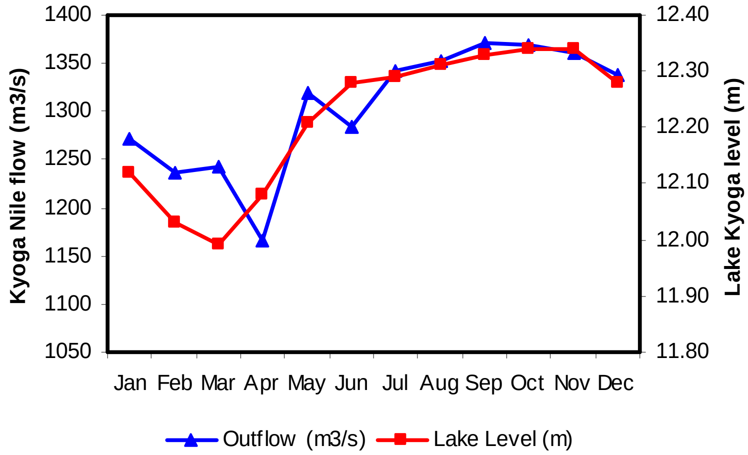


Figure 3.15 Seasonal variation of Lake Kyoga level and outflow
Data from Uganda Department of Water Resources (period 1960-1977)

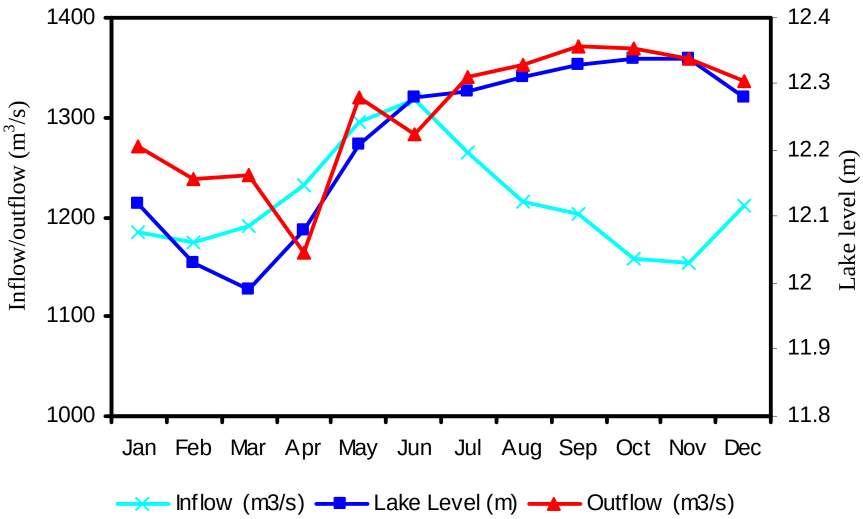


Figure 3.16 Seasonal variation of river Nile inflow to Lake Kyoga, lake level and outflow (period 1960-1977)

The behaviour of the Lake Kyoga level and outflow depicted in figure 3.16 is different from that of Lake Victoria whose level and outflow change with the main input: rainfall. This behaviour could be attributed to the runoff from the large area of Lake Kyoga basin. As was shown in figure 3.5, unlike rainfall in

Lake Victoria basin in the Lake Kyoga basin, the months of July to September have relatively high rainfall. This high rainfall during these months could be providing the runoff that causes the lake level and outflows to remain high. Sutcliffe and Parks (1999) compared Lake Kyoga inputs and outputs and they found that local runoff to the lake increased during wetter periods and together with lake rainfall exceeded lake evaporation, this they concluded led to net gains during wet periods. There is local tributary inflow from the eastern part of Lake Kyoga basin draining the slopes of mountain Elgon and surrounding areas unfortunately there was no record of measurements to ascertain what contribution this could be.

3.5 Lake Kyoga

Lake Kyoga is found in central Uganda and drains an area entirely within the territorial boundary of Uganda. The upper Victoria Nile River drains into Lake Kyoga in the south while the Kyoga Nile exits the lake in the north. The inflow comes from Lake Victoria through the regulated Nalubaale falls dam in Jinja and contributes over 90% of total inflow to the lake. Other important sources of water are the mountain Elgon region in the eastern part of the catchment on the border between Uganda and Kenya, and rainfall over the catchment.

Lake Kyoga as described in this study comprises two major water bodies, Lake Kyoga and lake Kwania, with open water surface areas of 1,800 km^2 and 783 km^2 respectively, and 4,510 km^2 of swamps. An estimate by WMO, (1982), however, puts the area of the lake and its adjoining swamp at 4,700 km^2, while literature from the International Centre for Research in Agro forestry (ICRAF) considers the lake to have an area of 4,000 km^2. Shahin, (1985) puts the area of the lake including its arms at 6,270 km^2. These differences in size of the lake demonstrate how variable Lake Kyoga is. This variation is due to the changing size of the lake that varies with the period of the measurement and the condition of precipitation in the region. The surroundings of the lake are dominated by swamps along the various arms of the lake and the topography is of moderate relief. The lake lies at 914 m above sea level in the flooded branches of the low west-flowing Kafu River. It is essentially a grass-filled shallow saucer-like depression with a depth of 3 m to 5 m at its western end with a maximum recorded depth of 7 m. The shoreline is everywhere fringed with papyrus and other swamps sometimes forming a belt of several miles width between land and the open water (figure 3.17). These large wetlands that surround the lake act as a buffer against sudden changes in inflow and they increase silting as a result of soil erosion from the uplands. The lake shores are slightly sloping and are therefore prone to flooding. There are numerous floating papyrus islands in the lake. The lake is drained northward and then westward over the low northern end of the Rift Valley escarpment (the Murchison Falls) to Lake Albert.

Figure 3.17 Lake Kyoga taken near Serere
Note the papyrus that surrounds the shoreline of the lake

The Hydrology of Lake Kyoga has not been given significant attention as compared to other water bodies in the Nile Basin. Because of this available data on the hydrologic performance of the lake is still scanty. A record of annual numbers of gaugings presented by Sutcliffe and Parks (1999), shows that the number of annual records along the Nile was lowest in Uganda as compared to Sudan and Egypt. The levels of the lake are recorded at two points located at Bugondo pier and Masindi port. Levels have been recorded at these locations since 1947 but with major gaps in the series.

Lake Kyoga is responsible for net losses in the Nile flow in dry years and for net gains in wetter years. This has been attributed to the evaporation from the lake exceeding direct rainfall and local runoff during relatively dry periods (Institute of Hydrology, 1984). In contrast the local runoff increases during wetter periods and together with lake rainfall exceeds lake evaporation. The high local runoff is due to the large area of the basin that allows large amounts of water as runoff to the lake. The lack of local runoff records means that it is not possible to derive precisely the water balance of the Lake Kyoga system. The World Meteorological Organisation (WMO, 1974), however, estimated the local runoff into the system for a normal year to be 2.91 km^3 or 50 mm over the effective basin of about 59,000 km^2 which implies a runoff coefficient of 3.7 % for an average rainfall of 1,350 mm (Sutcliffe and Parks, 1999).

Chapter 4 Developments and Pressures

4.1 Introduction

The main development projects that affect the water resources in the Victoria Nile basin are hydropower development and irrigation. Of these, hydropower development has dominated but it is anticipated that irrigation will rise high on the agenda in the near future due to the increasing need for food and erratic rainfall. Agriculture is the mainstay of populations living within the Victoria Nile basin and it will continue to be a main sector for development by Government. Because of the increasing demand for food and the changing climate it is anticipated that rain-fed agriculture will be replaced by irrigated agriculture which will increase the demand on available water resources.

Climate change, outdated trans-boundary legislation, high population growth and political instability are the key pressures exerted on the water resources. Climate change and outdated trans-boundary legislation are discussed in this chapter, the other two are outside the scope of the study.

4.2 Hydroelectric power Development

4.2.1 Hydroelectric Power Potential

To date about 300 MW of electricity in Uganda has been exploited representing only 15% of the total available potential; this is less than the average of exploited power for Africa which stands at 20% (FAO, 2008a). The electricity is distributed through a national grid concentrated in urban areas. Only 3% of households in rural areas and 8% in urban areas have access to grid electricity (MFPED, 2004). The lack of grid electricity in most rural areas and some urban areas have forced people especially businesses to resort to alternative energy sources such as use of fossil fuel powered generators which are relatively expensive leading to high production costs. Due to the high rate of industrialization in Uganda it is projected that peak power demand in 2010 will be up to 649 MW (MFPED, 2004) and may rise to 1,910 MW by 2025 (BKS Acres, 2004). This high anticipated demand has created an increasing need for generation of more electricity and the potential of the river

Nile presents a good option because it is a renewable resource. By 2008 construction of the Bujagali power facility (250 MW) was already underway. Other potential sites for Hydroelectric power generation in Uganda have been identified at locations in table 4.1 (all these sites are located along the Victoria Nile).

Table 4.1 Installed Capacities and Maximum Hydroelectric Power Potential in Uganda

No.	Site/ Location	Current Installed Capacity (MW)	Planned Capacity (MW)	Maximum Potential (MW)
1	Nalubaale (Owen falls)	180	180	180
2	Kiira (Owen Falls extension)	120	200	200
3	Bujagali Falls	-	240	320
4	Kalagala	-	350	450
5	Karuma (Kamdini)	-	150	180
6	Ayago (South)	-	-	234
7	Ayago (North)	-	-	304
8	Murchison Falls	-	-	642

Source: Uganda Ministry of Energy and Mineral Development, 2002

Economic analysis of the electricity sector in Uganda by the World Bank shows that the sector has been self sustaining since 2001 following an increase of electricity tariffs until 2005 when extended drought reduced the electricity power generated from the hydropower plants. From 2005 at the operational facilities at Jinja (Nalubaale and Kiira), only 120 MW of a peak capacity of 300 MW was being generated (World Bank, 2007). This reduced generation capacity of the facilities has been attributed to climate change, deterioration of the Nalubaale power plant and anomalies in the design of the Kiira plant (World Bank, 2007). During the period 2002-2007 electricity shortages and unreliable power supply were listed as one of the top five constraints to business development and economic growth in Uganda. This shows how important electricity is and will be in the future economic development of Uganda. Electric power development will continue to be high on the economic development agenda of Uganda as it is evident that electricity is a key driver for its development. In recognition of the urgent need to develop the energy sector the Government of Uganda in its national budget of 2006/07 set up the energy investment fund for collection of funds specifically for investments of hydroelectric power and related infrastructure. This signals the Government's determination to develop the hydroelectric power plants in the near future and it is therefore expected that the full potential of hydropower will be developed. The high fall in level and discharge of the Victoria Nile makes hydropower development a feasible source of highly needed electricity. For this reason and because hydropower is seen as the main benefit that Uganda can reap from the Nile, several studies have been undertaken to investigate hydroelectric power generation in the Victoria Nile.

4.2.2 Overview of hydropower studies in the Victoria Nile

The first studies on hydropower potential of the Victoria Nile were carried out in the 1950s by Kennedy & Donkin Power Ltd and Sir Alexander Gibb & Partners in which they published the Report on Investigations on the Victoria Nile hydropower development in April 1956. Following field observations it was concluded that one hydropower dam named Bujagali could be constructed in the vicinity of the falls at Bujagali, Buyala, and Busowoko and another one would be at Kalagala, all close to the source of the Nile at Jinja (figure 4.1). The final evaluation produced installed capacities in the range of 140 MW to 210 MW based on a maximum head of 20.4 m.

A second study was also carried out by Kennedy & Donkin Power Ltd with Sir Alexander Gibb & Partners in which they published their report titled 'Report on Nile investigations, North Uganda' in July 1957. This study considered the potential for hydropower development on the Nile between Karuma (Kamdini) and Murchison falls. In this study three potential sites were investigated at Karuma, Ayago and Murchison falls. Based on an assumed annual mean flow of 570m^3/s the installed capacities for Murchison and Karuma plants were 642 MW and 234 MW respectively. Ayago had no figure at that time due to insufficient data.

A third study again by Kennedy & Donkin Ltd with Sir Alexander Gibb on the Murchison falls hydro-electric scheme project was published in March 1970. This report recommended the construction of an underground power station which would be developed initially with a weir providing a net head of 60 m. Further additions were proposed to have a full design capacity of 600 MW. This capacity was based on a mean regulated discharge of 570m^3/s in the river which would depend on the annual regulation of Lake Victoria.

In June 1984 the Ayago Nile hydroelectric power project report was published by Norconsult and Electrowatt. This was a report of extended studies over the period 1978 to 1984 based on the 1973 study of Ayago carried out by Energo Project Engineering. This study was, however, disrupted several times due to civil unrest in the northern parts of the country. In this study planning was based on the assumption that lake Victoria would be regulated to give a minimum flow at Owen falls of 630 m^3/s and that downstream of Lake Kyoga the equivalent flow would be 570 m^3/s. The study concluded that based on a design head of 73.5 m a scheme involving a phased development of six 80 MW units with an ultimate installed capacity of 480 MW was a better option.

The power development study of the Uganda Electricity System was conducted by Kennedy & Donkin and Sir Alexander Gibb. Their final report dated September 1986 compared the hydropower sites downstream of Lake Kyoga with the site at Bujagali. This study rated capacities for Bujagali, Karuma (Kamdini), Ayago South, Ayago North and Murchison as 180 MW, 180 MW, 240 MW, 300 MW and 480 MW respectively.

The study on the extension of Owen falls generating station was carried out by Acres International Ltd whose report was submitted in October 1990 and an addendum in May 1991. The key conclusion of this feasibility study was that previous studies had seriously underestimated the long term mean outflows from Lake Victoria (Kennedy & Donkin Power Ltd et al., 1997). It argued that records prior to 1954 before commissioning the Owen falls dam should be treated as suspect and therefore the post 1954 Nile average flow of 1,196m^3/s should be used as the basis for generation planning. This report recommended that Owen falls extension should be developed ahead of both Bujagali and Murchison and further that the least cost development would comprise three 34 MW generators, giving a capacity of 102 MW. The engineering solution recommended was for a two stage development, with three 34 MW units installed initially followed by two more of the same capacity to give an ultimate development of 170 MW. By 1997, when the contract for extension of the Owen fall dam was underway, it provided for an ultimate capacity of five 40 MW units, two of which were to be installed under the contract which also had the option of a third 40 MW unit (Kennedy & Donkin Power Ltd et al., 1997). This facility was developed as recommended based on the design by Acres International. Unfortunately after its commissioning in 2002, the water levels of Lake Victoria continuously declined to very low levels that resulted in generating power below capacity.

The Bujagali Hydroelectric Power Project, pre-investment study was undertaken by Acres International Ltd. This report was submitted in May 1991 together with the addendum for the Owen falls extension feasibility study discussed in the foregoing paragraph. In this study, five potential dam sites were considered for Bujagali (Kennedy & Donkin Power Ltd et al., 1997):

- A site immediately downstream of Bujagali falls with capacity of 200 MW as per the agreed curve or 250 MW if regulated;
- A site at Dumbbell Island with capacity of 270 MW as per the agreed curve or 340 MW if regulated;
- Two sites at Buyala falls with capacities 295 MW and 315 MW as per the agreed curve respectively or 370 MW and 395 MW if regulated respectively; and
- A Site at Busowoko falls with capacity 460 MW per agreed curve or 580 MW if regulated.

Of these, the site at Dumbbell Island was recommended for development. For agreed curve operation an initial development of three 54 MW units was recommended, with the station designed to accommodate two additional units to give an ultimate site installed capacity of 270 MW. Based on the assumption that agreement on regulation of Lake Victoria could be negotiated the station would scale up to accommodate a total of five 68 MW units giving an ultimate capacity of 340 MW.

The National Electrification Planning study undertaken by Electricite de France International (EdFI) was completed in November 1992. In respect of generation planning this study was confined primarily to considerations of the flows available and the timing of the next station after Owen falls. A significant observation concerning the flows available for generation by this study was that EdFI was unconvinced by the arguments put forward by Acres that outflow gauging prior to 1954 was grossly in error. They expressed the view that the agreed curve which was developed based on a full historic record, pre-construction of Owen falls dam and power station should continue to be used as the means of relating flows to lake level. This study therefore considered the timing requirements for the next station after Kiira based on high and low flow scenarios based on mean flows for 1960-1989 and 1930-1959 respectively.

The Hydropower development master plan for the Uganda Electricity Board was undertaken by Kennedy and Donkin Power Ltd who submitted their report in November 1997. This was a comprehensive study on all available hydroelectric power options in the country and their implications for development. The objective of this plan was to review the medium and long term energy sector development options for Uganda and develop a master plan for a least cost programme for hydropower generation up to 2020. The report recommended that Bujagali be the next hydropower plant to be developed after Owen falls on the basis of low risk. The study however found that Murchison falls was a more cost effective alternative but was more susceptible to risk of delay. This report therefore concluded that development of hydropower be done at Bujagali followed by Kalagala and then the other schemes later. The recommendations of this study were implemented by the construction of the Bujagali hydropower facility that commenced in 2007.

The studies above covering a period of over 50 years involved considerable work in the development of hydroelectric power in Uganda. There is consistency in the findings of the studies regarding feasibility of projects and sequence of development. All designs were based on the agreed curve for discharge-head determination but with a possibility of regulation of flows from Lake Victoria. By regulating flows from Lake Victoria, more electric power generation is expected. This makes the regulation mode of operation of Lake Victoria outflows advantageous in terms of power output and therefore a possible alternative operation mode to the agreed curve. This however is conditional upon renegotiation of the agreement governing the Nile flow since the agreed curve was an agreement between Uganda and Egypt. Changing it would therefore require mutual consent between the two nations. The key contradiction of the studies is on the average river flow in which one study by Acres International considered the pre-1954 Nile flow as suspect but this assumption was not accepted for subsequent power generation designs. Because the post-1954 river flows were much higher (almost twice as high as the pre-1954 flows) they led to higher expectation for electricity generation and high capacity designs.

4.2.3 Planned Hydroelectric Power Plants

Additional hydroelectric power plants have been identified at five sites on the Victoria Nile with one of them, Bujagali already under construction (figure 4.1). A brief description of each of these plants follows in this section.

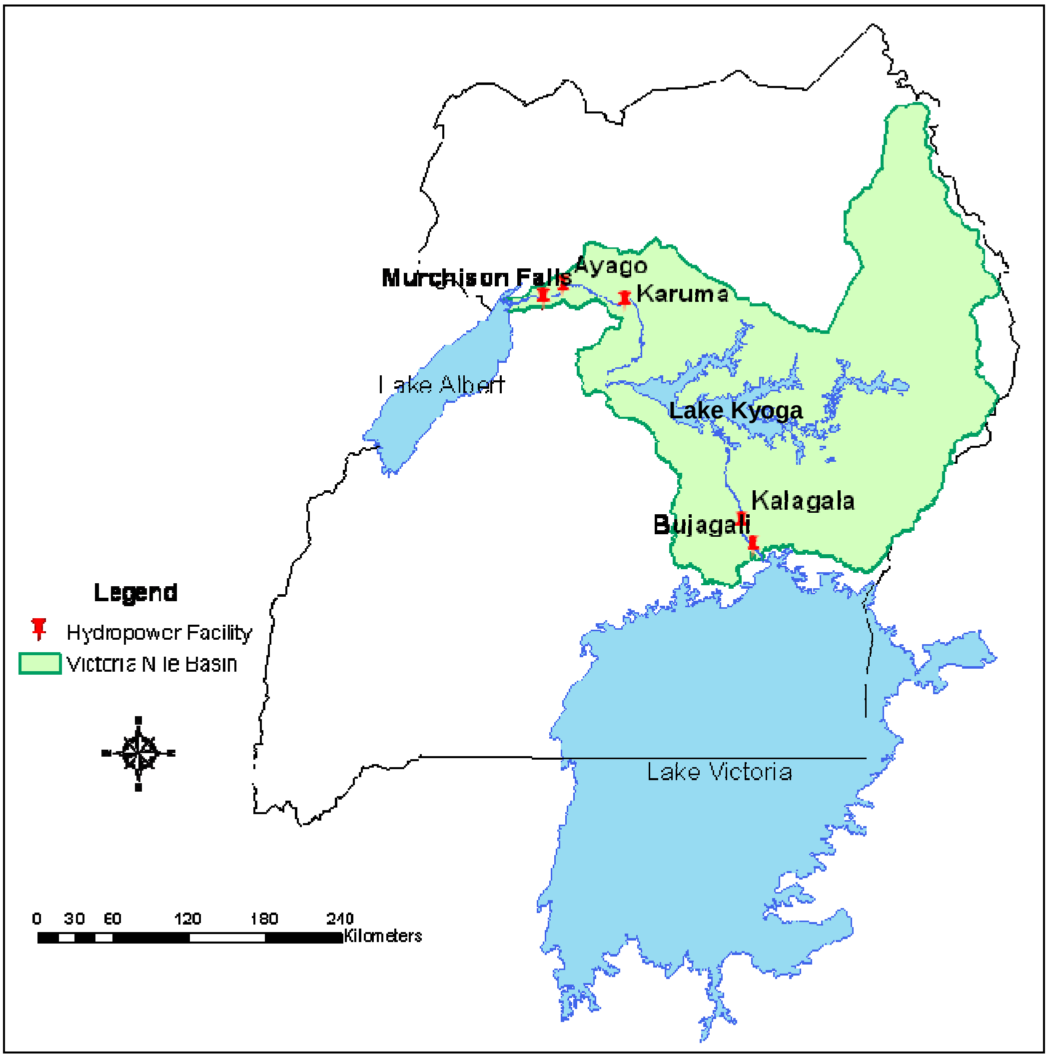


Figure 4.1 Map of Uganda showing location of planned hydroelectric power facilities

(a) Bujagali Project

Bujagali is a run-of-river scheme located 8 km north and downstream of the existing Nalubaale power station at Dumbbell Island (figure 4.1). At the time of writing this thesis, civil works for the facility were underway having started in 2007. It is expected to be commissioned in 2010. Development of the Bujagali Hydro Power Project was initiated by AES Nile Power Ltd (AESNP) in the late 1990s and has undergone a series of setbacks due to its anticipated socioeconomic and environmental impacts. Development of the Project was halted due to the withdrawal of AESNP in 2003 and a fresh procurement process started in which Bujagali Energy Limited (BEL) was selected as the best bidder in 2005.

The Bujagali hydropower facility will consist of a 28 m high earth-filled dam and spillway works, and associated power station housing for up to five 50 MW turbines. The dam will impound a reservoir that extends upstream to the tailrace area of the Nalubaale and Kiira facilities, inundating Bujagali falls. The reservoir will be 388 ha in surface area, comprising the existing 308 ha surface of the Victoria Nile and 80 ha of newly inundated land. The amount of newly inundated land is considered to be small, as the reservoir waters will be contained within the steeply incised banks of the river. In total the project will require a land-take of 125 ha for newly inundated land and permanent facilities. An additional 113 ha of land is needed temporarily for the construction of the facility. Most of the area in the vicinity of the Bujagali and Kalagala hydropower facilities is rural, with estate and small-scale subsistence agriculture being the predominant land uses.

The design of the facility was based on the agreed curve just as it was adopted previously by AESNP, there is however an allowance for operation by regulation of flows. The reservoir offers very little storage of water- essentially all water released at Nalubaale/Kiira will subsequently be released at Bujagali. The water levels in the reservoir may fluctuate by up to about 2 metres, depending on how the government chooses to control flows and power generation.

Socioeconomic and environmental impacts

Generation of electricity is the major positive impact resulting from development of Bujagali as it will boost the energy sector which is a pillar for the socioeconomic development of Uganda. Other benefits include source of employment for the local communities during construction and operational personnel.

The Key negative impacts are displacement of an estimated 85 households and 125 ha of land loss and flooding of household graves and cultural shrines (amasabo) of the local population. Because it is a run-of-river scheme the environmental effects are minimal. Details of socioeconomic impacts of Bujagali are in appendix 4.2

(b) Kalagala Project

The Kalagala falls project is located about 2 km further north and downstream of Bujagali (figure 4.1). Because of the closeness of these projects their socioeconomic and natural environments are similar. The key technical arrangements of the projects are also similar. The project is expected to have an ultimate generation capacity of 450 MW from a set of ten 45 MW turbines operating at an average design head of 28 m and average flow of 660 m^3/s.

Development of this project was put in balance as the Ugandan government guaranteed the preservation of the Kalagala falls and its surrounding area as an environmental offset for the construction of Bujagali project. This was through an agreement of the Uganda Government with the World Bank on 25th April 2001 in which it promised to conserve the Kalagala area including Mabira forest located near Jinja in order to lessen the environmental impacts of the Bujagali dam. This agreement signed between the then energy minister Syda Bbumba and the World Bank country manager Robert Blake states in part that, "The government of Uganda undertakes to conserve through a sustainable management program/budget the present ecosystem of Mabira Forest reserve and those portions of Mabira Forest Reserves on both banks of Kalagala Falls that have been degazeted," (Xinhua, 2007). This agreement seems to suggest that keeping Kalagala falls and Mabira Forest intact was a requirement of the World Bank for approving the Bujagali hydroelectric project. While this was a sensible gesture on the part of the government which it used as a result of the mounting pressure at the time of preparation of Bujagali project, it is likely to be overtaken in the future by the rising energy demand. Kalagala site has one of the highest hydropower potentials on the Nile in Uganda. It is doubtful that it will be left intact amidst an ever rising energy demand.

Socioeconomic and environmental impacts

Generation of electricity is the major positive impact resulting from development of Kalagala as it will boost the energy sector which is a pillar for the economic development of Uganda. Other benefits include source of employment for the local communities during construction and operational personnel.

The Key negative impacts are displacement of an estimated 1,500 people and 1300 ha of permanent take and increased risk of schistosomiasis in 1,900 ha of reservoir area. There will be loss of tourism income from white water rafting in over 15 km of the Nile. Because it is a run-of-river scheme the environmental effects are minimal. Details of socioeconomic impacts of Kalagala are in appendix 4.3.

(c) Karuma (Kamdini) Falls Project

The proposed Karuma falls hydropower facility is a run-of-river scheme located 1.5 km upstream of the Karuma bridge that connects northern and southern Uganda (figure 4.1). It is 80 km downstream of Lake Kyoga and is located near the Murchison falls national park and the Karuma wild life reserve.

The project is designed to utilize a natural river fall of 25 m by diverting some of the flow into an underground power station with 4 turbines each with generation capacity of 50 MW and flow capacity of 200 m^3/s. A comprehensive socioeconomic and environmental impact assessment for the project was carried out by Norplan A.S which shows no significant changes in river flow will be experienced upstream of the intake or downstream of the outlet (Norplan A.S., 1999; Norplan A.S., 1999). The most serious negative impacts of the project are related to the anticipated rapid growth of the population in the vicinity of the project which might cause a boom-town phenomenon, common with such large scale developments. Its strategic location close to the Karuma bridge, the only connection between southern Uganda and northern Uganda makes it strategic and prone to high trade and population migrations.

Development of this facility was in advanced stages at the time of writing this thesis. In its national budget of FY 2008/09 the government reaffirmed its commitment to increasing funds allocation for development of energy in the country. In that budget (2008/09) the government earmarked commencement of construction of this project as its main focus in the energy sector for the financial year 2009/10.

Socioeconomic and environmental impacts

Generation of electricity is the major positive impact resulting from development of the Karuma scheme as it will boost the energy sector which is a pillar for the economic development of Uganda. Other benefits include source of employment for the local communities during construction and operation and increased trade between the South and northern parts of the country.

The Key negative impacts are associated with loss of aquatic life in the nearby wildlife reserve and loss of tourism income. Rapid development of the area in the vicinity of the power facility is likely to cause high population growth. Because it is a run-of-river scheme the environmental effects are minimal. Details of socioeconomic impacts of Karuma are in appendix 4.1.

(d) Ayago Project

At Ayago, two schemes are proposed; Ayago south and Ayago north. They are similar except that the south scheme does not involve the construction of a dam. The dam construction in Ayago north will be during the second phase of the scheme. This dam is expected to be 30 m high and will have a total discharge capacity of about 3,700 m^3/s. The two schemes are about 4 km apart with the north and the south schemes situated 0.5 km downstream and 3.5 km upstream of the Ayago confluence. Like Karuma these schemes involve tunneling and use of underground power houses. Ayago south is designed to have 6 turbine units with generation capacity of 39 MW at a head of 73.5 m.

Generation at Ayago north is planned to be developed in three phases. Phase 1 will operate six units each with a generation capacity of 23.8 MW at a head of 50 m without a dam. In phase 2 the head will be increased by building a dam which will increase the capacity of each of the units to 38 MW thus making the station generation capacity up to 228 MW. Phase 3 will have the power plant expanded by addition of another tunnel and two extra units each with capacity of 38 MW thereby bringing the total generation capacity of the station to 304 MW.

The Ayago schemes have had the least attention of all the schemes and for this reason there is very scanty detail about its design and its prospects for construction.

Socioeconomic and environmental impacts

Electricity generation is the major positive impact resulting from development of the Ayago scheme as it will boost the energy sector which is a pillar for the economic development of Uganda. Other benefits include source of employment for the local communities during construction and operational personnel. There is expected to be more increased access to this rather remote area.

The Key negative impacts are associated with loss of tourism income and loss of aquatic life and barrier to fish movements. Because it is a run-of-river scheme the environmental effects are minimal. Details of socioeconomic impacts of Ayago are in appendix 4.4.

(e) Murchison Falls Hydropower Facility

The Murchison falls project will be located approximately 1.2 km from the Murchison falls on the Kyoga Nile. Like the other schemes in this section of the river, it will involve tunneling and will have an underground power house. Initially no dam will be constructed but in the proposed phase 2 a mass gravity dam, 40 m high will be constructed to increase the head for additional generation capacity.

Phase 1 of the scheme will have 6 turbine units operating without a dam. Because of the low head each of these units is expected to generate about 32.8 MW. Phase 2 will involve construction of a dam to increase the head to 75 m, thereby increasing the generation capacity of each unit to 52.5 MW such that the capacity of the station will be 315 MW after completion of phase 2. Phase 3 will see the power plant expanded by addition of another tunnel and 2 extra units bringing total output to 420 MW. Total discharge capacity is 3,700 m^3/s with a possible reservoir level rise of 1.5 m.

Like Ayago there is little information about detailed engineering design and the prospects for construction of this facility. Its closeness to the spectacular Murchison falls and national park makes it prone to resistance from environmental activists and the tourism sector. For this reason its construction is considered to be susceptible to risk of delay.

Socioeconomic and environmental impacts
Electricity generation is the major positive impact resulting from development of the Murchison Falls scheme as it will boost the energy sector which is a pillar for the economic development of Uganda. Other benefits include source of employment for the local communities during construction and operation. There is expected to be more increased access to this rather remote area.

The Key negative impacts are associated with loss of tourism income from the spectacular Murchison falls and loss of mist flora and associated faunal communities sustained by subsidiary falls. Because it is a run-of-river scheme the environmental effects are minimal. Details of socioeconomic impacts of Murchison Falls are in appendix 4.4.

4.3 Irrigation Development

4.3.1 Irrigation potential

Irrigation in Uganda has been practised by smallholders as early as the 1940s but by 2006 only 10% of the total irrigable area was equipped for irrigation and only 65% of the irrigation-equipped area was actually irrigated (FAO, 2008b). In the 1970s it was estimated that smallholder irrigation on the fringes of swamps for rice and vegetable production covered an area of 30,000 ha (FAO, 1998). The use of swamps for crop production has expanded since then. The 1994 Uganda national population and household census estimated the total area under rice production in Uganda to be 55,000 ha. This included about 1,650 ha of rice under formal irrigation, the rest being small scale informal irrigation. Feasibility studies were carried out in the Lake Kyoga basin, Kasese plains and Lake George flats commissioned by the Uganda Government and undertaken by Sir Alexander Gibb and William Halcrow and Partners in the 1950s and 1960s respectively to identify feasible areas for irrigated agriculture. The result of these studies was an estimate of the irrigation potential for Uganda (table 4.2)

Table 4.2 Irrigation Potential in Uganda
Results of studies done by Sir Alexander Gibb and William Halcrow and Partners in the nineteen fifties and sixties.

Area/Location	Estimated gross potential (ha)
1. L. Kyoga Catchment	81,810
2. Western Region Rift Valley	25,110
3. Albert Nile Valley	22,275
4. Jinja/Iganga	16,275
5. L. Bisina Catchment	11,340
6. Karamoja, Kumi, Soroti	10,125
7. Mbale, Kapchorwa	9,315
8. Aswa River Catchment	8,645
9. Koki Lakes and Oruchinga Valley	2,025
10. R. Katonga and Lake Wamala Catchment	1,215
Total	188,135

Source: (FAO, 1998)
Note: Shaded areas are within the study area

Table 4.2 shows that out of the 188,135 ha of land with a potential for irrigation in Uganda, 128,865 ha are within the Victoria Nile basin representing 68% of total irrigation potential.

A total of about 32,000 ha of land was estimated to be already under irrigation by 1998 (FAO, 1998). Practices regarding water application at that time indicated that approximately 200 million m^3 of water was used annually for irrigation. Swamps provide the largest irrigated areas, with approximately 30,000 ha of small-scale irrigation in Tororo and Iganga districts both in the Victoria Nile basin. The total irrigation potential for Ugandan was tentatively estimated between 200,000 and 400,000 ha in 1998. If fully developed, this corresponds to a water demand of 1,300 to 2,700 million m^3 per year or about 5% to 9% of the Nile flow. It may be anticipated that consumptive use of water for irrigation will impose an increase in demand on the water resources. All rivers that supply water for irrigation to schemes within the study area ultimately drain into Lake Kyoga (table 4.3). This means that increased demand for irrigation in these areas will reduce the amount of inflow to Lake Kyoga and consequently the river Nile flow.

Table 4.3 Status of water use for Crop production in Uganda as in 1998

Irrigation Project	District	Source of water	Main crops produced	Command area (ha)	Irrigated area (ha)
Formal schemes					
Mubuku	Kasese	Sebwe/Mubuku rivers	Onions, vegetables and alfalfa	600	430
Kibimba	Iganga	Kibimba reservoir	Rice	600	600
Doho	Tororo	River Manfwa	Rice	1,000	1,000
Kiige	Kamuli	Lake Nabigaga	Citrus	150	10
Ongom	Lira	River Owomeri/R. Ongom	Citrus	40	10
Labori	Soroti	L. Kyoga	Vegetables	40	0
Atera	Apac	L. Kyoga	Rice, Vegetables	20	0
Agoro	Kitgum	R. Agoro	Rice, Vegetables	120	120
Olweny	Lira	R. Agoro	Rice	50	50
Small-scale					
	Tororo	R. Mpologoma, Lumbika, Manafwa	Rice	24,500	24,500
	Iganga	R. Mpologoma, Kitumbe, Lumbuye	Rice	2,400	2,400
	Pallisa	R. Mpologoma	Rice	10,800	10,800
	Others		Rice	15,650	15,650
Commercial					
Nyamugasani	Kasese	R. Nyamugasani	Vegetables, cotton, sugar cane, maize, rice	360	10
Kakira	Jinja	L. Victoria	Sugar cane	2,000	50
Lugazi	Mukono	R. Sezibwa	Sugar cane	600	50
		Total		58,930	55,680

Note: Shaded areas are those within the study area
Source: (FAO, 1998)

The Uganda Water for Production Strategy and Investment Plan 2005-2015 estimated that by 2003 total land under irrigation in Uganda was only 14,418 ha of which 2.1% was small scale, 14.1% government schemes, 36.6% commercial plantations and 47.2% Kakira sugar plantation (DWD, 2005). This is far less than the estimate given by FAO in 1998. The figure by DWD seems to be on the low side, perhaps due to under estimation of irrigated areas under informal small scale irrigation.

4.3.2 Irrigation Projection

The actual irrigation potential in Uganda is in the range of 189,000 ha to 410,000 ha as estimated from different studies (table 4.4).

Table 4.4 Irrigation potential in Uganda as estimated from different studies

	Source document	Year Published	Author	Irrigation estimate (ha)
1	Report on the feasibility of Irrigation in Uganda by Government of the United Kingdom, Ministry of Overseas Development,	1964	Sir William Halcrow and Partners	189,000
2	A survey of the water requirements of Uganda. Ministry of Overseas Development, Miscellaneous Report No. 84 Land Resources Division	1970	Directorate of Overseas Surveys, UK	296,300
3.	Irrigation and water resources potential for Africa FAO, AGL/MISC/11/87	1987	FAO	410,000
4.	Irrigation potential in Africa – A Basin approach. FAO, Land and Water bulletin 4	1997	FAO	202,000

Source: DWD, 2005

In making the above estimates several assumptions were made by the respective authors. Notable among these is consideration of the economics of water supply for irrigation. By taking the economies of water supply into account and therefore assuming that expensive irrigation technologies (whose investment costs are between US$ 15,000-25,000 per ha) may not be used then irrigation potential reduces tremendously. With this assumption, DWD estimated that the irrigation potential could reduce to as low as 90,000 ha (DWD, 2005). This however will depend on the demand for irrigation as a result of global market and trade trends, rainfall patterns and changes in investment costs. The most recent estimate of irrigation potential of 202,000 ha by FAO (1997) appears to be a better compromise for planning purposes while the one by DWD (2005) of 90,000 ha is seen as an underestimate.

4.4 Other Developments in the Victoria Nile Basin

Other key economic developments in the Victoria Nile basin include fisheries and tourism. Lake Kyoga is the main water body in the basin in which fishing is practised. Although fishing is not one of the key variables considered in this study, it is a significant economic activity in Uganda that is heavily dependent on the availability of the water resources. Fish is one of Uganda's major export commodities and is reported to contribute up to 6% of Uganda's GDP

(MFPED, 2004). Over 1,000,000 people in Uganda are dependent on fisheries as their main source of household income. Lake Kyoga is the main habitat for fish in the basin although the Victoria Nile River also produces significant fish catches. The annual average fish catch in Lake Kyoga is not clearly known but data available for the period 1995-2002 give an average of 80 tonnes per year (Kaelin and Cowx Ian G., 2002). People living on the shores of Lake Kyoga depend on fishing in Lake Kyoga as their main source of income and protein. Even though fishing is an important contribution to the welfare of people in the study area, it is outside the scope of the study and is therefore left out.

Tourism is based along the Victoria Nile River at locations where there are rapids such as Kalagala, Bujagali and Murchison falls and also in the Murchison falls national park. There is a conflict between tourism and hydro power development sites since proposed hydropower projects are all located at potential tourist attractions. Murchison falls and Kalagala hydropower projects have the highest hydropower generation capacity but at the same time are located in the most appealing tourist areas. It is not surprising that even with their high hydropower potential these two have been given least attention for development.

4.5 Pressures and Challenges

4.5.1 Climate Variability and Change

Despite the high level of vulnerability of the African continent to climate variability and change, there are few studies on this subject specifically for the Nile basin. The basin is vulnerable to El Niño-Southern Oscillation (ENSO) and extreme events like droughts, floods and changes in hydrologic patterns. Changes in the weather patterns have been evidenced in Uganda particularly in 1997/98 and 2004/06. Variations in basin rainfall over the years cause considerable variations in river discharges and lake levels. For this reason, annual river Nile discharge figures vary greatly depending on the period under consideration (FAO Land and Water Division, 1997), (Figure 4.2).

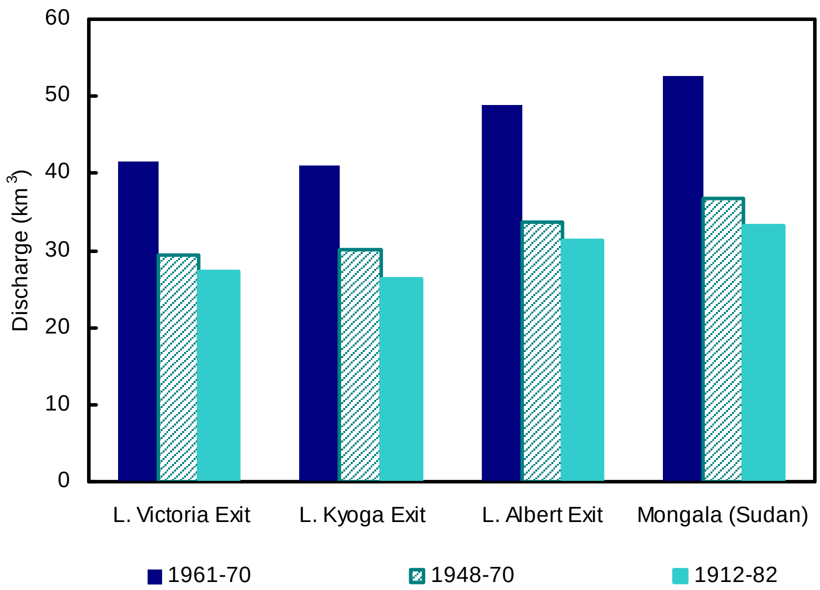


Figure 4.2 Variations in annual average White Nile flows at different locations and periods
Source: FAO, 1997

Within the twentieth century, decadal precipitation changes in the Nile have been up to 20% of the Holocene changes (Hulme, 1994). Precipitation over the basin is sensitive to both natural (e.g. changes in evaporation) and anthropogenic (e.g. land cover change, creation of artificial reservoirs) forcing factors which operate on a variety of time and space-scales. For this reason, historical precipitation assessments and future water availability need to be carefully assessed whenever large water consuming development projects are planned.

Climate change projections indicate that throughout the African continent, warming is very likely to be larger than the global annual mean. In all four regions of West Africa, East Africa, South African and the Sahara and in all seasons, the median temperature increase lies between 3°C and 4°C, roughly 1.5 times the global mean response (IPCC, 2007b). The IPCC predicts an increase or little change in rainfall in the tropics with increasing drying in much of the subtropics thus increasing the rainfall gradients. Rainfall in East Africa is predicted to increase.

The few available climate change studies in the Nile basin agree that temperature will rise throughout the basin, however there is considerable uncertainty and disparity in spatial and temporal predictions of changes in precipitation regarding both magnitude and direction (IPCC, 2007b);(Beyene et al., 2008). This complicates and makes uncertain any attempt to establish the impact of climate variability and change to the water resources in the basin. Since this makes predictions of the likely river flows difficult it also renders developments for hydropower and irrigation projects difficult. In Uganda for example, the design of the Kiira hydroelectric plant in Jinja was based on the assumption that pre-1954 Lake Victoria levels data could mislead estimating the design flows for the facility because these were considered to be so low compared to those after 1954. However, by 2005 lake levels were seen to return to the pre-1961 levels. This caused disruption to hydropower generation on which the entire country relies for electricity.

The IPCC considers Africa as one of the most vulnerable continents to climate variability and change. This vulnerability is exacerbated by existing development challenges such as endemic poverty, poor governance and civil strife. Climate exerts a significant impact on the day-to-day economic development of Africa, particularly for the agricultural and water resources sectors (IPCC, 2007b). For the Victoria Nile where majority of people rely on the basin water resources for their livelihood, impacts of climate variability and change are seen to be a major threat to development in the region. Being upstream of the main consumers of the Nile waters puts the basin in a delicate position as there will be considerable pressure from downstream states. These downstream states will be in need of more water as their temperatures are predicted to increase higher and therefore higher losses of water from evaporation is expected. Egypt, one of the lower riparian states is seen as one of the countries that could be vulnerable to water stress as a result of climate change (IPCC, 2007b). The consequent high water demand from downstream riparian states will pose pressure to the Victoria Nile hydropower and irrigation developments. The influence of Lake Victoria on the Victoria Nile basin increases the basin’s vulnerability to climate variability and change. Inter-annual Lake Victoria level fluctuations have been observed keenly probably owing to periods of intense droughts followed by increases in rainfall and extreme rainfall events in 1997/98 which saw the lake rise by over 1.7 metres. This however was followed by a lake level decline of up to 2 m only seven years later, the lowest recorded in 50 years.

4.5.2 Trans-boundary Water Legislation

Agreements on the use of the river Nile waters date way back to 1891 when the United Kingdom government and Italy agreed that the Italian government (which was governing Eritrea) would not construct any works that could divert or modify the flow of the Atbara River into the Nile. There were later agreements, notably those of 1929 and 1959 which have impacted heavily on developments in the Nile basin. Details of Nile water use agreements have been documented by Okidi, (1990).

The prevailing water use legislation for the river Nile is the “Nile Waters Agreement” (NWA) which was concluded on 7th November 1929 between Egypt and the British government acting on behalf of Sudan and the equatorial states that were then colonies of Britain. This agreement states in part that no works would be undertaken on the Nile, its tributaries and the lake basin that would reduce the volume of water reaching Egypt. It also gave Egypt the right to inspect and investigate the whole length of the Nile to the most remote sources of its tributaries in the basin. It allocated 48 $x10^9 m^3$/year of the Nile flow to Egypt and 4 $x10^9$ m^3/year to Sudan as their respective rights. These allocations were later in 1959 under a bilateral agreement coined “the agreement for the full utilization of the Nile waters” increased to 55.5 x 10^9 m^3/year for Egypt and 18.5 $x10^9$ m^3/year for Sudan after the two countries agreed on the construction of the Aswan high dam in Egypt and the Roseires dam in Sudan.

The 1959 bilateral agreement allocated virtually all the Nile flow estimated as 84 x 10^9 m^3/year measured at Aswan to Egypt and Sudan with 10 x 10^9 m^3 being the estimated waste. The agreement further provided that any benefit resulting from an increase in average yield of the Nile flow was to be divided between the two nations in equal shares. As a result of the agreement a permanent joint technical commission was created comprising of an equal number of members from both countries (Egypt and Sudan). This commission was given the mandate to oversee planning and execution of all projects on the Nile both within these two nations and within other riparian states. Under provisions of this agreement, Egypt and Sudan are to have a unified position in all cases requiring negotiation with any riparian state outside the boundaries of the two nations.

At the time of the bilateral agreement between Egypt and Sudan, all other riparian states except Ethiopia were under colonial rule. None of the upper riparian states, even Ethiopia from which about 80% of the water comes, was consulted at the time of drawing the agreement. For this reason, and also because Egypt and Sudan gave themselves the largest share of the Nile waters, the other riparian states feel cheated and they have been advocating a change in the law. This is augmented by the ever increasing demands resulting from population growth, industrialization and climate variability and change. Tension among the Nile basin countries builds up whenever a new project is proposed in the basin. It is therefore not surprising that Egypt, being the hegemonic power, has been directly involved, to the displeasure of other countries, in the development of any projects along the River Nile. This has culminated in the signing of some form of agreement or into threats whenever a project is proposed for development in the basin (table 4.5). Below is a summary of indicators of the rising tension and conflict within the Nile which appears to be partly as a result of the prevailing archaic law on the Nile water use.

Table 4.5 Examples of rising conflicts over the use of the Nile waters
Source: Various

	Incident description
1.	In the Ugandan parliament in 2002, an MP Amon Muzoora proposed a motion to renounce the pre-independence Nile water agreements, and made claims for annual compensation of some US $1.2 million.
2.	In August 1995 Sudan threatened to withdraw from the 1959 bilateral agreement on grounds that it was unable to use the Nile water as needed to develop its economy.
3.	The Addis Tribune of Ethiopia reported on 6th January 2004 that the Ethiopian

	Incident description
	minister of water resources said the agreement to participate in the Nile Basin Initiative reserves Ethiopia’s right to implement any project in the Blue Nile sub-basin unilaterally, at any given time adding that the 1959 agreement between Egypt and Sudan impedes sustainable development in the basin and called for its nullification.
4.	After Tanzania got independence from Britain in 1961, then President, Julius Nyerere announced the “Nyerere doctrine” under which, independent Tanzania refused to recognize agreements signed by Britain on its behalf. This included the Nile waters agreement. Indeed in early February 2004, Tanzania launched a project to draw water from lake Victoria to supply the dry north eastern Shinyanga region. Egypt expressed its irritation to this arguing that under the 1929 agreement it had the right to veto any project that could threaten its share of the Nile waters. Tanzania was however firm on its sentiments about the legality of the water agreement.
5.	The Al-Sharq Al-Awsat, newspaper of December 17, 2003 reported that the Egyptian minister of irrigation and water resources Mahmoud Abu Zeid said in retaliation to Kenya’s desire to withdraw from the 1929 Nile waters agreement that “Egypt considers the withdrawal of Kenya from the agreement as tantamount to official declaration of war and a threat to its vital interests and national security.” Kenya however continued its demand for revision of the agreement because it was not consulted prior to its signing and yet eight of Kenyan rivers drain into the Nile basin.
6.	In 1991, Egypt warned that it was ready to use force to protect its access to the waters of the Nile, should Ethiopia and Sudan plan to build dams on the river (Tadesse 2008).
7.	In a BBC programme in 2006, an Ethiopian minister acknowledged the risk of conflict with Egypt and said Cairo was indeed preparing for that eventuality, as it was busy "training its army for jungle warfare, yet it has no jungles." He argued that the only logical use for the force would be against the countries upstream of the Nile in the event that there was a crisis over the sharing of water.
8.	According to the BBC (2006) analysts warned of conflict, as East African nations compete for water. This was as a result of the lowering L. Victoria water levels (in 2005, lowest in the last 50 years) this led to shifting of blame between the East African states that share L. Victoria.
9.	Former UN Secretary General Mr Boutros Boutros Ghali urged the international community to ensure a fair division of water between nations. He said military confrontation between the countries of the Nile basin was almost inevitable. If the situation is not pragmatically dealt with, riparian states may face regional wars on the river Nile at two fronts; Environmental war and political war

Chapter 5 Research Approach

5.1 Introduction

This chapter describes the approach used in the study including collection and analysis of data, model selection and documentation of results. The literature was searched to identify appropriate approaches and previous interventions that were used to solve similar problems. Quantitative and qualitative data were collected from historical measurements and unstructured discussions took place with experts in the fields of water resources, hydrology, irrigation, environment and hydropower development. A detailed description of the development of the Bayesian model is dealt with separately in chapter six.

5.1.1 Literature Review

Research preparation included conceptualisation of the problem and setting the context in terms of understanding the problem and formulation of research objectives. This involved a literature review to identify relevant literature and possible approaches that were used in the past. The literature reviewed can be classified into: journal peer reviewed articles, government action plans and reports, project documents and reports, text books on relevant topics in water and environmental engineering and management; websites on the internet and media reports and articles.

Journal articles were the most widely consulted literature. The material studied was predominantly from the field of water resources management, hydrology, hydropower development, environmental management, probabilistic networks and decision support systems. National government reports included reports prepared by the colonial governments in the period prior to Uganda's independence in 1962, Egyptian government reports on the plans and developments on the river Nile and related reports from other Nile riparian states. Project documents mainly from the NBI projects and United Nations (UN) agencies such as United Nations Development Program

(UNDP), Food and Agricultural Organisation (FAO) and the World Bank provided situation reports and plans on developments in Uganda and the river Nile Basin. Media reports and articles on the subject matter especially on the problems of the Nile, lake Victoria and the escalating effects on the people affected by the problems, were studied. The literature is presented in context whenever it is referred to as there is no particular chapter on literature review.

5.2 Tools

5.2.1 Data Analysis

Statistical data analyses were done wherever large quantities of data were available and used to make inferences about patterns of rainfall, lake levels and water flow events. For determination of probabilities of occurrence of events frequency distributions were used in cases where historical data was available and personal estimates were made in cases where no data was available. Personal estimates were made by reasoning based on other available information related to the subject matter. In cases where personal estimates were made the basic assumptions behind the reasoning were explained.

5.2.2 Production of Maps

Geographical Information Systems (GIS) program ArcGIS 9 was used for producing study area digital maps. Where there was no geographic referenced data, location of key areas in the study area were mapped by digitization of satellite images.

5.3 Data Sources

Several data sets were used comprising data from previous studies in the literature and in Government archives, raw data from river flow and lake level measurements, rainfall data collected from weather stations. All raw data for river flow measurements, lake levels and rainfall data were obtained from the government of Uganda Water Resources and Meteorology departments. In cases of missing data whenever possible these gaps were filled by additional data obtained from the literature. The Centre for Ecology and Hydrology (CEH) in the UK provided most of the hydrological data for earlier years, which was missing from the government departments. Data consistency was checked by comparing raw data from the collection stations, government databanks, data used in past studies and modelled data.

5.4 Timeframe

Overall the research took 3½ years including preparation, analysis and writing. There were two field visits to the study area. The first took place during the first year of the research and it involved establishing availability of data and collecting raw data from collection stations and government archives. During this first field visit, government and key stakeholders in the area of water resources in Uganda were met to inform them of the intentions of the research and getting their views on the proposed approach.

The second field visit took place during the second year of study and it involved discussions of the preliminary findings with stakeholders- NEMA, Ministry of Energy, Ministry of Water and Environment and the World Bank. During this field visit data on socioeconomic and environmental impacts of hydroelectric power plants was obtained from the Social and Environmental impact assessment reports produced by the firms that carried out the individual assessments. The National Environment Management Authority (NEMA) and Norplan Ltd provided the reports for the Social and Environmental assessments for proposed Bujagali and Karuma hydroelectric power facilities. Other data on hydropower development was obtained from the World Bank publications. Discussions were held with personnel from these three organisations regarding the use and confidentiality of the data.

5.5 Decision Modelling Approach

In management decision making there are several procedures and approaches that can be used to support managers to make decisions. In many cases making the decision on what approach to use is as difficult as making the management decision itself. As such, the choice of approach to use depends very much on the type of problem at hand, the data available, the decision maker, the people involved in the project, the operational environment and the time available for implementing results. It could be argued that a particular tool selected for a decision environment may adequately guide the decision making but this does not necessarily mean the selected tool is the best available approach for that situation. This study was also faced with such considerations in selecting the appropriate tool to use.

Bayesian Networks (BN), were selected as the tool for use in assessing the impact of carrying out selected developments under a set of different rainfall conditions in the Victoria Nile Basin. Before selecting BNs several other approaches were studied to ascertain whether they were likely options for use in the study. These included hydrological models, use of GIS and Remote Sensing. Needless to say, these were not the only available approaches but consideration was limited to these given the background information available to the researcher at the time of commencement of the study and the time available for the research.

The following sections outline the key considerations that were made in arriving at the use of Bayesian Networks as the decision support tool that was used to determine the effects of development decisions to the basin. It describes in summary hydrological modelling, remote sensing and the use of GIS as some of the modelling approaches commonly used in water resources management. A review of these approaches was made initially as alternatives that could be used. Finally a detailed description of the Bayesian Networks approach which was selected and used in this research is given. Details of how the BN for the Victoria Nile basin was developed are covered separately in Chapter 6.

5.5.1 Decision Support Systems

Decision making can be a complex process that can take years and that may require analysis of volumes of information and comparison of many possible alternatives. For complex decisions involving or affecting many people and costing large sums of money, for instance developing large hydropower projects, due consideration has to be given to the likely impacts of the projects and the economic benefit of the chosen option compared with other alternatives. In such cases, decision analysis is important and information is synthesized before making decisions. Often such information is not readily available and, where it is available, its validity and accuracy are questionable. In water resources and environmental management there can be considerable uncertainty that makes decision-making even more difficult. The more complicated the management system and the greater the volume of information to be considered, the more likely it is that poor decisions will be made. This is commonly the case for water resources developments where a lot of data spanning decades have to be considered before the development of new projects can proceed. Moreover, due to the complexity of water resources systems, there are often many conflicting demands such as irrigation, flood control, hydropower development and environmental preservation. Managing trade-offs between these demands presents more problems for decision making. In these situations, tools for guiding decision making may be a necessity for sustainable development. Decision support systems (DSS) are used to guide decision making for such complex systems.

The concept of DSS in management science was crystallised in the early 1970s probably arising from an article written by J.D. Little in 1970 titled “Models and Managers: The concept of a Decision Calculus” (Marakas, 1999) in which he argued that in many respects the biggest bottleneck in the managerial use of models is not their development but getting them used. The emphasis of model developers should therefore be drawn to making models that are simple, robust, easy to control, adaptive, as complete as possible and easy to use as a communication tool (Little, J.D., 1970). In view of the differences between model users and developers, he suggested a special requirement for model design, which he called “decision calculus”, defined as a model-based set of procedures for processing data and judgments to assist a manager in his decision making. The term decision support system was however, first coined in 1989 by Gorry and Scott Morton (1989) in their article “A Framework for Management Information Systems”. In this article the authors introduce DSS as systems that deal with the unstructured problems that have a significant effect on the organization and thus are of the greatest concern to managers. It was also suggested that the most important role of a DSS is educational (Gorry and Morton Micheal, 1989).

A DSS is a tool that allows the user to make better informed decisions through the integration of information. At its broadest definition, a DSS can be considered to be any methodology that is helpful to a decision maker to resolve issues of trade-offs through the synthesis of information. Because there are many approaches to decision-making and because of the wide range of domains in which decisions are made, the concept of DSS is very broad. There are many types of Decision Support Systems, including influence diagrams, decision trees, mathematical models, multi-criteria analysis, spreadsheets and Bayesian networks. But which of these is most appropriate for the problem at hand needs to be given careful consideration at an early stage in the decision making process (Bromley et al., 2005). It is important to recognize that while a DSS is an important tool it does not replace the wisdom of the decision maker, rather it supports the decision maker to make better decisions. The type of support offered by a DSS was elaborated by Marakas (1999) and includes among others exploration of multiple analysis scenarios for a given decision context, exploration of multiple perspectives of a decision context, generation of multiple and higher quality alternatives for consideration, discourages premature decision making and alternative selection, improves response time of the decision maker and provides control over multiple and disparate sources of data. These types of support apply to water resources decision making situations.

For a water resources system, many factors impact on one another and therefore a decision on one is likely to affect the state of another. These factors may be environmental, social and economic making it even more difficult to consider them together, since some are quantifiable while others are not, and those that are quantifiable often have different units of measurement. A good DSS is one that can provide a methodology that can capture and integrate these differences into one system. This is however difficult to achieve since different experts can better deal with decisions that are confined only to their expertise. Domain experts have the relevant scientific knowledge for planning and management in their respective fields but they do not make decisions for society. Decision making is often a role for public policy actors like politicians, government departments, non-governmental organization and the general public. The role of DSS in the field of water resources is to leverage current scientific and technology advances held by the domain experts in developing and evaluating specific policy options for possible adoption in the integrated water resources management (IWRM) process (Georgakakos, 2004). In order to determine an appropriate DSS for a given system it is vital to understand decision analysis.

5.5.2 Decision Analysis

Decision analysis is the interdisciplinary field which examines how to improve decision making (Golub, 1997). There are two main problems encountered in decision analysis; uncertainty and multiple conflicting objectives. Uncertainty arises when the outcomes of a decision problem are partly determined by factors outside the decision makers control and whose occurrence is often probabilistic in nature, for instance climatic factors. Multiple conflicting objectives arise where there are two or more desirable objectives but whose achievement is obtained through conflicting actions. In water resources management, multiple conflicting objectives often revolve around the conflict between the environment and economics.

5.6 Model Selection

There are several reasons for modelling, which influence the type of framework, modelling family or families selected to represent a system. These include (Jakeman et al., 2005):

i. To enhance system understanding
ii. For knowledge discovery, acquisition or elicitation
iii. For social learning among interest groups
iv. Prediction/ Forecasting the future or simulation
v. Management and decision making
vi. Discovering limitations, inconsistencies and gaps in data.

Models are invaluable tools for resource management. They help resource managers develop a shared conceptual understanding of complex natural systems, allow testing of management scenarios, predict outcomes of high risk and high cost environmental manipulations and set priorities. The modeller has to establish coverage and priorities within the above list in order to select the modelling approach that is applicable to the context. Unfortunately there will always be some degree of uncertainty because models are only a simplification of reality. What features of the actual system are incorporated into a model and what features are not depends partly on what the modeller thinks is important with respect to the issues being discussed or the questions being asked. How well this is done will depend on the skill of the modeller, the time and money available and perhaps more importantly the modeller's understanding of the real system (Loucks Daniel, 1992). The choice of approach therefore depends mainly on the issues that the researcher is investigating and also importantly the availability and accuracy of the data used.

The concept of probability occupies an important place in the decision making process, especially because most decisions are taken in situations of incomplete knowledge and uncertainty. Probability is used in such situations as a substitute for complete knowledge. Arsham (2008) shows that there is a continuum from pure certainty to uncertainty in which the domain of decision models may fall. He shows that decision models fall between two extreme cases depending on the degree of knowledge available about the outcome of our actions. This is represented on the scale in table 5.1 below.

Table 5.1 Modelling approach depending on available knowledge

Ignorance	Risky Situation	Complete Knowledge
Pure uncertainty model	Probabilistic model	Deterministic model

Between the two extremes of complete knowledge and ignorance are situations under risk. The degree of certainty varies depending on how much knowledge is available for the problem at hand. According to this scale, selection of a particular approach to decision making is influenced by the level of knowledge available. Deterministic models are inadequate for representing problems where the most crucial parameters are either unknown or based on an uncertain future (Pallottino et al., 2005). Water and environmental resources problems are typically characterized by uncertainty and because of this more effort should be put in trying to use systems that incorporate uncertainty.

5.7 Decision Support Systems in Water Resources Management

Modelling is widely used to study systems and to guide decision making in water resources management and many other disciplines. For water resources management, most countries now use models for policy making and at operational level. In the Netherlands which is considered one of the most advanced countries in water management both policy making and water management are pursued at national level and regional scales supported by models (Marcela Brugnach et al., 2007). These models are widely used by scientists to provide a foundation for making forecasts.

By modelling we can often predict the nature or outcome of an event under certain conditions without having to actually experience the event under study. The value of this is the reduced cost, effort and time derived by studying the model rather than the system itself. In addition modelling is a useful source of information for decision making. In water resources management, modelling is the principal way of predicting the future behaviour of water resources systems. In order to develop a reasonable prediction it is necessary to obtain probabilities associated with uncertain events within a system. For this purpose probability can be used in three different ways: to express the long term frequency of a recurring chance event, to quantify a lack of knowledge about a past event and to express the likelihood that a unique future event will occur (Golub, 1997).

5.7.1 Hydrological Models

The high technology advancement in data acquisition and processing combined with modern computers permit rapid processing of hydrological and meteorological data of all types. This has contributed to improvement of hydrodynamic modelling, which is based on a refined space discretization of the catchment and on numerical integration of equations of momentum and mass conservation that describe the physical processes in the basin (WMO, 1994). As such, hydrodynamic modelling does not capture some key parameters of management relevance, for example the multiple interdependent physical, ecological, environmental, social and economical processes that affect water resource systems. Hydrodynamic models are generally complex and require considerable simplification to make them easy to understand and to use by planners and managers. Such simplification however may make the results of the models uncertain and questionable. Availability of data is often the main determinant for model complexity and the outcome of the model very much depends on its purpose. Modellers who develop models to be used operationally are usually more concerned that the models can produce results that are in accordance with measured time series than with the fact that they do it for the right reason (Olsson and Andersson, 2007).

Modelling of hydrological systems involves the application of mathematical and logical expressions that define quantitative relationships between flow-forming factors (input) and flow characteristics (output). It requires solving the mathematical equations that describe water flow and quality (Maidment, 2002). These models range from purely empirical or black-box techniques to hydro-dynamic techniques involving complex systems of equations based on physical laws and theoretical concepts that govern hydrological processes. Whether black-box or hydrodynamic, these models yield outputs without associated probabilities of occurrences and for this reason are often referred to as deterministic models. Hydrologic modelling however is sometimes considered to include stochastic modelling where the emphasis is on reproducing the statistical characteristics of hydrologic time-series and no attempt is made to model input-output relationships (WMO, 1994). These models consider inputs and outputs of hydrological variables without consideration of other factors in a catchment such as environmental and socioeconomic factors, which are equally important for development of the catchment as a whole. They are therefore adequate only when the hydrology of a system is being studied, but cannot implicitly support integrated basin-wide decision making. They perform best when hydrologic data relating to all important variables spanning long periods are available with few or no missing records. Their outputs can however be integrated into a basin-wide decision support tool.

5.7.2 Remote Sensing

Technological advancement in remote sensing has led to a shift from providing water resources information by using conventional means such as rain gauges and river level and water quality monitoring to more rapid means using remote sensing. This shift is an improvement on the rather, expensive, slow and inefficient conventional methods that cannot satisfy the requirements of water resources management (Xiuwan et al., 1997).

Remote sensing describes the use of aerial and satellite imagery to record geographical information on the earth. It involves measurement or analysis of properties of the earth's surface from a location not in physical contact with the objects in view. This characteristic of remote sensing makes it very convenient to provide information in locations that are relatively inaccessible or remote from social amenities. The viewing platforms used for remote sensing instruments are typically airplanes or earth-orbiting satellites. Such instruments include the Landsat satellites, radar, lidar (Light Detection and Ranging), and microwave sensors. The variations in spectral response of various earth surface materials (soil, rock, vegetation, water) enable discrimination and identification of landscape properties, depending on the spatial and spectral resolution of the sensor. By plotting an object's surface reflectance as a function of wavelength, the state and condition of the earth's surface can be characterized. Satellite remote sensing has many advantages including accessibility, synoptic viewing, uniformity of collected information, repetitive coverage and cost effectiveness (Baban, 1997). Remote sensing data is particularly useful in the field of hydrological modelling where such information can be used for both the estimation of hydrological model parameters and as input to hydrological models (Schultz, 1997).

In water resources management remote sensing can be used for the following purposes:

- Determination of water boundaries and surface water areas

- Mapping of floods and flood plains
- Determination of areal extent of snow and ice
- Measurement of glacial features
- Measurement of sediment and turbidity patterns
- Delineation of irrigated fields
- Inventory of lakes
- Estimating snow melt runoff
- Monitoring environmental effects of man's activities (Lake eutrophication, defoliation)
- Mapping and monitoring of water pollution

Schultz (1997) presented a technique to extend short observed runoff data time series for the Tano river basin in Ghana using the European satellite Meteosat. In his study a mathematical model was developed which connected the observed short time series runoff data with data obtained from satellite imagery. After the calibration procedure, it was possible to reconstruct historical river flows with the aid of the mathematical model based solely on satellite data for the whole period of time for which satellite information was available. With the aid of this extended runoff time series, it was possible to estimate the expected future performance of the intended water project.

Gupta et al., (1997) estimated the rain water harvesting potential of a semi-arid area covering part of the Banswara district of Rajasthan state in India using GIS and remote sensing. In this study the researchers were able to determine the annual runoff potential and its distribution within the study area. Remote sensing information was found particularly useful in deriving the hydrologic soil cover complex Curve Number (CN) values and the latest land cover information which was needed for runoff estimation using a GIS.

The applications shown above illustrate that remote sensing can be a useful tool for determining information when used for hydrological modelling. It is however insufficient as a standalone tool to guide decision making where an integrated approach is needed to consider the many factors required for effective decision making. Remote sensing can be used to provide information that can be used as input to other tools that can integrate the other relevant factors for decision making.

5.7.3 Use of GIS

A GIS is a computer system capable of capturing, storing, analysing and displaying geographically referenced information-data identified according to location. GIS support hydrologic analysis and modelling by describing the physical environment through which water flows. During the 1990s, GIS emerged as a significant support tool for hydrological modelling (Maidment, 2002). GIS can be used among other things to: identify potential problems in a river basin and their geographical locations; establish various management scenarios responding to different conditions of the identified problem and to run these scenarios and reflect on the resource management, environmental, economical and social consequences of each action over various periods of time (Baban, 1997). The ability of GIS to manage, correlate, predict, model, and share geographic information makes it a powerful analytical tool for those who have the capability to use it.

GIS can be used in various ways to support hydrological modelling (Maidment, 2002):

- Management of data - GIS performs basic geospatial data-management tasks (data storage, manipulation, preparation and extraction) and spatial data processing (overlays and buffering)
- Extraction of parameters - GIS provides characteristic properties of watersheds and river reaches for hydrological modelling.
- It provides visualisation - GIS displays data either before the hydrological analysis is performed to verify the basic information or after the analysis to evaluate the results.
- To model surfaces - GIS delineates watersheds and represents channel shapes based on digital terrain or elevation models.
- Development of interfaces - map based interfaces to hydrological models can be developed using GIS tools.

When hydrological modelling is done using GIS, the numerical algorithms are based on GIS data and therefore it requires more complex GIS analysis than simple geographic modelling using maps (Baxter, 2004). A critical component of GIS is its ability to produce graphics on screen or on paper to convey the results of analysis to people who make decisions about resources. Wall maps, internet ready maps, interactive maps and other graphics can be generated allowing the decision-makers to visualise and thereby understand the results of analysis or simulations of potential events. Striking as the graphics may seem on screen, their potential to guide good decisions depends more on the proper collection and analysis of data and information that is used to generate the graphics. The desire to generate attractive graphs could undermine the more important task of analysis that requires much skill from the modeller. Collection of data for GIS is costly, as it often requires much specialised computer equipment and technical expertise. Preparation of GIS materials such as maps and presentations is also very time consuming and requires highly skilled persons. Like remote sensing, GIS can be used together with other decision or modelling techniques.

5.7.4 Bayesian Networks

Bayesian Networks (BN) also known as Bayes' Nets, Causal Probability Networks, Bayesian Belief Networks or simply Belief Networks are a type of decision support system based on probability theory using Bayes' theorem. This describes mathematically how existing beliefs can be modified with the input of new evidence or data. Bayes' theorem is a consistent way to modify our beliefs about variables given the data that has already occurred (Bolstad, 2004). This means that the inference is based on the actual data, not on possible data sets that might have occurred, but did not. Decision support models based on Bayes' theorem use it to update belief values in a casual network. Bayes' theorem can be stated as in equation 5.1 below (Said, 2006):

$$P(A_j|B) = \frac{P(A_j)\,P(B|A_j)}{\sum_{i=1}^{n} P(A_j)\,P(B|A_j)} \qquad \text{Equation 5.1}$$

This equation describes the essence of Bayesian networks when they are used to determine probabilities of events in a system. If A_j are the possible causes of event B and if A_j have prior probabilities of $P(A_j)$ then using equation 5.1 we can deduce the conditional probabilities $P(A_j|B)$ provided we know the probability $P(B|A_j)$ or vice versa. Because of the characteristic of updating belief with additional data, BNs are very useful as tools for decision support especially in situations of data scarcity.

Bayesian networks are graphical models of causal interactions among a set of variables, where the variables are represented as nodes of a graph and the interactions as directed links between the nodes (Kjaerulff and Madsen, 2006). They provide a framework for graphically representing the logical relationship between variables and for quantifying the strength of this relationship using conditional probabilities (Castelletti and Soncini-Sessa, 2007b). Using Bayesian networks, the cause-effect relationship between a set of variables can be shown graphically and quantitatively using conditional probability tables (CPT) that are behind each variable.

Bayesian networks have been developed to allow the impact of uncertainty about management systems to be accounted for in the decision-making process (Cain, 2001). Hydrology, which is the basis for water resources planning, is built largely on uncertainty related to the expectation of occurrence of events. Bayesian networks can therefore be a useful tool in guiding decision-making that involves prediction of hydrologic regimes. Bayesian networks allow users to estimate the chance that a management intervention will have a particular effect and then investigate the consequences of this uncertainty. They are particularly useful when observed data are inadequate but other sources of information are available. As more data about an environmental system becomes available our understanding of the system and how it will respond to future impacts will become better. This characteristic is very useful for water resources management in catchments where few hydrological data exist. Unlike other integrated modelling approaches, Bayesian networks use probabilistic instead of deterministic methods to describe the relationship among variables (Jakeman et al., 2005).

This means that the user of BNs does not have to know accurately the mechanisms causing certain events to occur so long as they can elicit probabilities of past occurrences of the events.

5.8 Decision Support Systems in the Nile Basin

The river Nile has a human history that dates back 5000 years. It is considered to be the life blood of Egypt the origin of civilisation and of major importance to all the ten countries that share it. As such a lot of work has been carried out to study and model the Nile for various reasons. This section outlines the key efforts that have been made to study or model the Nile River generally and the Victoria Nile in particular.

5.8.1 Decision Support System for the Equatorial Lakes

The decision support system for the equatorial Lakes was developed in 1995 by Aris Peter Georgakakos and Huaming Yao of the Georgia Institute of Technology. It was primarily developed for the Ministry of Public Works and Water Resources of Egypt, the Food and Agricultural Organisation (FAO) of the United Nations and The United States Agency for International Development (USAID) (Georgakakos and Huaming, 1995). The system addresses problems such as the possibility of fully regulating the equatorial lakes system using advanced reservoir management methods; the likely impact of the Jonglei canal; the reliable energy output of the Owen Falls hydroelectric facility; the benefit of inflow forecasting and the tradeoffs that may exist between energy generation, drought occurrence and Sudd loss. Regression analysis and neural networks were used to develop the models. A key assumption used in developing the lake control models was that each lake (Victoria, Kyoga and Albert) is fully controlled by an outlet structure which regulates releases. Of these lakes only Lake Victoria has an outflow control structure.

This system gives a general view of how the lake system could operate under different scenarios if regulation is effectively carried out, however, at a sub-catchment level it is difficult to assess how this would impact on possible developments.

5.8.2 Lake Victoria Decision Support System (LVDSS)

The LVDSS was a collaborative effort of the Food and Agricultural Organization (FAO), Lake Victoria water Resources Project and the Georgia Institute of Technology. It is described as a user friendly modelling system which integrates: a water resources modelling network, a database system, a water availability component, a water demand component and an integrated water management component. Like most other decision support systems developed for trans-boundary waters it emphasises a “shared vision” approach, mutually agreed upon management strategies and ability to be appreciated and used by all riparian states. The system consists of a decision model based on the Georgia Tech state-of-the-art reservoir control and water management scenario analysis in the Lake Victoria region.

5.8.3 Nile Basin Decision Support Tool (DST)

The Nile Basin DST was developed in 2003 by the Georgia Water Resources Institute in the United States of America. This prototype software models the entire Nile Basin system that covers 3,112,369 km^2. The tool was released by the Nile Council of Ministers in February 2003. It represented the first time that all the basin states were able to use a common water resources assessment tool. The system assesses the tradeoffs and consequences of various cross-sector and basin-wide development scenarios and allows the impacts of various levels of regional coordination to be examined, and serves as a cornerstone for information integration. This system incorporates models for river simulation and reservoir operation, agricultural planning, and watershed hydrology. It also includes a comprehensive data-querying and visualization tool.

5.8.4 Nile Basin Decision Support System (NB-DSS)

The NB-DSS is a component of the Water Resources Planning and Management Project of the Nile Basin Initiative (NBI). At the time of writing this thesis the plan to have the NB-DSS had reached the tendering stage, where a request for expressions of interest was published on the project website with submission deadline set for February 2008. The planned NB-DSS is envisaged to be an all-inclusive decision support system to be used for the entire Nile Basin. The primary objective of the NB-DSS is to provide a shared knowledge base, analytical capacity and support for stakeholder interaction for cooperative planning and management decision making for the Nile River basin. As such it is expected to provide a common, basin-wide platform for communication, information management and analysis of the Nile water resources. The essential components of the system are:

(i) the Nile Basin Knowledge Base with a basin-wide communication system and Information Management System (IMS) to support national and basin-wide decision-making processes,

(ii) a regional river basin planning model to assist in the evaluation of alternative regional and national development scenarios and the identification of joint investment projects at the sub-regional and regional level,

(iii) a suite of analytic tools to support multi-objective analysis of investment alternatives and

(iv) the development of core national capabilities.

If well implemented the NB-DSS is seen as a cornerstone to the management of the water resources of the Nile basin. The nature in which it is packaged emphasizes common understanding, shared knowledge, regional planning, basin-wide decision-making all of which are subjective to the acceptance of the riparian states. Cooperation is therefore a key requirement to the success, acceptance and use of the tool. The key challenge of the NB-DSS is therefore for it to be developed in such a way as to satisfy the individual needs of all the riparian states and sub-catchment interests. Satisfaction of all riparian states is not easy given that they have different interests and differences in terms of resources, skills and priorities.

5.9 Challenges of Decision Models for the Nile

The above models are all deterministic in nature and were developed with clear objectives. At the basin scale they may be able to achieve their objectives, however, at the local level it is debatable whether they answer questions that are central for local stakeholders. The fact that the bulk of river Nile flows are from two regions (the Ethiopian highlands and the Equatorial Lakes Plateau) with very different climatic characteristics complicates climate change modelling studies on the basin as a whole. The Ethiopian highlands, with localized convective storms and annual variations, lead to variability in the Nile flows, while the equatorial lakes plateau have variable flows, which are heavily damped by the large storage in lakes and swamps. These differences in climate, large spatial variations, large losses and storage effects mean that it is difficult to calibrate river flow models even before considering impacts of climate change (Sene et al., 2001).

An interesting observation is that three of the Nile decision tools were developed by one institution as the key developer, The Georgia Institute of Technology. Egypt has played a central role and initiative in the development of these models. The challenge to these models is the acceptability and usability by the stakeholders. Given the large spatial coverage that includes ten nations with different conditions, acceptability is a big challenge. It is not therefore surprising that cooperation among the riparian states is a key prerequisite in the use of these models. Johanna and Lotta (2007) stress that for most local stakeholders, fairness and justice is an important factor to consider about acceptance of model results. If the suggested actions based on model-generated information are seen as unfair, they are unlikely to be accepted. In addition, acceptance of model-derived results also depends on stakeholders' trust in the institutions that develop the models and the authorities that apply them. Earlier experiences of the involved authorities or riparian states will influence acceptance of the model. For the river Nile, the colonial legislation on the management and sharing of the river leave a significant level of mistrust. Most riparian states perceive the prevailing legislation (Nile waters agreement, 1929) to favour Sudan and Egypt. Earlier negative experiences may block endeavours to create a model-based dialogue that truly aims to respect and consider all involved stakeholder opinions in the local implementation of water resource management (Johanna Alkan Olsson and Lotta Andersson, 2007). Decision makers prefer models that are easily adaptable to their circumstances, but do not favour rapid changes to models when they start using them. One of the over-riding concerns raised by policy makers using models was the changing nature of some models (Marcela Brugnach et al., 2007). In the Nile basin, several projects have introduced models which have been changed by the onset of new projects or funders. While projects and their donors change, the stakeholders and decision makers do not. Rapid changes of models could cause a fatigue that may increase stakeholder resistance against them.

5.10 Decision Support Using Bayesian Networks (BNs)

In recent years, the emphasis in management of water resource systems has been on complete development of the water system to meet all possible aspects or objectives instead of development through a single goal (Mohan and Raipure, 1992). This paradigm shift arose because different specialists realized that there are aspects that are interrelated and therefore planning one aspect in isolation would not lead to sustainable development. For instance, planning for domestic water supply alone without recognizing its effect on water for agriculture is not enough. Water releases for hydropower generation may have a negative impact on upstream lake levels, which in turn may have adverse impacts on navigation upstream of the hydropower plant. Modelling all these interrelated aspects of a system would be the better way to proceed if sustainable development is to be achieved. Unfortunately models that capture all the variables in a water resources system are complex and difficult to build and where they are built they create inaccuracies in the results. A compromise has therefore to be reached on which variables to include in the model and the accuracy expected from the results of the model.

If models are to become part of decision making, a new conception of modelling is needed that embraces uncertainties as an integral and sometimes irreducible part of the modelling activity (Marcela Brugnach et al., 2007). Probabilistic modelling is one way of incorporating uncertainty in the modelling process. As such Bayesian networks have gained popularity in water and environmental modelling because of their ability to deal with uncertainty. They are an increasingly popular method of modelling uncertain and complex domains such as ecosystems and environmental management

(Uusitalo, 2007). Uncertainty is a central theme in integrated and adaptive water management, where different disciplines need to be brought together to find a solution that is adequate from multiple perspectives (Henriksen and Barlebo, 2008). As such tools used for water resources management should recognize this central role and include uncertainty as an essential factor. Bayesian Networks attracted a great deal of attention as a framework for building normative systems during the 1990s (Jensen, 2001). They are based on a coupling of an interactive graph which shows the cause-effect scenarios in a system to a probabilistic model. Because of this probabilistic component they can easily deal with uncertainty, which as mentioned earlier, is a key consideration in water resources and the environment. They were first developed by the artificial intelligence (AI) and machine learning community and successfully applied in the fields of medical diagnosis and system maintenance and reliability (Castelletti and Soncini-Sessa, 2007a). Their wide application in water resources and environmental management is attributed to the following characteristics:

1. They have a potential to improve participation which is a key requirement for sustainable management in water resources,
2. Once the cause-effect relationship is graphically represented they are simple to use,
3. There are possibilities to integrate Bayesian Networks with other models. This characteristic is particularly important in Water resources management since in a water catchment several variables interlink, each of which can be better described by a different modelling approach thereby making possibilities of integration quite advantageous,
4. They are easy to apply because of the many available ready-to-use software which can be used to design BN models,
5. They offer flexibility because of the ease with which the model can be updated when new information is acquired.

Bayesian Networks can be used for two main purposes: modelling in which case they are used to describe the system, and as a decision-support tool in which case decision and utility variables are incorporated in the network to guide rational decision making. As a modelling technique, Bayesian Networks are very useful when there is no theory that the modeller can draw support from when he is quantitatively formulating the model, but when there are statistical observations of the modelled phenomena. These observations can be obtained from measured data or from domain experts or stakeholders. This characteristic is particularly useful because it enhances ownership of the model and therefore makes application of the model sustainable. In addition Bayesian Network techniques are very useful where there is little or no established knowledge explaining the internal operating mechanisms in the system being modelled such that it is difficult to quantitatively model the system mechanistically.

A checklist developed by Kjaerulff and Madsen, (2006) for the suitability of Bayesian Networks as a preferred option for decision making is a quick guide to use in determining whether BNs are appropriate for use in a given situation (table 5.2).

Table 5.2 Kjaerulff and Madsen, (2006) checklist for the suitability of Bayesian Networks

(i)	The variables and events (possible values of the variables) of the problem domain need to be well-defined.
(ii)	The problem domain should be highly structured and should have easily identifiable cause-effect relations.
(iii)	There should be a level of uncertainty associated with the cause-effect relations.
(iv)	The problem to be solved should be of a repetitive nature. This is due to the large effort normally invested in building the networks.
(v)	The problem at hand should contain an element of decision making involving a desire to maximise the expected utility of a decision.

The Victoria Nile basin study context fits well into the above checklist, but the aims of this research are broader than maximising the expected utility. The participation of stakeholders in developing the Bayesian Network for the Victoria Nile was limited to experts from NEMA, Norplan group and the

Ministry of Water and Environment because of constraints of funds and time which made it difficult to consult the local population.

In Water resources management and the Environmental sciences there is a high level of uncertainty of the states of variables and their causes. In this regard Bayesian networks are useful in many real life situations concerning water resources management as can be seen from the examples in the section that follows.

5.10.1 Application of Bayesian Networks

Application of Bayesian Networks was tested in a European Union (EU) research project-MERIT in 2001-2004 (Bromley, 2005). The MERIT research project aimed at developing a methodology for integrated water resource management that could be applied throughout Europe. In this project BNs were applied to various decision areas, namely:

- management of domestic water demand in the UK,
- investigation of the potential of compensation payments to encourage farmers to reduce the use of pesticides and potential of flooding problem resulting from the creation of new wetlands in Denmark,
- investigation of increasing water requirements for irrigation in the face of competing demand for hydropower and assessing environmental flows needed to satisfy different stakeholder groups in Italy, and
- Assessing intensive competition for water between domestic, environment and agriculture sector requirements in Spain.

The results of the project were positive and hence give a sound reason as to the use of BNs for resource management in similar situations.

Based on ex-post review by the New Approaches for Adaptive Water Management under Uncertainty (NEWATER) research project on a Danish case study done on the use of BNs, it was concluded that BNs are able to simplify and deal with complex qualitative and quantitative issues of a ground water system exposed to contamination risks (Henriksen and Barlebo, 2008). The reflections on the use of BNs in this case study emphasise their ability to allow integration of different domains and knowledge bases like expert knowledge, modelling results and monitoring data from hydrology, economy, ecology and social domains.

BNs have been successfully applied in climate change impact assessments. Varis and Kuikka, (1999) report the outcomes of a final evaluation of a case of assessment for the climate change impacts on the watersheds of southern Finland. A range of results were produced in this case, including analysis of both the roles of different causalities in the models as well as those of the states of the climatic, watershed and socioeconomic variables. The assessment showed that it was very useful that using BNs both the states and the causality uncertainties could be analyzed at the same time.

A Bayesian Network was used to evaluate the Total Maximum Daily Loads (TMDLs), water quality development plans and conservation schemes in the Big Lost River watershed of Idaho, USA from the socio-economic and environmental point of view (Said, 2006). The Big Lost River is one of the largest tributary basins to the Snake River in south-central Idaho and covers a watershed of over 3,750 km^2 with an irrigation potential of 40,470 ha. The HUGIN Expert shell was run to get the results of the different situations in this analysis. A Bayesian Network comprising eleven chance nodes, three decision nodes and four utility nodes was constructed for this project. Using this network it was possible to answer three pertinent decision problems for the watershed: would the proposed conservation schemes affect the river flow considering the current conditions as the base case, how would the TMDLs affect the water quality and the river flow and how would the riparian vegetation restoration affect the water quality of the Big Lost River?

In ecological modelling, BNs have gained popularity too. Borsuk et al., (2004) developed a BN representing eutrophication in the Neuse river estuary in North Carolina. Using the network it was possible to generate probabilistic predictions of ecosystem response to management strategies. Because BNs utilise probabilistic rather than deterministic expressions to describe relationships among variables, they are essentially useful as an ecosystem model used to guide decision making (Borsuk et al., 2004).

Bayesian Networks as a modelling and decision support tool as documented above are adequate and their popularity is growing in water resources management. For the river Nile basin their use has not been tried before. This research presents an opportunity to explore the use of BNs as a worthy approach that can be used as a stand alone or together with other models, probably even as an addition to those already developed. Since the concept of catchment based planning is increasingly being advocated this approach could further be used to model other catchments in developing countries. The EU MERIT project and others documented above show that Bayesian Networks could be applied for decision making for water and environmental resources. This research demonstrates how Bayesian networks were used to support decision making in the Victoria Nile basin. Considering the problems and the decisions expected to be made on developments in the Victoria Nile basin and other water catchment-based developments, use of Bayesian networks appears to be a suitable option. Additionally, since Bayesian Networks as a modelling approach have not been tried before in the study area, their use presents an opportunity to explore their further application in other water catchments where data is limited.

5.11 The Victoria Nile Bayesian Network

A Bayesian network can be developed using various computer programmes such as Netica developed by NORSYS Software Corp. or HUGIN expert®. In this research the HUGIN expert® software version 6.9 was used to develop the network. Using the HUGIN Expert® software researcher version 6.9 a Bayesian Network model for the Victoria Nile basin was built comprising twenty one variables (nodes) shown in Figure 5.1. This is the final model developed after a progressive model development exercise that had a total of twelve intermediate versions before this final version was made.

The process of developing the network involved the following stages:

a. ***Identification of the system boundaries***: Using a map of Uganda the area that lies within the Victoria Nile basin was delineated using GIS in order to establish the essential features.

b. ***Identification of key variables:*** With the help of geographical maps and situational reports, the key variables in the system that impact on water resources of the Victoria Nile were identified. Initially all relevant variables that came up were listed by brainstorming. These included some such as livestock and fisheries that were later eliminated from the network.

c. ***Collection and analysis of data for each of the identified variables:*** Data on quantities and occurrence of variables was collect from the field and from literature. This data was analysed using statistical analyses to determine frequency distributions.

d. ***Elimination of variables:*** In order to keep the network simple and within scope of the research objectives, some variables that were considered not suitable for further analysis were eliminated. These variables included those that lacked data and those that would make the network very broad in scope for instance fisheries, livestock, industry, water quality and ground water.

e. ***Establishment of the different variable states:*** For each variable, the different states that they can be in were selected. The selection of the states was based on the principle that each variable should have few states yet descriptive enough not to miss out any relevant state.

f. ***Determination of the probabilities of the different variable states:*** Probabilities of occurrence of the different states were obtained from frequency distributions whenever data was available. In some cases where data was not available probabilities were elicited by personal reasoning and experience. The method used for estimating probabilities for each variable is explained in the relevant sections in chapter 6.

g. ***Studying the cause-effect relation between variables:*** Once the variables were defined, the relationship between them was studies in order to determine how variables cause or affect one another. It is these cause-effect relationships that were used to construct the network.

h. ***Construction of the network:*** Using the HUGIN software, the network was constructed as nodes and links. All nodes were chance nodes and their names were the variables they represent.

i. ***Checking consistency and validation:*** After completion of each attempted network, the programme was run to see results. By changing states of variables and seeing the results of running the program it was possible to check consistency of the network. The validity of results from the network was done by inputting known states and confirming the result.

j. ***Reviewing results of the network and reconstruction:*** Following the stages above, several changes were made and in total 12 intermediate networks were developed. Each of which was revised subsequently to ensure that the key variables are captured, their states well defined and the cause-effect relationships are correct. The first network had so many variables some of which were not showing significant changes in the water resources and yet it was so large. Following on this, changes were made using criteria of data availability, scope and simplicity.

Stakeholders were not involved in the network development because of limited funds to organise stakeholder meetings and time constraint. The final network was however discussed with officials from the ministry of Water Resources and NEMA.

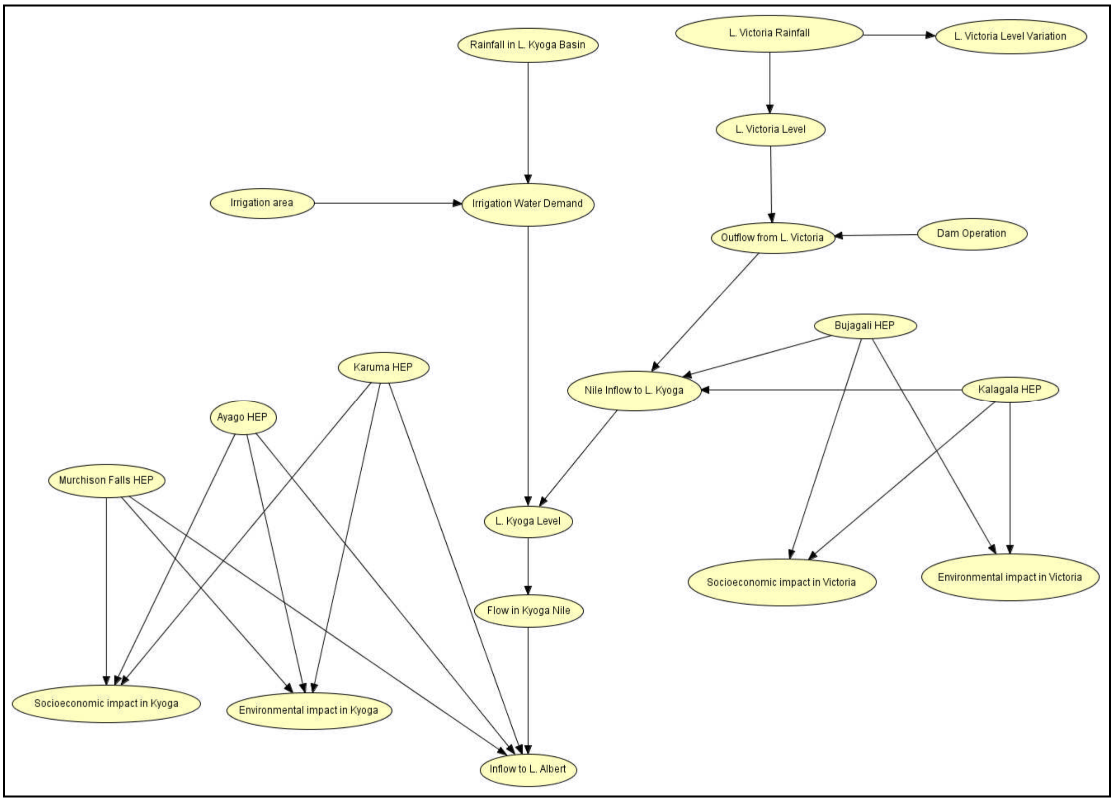


Figure 5.1 Bayesian network for the Victoria Nile Basin

The 21 variables (nodes) that make up the Bayesian network for decision making on the Victoria Nile basin shown in figure 5.1 are described in chapter 6.

Chapter 6 Bayesian Network Development

6.1 Introduction

Bayesian theory upon which BNs are built is an approach to statistics which applies the laws of probability directly to the problem at hand. This approach is based on the following ideas (Bolstad, 2004):

- Since there is uncertainty about the true value of the parameters they are considered as random variables,
- The rules of probability are used directly to make inferences about parameters,
- Probability statements about parameters must be interpreted as "degrees of belief". The prior probability distribution must be subjective. Each person can have his/her own prior, which measures how "plausible" the person considers each parameter value to be before observing the data.

The beliefs about parameters are revised after receiving new evidence by using Bayes' theorem. This provides the posterior distribution which gives the relative weights given to each parameter value after analysing the data. The posterior distribution comes from two sources; the prior probability distribution and the observed data.

A Bayesian Network consists of the following (Jensen, 2001):

- a set of variables and a set of directed links between variables,
- each variable has a finite set of mutually exclusive states,
- the variables together with the directed links form a Directed Acyclic Graph (DAG),
- to each variable B with parents (direct causes) $A_1, \ldots, A_n$ there is attached the conditional probability table $P(B|A_1, \ldots, A_n)$ giving the probability of B given that $A_1, \ldots, A_n$ has occurred.

Figure 6.1 illustrates the above notion for variable B with parents A_1 and A_2. The probabilities to specify are marginal or prior probabilities $P(A_1)$, $P(A_2)$, and conditional probability $P(B|A_1,A_2)$. Each of the variables above has a finite set of mutually exclusive states depending on what the variable is. The probabilities $P(A_1)$, $P(A_2)$ and $P(B|A_1,A_2)$ are the probabilities that the variables will be in a given state.

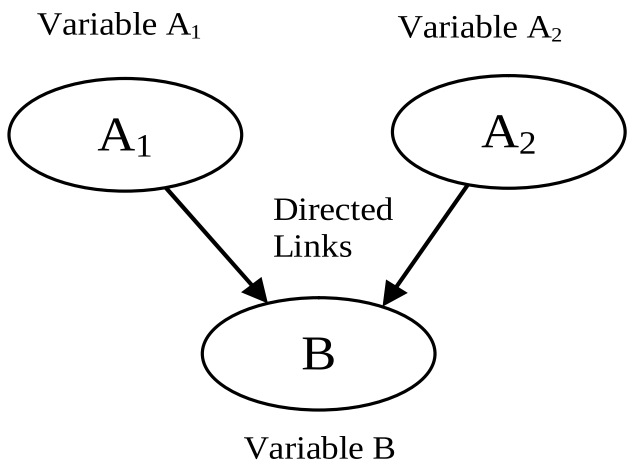


Figure 6.1 Representation of a Bayesian Network for parents A_1 and A_2 and child B

The variables (nodes) represent the factors relevant to a particular system or problem, the links between these variables represent the causality between them and the conditional probability tables (CPTs) behind each node are used to calculate the state of the node. When these networks are used in modelling and decision analysis the probabilities of occurrence of prior events are used for predicting outcomes or states of the variables.

The next section describes the model/network development and elaborates the key variables that influence developments and decisions made in the basin. The section presents the final network constructed and describes each of the variables in detail showing how the variable states are defined and how the probability tables for each variable were obtained.

6.2 System Description

In order to sufficiently understand the variables that influence decision making in a system it is important to define the system boundaries. The key variables in the study area were selected after defining the system boundaries. The study area is described in detail in chapter 2. It comprises Lake Kyoga and the Victoria Nile river sub basins extending from the point at which the Nile exits Lake Victoria to its entry into Lake Albert. Figure 6.2 shows a satellite image of the study area. A digital map of the study area boundary was presented in chapter 2, figure 2.3.

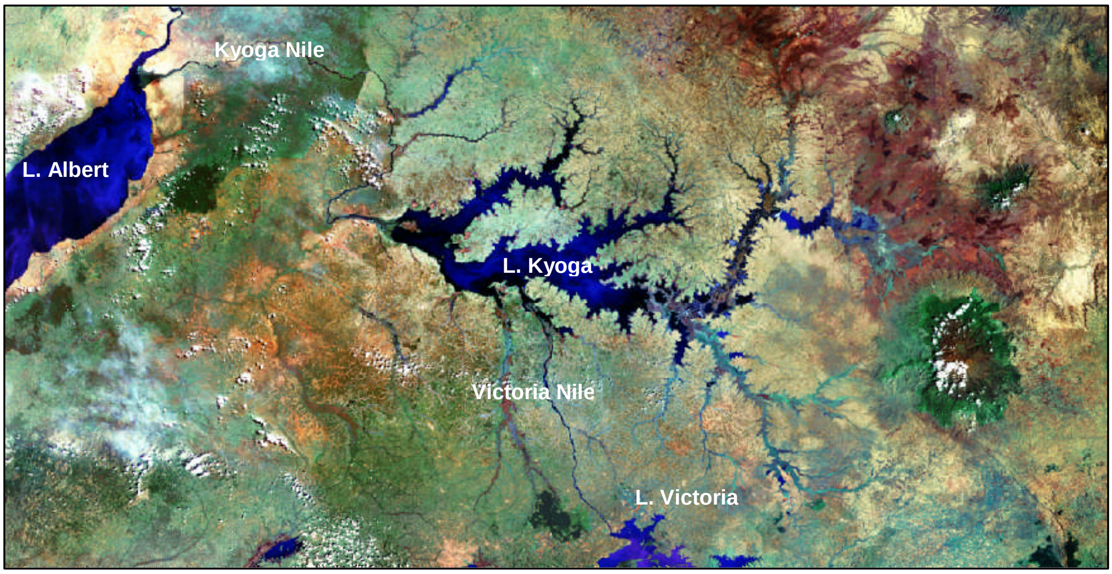


Figure 6.2 Satellite image of the study area

Source: ESRI, 2005 Geographical Network services Satellite images

Lake Victoria rainfall and rainfall in Lake Kyoga basin are external inputs to the system. The only physical output from the system considered by the model is the lower Victoria Nile river (Kyoga Nile) flow. Outputs arising from the interactions between input variables and internal variables are socio-economic and environmental impacts and they are representative of the impacts of decisions made to the use of resources in the system under various states of inputs.

6.3 The Bayesian Network Variables

This section describes the different variables that make up the nodes of the Bayesian network for the Victoria Nile (figure 5.1). The description below is confined to the cause-effect relations, the importance that each of the variables has on decision making and the derivation of the marginal and conditional probabilities of each of the variables. The detailed description of water resources occurrence and variations is dealt with in chapter 3.

6.3.1 Lake Victoria Rainfall

Lake Victoria and its basin is not part of the study system; however its influence on the system is essential because of the contribution of Lake Victoria rainfall to the Victoria Nile flow. The Victoria Nile flow, which is the only outflow from Lake Victoria, is determined by the lake levels which in turn are dependent on the rainfall over the lake and the tributary flows to the lake. These relationships are shown in the cause-effect relation diagram (figure 6.3). In order to establish the level of dependence from which inference can be made on the expected flows of the Victoria Nile, historical data for Lake Victoria rainfall was used to determine the probability of rainfall occurrence. A detailed description of Lake Victoria rainfall and its effect on the hydrology of the Victoria Nile basin was presented in Chapter 3. The analysis in this section explains the strength of the dependence of Victoria Nile flows on rainfall over Lake Victoria. This strength is quantified as the probability that a certain level of rainfall will occur.

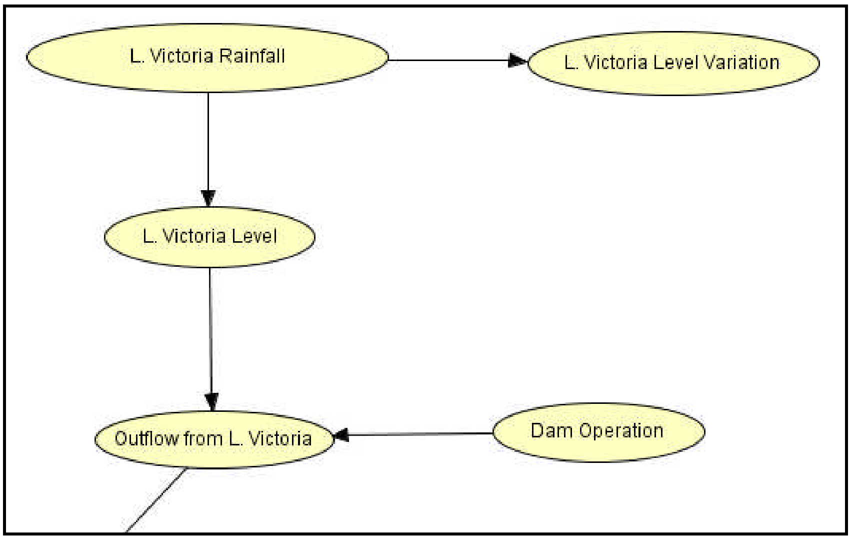


Figure 6.3 Causal relationships between rainfall on Lake Victoria and outflow

Data from the ARTES World Bank database was used to determine the probability that a specified magnitude of rainfall occurs in and around lake Victoria. This data shows that for the period of 54 years record (1948-2001), mean annual rainfall was 1,292 mm with rainfall magnitudes ranging from 1,016 mm to 1,708 mm. Three categories or classes of rainfall years can be distinguished depending on the annual rainfall; wet (high rainfall) years, moderate (average rainfall) years and dry (low rainfall) years. Therefore depending on how much annual rainfall is received, a year can take any of the three states: dry, moderate and wet. This will have a direct impact on the lake level and subsequently the Victoria Nile flow as seen in the causal relationship above (figure 6.3).

Definitions

The definitions of the different classes of rainfall occurrence were arrived at based on the probability distribution of the available rainfall data. The ARTES rainfall data used had a mean of 1,292 mm and a standard deviation of 141.2 and showed a normal distribution. The three classes/states of rainfall for Lake Victoria chosen were defined as follows:

- ***A dry year*** was defined as a year in which the average annual rainfall is less than 1,186 mm.
- ***A moderate rain year*** is one in which the average annual rainfall lies between 1,186 and 1,398 mm. This class was chosen so as to lie within $\pm 0.75\sigma$ (σ is the standard deviation).
- **A wet year** is one in which the average annual rainfall is greater than 1,398 mm.

The moderate rain year class lies within the mean annual rainfall range for Lake Victoria basin estimated in earlier studies to be 1200-1600 mm (Yin and Nicholson, 1998), which confirms the assigned rainfall classes for the basin to be realistic.

Table 6.1 Probability distribution for occurrence of lake Victoria rainfall

Class/State	Definition/ Rainfall range (mm)	Probability of occurrence (%)
Dry Year	< 1,186	28
Moderate Year	1,186-1,398	55
Wet Year	> 1,398	17

Probabilities in table 6.1 were derived from a frequency distribution analysis of mean annual rainfall for Lake Victoria basin for records for the period 1948-2001(Appendix 1).

6.3.2 Lake Victoria Level

Historical events show that the Lake Victoria level is dependent on rainfall over the lake and its catchment. All high rainfall years (1961, 1963, 1972, and 1998) have resulted in high lake levels while low rainfall years (1918, 2005, and 2006) have resulted in low lake levels. Because of this tendency Lake Victoria rainfall is constructed in the model as the cause of Lake Victoria level (figure 6.3). A plot of the end of year lake level against mean annual rainfall does not however, show a strong correlation between the two variables (figure 6.4). The figure shows a scatter graph of lake level and rainfall for records for the period 1948-2001. For this relationship r^2 is only 0.225 which shows that the dependence of end of year lake level on annual rainfall is small. Other data obtained in the literature show similarly low correlations (r^2 for data obtained from Yin and Nicholson (1998), Tate et al (2004), and Jinja data are 0.281, 0.228, and 0.1763 respectively). These data are all for average rainfall over the lake and surroundings except Jinja which is for a single rain gauge at the shore of the lake. The low correlations suggest that there are other factors that cause changes in lake levels for instance evaporation over the lake and lake outflows. Outflows from the lake always tend to return the lake to its original level so for an interval of a year, this masks the effect of the rainfall. Since Bayesian networks are acyclic this cyclic dependence of lake level and outflow could not be captured. This inability of Bayesian networks to model cyclic relationships weakens the model but this construction gives the best relationship between rainfall, lake level and lake outflow.

The Lake Victoria level is a very important variable for management of the Victoria Nile river because it controls the outflows at the exit of the lake. Therefore even though the correlation for rainfall and lake level is small, it is considered an important variable that determines what happens downstream of the river.

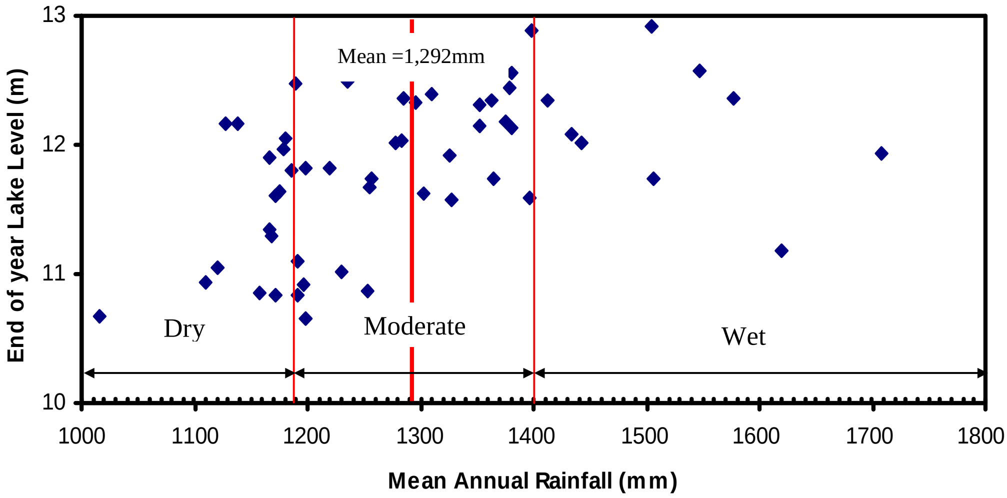


Figure 6.4 Lake Victoria end of year level and rainfall

Data Source: Rainfall, from ARTES World Bank (2003)
Lake Levels: Institute of Hydrology (1993) as supplemented by Kennedy and Donkin Power Ltd. (1997). Level data from 1996-2005 sourced from Directorate of Water Development, Ministry of Water &Environment, Uganda

Using the same set of data the probability distribution for lake levels given rainfall were determined by a frequency distribution and are given in table 6.2. In table 6.2 for each of the rainfall states the column titled No. shows the number of years in which the lake level was within the specified range. This number divided by the total number of years with the specified rainfall state gives the probability that the lake level will be in that range. These are the probabilities entered in the conditional probability table for the Lake Victoria level.

Table 6.2 Probability distribution for lake Victoria end of year level at different rainfall regimes

Lake Level (m)	Rainfall State					
	Dry		Moderate		Wet	
	No.	Prob.	No.	Prob.	No.	Prob.
< 10.8	1	0.07	1	0.03	0	0.00
10.8 - 11.2	4	0.27	5	0.17	1	0.11
11.2 - 11.6	3	0.20	2	0.07	0	0.00
11.6 - 12.0	4	0.27	7	0.23	2	0.22
> 12.0	3	0.19	15	0.50	6	0.67

6.3.3 Lake Victoria Level Variation

Changes in lake level are important in navigation, human settlements around the lakes and water supply abstractions. In the case of water supply abstraction the degree of level change will have an impact on how far into the lake the intake works can be installed; for navigation it determines how accessible the ports are throughout the year. For this reason, lake level variation has been included in the network as a node but with no “child” or direct effect. This node describes the annual change of Lake Victoria level given as the difference between beginning and end of year lake level. Lake level change is dependent on rainfall over the lake; this relationship is stronger with an r^2 of 0.626, compared to 0.225 for lake level. No further analysis is made on lake level variation to establish how the lake level variation impacts on other variables because it is not within the scope of this study. Its inclusion here is mainly to show how rainfall can cause level variations. The degree of lake level change for each of the rainfall states can be seen from Table 6.3 which shows the probability of different annual lake level changes given a range of Lake Victoria annual rainfall conditions. These probabilities were obtained from a frequency distribution using a similar approach as described in section 6.3.2 and were entered in the probability tables in the network.

Table 6.3 Probability distribution for Lake Victoria level variation given Dry, Moderate and wet years

	Dry Year	Mod. Year	Wet Year
Class intervals for lake level change		Probability (%)	
dL < -0.4m	33	3	0
-0.4 < dL < 0.0 m	60	47	0
0.0 < dL < 0.4m	7	43	55
dL > 0.4m	0	7	45

*dL is annual change in lake level

The table shows that annual lake level change is predominantly within ± 0.4 m for moderate years. For dry years there is a 33% probability that the level will reduce below -0.4 m while for wet years the probability that the level will increase by more than 0.4 m is 45%.

6.3.4 Dam Operation

The Lake Victoria level influences the outflow from the lake at Jinja. In addition to the lake level, the dam operation mode also has a direct influence on the outflow. This is because the dam operator has to strike a compromise between downstream and upstream demands, which sometimes conflict. The operational mode for releasing outflows at the Jinja outflow can be either of two modes:

- Adhering to the so-called “Agreed curve”
- Regulation by other flexible means or the “regulated mode”.

Dam operation involves a decision by the operator on how to operate the dam, in terms of how much water to release through the dam during different periods. The decision taken will influence the expected outflow from the lake. The variable “Dam Operation” in the network therefore has two states: agreed curve mode and regulated mode. From records available, the agreed curve mode has been followed most of the time but there are times when this has not been the case (Mangeni, 2006; Kull, 2006). It will be assumed that the choice on which mode to adopt is a Boolean decision which means there are two states: Yes and No. Therefore probabilities for either state can be either 0 or 1. This means if either of the states is selected; the probability is one while for the other it is zero.

6.3.5 Lake Victoria Outflows

The outflow from Lake Victoria exit at Jinja depends on two variables: the lake level and the dam operational mode selected by the operator. This dependence is shown in the relationship model (figure 6.3). Conditional probabilities of having lake outflows given specified lake levels and dam operational mode were obtained as detailed below.

Agreed Curve

The agreed curve model as a control for Lake Victoria outflows was discussed in chapter 4. It was developed as the operating rule for the Owen Falls dam to dictate how much water should be released from Lake Victoria based on the water level of the lake. The purpose of the operating rule was to have the dam operated in such a way as to retain the original natural pre-dam relationship between Lake Victoria level and outflow. Application of this operating rule meant that dam operators adjust the outflow at the dam based on the water level of the lake upstream of the dam. In this way, lake inputs (direct rainfall and tributary flows), outputs (evaporation and "natural" outflow) and lake level are related as they would have been in the natural state without the dams. The agreed curve model is an equation in the form (DWD, 2005):

$$Q = 132.9\left(H - 1131.386\right)^{1.68} \qquad \text{Equation 6.1}$$

Where: Q = Discharge at Jinja, m^3/s

H = Lake Victoria water level in metre above sea level (msl)

Since the reference point at the Jinja gauge is 1122.9 msl (Holli, 2008; Wardlaw et al., 2005) to convert readings on the Jinja gauge to msl, 1122.9 is added to the reading. Equation 6.1 therefore becomes

$$Q = 132.9\left(h - 8.486\right)^{1.68} \qquad \text{Equation 6.2}$$

Where: h = Reading on the Jinja gauge, m.

The above model yields the so-called agreed curve (figure 3.12) which is used to derive Lake Victoria outflows for every level of the lake. To determine the probability distribution for outflows for specified lake levels, the agreed curve above and the lake level intervals discussed before were used. Table 6.4 gives the probability distributions that were entered in the conditional probability tables (CPT) of the network.

Table 6.4 Probability Distribution for Lake Victoria outflows for specified Lake Levels - Agreed curve mode

	Lake Level (m)				
	< 10.8	10.8 - 11.2	11.2 - 11.6	11.6 - 12.0	>12.0
Agreed curve range (m^3/s):	416-544	544 - 711	711 - 896	896 - 1098	1098-1730
Outflow (m^3/s)	Probability (%)				
< 500	66	0	0	0	0
500 - 750	34	100	21	0	0
750 - 1000	0	0	79	51	0
1000 - 1250	0	0	0	49	24
> 1250	0	0	0	0	76

The outflow classes in table 6.4 were chosen based on the data available, in such a way that there are not too many classes and with a class interval of 250 m^3/s considered to be reasonable (minimum recorded outflow was 416 m^3/s and maximum was 1596 m^3/s). For the agreed curve mode each lake level corresponds to a definite discharge as seen from the graph (figure 3.12), this however is not practical for the dam operator as it is expected that the actual chosen discharge would lie within a margin. Secondly to study the flow regimes all the way along the river it is better for consistency to have similar classes for the flow. It is these outflow classes that have been used for all statistical analysis of flows along the river.

Probabilities in table 6.4 were obtained by determining what proportion of the flow as obtained from the agreed curve lies within a selected outflow class (column1). For instance from the agreed curve (equation 6.2 or figure 3.12), for a lake level of <10.8 m, the flow is between 416 m^3/s (lowest recorded) and 544 m^3/s (flow corresponding to a lake level of 10.8 m on the graph). For this range 66% (84/128) lies within the class <500 while 34% (44/128) lies in the class 500-750. This procedure is used to estimate the probabilities in the table.

Regulated Mode

The other option of controlling outflows at the exit of Lake Victoria is regulating outflows in a flexible way according to the demand for hydropower and other downstream demands and demands of upstream users, for example navigation and irrigation. This option is referred to as the regulated mode. This option becomes increasingly important as more developments are made along the Nile, and also since there are indications that the 1929 agreement for use of the Nile waters is likely to be revised to cater for the interests of all Nile riparian countries.

To determine the lake discharge the regulated mode would consider three factors: downstream demands, upstream demands and lake levels. This means that it is based on the principle of satisfying upstream demands in terms of maintaining a certain lake level range before releasing flows as per downstream demands. This operating mode does not completely ignore the agreed curve model but rather gives an option of considering upstream and downstream demands in cases where lake levels are very low or too high. The agreed curve principle has dominated all research on releases of water from Lake Victoria, so there is little available literature on other alternative release options. Whatever options may exist, it is likely that they will be based on the principle of satisfying upstream demands, in terms of maintaining a minimum or maximum lake level, before releasing water for downstream demands. This was the basis of determining the outflows under the regulated mode.

In order to capture the behaviour of lake outflows given the regulated mode, a key assumption was made that the agreed curve principle is followed so long as the annual lake level change does not reduce or increase by more than 0.4 m. This assumption is based on the fact that lake level change has been predominantly within this range (figure 6.6). It has been greater than 0.4 m only about 20% of the time during the recorded period (1899-2005). Complaints by lake users about changing levels have occurred only when the level change was great, notably in early 1960s when the level rose by up to 1 m and around 2005 when navigation on the lake and water supplies were affected by very low water levels, which reduced by over 1 m.

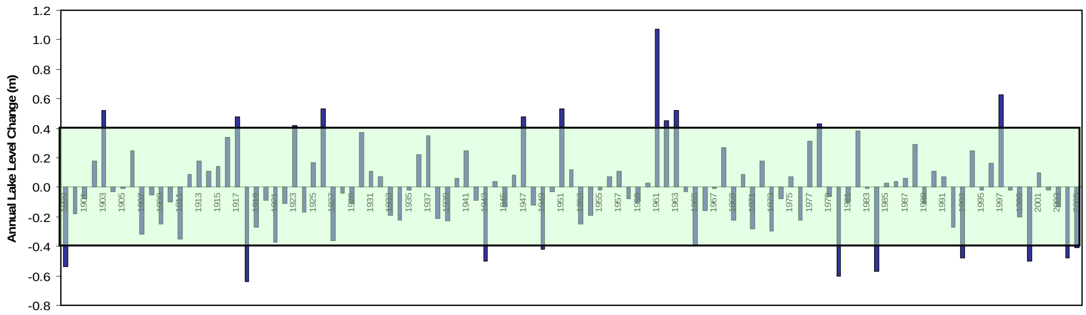


Figure 6.5 Annual Lake Victoria level changes (1899-2005)

Shaded area shows annual level change within +/- 0.4 metres

The conditional probabilities for outflows when the regulated mode is in operation are shown in table 6.5. These probabilities were obtained from a frequency distribution that shows the probability that the lake outflow will be in a specified range given a specified lake level and that the annual lake level change is greater than 0.4 m. The procedure of obtaining the conditional probabilities is illustrated in table 6.6.

Table 6.5 Probability distribution for Lake Outflow given specified lake levels-Regulated Mode

Outflow (m^3/s)	Lake Level (m)				
	< 10.8	10.8 - 11.2	11.2 - 11.6	11.6 - 12.0	> 12.0
	Probability of outflows given that │dL│* > 0.4 m (%)				
< 500	25	0	0	0	0
500 - 750	50	50	60	25	0
750 - 1000	13#	25	20	25	25
1000 - 1250	12#	13#	20	25	50
>1250	0	12#	0	25	25

*dL: Annual change in lake level

Because the probability for the outflow classes 750-1000 and 1000-1250 was 0 (no data was available) for the lake levels <10.8 and 10.8-11.2m respectively the probabilities of the next class were distributed to obtain the values in the table.

Table 6.6 Determination of conditional probabilities for the regulated mode

Level Class (m)	End Year Lake Level (m)	Annual Lake Level Change (m)	Annual lake Outflow (m^3/s)		<500	500-750	750-1000	1000-1250	>1250
< 10.8	10.68	-0.42	591			1			
	10.70	-0.41	1,177					1	
	10.75	-0.50	681			1			
	10.76	0.42	470		1				
				Total	1	2	0	1	0
	Conditional Prob. (%)				**25**	**50**	**0**	**25**	**0**
10.8 - 11.2									
	10.90	-0.54	734			1			
	11.11	-0.48	1,329						1
	11.18	-0.64	876				1		
	11.18	0.53	554			1			
				Total	0	2	1	0	1
	Conditional Prob. (%)				**0**	**50**	**25**	**0**	**25**
11.2 - 11.6									
	11.22	0.48	721			1			
	11.29	0.53	694			1			
	11.34	0.52	725			1			
	11.34	-0.48	1,009					1	
	11.60	-0.57	987				1		
				Total	0	3	1	1	0
	Conditional Prob. (%)				**0**	**60**	**20**	**20**	**0**
11.6 - 12.0									
	11.64	-0.50	1,119					1	
	11.82	0.48	964				1		
	11.90	-0.60	1,463						1
	11.94	1.07	652			1			
				Total	0	1	1	1	1
	Conditional Prob. (%)				**0**	**25**	**25**	**25**	**25**
> 12.0									
	12.36	0.63	923				1		
	12.39	0.45	1,227					1	
	12.56	0.43	1,249					1	
	12.91	0.52	1,304						1
				Total	0	0	1	2	1
	Conditional Prob. (%)				**0**	**0**	**25**	**50**	**25**

Column 1 shows the lake level classes,
Column 2 shows lake levels for years when the annual lake level change was < -0.4 m or > +0.4 m, this is when the regulated mode is applied,
Column 3 shows the annual lake level change corresponding to the lake levels in column 2,
Column 4 shows the corresponding lake outflow for lake levels in column 2,
Columns 1-4 are all filled from data (appendix 2)
Columns 6-10 show the probabilities of having outflows within the classes specified at the top of the columns when lake levels are within the range given in column 1.

To illustrate how probabilities were determined, the level class of <10.8m is used. For this lake level, annual lake level change greater than 0.4 m occurred 4 times in the available record; during these 4 times the outflows from the lake were; < 500 m^3/s in 1 out 4 (25%); between 500-750 m^3/s in 2 out of 4 (50%); between 750-1000 m^3/s in 0 out of 4 (0%); between 1000-1250 m^3/s in 1 out of 4 (25%) and >1250 m^3/s in 0 out 4 (0%). This procedure is used to determine all probabilities for other outflow classes.

6.3.6 Inflow to Lake Kyoga

The outflow from Jinja directly determines the Victoria Nile flow into Lake Kyoga. In order to determine the probability distribution for the Nile inflow to Lake Kyoga the outflow from Lake Victoria at Jinja was used (Appendix 2). This gives a data series of 110 years, 1896-2005. From the data available the probability distribution for flows in the river Nile between Jinja and Lake Kyoga is shown in table 6.7 below. These probabilities are determined by a frequency distribution of Lake Victoria outflows of the specified ranges shown in column 1, table 6.7. The frequency distribution shows what proportion (in percent) of the recorded outflow lie within the outflow class. This is given as the probability for the class.

Table 6.7 Probability distribution of Nile flows in the Upper Victoria Nile

Outflow	Occurrences	Probability (%)
< 500	5	5
500 - 750	45	40
750 - 1000	23	21
1000 - 1250	26	24
> 1250	11	10

Development of hydroelectric power facilities at Bujagali and Kalagala is expected to change the Victoria Nile flows. There is therefore a causal relationship between hydroelectric power developments along the upper Victoria Nile and river flow to Lake Kyoga in addition to Lake Victoria outflows (figure 6.6). Development of any combination of these power plants is likely to cause the inflow to Lake Kyoga to change. The variables Bujagali HEP and

Kalagala HEP have the Boolean states true or false. True means the facility is developed while false means it is not developed. The question is how the Victoria Nile flow will change as a result of development of any combination of the facilities. It is reasonable to assume that construction of a dam along the river course can reduce the annual flow, but cannot increase it. The level of reduction depends on the configuration of the dam(s). Secondly the level of reduction due to both dams will be higher than that due to any one of the dams. Given these basic assumptions, the flow pattern of the Nile inflow to Lake Kyoga will be the same as the outflow at the Jinja outlet when no hydroelectric power developments are made (table 6.7). This pattern will however change depending on what combinations of hydroelectric power plants are developed. The ultimate Nile flow to Lake Kyoga will therefore depend on the outflow at Jinja and on the combination of the hydroelectric power dams developed as seen from the causal diagram (figure 6.6). The other direct consequences of developing the hydroelectric power facilities are the socioeconomic and environmental impacts which will be covered later in this chapter. The probability distribution for flows before and after dam construction is shown in tables 6.8 a & b.

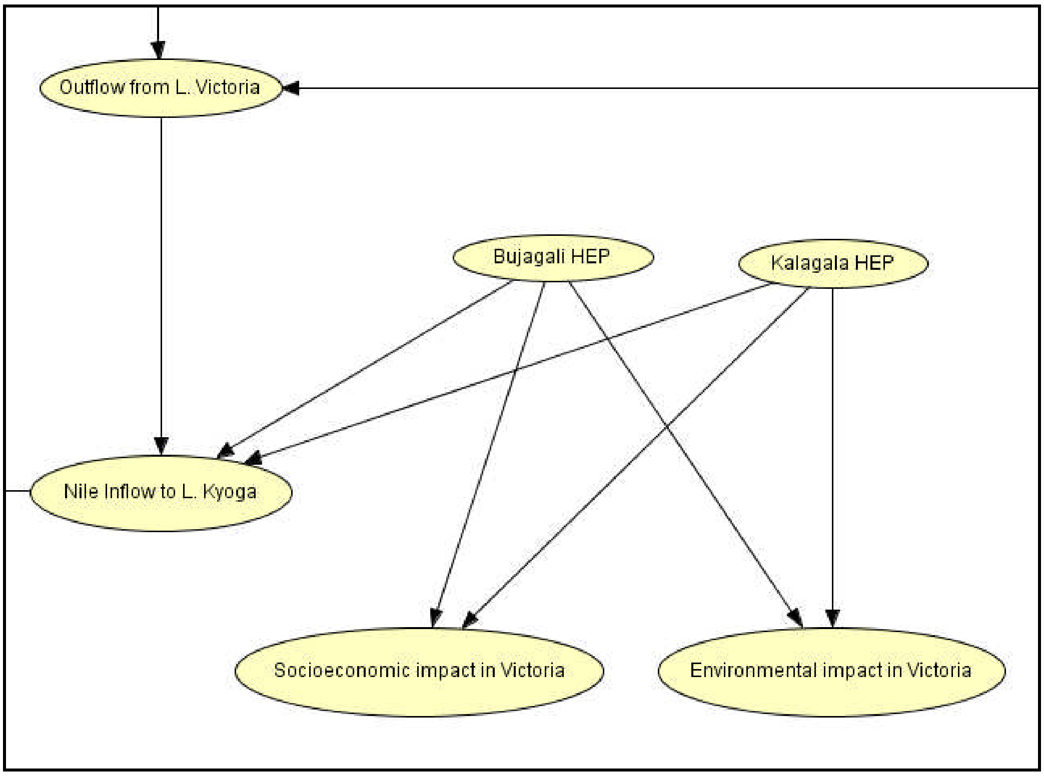


Figure 6.6 Causal relationship diagram for Nile inflow to lake Kyoga

Table 6.8 Probability distributions for Nile inflow to L. Kyoga with different hydroelectric power plants developed

Table 6.8 (a) Probability distribution for Nile inflow to L. Kyoga when only one hydroelectric power plant is developed

Jinja Outflow	< 500	500 - 750	750 - 1000	1000 - 1250	>1250
L. Kyoga Inflow					
< 500	100	10	5	3	0
500 - 750	0	90	10	7	5
750 - 1000	0	0	85	15	5
1000 - 1250	0	0	0	75	15
> 1250	0	0	0	0	75

Table 6.8 (b) Probability distribution for Nile inflow to L. Kyoga when both hydroelectric power plants are developed

Jinja Outflow	< 500	500 - 750	750 - 1000	1000 - 1250	>1250
L. Kyoga Inflow					
< 500	100	20	10	3	0
500 - 750	0	80	10	7	4
750 - 1000	0	0	80	20	8
1000 - 1250	0	0	0	70	18
> 1250	0	0	0	0	70

Notes

1. It is assumed that the change in flow due to Bujagali is similar to that due to Kalagala.
2. The probabilities are estimates obtained by logical reasoning and considering that hydroelectric power development can only cause a reduction in flow but cannot cause an increase in the flow.
3. Probabilities given as % in all cases table 6.8 a&b.

The reduction in outflows has been made small because all the facilities are run-of-river type and therefore do not need large storage. This means water losses from evaporation are likely to be small.

6.3.7 Lake Kyoga Basin Rainfall

The Lake Kyoga basin rainfall like that of Lake Victoria is an input variable to the system. Rainfall in Lake Kyoga basin was taken as the annual rainfall measured at the Soroti rain gauge. Soroti rainfall was chosen because Soroti has a moderate altitude, is centrally located, has a long rainfall record and its rainfall pattern is close to that of the average of the other stations in the study area. Details of the rainfall distribution in the study area were covered in chapter 3.

The occurrence of rainfall in the basin has a direct impact on the irrigation water demand and is therefore represented in the network as one of the causes of water demand for irrigation (Figure 6.7). The nature of the relationship is that high rainfall in the basin causes irrigation demand to reduce while low rainfall increases irrigation water demand.

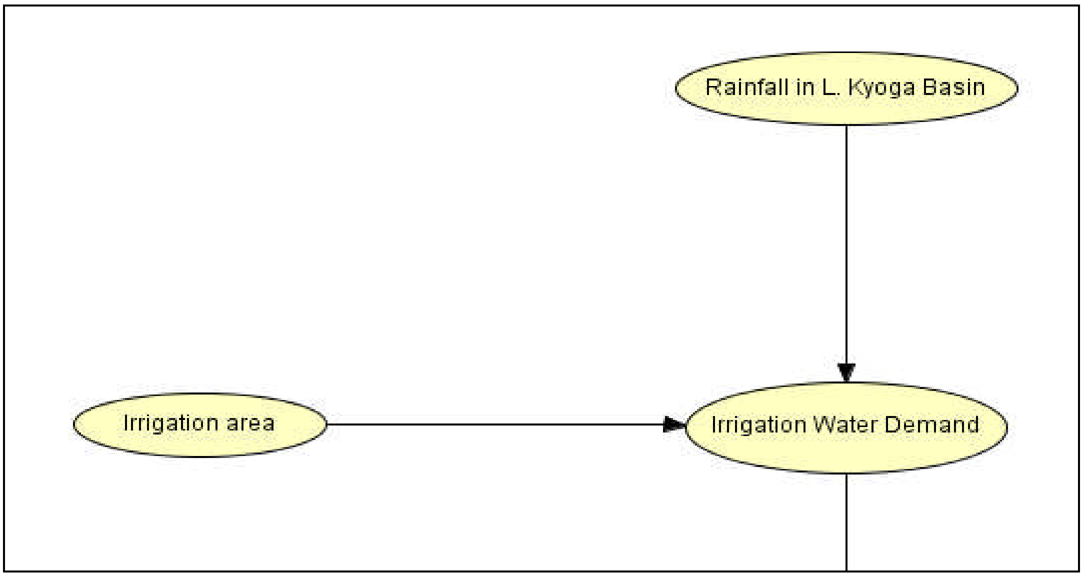


Figure 6.7 Cause-effect relationship between Rainfall in L Kyoga Basin, irrigation area and irrigation water demand

Rainfall records for the period 1938-2004 were available and a frequency distribution analysis from the data was used to elicit the probabilities of occurrence of rainfall within the classes defined below (table 6.9).

Definitions:

- **Dry year**: A year with annual rainfall (measured at Soroti rain gauge) of less than 1,200 mm
- **Moderate year**: A year with annual rainfall (measured at Soroti rain gauge) lying between 1200-1600 mm.
- **Wet year**: A year with annual rainfall (measured at Soroti rain gauge) is greater than 1,600 mm

These definitions were prompted by the statistics of the rainfall occurrence as described in chapter 3, and the water requirements of rice, which is the main irrigated crop in the catchment. Rice has a crop water demand of about 700 mm (Brouwer and Heibloem 1986) per season and for two seasons as is the case in the Kyoga basin, this means the annual crop water need is 1,400 mm. This is therefore taken as the median of the moderate rainfall year class. Secondly the average rainfall in the Victoria Nile region is 1,334 mm which lies within the moderate rainfall band and is close to the rice crop water requirement.

Table 6.9 Probability distribution for occurrence of Lake Kyoga Basin rainfall

Class/State	Definition/ Rainfall range (mm)	Probability of occurrence
		Rainfall at Soroti
Dry Year	< 1200	0.30
Moderate Year	1200-1600	0.55
Wet Year	> 1600	0.15

6.3.8 Irrigation area

In addition to rainfall in the basin, the area of land under irrigation determines the irrigation water demand (figure 6.7). Depending on the prevailing circumstances the area of land under irrigation can grow at different rates up to the full irrigation potential. From the available information, irrigation in Uganda has grown at a slow pace. In the Victoria Nile basin rice is the main irrigated crop and by 2006 there were an estimated 60,418 ha of land under rice irrigation in the basin (WWAP, 2006). This area is likely to grow up to the full potential, but the rate of growth to the full potential can only be estimated from the rate of growth in past years. In this model, the irrigation area can take up any of three states:

- maintain 2006 irrigation area,
- increase 2006 irrigation area by 50 % or
- utilize full irrigation potential in the catchment.

According to the irrigation growth in Uganda in past years, it is unlikely that irrigation will reach its full potential in the near future. Table 6.10 shows the irrigation area and the assumed corresponding probabilities.

Table 6.10 Irrigation area and assumed probabilities

	Irrigation area states		
	Maintain 2006 area	Increase 2006 area by 50%	Full irrigation potential
Area (ha)	60,418	90,627	128,865
Probability (%)	60	30	10

6.3.9 Irrigation water demand

Irrigation water demand is the difference between the total water need of the crops and the amount of rainfall which is available to the crops. For the entire water demand in the basin, irrigation water demand depends on the rainfall in the catchment and the available area under irrigation (Figure 6.7). For the irrigated area the water demand was estimated in m^3/year by conversion of depth of water to volume of water. The irrigation water demand in the catchment is therefore affected by the rainfall in the catchment and the available land for irrigation. Table 6.11 shows the irrigation water needs given the different irrigation areas and different rainfall regimes.

Table 6.11 Irrigation water needs for the rice crop

State	2006 irrigation area			50 % increase of the 2006 area			Full Irrigation potential		
Area (ha)	60,418			90,627			128,865		
Crop water need (mm/year)	1,400			1,400			1,400		
Rain water supply (mm/year)	Wet Year (>1600)	Moderate Rain Year (1200-1600)	Dry Year (<1200)	Wet Year (>1600)	Moderate Rain Year (1200-1600)	Dry Year (<1200)	Wet Year (>1600)	Moderate Rain Year (1200-1600)	Dry Year (<1200)
Water deficit (mm/year)	0	0 - 200	200-1,400	0	0 - 200	200-1,400	0	0 - 200	200-1,400
Irrigation water needs in the area (x 10^6 m^3/year)	0	0 - 121	121-846	0	0 - 181	181-1,269	0	0 - 258	258-1,804

From table 6.11 above it is suggested that irrigation water demand may fall into the following states:

	State	Description
1.	No irrigation needed	Irrigation water demand is 0
2.	Low irrigation demand	Irrigation water demand is 0-120 x 10^6 m^3/year
3.	Moderate irrigation demand	Irrigation water demand is 120-180 x 10^6 m^3/year
4.	High irrigation demand	Irrigation water demand is 180-250 x 10^6 m^3/year
5.	Very high irrigation demand	Irrigation water demand is greater than 250 x 10^6 m^3/year

Irrigation demand can fall in any of the above states but this is conditional upon available irrigation area and rainfall regime (dry/moderate/wet). The estimated conditional probabilities in the form P(irrigation water demand│irrigation area, rainfall regime) gives the probability that irrigation water demand will fall in a state given a certain state of irrigation area and rainfall regime are shown in table 6.12.

Table 6.12 Conditional probabilities for Irrigation water demand given irrigation area and rainfall regime

State of Irrigation demand	Irrigation land available								
	Irrigate only 2006 Area			Irrigate 2006 Area+ 50%			Utilize Full Potential		
Rainfall year	Wet	Moderate	Dry	Wet	Moderate	Dry	Wet	Moderate	Dry
No Irrigation needed	1	0	0	1	0	0	1	0	0
Low Irrigation demand	0	0.8	0	0	0.2	0	0	0.1	0
Moderate demand	0	0.2	0.7	0	0.7	0	0	0.2	0
High demand	0	0	0.2	0	0.1	0.8	0	0.6	0.1
Very high Demand	0	0	0.1	0	0	0.2	0	0.1	0.9

These probabilities were estimated from irrigation water requirements given in table 6.11 as a guide. Irrespective of the irrigation area, no irrigation is needed when it is a wet year. This is because for a wet year the annual rainfall is greater than 1,600 mm which is higher than the annual rice crop water needs.

6.3.10 Lake Kyoga Level

The level of Lake Kyoga depends on the amount of inflow from Lake Victoria and the rainfall over Lake Kyoga catchment. The effect of rainfall in the catchment is manifested in the irrigation water demand which is shown as the direct cause of lake levels as shown in figure 6.8.

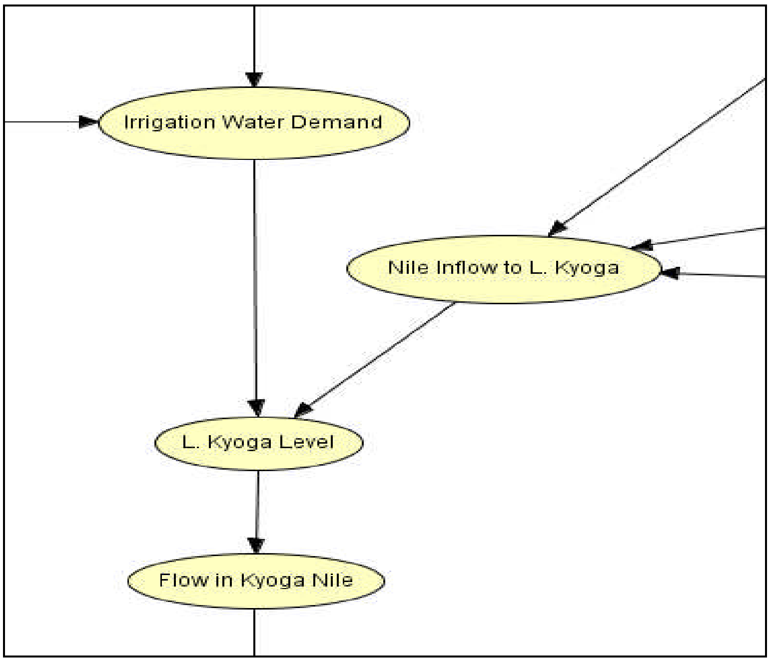


Figure 6.8 Causal relationship for irrigation water demand, Nile inflow to lake Kyoga, lake Kyoga level and Outflow from lake Kyoga

Analysis of available data for the period 1947-2005 (appendix 2.2.) shows that the lake level variation is more dependent on the inflow to the lake (with r^2 = 0.65) than catchment rainfall (r^2 = 0.09). It was assumed therefore, that with no irrigation, the level of the lake will depend only on the inflow from Lake Victoria. With this assumption, the probability distribution for lake level given different states of inflow is shown in table 6.13.

Table 6.13 Probability distribution for Lake Kyoga level given river Nile inflow-no irrigation needed

Lake Level (m)	Nile Inflow to Lake Kyoga (m^3/s) < 500	500 - 750	750-1000	1000-1250	> 1250
< 11	0.90	0.80	0.00	0.00	0.00
11 - 12	0.10	0.13	0.75	0.30	0.00
12 - 13	0.00	0.07	0.25	0.60	0.80
> 13	0.00	0.00	0.00	0.10	0.20

The above probabilities were obtained from a frequency distribution of Lake Kyoga level and Victoria Nile inflow to Lake Kyoga (data in appendix 2.2).

The effect of increasing the irrigation demand is to lower the lake level since irrigation is expected to reduce the amount of tributary inflow to the lake. Therefore as you move from the “no irrigation demand” state to the “very high demand” state, the lake level state tends to move from the high lake level towards the low lake level state. On the other hand as the inflow to Lake Kyoga increases, the lake level also increases. The probabilities are obtained by making logical estimates and are given in table 6.14a-d below.

Table 6.14 Conditional Probability distribution table for Lake Kyoga Level given specified irrigation demand and Victoria Nile flow to Lake Kyoga

Irrigation demand	**a. Low irrigation demand**				
Nile Inflow to L. Kyoga (m^3/s)	< 500	500 - 750	750-1000	1000-1250	>1250
Lake Level (m)					
< 11	90	85	20	10	0
11 – 12	10	15	60	40	10
12 – 13	0	0	20	50	70
> 13	0	0	0	0	20

Irrigation demand	**b. Moderate irrigation demand**				
Nile Inflow to L. Kyoga (m^3/s)	< 500	500 - 750	750-1000	1000-1250	>1250
Lake Level (m)					
< 11	91	88	30	20	10
11 – 12	9	12	55	50	20
12 – 13	0	0	15	30	60
> 13	0	0	0	0	10

Irrigation demand	c. High irrigation demand				
Nile Inflow to L. Kyoga (m^3/s)	< 500	500 - 750	750-1000	1000-1250	>1250
Lake Level (m)					
< 11	92	90	35	25	15
11 – 12	8	10	50	55	25
12 – 13	0	0	15	20	55
> 13	0	0	0	0	5

Irrigation demand	d. Very high irrigation demand				
Nile Inflow to L. Kyoga (m^3/s)	< 500	500 - 750	750-1000	1000-1250	>1250
Lake Level (m)					
< 11	95	92	40	30	18
11 – 12	5	8	50	60	25
12 – 13	0	0	10	10	52
> 13	0	0	0	0	5

6.3.11 Flow in Kyoga Nile

Kyoga Nile flow is directly caused by the level of Lake Kyoga (Figure 6.8). The flow in the Kyoga Nile is highly dependent on the level of Lake Kyoga (r^2 is 0.789); Figure 6.9 shows this dependence for data for the period 1947-2005 (appendix 2.2).

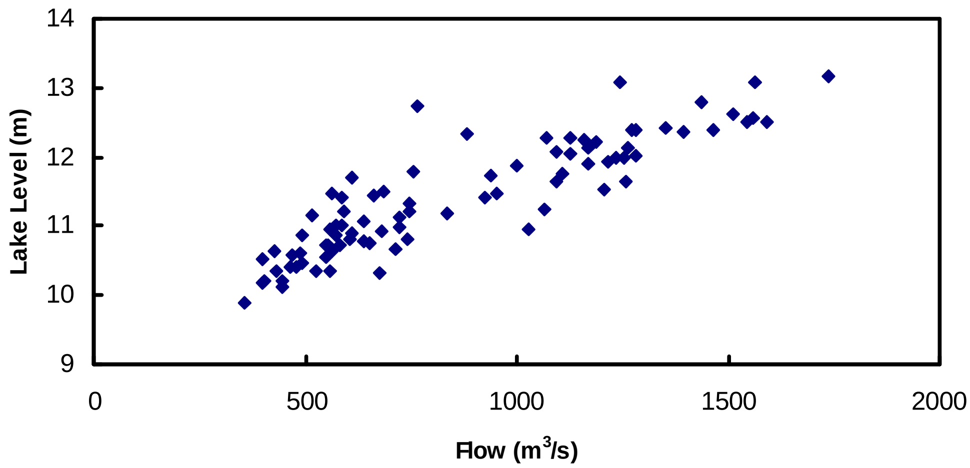


Figure 6.9 Lake Kyoga outflow v lake level measured at Masindi Port

Using the data from figure 6.9 (appendix 2.2) a frequency distribution analysis yielded the following probabilities (table 6.15) for Kyoga outflows and lake levels when there are no hydroelectric power developments along the Kyoga Nile reach. Development of hydroelectric power plants will change this probability distribution according to the plants' configuration and the combinations of plants developed.

Table 6.15 Probability distribution for Nile flow given specified Lake Kyoga levels

Lake Level (m)	< 11	11 - 12	12 - 13	> 13
Kyoga Nile flow (m^3/s)				
< 500	0.42	0.00	0.00	0.00
500 - 750	0.55	0.46	0.05	0.00
750 - 1000	0.02	0.29	0.05	0.00
1000 - 1250	0.01	0.18	0.33	0.33
> 1250	0.00	0.07	0.57	0.67

6.3.12 Hydroelectric Power Developments on the Kyoga Nile

There is potential for three hydroelectric power facilities along the Kyoga Nile stretch at Murchison Falls, Ayago and Karuma (Kamdini). Development of any combination of these will depend on a decision made by the Ugandan Government. The relationships between these hydroelectric plants and other variables in the system are shown in figure 6.10. As can be seen, hydroelectric power plants (HEP) do not have any “parents” as they only cause effects but are not themselves affected by any other variable studied here. The variables Murchison Falls HEP, Ayago HEP and Karuma HEP can take the states true and false. True means the hydroelectric power facility is developed while false means it is not developed.

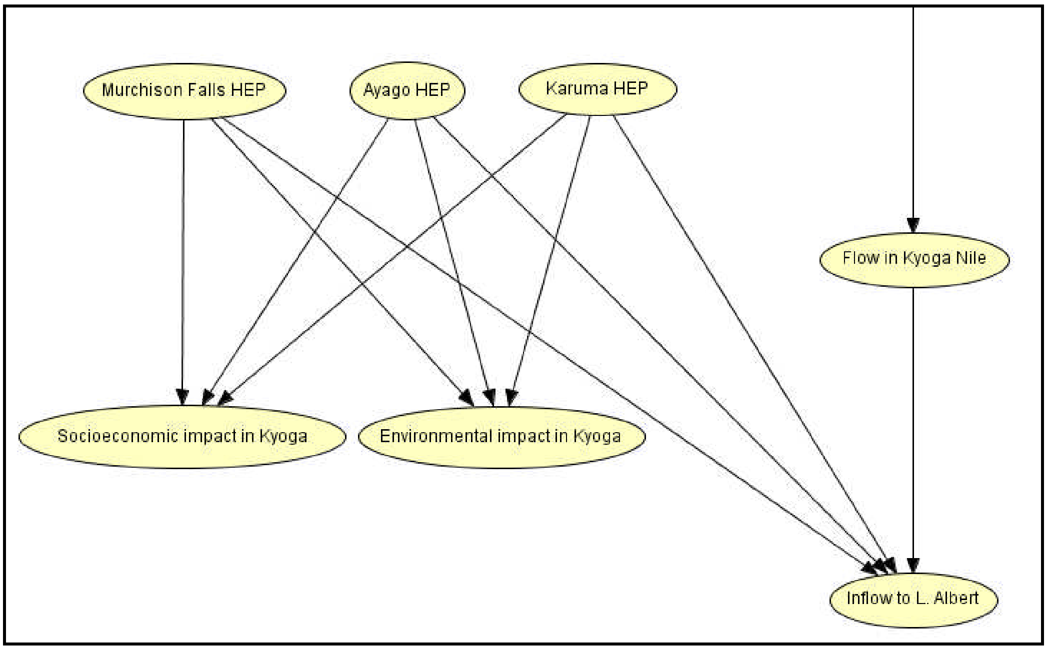


Figure 6.10 Causal relationship for hydroelectric power facilities with Kyoga Nile flow

To find out the effect of developing any combination of the dams to the system entails making the necessary states true. The model assesses the effect of these developments to the Kyoga Nile flow to Lake Albert and also the socioeconomic and environmental impacts. The variables that are directly affected by hydroelectric power developments are therefore river Nile inflow to Lake Albert (exit from the system under study), socioeconomic and environmental impacts in the Kyoga catchment.

6.3.13 Nile Inflow to Lake Albert

The flow pattern at the exit from Lake Kyoga measured at Masindi is deemed to be similar to that at entry to Lake Albert when there are no hydroelectric power developments. This flow pattern is, however, expected to be interrupted by the developments of hydroelectric power stations along this stretch. The extent of interruptions cannot be ascertained precisely, but the flow is expected to reduce depending on what combinations of developments are undertaken. Without any HEP developments the flow will follow the trend that it has been following from the historical observations as presented in section 6.3.6. In this case the Kyoga Nile flow to Lake Albert will be dependent on Lake Kyoga level as shown in figure 6.9 and 6.11 and therefore the probability distributions will be as in table 6.15. One effect of the hydropower developments is to reduce the flows depending on the plant configuration. When developments are undertaken the effect is to reduce the flows and therefore the probabilities of having higher flows will reduce while those of having lower flows will increase. These probabilities were therefore estimated using this assumption and are shown in table 6.16. This section of the Nile slopes steeply: a drop of about 400 m over a distance of 90 km compared to 100 m over a distance of about 150 km for the lake Victoria-lake Kyoga section. Therefore the projects do not cause high water loses because these schemes involve tunnelling as opposed to damming.

Table 6.16 Probability distribution for Kyoga Nile exit flow given various hydroelectric power developments

Table 6.16 (a) Only one HEP is developed on the Kyoga Nile

Kyoga Nile Flow	< 500	500 - 750	750 - 1000	1000 - 1250	>1250
Exit Flow					
< 500	100	5	5	2	0
500 - 750	0	95	5	5	3
750 - 1000	0	0	90	5	5
1000 - 1250	0	0	0	88	7
> 1250	0	0	0	0	85

Table 6.16 (b) Any two HEPs are developed on the Kyoga Nile

Kyoga Nile Flow	< 500	500 - 750	750 - 1000	1000 - 1250	>1250
Exit Flow					
< 500	100	10	5	3	0
500 - 750	0	90	10	7	3
750 - 1000	0	0	85	10	7
1000 - 1250	0	0	0	80	10
> 1250	0	0	0	0	80

Table 6.16 (c) All three HEP are developed

Kyoga Nile Flow	< 500	500 - 750	750 - 1000	1000 - 1250	>1250
Exit Flow					
< 500	100	15	10	5	0
500 - 750	0	85	10	5	5
750 - 1000	0	0	80	15	5
1000 - 1250	0	0	0	75	15
> 1250	0	0	0	0	70

Notes about probabilities:

1. It is assumed that the reduction in flow due to Ayago is similar to that due to Murchison falls and Karuma because of the similarity in configuration of the projects. Therefore the probabilities of having exit flows given development of any one of the projects are the same (Table 6.16b).
2. Similarly the probabilities for having exit flows given development of any combination of two schemes is the same(Table 6.16c)
3. Probabilities of having flow within any of the ranges above are obtained by rational estimates using assumptions in notes 1 and 2.

6.3.14 Socioeconomic and Environmental Impacts

Socioeconomic impacts of hydroelectric power developments in both the upper Victoria Nile and the Kyoga Nile reaches are discussed here. The causal relationships are shown in figure 6.6 and figure 6.10. The information used for socioeconomic and environmental assessments was obtained from reports of studies carried out by various consultants who were hired by the Government of Uganda to determine the potential of hydropower development in the country and also to make social and environmental assessments on individual projects. The main sources of information were the documents below:

- Karuma Falls Hydropower Project, Uganda; Environmental Impact Assessment, May 1999 by Norplan A.S.
- Bujagali Hydro power Project Social and Environmental Assessment Main Report, 2006 By R.J. Burnside International Ltd and Bujagali Energy Limited, Uganda.
- Hydropower Development Master Plan Final Report, Volume 8 Environmental Impact Assessment (stage 1) 1997, By Kennedy and Donkin Power Ltd, Sir Alexander Gibb and partners and Kananura Melvin Consulting Engineers.

Additional information was obtained from discussions with experts who participated in different ways in the studies from Norplan A.S Uganda; the Uganda National Environmental Management Authority (NEMA); The World Bank, Uganda Country Office; Uganda Ministry of Energy and the Uganda Electricity Transmission Company (Formerly Uganda Electricity Board).

The assessed impacts of each of the projects were obtained from the social and environmental impact reports from the previous studies mentioned above (Kennedy & Donkin Power Ltd et al., 1997; Norplan A.S., 1999; R.J. Burnside International Ltd et al., 2006). For the purpose of making a comparison of impacts from the different projects, a summary of the impacts assessed for each project was prepared from the study reports. Different authors used different approaches and scales and therefore it was difficult to prepare a summary of project impacts from the different assessments. Use of different approaches and scales could be attributed to the fact that the aim of the assessments in the previous studies was to come up with a statement of whether the particular project could be implemented or not. Assessors of social and environmental impacts of these hydropower plants in the Victoria Nile used a combined total of 27 different but related variables to assess the likely impacts of the projects. Norplan A.S, (1999) used 13 variables for Karuma; Burnside et al., (2006) used 9 variables for Bujagali and Kennedy and Donkin et al., (1997) used 5 variables for making comparisons of all the potential sites. Details of these are in appendix 4. The difference in variables assessed and the different level of detail of each assessment made it difficult to accurately compare on a similar scale the impact of the different projects. Furthermore, some of the factors that were assessed are neither quantifiable nor comparable. In order to deal with this difficulty four categories were identified in which the above variables were grouped. Two key variables for each category were listed as shown in figure 6.11.

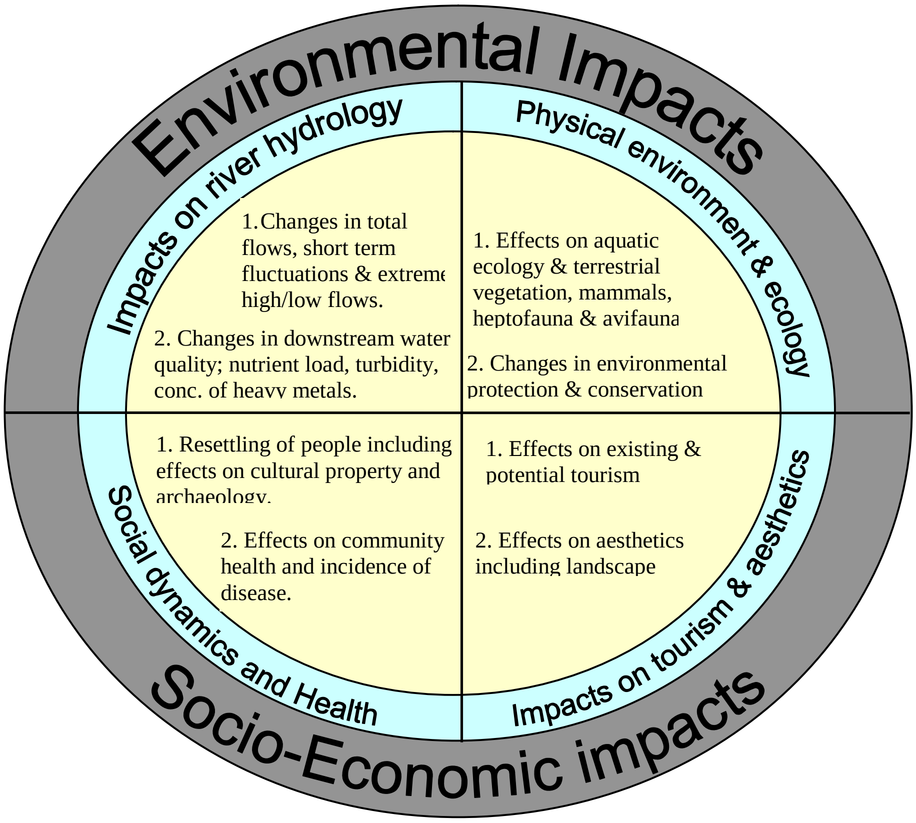


Figure 6.11 Summary of key socioeconomic and environmental impact variables

This approach was followed in order to make it possible to define a set of probabilities that the impact assessed will be of a specified magnitude. These probabilities define the magnitude of the impacts of a hydropower plant development on the social and environment conditions in the vicinity of the project. Such probabilities can be elicited from experts or from data from historical events. The approach here was to use simple proportions to determine these probabilities rather than entirely depending on probabilities elicited from experts. In tables 6.17 and 6.18, the probability of having any magnitude of impact specified in table 6.19 was determined by the number of times that magnitude of impact occurs out of the total possibility of four times for each project. This is the case for both environmental and socioeconomic impacts. This gives an estimate of the probability that the environmental and social state in the vicinity of the project will be impacted by a project to a certain magnitude. Whereas the probability given by an expert would be based on his/her experience in the field, here simple arithmetic was used to give guidance on how to arrive at the probability.

Table 6.17 Environmental impacts expected from hydropower projects

	Impact Summary	Hydropower project				
		Bujagali	Kalagala	Karuma	Ayago	Murchison Falls
		Level of expected impact to the Victoria Nile and vicinity of project				
1.	*Impacts on river hydrology*					
(i)	Changes in total river flow, seasonal flows, short-term fluctuations and extreme high/low flows	++	++	++	++	++
(ii)	Changes in downstream water quality; nutrient load, turbidity, concentration of heavy metals	+	+	+	+	+
2	*Impacts on the physical environment and ecology*					
(iii)	Changes in environment protection areas	++	0	0	++	+++
(iv)	Effects on aquatic ecology and terrestrial vegetation, mammals, heptofauna and avifauna.	++	+	++	++	+++
	<u>Summary*</u>					
	0	0.00	0.25	0.25	0.00	0.00
	+	0.25	0.50	0.25	0.25	0.25
	++	0.75	0.25	0.50	0.75	0.25
	+++	0.00	0.00	0.00	0.00	0.50
	++++	0.00	0.00	0.00	0.00	0.00

Table 6.18 Socioeconomic impacts expected from hydropower projects

	Impact Summary	Hydropower project				
		Bujagali	Kalagala	Karuma	Ayago	Murchison Falls
		Level of expected impact to the Victoria Nile and vicinity of project*				
1.	*Impacts on Social dynamics and health*					
(i)	Resettlement of people including effects on their cultural property and archaeology.	++	+++	+++	+	+
(ii)	Effects on community health such as incidence of diseases e.g. Schistosomiasis& malaria.	+++	+++	+++	+	++
2	*Impacts on tourism and aesthetics*					
(iii)	Effects on existing and potential tourism	+++	+++	++	++	++++
(iv)	Effects on aesthetics including landscape changes	++	++	++	++	+++
	Summary*					
	0	0.00	0.00	0.00	0.00	0.00
	+	0.00	0.00	0.00	0.50	0.25
	++	0.50	0.25	0.50	0.50	0.25
	+++	0.50	0.75	0.50	0.00	0.25
	++++	0.00	0.00	0.00	0.00	0.25

*See table 6.20 for notation description

Table 6.19 Magnitude of Impact Rating

Description**	**Notation**
Insignificant impact	0
Little negative impact	+
Moderate negative impact	++
Large negative impact	+++
Very large negative impact	++++

**From Norplan, 1999

Using the summary in Figure 6.11 the various project impacts were assessed under the broad classification of environmental and socioeconomic impacts as in tables 6.17 and 6.18 respectively. The magnitude of impact was based on the notation in table 6.19. By limiting the number of parameters to assess to only four it was easy to compare the impacts from each project and also to determine the probabilities that the impact from a particular project can be classified as any of the classes in table 6.19. The important question to answer for each project after the assessment in tables 6.17 and 6.18 is what level of impact is expected to arise from implementation of that project. In probabilistic terms it is possible to determine the probability that that magnitude of impact will occur. Tables 6.17 and 6.18 show the number of times a specified magnitude of impact occurs for each project. These figures show the probability that the impact of a project will belong to any of the ratings in table 6.19.

The cumulative impact of hydropower developments in each stretch of the Victoria Nile depends on which combination of projects is implemented. Possible combinations of hydropower developments are shown in table 6.20.

Table 6.20 Combinations of Projects

Upper Victoria Nile reach	Lower Victoria Nile (Kyoga Nile) Reach
1. Bujagali only	1. Karuma only
2. Both Bujagali and Kalagala	2. Ayago only
3. Kalagala only*	3. Murchison Falls only
	4. Karuma and Ayago
	5. Karuma and Murchison Falls
	6. Ayago and Murchison Falls
	7. Ayago and Karuma and Murchison Falls
	8. No Development at all

*This option is not possible any more since construction of Bujagali hydropower plant had started by 2008.

It is difficult to assess the resultant impact of more than one project; however we can assume that the resultant impact from more than one project is at least as great as that of the worst individual project. With this assumption we can therefore say that when more than one project is carried out the combined impact can be either similar to that for the project with the worst impact or greater. For consistency the probability distribution for more than one project was taken to be similar to that of the worst project as seen in tables 6.21 and 6.22.

Table 6.21 Probability tables for Bujagali and Kalagala impacts
Socioeconomic impacts in the Upper Victoria Nile

Kalagala	False		True	
Bujagali	False	True	False	True
Insignificant impact	100	0	0	0
Little negative impact	0	0	0	0
Moderate negative impact	0	50	25	0
Large negative impact	0	50	75	75
Very large negative impact	0	0	0	25

Environmental Impacts in the Upper Victoria Nile

Kalagala	False		True	
Bujagali	False	True	False	True
Insignificant impact	100	0	25	0
Little negative impact	0	25	50	0
Moderate negative impact	0	75	25	75
Large negative impact	0	0	0	25
Very large negative impact	0	0	0	0

Table 6.22 Probability tables for Karuma, Ayago and Murchison Falls impacts
Social impacts in the Lower Victoria Nile

Murchison Falls	False				True			
Ayago	False		True		False		True	
Karuma	False	True	False	True	False	True	False	True
Insignificant impact	100	0	0	0	0	0	0	0
Little negative impact	0	0	50	0	25	0	0	0
Moderate negative impact	0	50	50	25	25	25	50	0
Large negative impact	0	50	0	50	25	50	25	50
Very large negative impact	0	0	0	25	25	25	25	50

Environmental impacts in the Lower Victoria Nile

Murchison Falls	False				True			
Ayago	False		True		False		True	
Karuma	False	True	False	True	False	True	False	True
Insignificant impact	100	25	0	0	0	0	0	0
Little negative impact	0	25	25	0	25	0	0	0
Moderate negative impact	0	50	75	75	25	25	25	0
Large negative impact	0	0	0	25	50	50	50	50
Very large negative impact	0	0	0	0	0	25	25	50

Chapter 7 Bayesian Network Results

7.1 Introduction

Results of the Bayesian network described in chapter six were obtained by running the network using the HUGIN expert software. From the runs, the expected behaviour of the system under different rainfall conditions and development scenarios can be observed. These scenarios vary from the worst to the best case, with intermediate situations between. Results of running the network are obtained as responses to “what if…” questions. By assuming a rainfall state, running the network gives the effect of undertaking any of the possible hydropower and irrigation development alternatives. Each of the scenarios is presented in turn and a comparison is made with the baseline scenario which corresponds to the situation of development in 2006.

7.2 Scenario Assessment

The Bayesian network can be used to observe what would happen in the system when certain changes occur. There are two types of changes that can be distinguished; climatic changes that can be deduced from occurrence of dry or wet periods and changes that may occur due to development decisions made by Government or other policy makers. The possible development decisions include:

- The mode of operation for outflows at Jinja; this could be either following the “agreed curve” principle or by outflow regulation mode,
- Which hydroelectric power plants to develop; this could be all possible hydropower developments or a selection of some,
- The area of land put to irrigation in the catchment.

The effects of climate variability and change on the system can be deduced from the amount of rainfall in the Kyoga and Victoria catchments. Rainfall patterns for the Lake Kyoga and Lake Victoria catchments are similar, although the rainfall magnitudes are different. Because of this similarity in rainfall pattern, it was assumed that dry, moderate and wet years occur in the Kyoga and Victoria catchments during the same years. This means that to assess the effect of rainfall, both Kyoga and Victoria rainfalls were set to the same state.

The framework in figure 7.1 was used to assess various effects on the catchment given the rainfall state and the decisions taken.

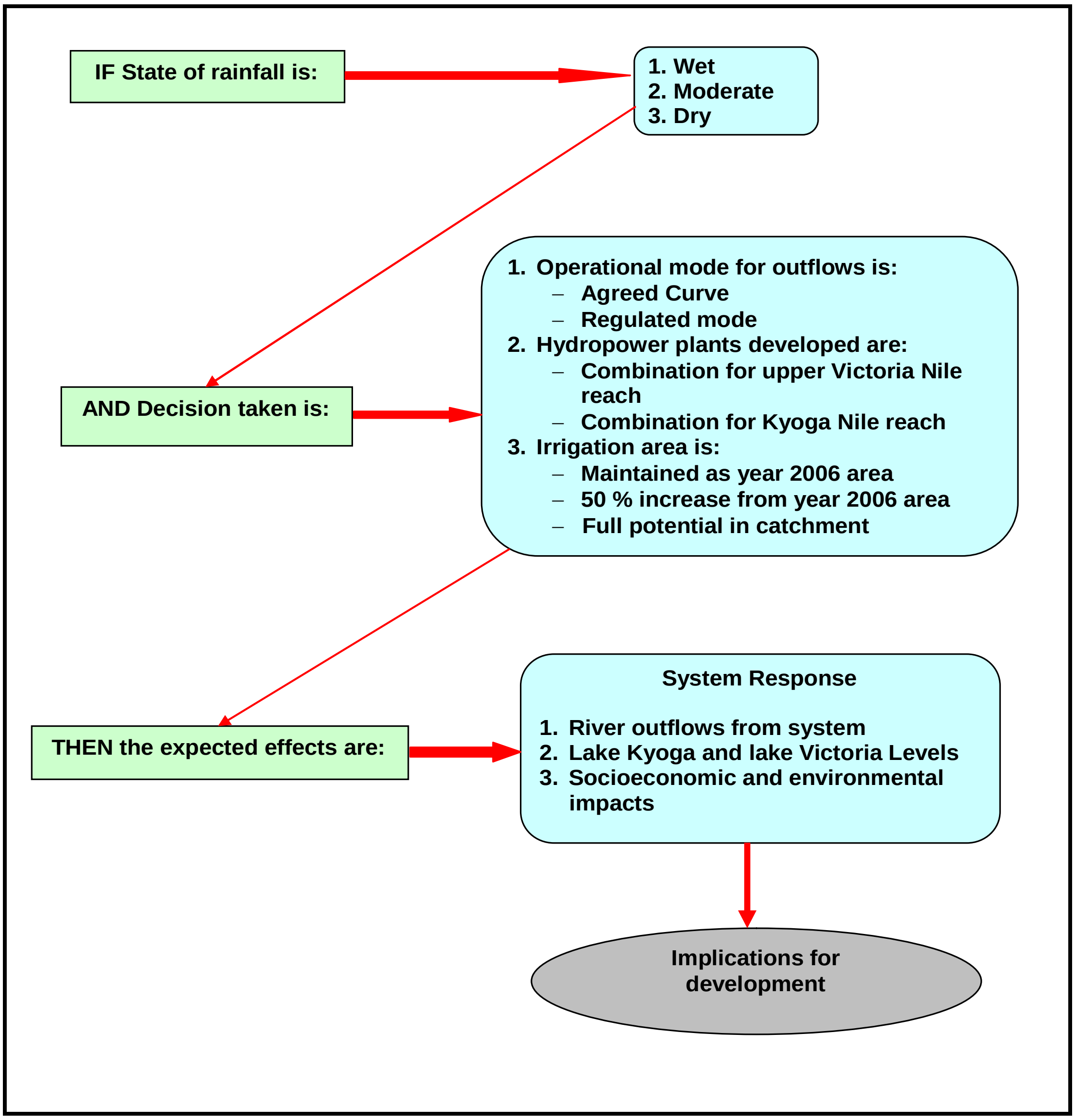


Figure 7.1 Framework for assessing effect of decisions

The framework explains that by assuming a rainfall state the resultant effects caused by the various development decisions can be predicted. Three main conditions were distinguished and used to assess the effect of developments on the basin.

Baseline situation

The baseline is taken as the situation in 2006, when no new hydroelectric power plants are developed and irrigation area is that for the year 2006. Rainfall occurrence was considered to be moderate. This scenario provided a benchmark from which comparison with future developments was made. Using this as a benchmark condition, the effects of hydroelectric power development and irrigation area are investigated when the rainfall state remains moderate.

High water use/low rainfall scenario

This scenario occurs when there is a high demand for water for irrigation and a high level of hydroelectric power development but when water supply from rainfall is low. This occurs during a dry year.

Low water use/high rainfall scenario

This scenario occurs when there is minimal water demand for irrigation and minimal hydropower development. This scenario occurs during a wet year.

In the following sections, the effect of hydroelectric power development and irrigation is investigated under the three main conditions above. The effect of mode of operation of Lake Victoria outflows at Jinja is also investigated for dry, moderate and wet states.

7.3 Baseline situation

The baseline scenario can be described as follows:

- None of the proposed hydroelectric power plants is developed
- Area under irrigation is similar to the 2006 level,
- Lake Victoria outflows are controlled by the agreed curve,
- Rainfall occurrence for Lake Victoria and Lake Kyoga basins are moderate (annual rainfall is 1,186-1,398 mm for Lake Victoria and 1,200-1,600 mm for lake Kyoga basin).

A summary of the states and the results of running the baseline scenario for key variables are shown in table 7.1. Figure 7.2 shows the Bayesian network of the results for the entire system under the baseline scenario. Four key variables that were used to compare the system behaviour under different scenarios are; the Lake Victoria level, Lake Kyoga level, river flow from Lake Victoria to Lake Kyoga and the Victoria Nile flow out of the basin.

In the results tables P refers to the probability of a variable.

Table 7.1 States and results of key variables for the baseline scenario

Variable	**State**
Natural events	
Rainfall in L. Victoria basin	Moderate
Rainfall in L. Kyoga basin	Moderate
Decision events	
Irrigation area	Irrigation area of 2006
Dam operation mode	Agreed curve
New hydropower plants in Victoria Nile	None
Hydropower plants in Kyoga Nile	None
Results	
L. Victoria level (Jinja gauge)	• P*(level < 10.8 m) = 3% • P (level is 10.8-11.6 m) = 24% • P (level > 12 m) = 50%
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 25% • P (level is 11-12 m) = 28% • P (level > 13 m) = 7%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 19% • P (flow >1,250 m^3/s) = 38%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 11% • P (flow is 500-750 m^3/s) = 29% • P (flow > 1,250 m^3/s) = 29%
Irrigation water demand	Low (< 120 million m^3/year)
Social impacts in Kyoga Nile region	None
Environmental impacts in Kyoga Nile	None
Social impacts in Victoria Nile region	None
Environmental impacts in Victoria Nile	None

*P(X) Probability of X

The baseline scenario shows moderate conditions on most of the variables of interest. It is used as the starting point to show the effect of irrigation and hydroelectric power developments under different rainfall conditions.

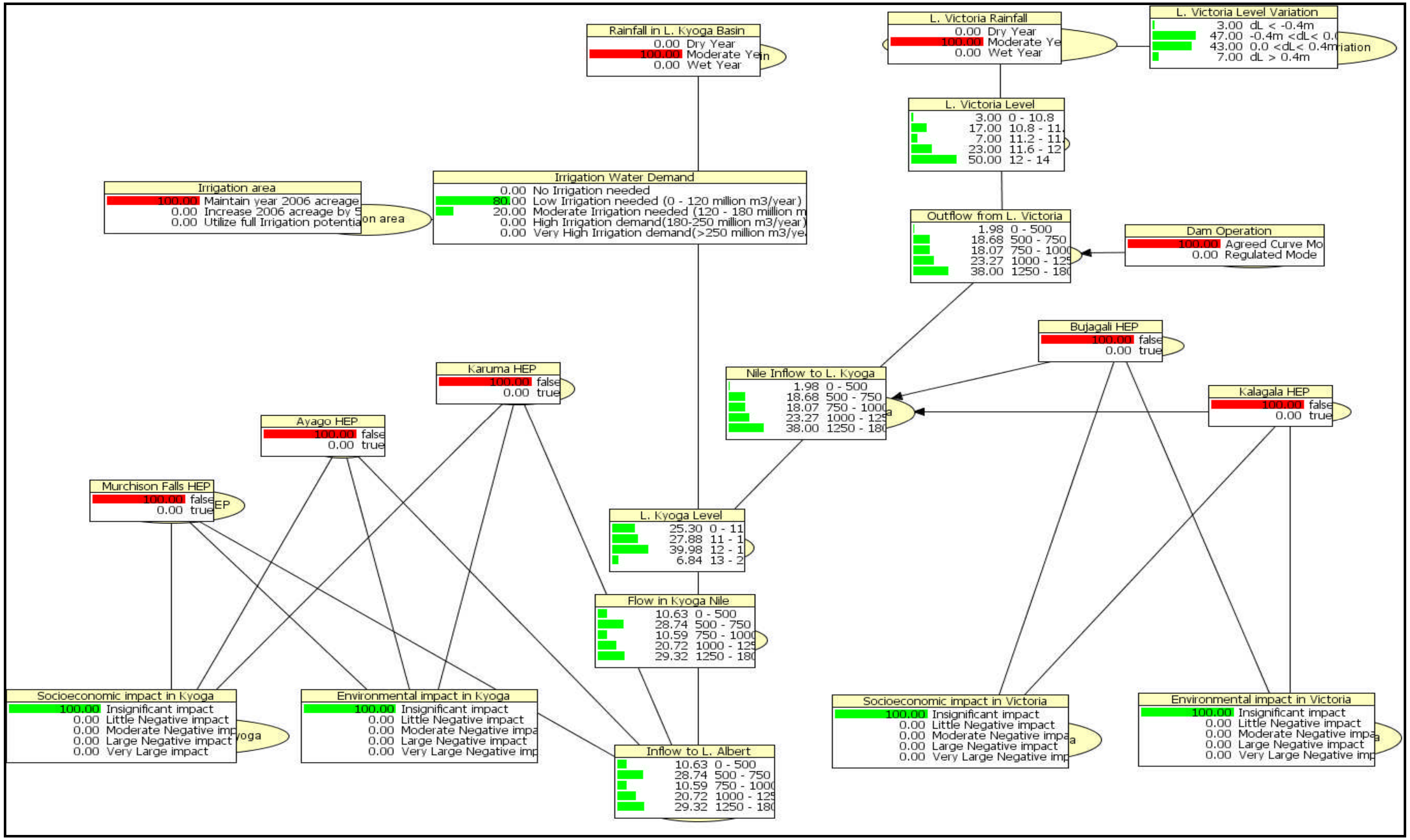


Figure 7.2 Bayesian network of the result of the baseline scenario

7.4 Effect of Hydroelectric power development

The results in this section show the effect of development of hydroelectric power plants along the Victoria Nile. Two scenarios are investigated; one showing the effect of developing one plant in each of the sections of the Victoria Nile while the other shows the effect of developing all possible plants. The irrigation potential and rainfall occurrence remain as for the baseline scenario. The results obtained in this section show changes resulting from hydroelectric power development only and therefore relate to the baseline condition.

7.4.1 Bujagali and Karuma Plants Scenario

This scenario investigates the effect of developing only one hydroelectric power plant in each of the two reaches of the Victoria Nile River without changing the irrigation area and the rainfall state. The Karuma and Bujagali plants are chosen because Bujagali was already under construction at the time of writing this thesis while plans for developing Karuma were in an advanced stage. The variable states and results of running the Karuma and Bujagali scenario are shown in table 7.2 and figure 7.3 shows the details of all variables states. In table 7.2 the results for the baseline scenario are also presented to make comparison easy.

The Lake Victoria level does not change with addition of hydroelectric power plants, so the results obtained for Lake Victoria level are the same as those for the baseline scenario. The changes to Lake Kyoga level are small. As in the baseline scenario lake Kyoga levels are predominantly less than 12 m. River flow from lake Victoria to lake Kyoga and the river flow exiting the basin show similar and small changes. In both cases the probability of having river flows greater than 1,250 m^3/s are reduced by about 8% only. Environmental and socioeconomic impacts are those arising from the individual plants and they range from little to large.

Table 7.2 Description of states of variables and results for Bujagali and Karuma scenario

Variable	State/ Scenario	
	Baseline	**Bujagali & Karuma**
Natural events		
Rainfall in L. Victoria	Moderate	Moderate
Rainfall in L. Kyoga basin	Moderate	Moderate
Decision events		
Irrigation area	Irrigation area of 2006	Irrigation area of 2006
Dam operation mode	Agreed curve	Agreed curve
New hydropower plants in Victoria Nile	None	Bujagali
Hydropower plants in Kyoga Nile	None	Karuma
Results		
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 3% • P (level is 10.8-11.6 m) = 24% • P (level > 12 m) = 50%	As for baseline
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 25% • P (level is 11-12 m) = 28% • P (level > 13 m) = 7%	• P (level < 11 m) = 32% • P (level is 11-12 m) = 29% • P (level > 13 m) = 5%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 19% • P (flow >1,250 m^3/s) = 38%	• P (flow < 500 m^3/s) = 5% • P (flow is 500-750 m^3/s) = 22% • P (flow >1,250 m^3/s) = 29%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 11% • P (flow is 500-750 m^3/s) = 29% • P (flow > 1,250 m^3/s) = 29%	• P (flow < 500 m^3/s) = 16% • P (flow is 500-750 m^3/s) = 33% • P (flow > 1,250 m^3/s) = 21%
Irrigation water demand	Low (< 120 million m^3/year)	As for baseline
Social impacts in Kyoga Nile region	None	Moderate to large negative
Environmental impacts in Kyoga Nile	None	Little to moderate negative
Social impacts in Victoria Nile region	None	Moderate to large negative
Environmental impacts in Victoria	None	Little to moderate negative

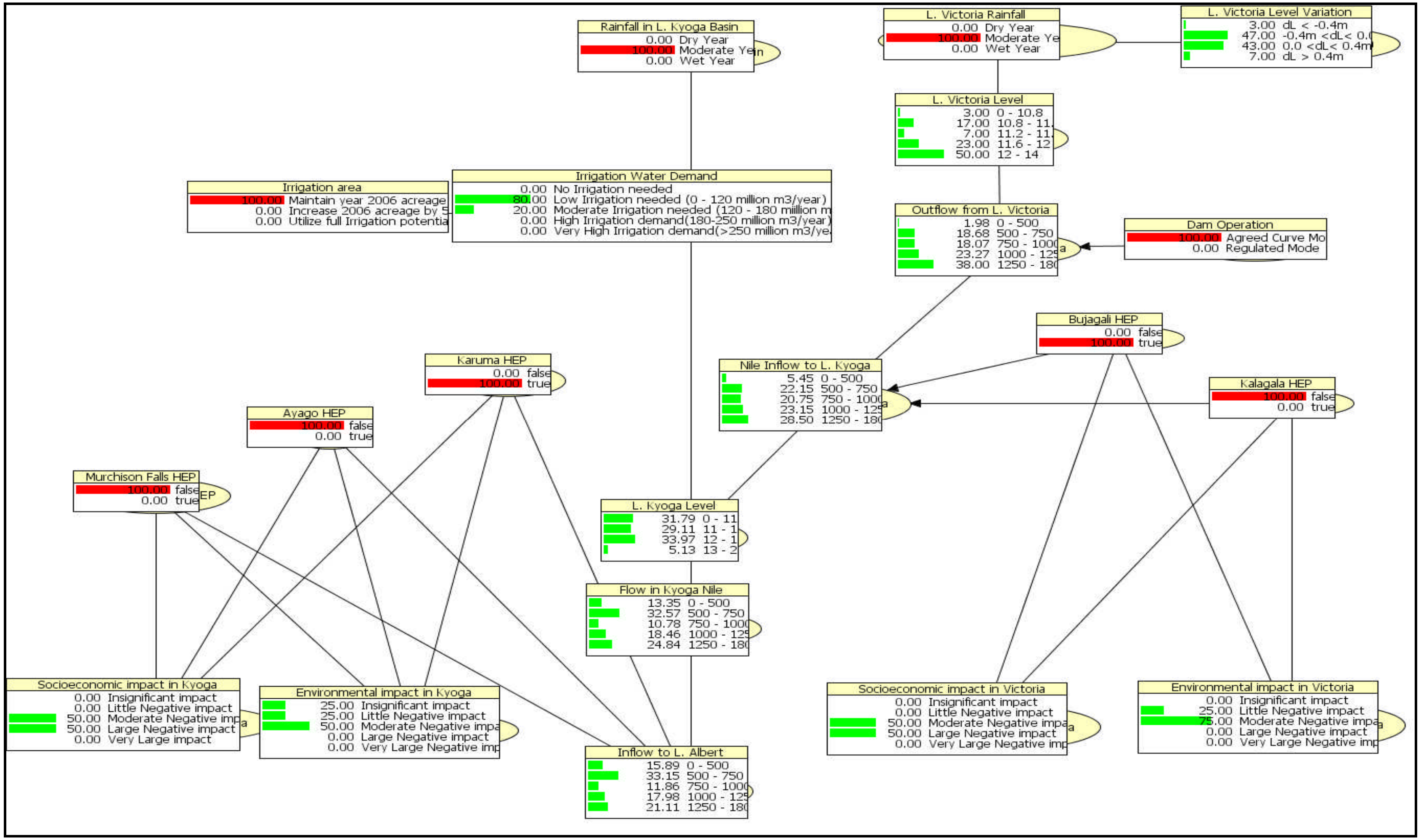


Figure 7.3 Bayesian network of the result for the Bujagali and Karuma scenario

7.4.2 All Possible Hydropower Plants Scenario

This scenario investigates the effects of developing all possible hydroelectric power plants along the Victoria Nile when rainfall and irrigation states remain the same as the baseline situation. There are intermediary scenarios of having two plants in one section of the river with one in the other but results of these have not been presented here because their effects are within these extreme cases. For this scenario all other variable states remain the same as for the baseline scenario except hydropower plants. Table 7.3 and figure 7.4 show the results.

Table 7.3 Description of states of variables and results for all hydroelectric power plants scenario

Variable	State/ Scenario		
	Baseline	**Bujagali and Karuma only**	**All hydroelectric power plants**
Natural events			
Rainfall in L. Victoria	Moderate	Moderate	Moderate
Rainfall in L. Kyoga basin	Moderate	Moderate	Moderate
Decision events			
Irrigation area	Irrigation area of 2006	Irrigation area of 2006	Irrigation area of 2006
Dam operation mode	Agreed curve	Agreed curve	Agreed curve
New hydropower plants in Victoria Nile	None	Bujagali	Bujagali & Kalagala
Hydropower plants in Kyoga Nile	None	Karuma	Karuma, Ayago and Murchison falls
Results			
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 3% • P (level is 10.8-11.6 m) = 24% • P (level > 12 m) = 50%	As for baseline	As for baseline
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 25% • P (level is 11-12 m) = 28% • P (level > 13 m) = 7%	• P (level < 11 m) = 32% • P (level is 11-12 m) = 29% • P (level > 13 m) = 5%	• P (level < 11 m) = 33% • P (level is 11-12 m) = 30% • P (level > 13 m) = 5%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 19% • P (flow >1,250 m^3/s) = 38%	• P (flow < 500 m^3/s) = 5% • P (flow is 500-750 m^3/s) = 22% • P (flow >1,250 m^3/s) = 29%	• P (flow < 500 m^3/s) = 8% • P (flow is 500-750 m^3/s) = 20% • P (flow >1,250 m^3/s) = 27%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 11% • P (flow is 500-750 m^3/s) = 29% • P (flow > 1,250 m^3/s) = 29%	• P (flow < 500 m^3/s) = 16% • P (flow is 500-750 m^3/s) = 33% • P (flow > 1,250 m^3/s) = 21%	• P (flow < 500 m^3/s) = 21% • P (flow is 500-750 m^3/s) = 31% • P (flow > 1,250 m^3/s) = 18%
Irrigation water demand	Low (< 120 million m^3/year)	As for baseline	As for baseline
Social impacts in Kyoga Nile region	None	Moderate to large negative	Large to very large negative
Environmental impacts in Kyoga Nile	None	Little to moderate negative	Large to very large negative
Social impacts in Victoria Nile region	None	Moderate to large negative	Large negative
Environmental impacts in Victoria Nile	None	Little to moderate negative	Moderate negative

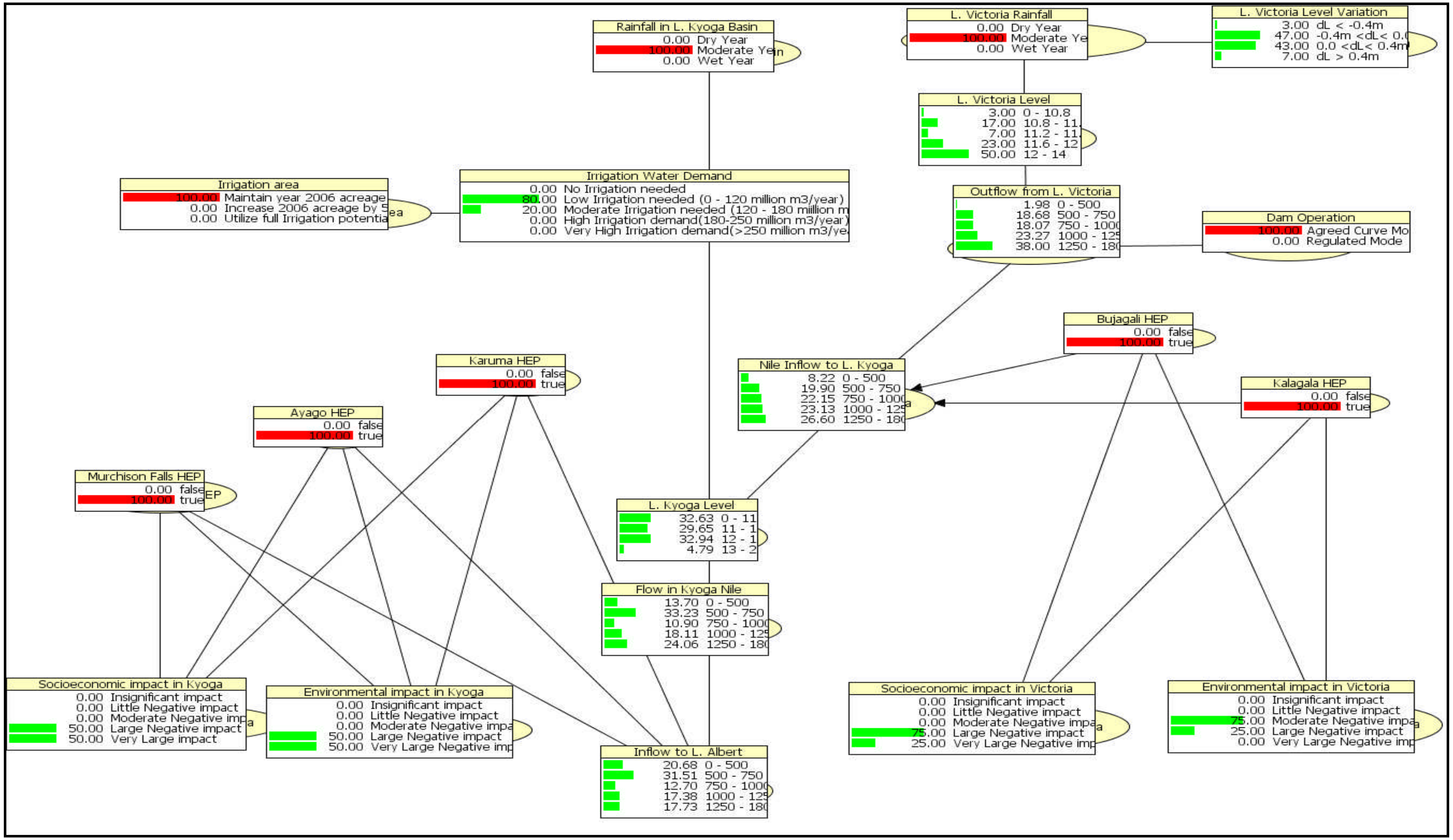


Figure 7.4 Bayesian network of the result for all hydropower plants scenario

By having the Kalagala plant in addition to Bujagali in the upper Victoria Nile reach does not cause any significant changes to the level of Lake Kyoga and the Nile flow to Lake Kyoga. This can be seen from the results of the probabilities of the states of these variables being the same for the baseline and this scenario. River Nile flow out of the basin reduces but again only slightly.

From the results above it is concluded that development of hydroelectric power plants in the upper Victoria Nile increases the probability of having Lake Kyoga levels lower than 11m, but by a small margin of about 7% only. River flows out of the basin reduce when hydroelectric plants are developed but there is no significant difference of having only one plant or all plants developed. The main effect of hydropower plants is increasing the socioeconomic and environmental impacts in the vicinity of the projects.

7.5 Effect of Irrigation Area

The effect of irrigation area was investigated by adjusting the irrigation area while leaving other variables the same as they were for the baseline scenario. Two scenarios were investigated; one with an irrigation area of 2006 increased by 50% and the other with full irrigation potential. The results of these two scenarios were compared to the baseline.

7.5.1 Irrigation Area Increased by 50% of 2006 level

This scenario gives the results of the case where the irrigation area is increased by 50% of the area available for irrigation in 2006. The results obtained show the effect of drawing irrigation water on the water resources in the basin. All other variables are left in the states of the baseline scenario. Table 7.4 and figure 7.5 show the results.

Table 7.4 Description of states of variables and results for irrigation area increased by 50% scenario

Variable	State/ Scenario	
	Baseline	**Irrigation increased by 50%**
Natural events		
Rainfall in L. Victoria	Moderate	Moderate
Rainfall in L. Kyoga basin	Moderate	Moderate
Decision events		
Irrigation area	Irrigation area of 2006	Irrigation area increased by 50%
Dam operation mode	Agreed curve	Agreed curve
New hydropower plants in Victoria Nile	None	None
Hydropower plants in Kyoga Nile	None	None
Results		
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 3% • P (level is 10.8-11.6 m) = 24% • P (level > 12 m) = 50%	As for baseline
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 25% • P (level is 11-12 m) = 28% • P (level > 13 m) = 7%	• P (level < 11 m) = 31% • P (level is 11-12 m) = 31% • P (level > 13 m) = 4%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 19% • P (flow >1,250 m^3/s) = 38%	As for baseline
R. Nile flow from the system	• P (flow < 500 m^3/s) = 11% • P (flow is 500-750 m^3/s) = 29% • P (flow > 1,250 m^3/s) = 29%	• P (flow < 500 m^3/s) = 13% • P (flow is 500-750 m^3/s) = 33% • P (flow > 1,250 m^3/s) = 24%
Irrigation water demand	Low (< 120 million m^3/year)	Moderate water demand (120-180 million m^3/year)
Social impacts in Kyoga Nile	None	None
Environmental impacts in Kyoga	None	None
Social impacts in Victoria Nile	None	None
Environmental impacts in Victoria	None	None

The states of the variables show little difference with those in the baseline scenario indicating that increasing irrigation area by 50% of the 2006 level does not have a significant impact on Lake Kyoga level and the flow of the Nile exiting the basin.

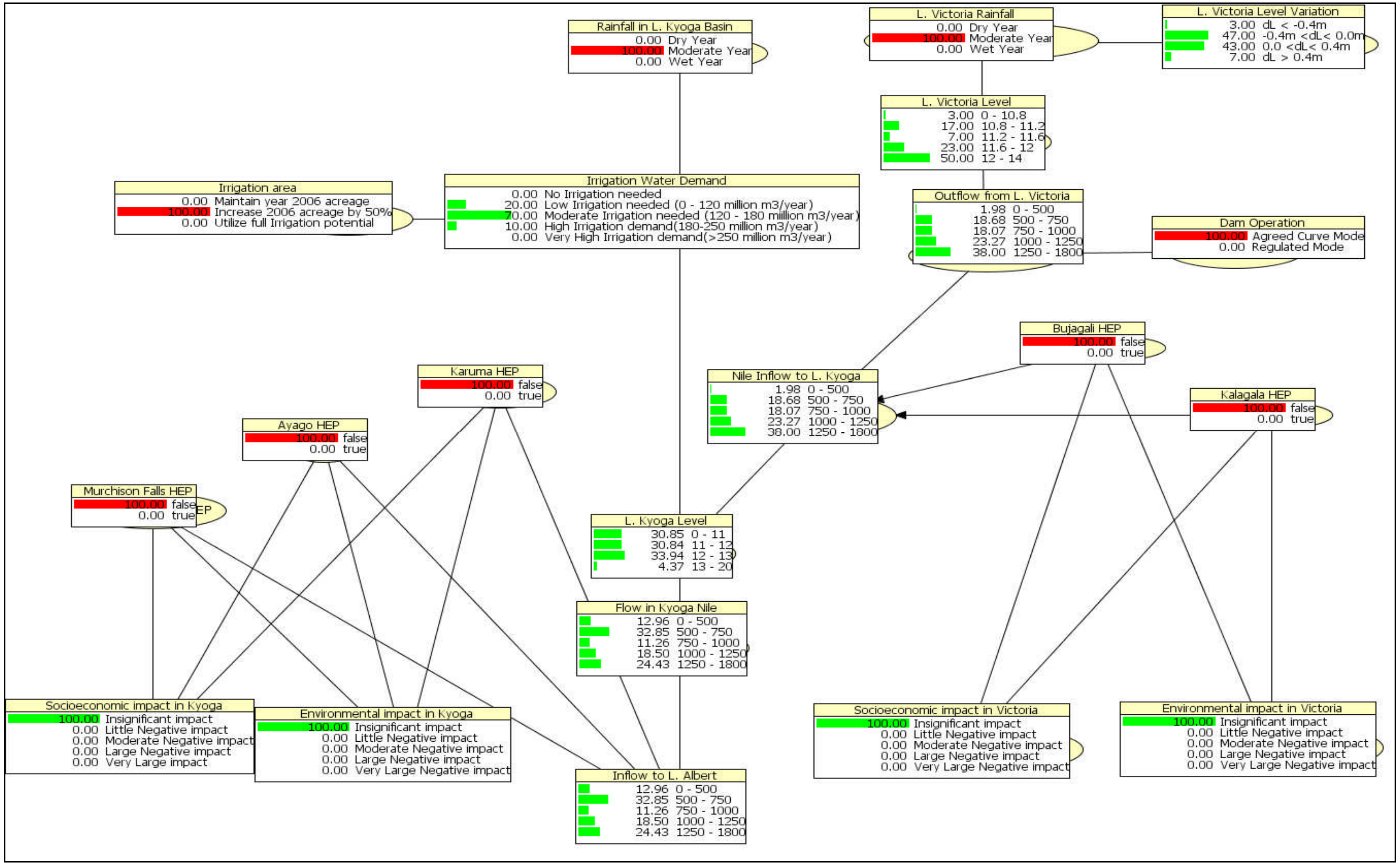


Figure 7.5 Bayesian network of the result for irrigation area of 2006 increased by 50% scenario

7.5.2 Utilizing Full Irrigation Potential in the Basin

This scenario shows the case when all the available area for irrigation is put to use. It shows the situation of maximum water use for irrigation during moderate rainfall years. All variables assume the states of the baseline scenario except the irrigation area which is put to full irrigation potential. Table 7.5 and figure 7.6 show the results.

By increasing irrigation to the full potential there is an increased probability of having Lake Kyoga levels less than 11 m of 10% from that for the baseline scenario. The probability of having the river Nile flows exiting the system being greater than 1,250 m^3/s is reduced by 8%. This result shows that the effect of irrigation to the river flow and Lake Kyoga level becomes noticeable only when the full irrigation potential is utilized. Even then, for moderate rainfall conditions the reduction in Lake Kyoga levels and the flow of the Nile exiting the basin is low.

Table 7.5 Description of states of variables and results for full irrigation potential scenario

Variable	**State/ Scenario**		
	Baseline	**Irrigation increased by 50%**	**Full Irrigation**
Natural events			
Rainfall in L. Victoria	Moderate	Moderate	Moderate
Rainfall in L. Kyoga basin	Moderate	Moderate	Moderate
Decision events			
Irrigation area	Irrigation area of 2006	Irrigation area increased by 50%	Full Irrigation
Dam operation mode	Agreed curve	Agreed curve	Agreed curve
New hydropower plants in Victoria Nile	None	None	None
Hydropower plants in Kyoga Nile	None	None	None
Results			
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 3% • P (level is 10.8-11.6 m) = 24% • P (level > 12 m) = 50%	As for baseline	As for baseline
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 25% • P (level is 11-12 m) = 28% • P (level > 13 m) = 7%	• P (level < 11 m) = 31% • P (level is 11-12 m) = 31% • P (level > 13 m) = 4%	• P (level < 11 m) = 35% • P (level is 11-12 m) = 32% • P (level > 13 m) = 3%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 19% • P (flow >1,250 m^3/s) = 38%	As for baseline	As for baseline
R. Nile flow from the system	• P (flow < 500 m^3/s) = 11% • P (flow is 500-750 m^3/s) = 29% • P (flow > 1,250 m^3/s) = 29%	• P (flow < 500 m^3/s) = 13% • P (flow is 500-750 m^3/s) = 33% • P (flow > 1,250 m^3/s) = 24%	• P (flow < 500 m^3/s) = 15% • P (flow is 500-750 m^3/s) = 35% • P (flow > 1,250 m^3/s) = 21%
Irrigation water demand	Low (< 120 million m^3/year)	Moderate (120-180 million m^3/year)	High (180-250 million m^3/year)
Social impacts in Kyoga Nile	None	None	None
Environmental impacts in Kyoga	None	None	None
Social impacts in Victoria Nile	None	None	None
Environmental impacts in Victoria	None	None	None

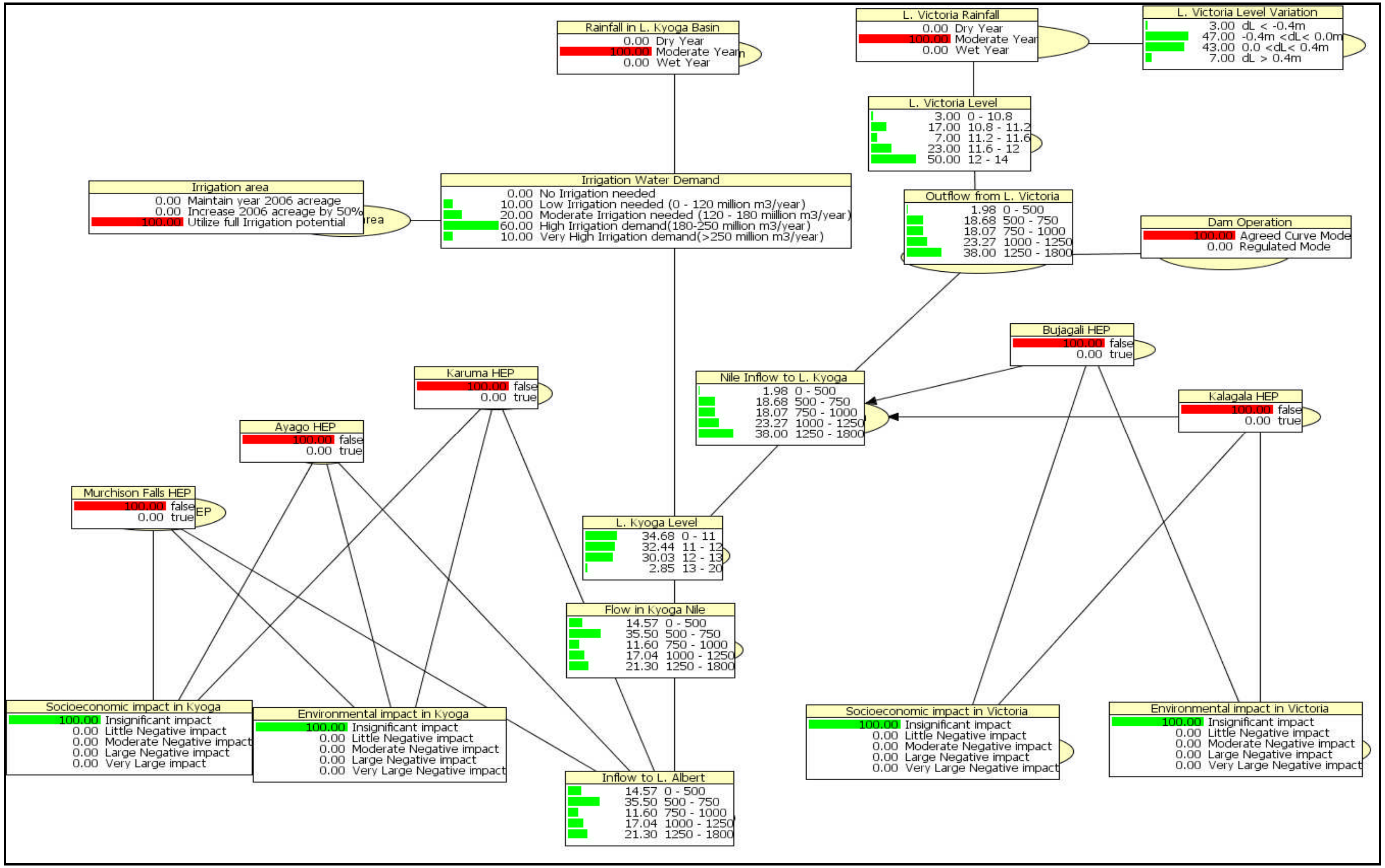


Figure 7.6 Bayesian network of the result for full irrigation potential scenario

7.6 Effect of Rainfall

The effect of rainfall on the basin was investigated by assuming a low rainfall year and then a high rainfall year. Leaving irrigation area and hydropower plants states the same as for the baseline scenario the results were compared with the baseline results.

7.6.1 Low Rainfall Scenario

The low rainfall scenario occurs when the rainfall state is dry but all other variables are as in the baseline scenario. Table 7.6 and figure 7.7 show the results of the low rainfall scenario. The results for the high rainfall scenario (discussed in the next section) are also presented in the last column to make comparison easy.

The effect of low rainfall is to reduce Lake Victoria and Lake Kyoga levels and the river flow out of the basin. For Lake Kyoga the probability of having lake levels greater than 13 m is reduced to 1% while for Lake Victoria the probability of having levels greater than 12 m is reduced by 30%. River flows out of the basin have probability of being greater than 1,250 m^3/s reduced by 16%.

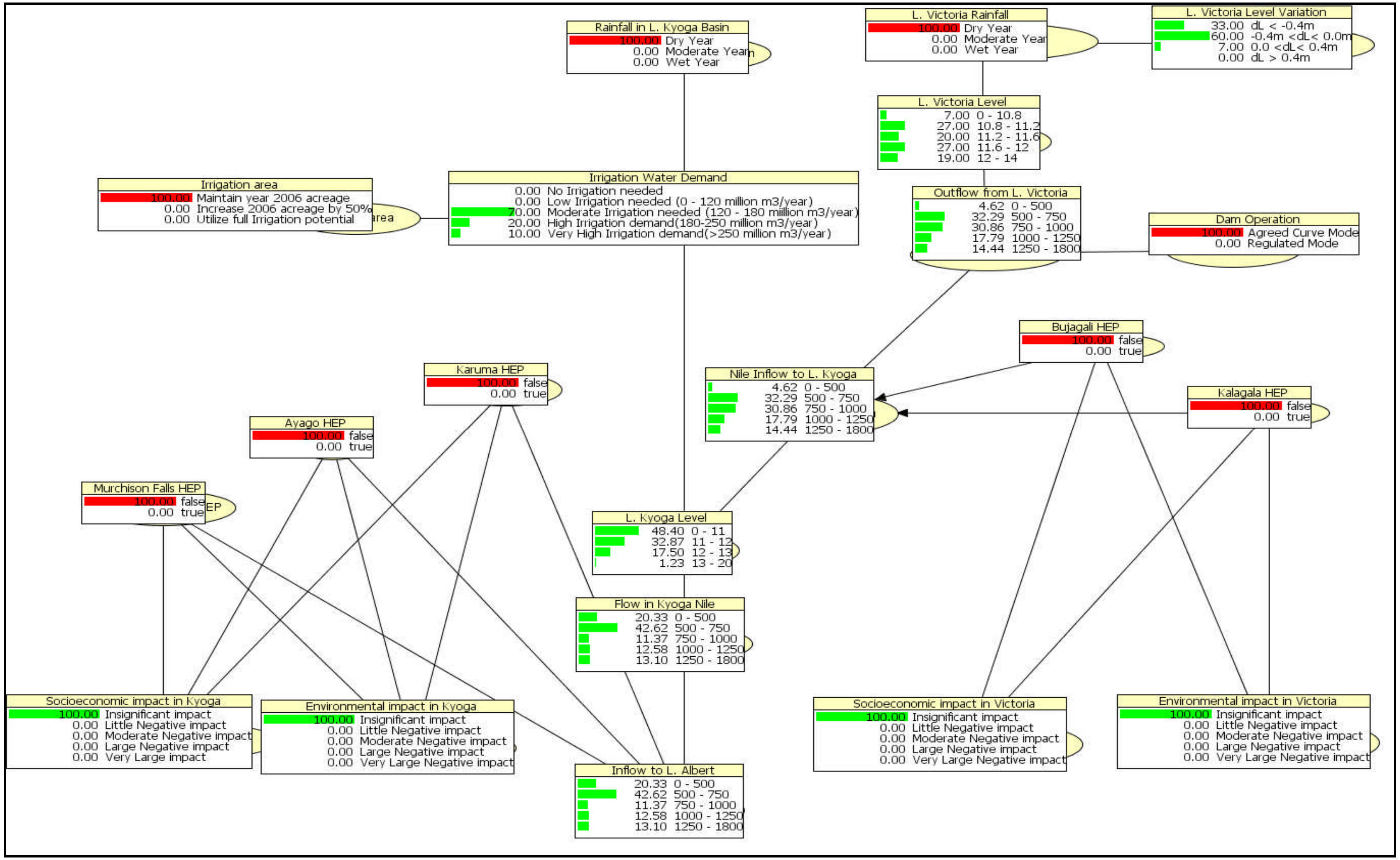


Figure 7.7 Bayesian network of the result for low rainfall scenario

Table 7.6 Description of states of variables and results for the low rainfall and high rainfall scenarios

Variable	State/ Scenario		
	Baseline	**Low rainfall**	**High rainfall**
Natural events			
Rainfall in L. Victoria	Moderate	Dry year	Wet year
Rainfall in L. Kyoga basin	Moderate	Dry year	Wet year
Decision events			
Irrigation area	Irrigation area of 2006	Irrigation area of 2006	Irrigation area of 2006
Dam operation mode	Agreed curve	Agreed curve	Agreed curve
New hydropower plants in Victoria	None	None	None
Hydropower plants in Kyoga Nile	None	None	None
Results			
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 3% • P (level is 10.8-11.6 m) = 24% • P (level > 12 m) = 50%	• P (level < 10.8 m) = 7% • P (level is 10.8-11.6 m) = 47% • P (level > 12 m) = 19%	• P (level < 10.8 m) = 0.01% • P (level is 10.8-11.6 m) = 11% • P (level > 12 m) = 67%
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 25% • P (level is 11-12 m) = 28% • P (level > 13 m) = 7%	• P (level < 11 m) = 48% • P (level is 11-12 m) = 33% • P (level > 13 m) = 1%	• P (level < 11 m) = 8% • P (level is 11-12 m) = 18% • P (level > 13 m) = 13%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 19% • P (flow >1,250 m^3/s) = 38%	• P (flow < 500 m^3/s) = 5% • P (flow is 500-750 m^3/s) = 32% • P (flow >1,250 m^3/s) = 14%	• P (flow < 500 m^3/s) = 0.01% • P (flow is 500-750 m^3/s) = 10% • P (flow >1,250 m^3/s) = 51%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 11% • P (flow is 500-750 m^3/s) = 29% • P (flow > 1,250 m^3/s) = 29%	• P (flow < 500 m^3/s) = 20% • P (flow is 500-750 m^3/s) = 43% • P (flow > 1,250 m^3/s) = 13%	• P (flow < 500 m^3/s) = 3% • P (flow is 500-750 m^3/s) = 16% • P (flow > 1,250 m^3/s) = 44%
Irrigation water demand	Low (< 120 million m^3/year)	Moderate (120-180 million m^3/year)	No irrigation required
Social impacts in Kyoga Nile	None	None	None
Environmental impacts in Kyoga	None	None	None
Social impacts in Victoria Nile	None	None	None
Environmental impacts in Victoria	None	None	None

7.6.2 High rainfall Scenario

The high rainfall scenario occurs during the wet years as defined in 6.3.1 and 6.3.7. For this scenario all variables except rainfall in Lake Victoria and Kyoga catchment are the same as those of the baseline scenario. Figure 7.8 shows the variable states and the results for the entire network. The summary results for the key variables are presented in table 7.6 together with the low rainfall scenario.

High rainfall like low rainfall has a large effect to the system. For a wet year, Lake Victoria levels are less than 11.6 m only 11% of the time while those for Lake Kyoga are less than 11 m in only 8% of the time. River flow exiting the basin is high and is very unlikely to be less than 500m^3/s.

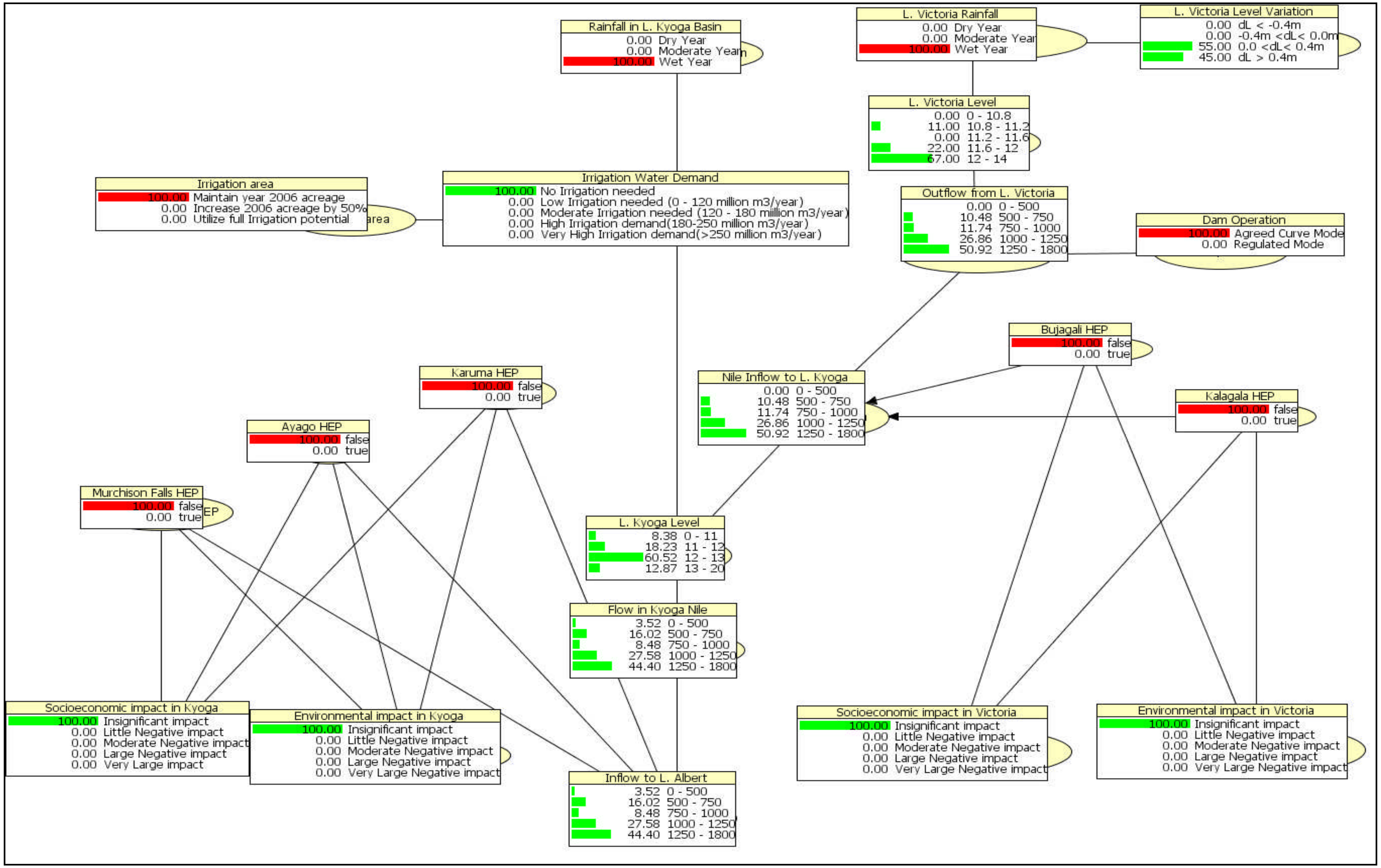


Figure 7.8 Bayesian network of the result for high rainfall scenario

7.7 High Water Demand Scenario

Water demand in the basin increases with the amount of development and the scarcity of rainfall. Water demand is expected to be highest during the dry years. Therefore, for this scenario, simulations of the different development options were made for the dry year state only. This section gives the results for the worst case scenario when irrigation potential is fully utilized and all possible hydroelectric power stations are developed. Additional simulations are for the cases when some hydropower plants are developed while others are not. The results show the water resources state in the basin when subjected to different water use developments when the water supply is low.

7.7.1 Highest water demand scenario

The highest water use scenario occurs during dry years when there is maximum demand for irrigation water and all possible hydroelectric power plants are developed. This scenario therefore describes the situation in which water use in the catchment is at the maximum level. The results obtained for this scenario show the water resources state in the basin when subjected to maximum water and energy demand. The following characteristics prevail:

- Rainfall state is dry.
- The full irrigation potential is utilized (estimated as 128,865 ha) and therefore very high water demand estimated at 250-1800 million m^3per year. This is equivalent to about 7% of the Nile flow exiting the Victoria Nile basin. The average annual Victoria Nile flow for the period 1896-2005 is estimated to be 27,350 million cubic metres,
- All possible hydroelectric power plants along the Victoria Nile are developed.

A summary of the states of the different variables and results of this scenario together with those of the baseline scenario are given in table 7.7. The behaviour of the entire system with details of results of other variables is shown in the results network in figure 7.9.

Table 7.7 Description of states of variables and results for the highest water use scenario

Variable	State/ Scenario	
	Baseline	**Highest water demand**
Natural events		
Rainfall in L. Victoria	Moderate	Dry
Rainfall in L. Kyoga basin	Moderate	Dry
Decision events		
Irrigation area	Irrigation area of 2006	Full Irrigation
Dam operation mode	Agreed curve	Agreed curve
New hydropower plants in Victoria Nile	None	Bujagali and Kalagala
Hydropower plants in Kyoga Nile	None	Karuma, Ayago and Murchison
Results		
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 3% • P (level is 10.8-11.6 m) = 24% • P (level > 12 m) = 50%	• P (level < 10.8 m) = 7% • P (level is 10.8-11.6 m) = 47% • P (level > 12 m) = 19%
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 25% • P (level is 11-12 m) = 28% • P (level > 13 m) = 7%	• P (level < 11 m) = 60% • P (level is 11-12 m) = 29% • P (level > 13 m) = 0.5%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 19% • P (flow >1,250 m^3/s) = 38%	• P (flow < 500 m^3/s) = 15% • P (flow is 500-750 m^3/s) = 31% • P (flow >1,250 m^3/s) = 10%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 11% • P (flow is 500-750 m^3/s) = 29% • P (flow > 1,250 m^3/s) = 29%	• P (flow < 500 m^3/s) = 34% • P (flow is 500-750 m^3/s) = 42% • P (flow > 1,250 m^3/s) = 6%
Irrigation water demand	Low (< 120 million m^3/year)	Very high water demand (>250 million m^3/year)
Social impacts in Kyoga Nile region	None	Large to very large negative
Environmental impacts in Kyoga	None	Large to very large negative
Social impacts in Victoria Nile region	None	Large negative
Environmental impacts in Victoria	None	Moderate negative

Comparing the highest water use scenario with the baseline shows that when the dry years prevail the probability of Lake Victoria levels being greater than 12 m is reduced by 30%. Lake Victoria levels vary over a wide range of 10.8-12 m. Lake Kyoga levels have a high probability of 60% of being less than 11 m and with almost no possibility of rising above 13 m. The river flows exiting the basin have an increased probability of 36% of being less than 750m^3/s.

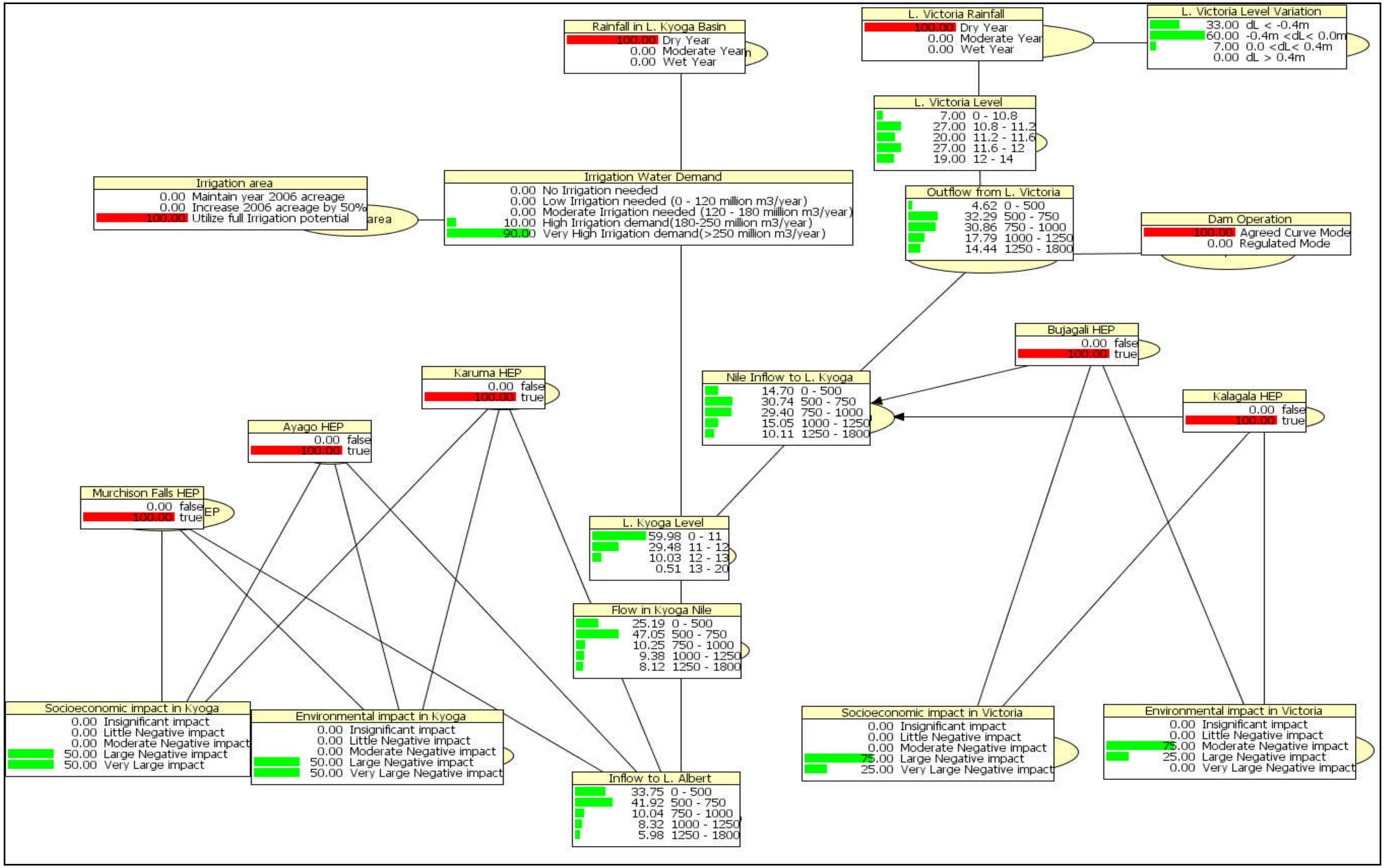


Figure 7.9 Bayesian network for the system under the highest water use scenario

The following simulations show the effect of varying irrigation area and hydropower developments during the dry years.

For the simulations that follow it was assumed that the Bujagali plant was in operation for all cases since it was clear at the time of writing this thesis that any other plant would be put into service after Bujagali. Since the development of Karuma was also in an advanced stage it was further assumed that any development of plants in the Kyoga Nile would be additional to Karuma.

7.7.2 Karuma Plant Scenario

2006 level of Irrigation

This scenario is when the Karuma hydroelectric plant is developed in addition to Bujagali and the 2006 level of irrigation is maintained. The rainfall state is dry. The results together with the baseline and the maximum water demand scenarios are presented in table 7.8 and figure 7.10.

As can be seen from the results in table 7.8 and figure 7.10 for this scenario results are fairly similar to those for the highest water demand scenario. This implies that for the dry years when irrigation is maintained at the 2006 area, having only one hydropower plant in each section of the Victoria Nile gives same results as having all plants developed.

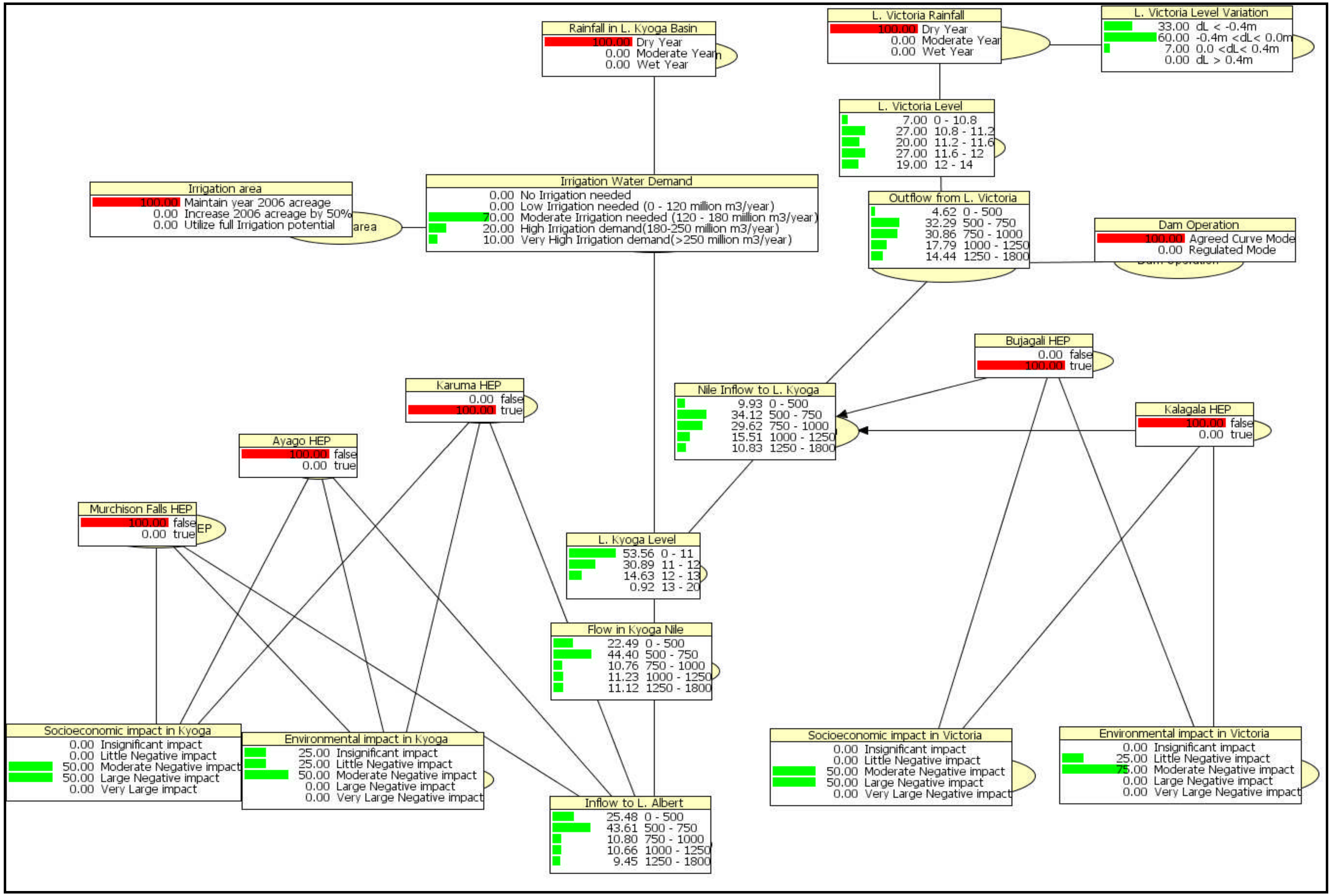


Figure 7.10 Bayesian Network for the Karuma with 2006 Irrigation scenario

Table 7.8 Description of states of variables and the results for the Karuma with 2006 irrigation scenario

Variable	**State/ Scenario**		
	Baseline	**Karuma & 2006 Irrigation**	**Highest water Demand**
Natural events			
Rainfall in L. Victoria	Moderate	Dry	Dry
Rainfall in L. Kyoga basin	Moderate	Dry	Dry
Decision events			
Irrigation area	Irrigation area of 2006	Irrigation area of 2006	Full irrigation utilisation
Dam operation mode	Agreed curve	Agreed curve	Agreed curve
Hydropower plants in Victoria Nile	None	Bujagali	Bujagali & Kalagala
Hydropower plants in Kyoga Nile	None	Karuma	Karuma, Ayago and Murchison
Results			
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 14% • P (level is 10.8-11.6 m) = 43% • P (level > 12 m) = 31%	As for highest water demand	• P (level < 10.8 m) = 7% • P (level is 10.8-11.6 m) = 47% • P (level > 12 m) = 19%
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 42% • P (level is 11-12 m) = 27% • P (level > 13 m) = 4%	• P (level < 11 m) = 53% • P (level is 11-12 m) = 31% • P (level > 13 m) = 1%	• P (level < 11 m) = 60% • P (level is 11-12 m) = 29% • P (level > 13 m) = 0.5%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 9% • P (flow is 500-750 m^3/s) = 32% • P (flow >1,250 m^3/s) = 24%	• P (flow < 500 m^3/s) = 10% • P (flow is 500-750 m^3/s) = 34% • P (flow >1,250 m^3/s) = 11%	• P (flow < 500 m^3/s) = 15% • P (flow is 500-750 m^3/s) = 31% • P (flow >1,250 m^3/s) = 10%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 18% • P (flow is 500-750 m^3/s) = 37% • P (flow > 1,250 m^3/s) = 20%	• P (flow < 500 m^3/s) = 25% • P (flow is 500-750 m^3/s) = 44% • P (flow > 1,250 m^3/s) = 9%	• P (flow < 500 m^3/s) = 34% • P (flow is 500-750 m^3/s) = 42% • P (flow > 1,250 m^3/s) = 6%
Irrigation water demand	Low (< 120 million m^3/year)	Moderate (120-180 million m^3/year)	Very high (>250 million m^3/year)
Social impacts in Kyoga Nile	None	Moderate to large negative	Large to very large negative
Environmental impacts in Kyoga	None	Moderate negative	Large to very large negative
Social impacts in Victoria Nile	None	Moderate to large negative	Large negative
Environmental impacts in Victoria	None	Moderate negative	Moderate negative

Full irrigation potential utilized

In this case the full irrigation potential in the basin is utilized instead of the 2006 level. The results are shown in table 7.9 and figure 7.11.

Increasing the irrigation area from the 2006 level to the full irrigation potential increases the probability of having Lake Kyoga levels less than 11 m by 6% only. The rest of the variables are not significantly different from the 2006 irrigation level results. This could be because irrigation water in the basin is drawn from tributaries that flow into Lake Kyoga. The magnitude of this tributary flow to Lake Kyoga is small compared to the Nile inflow to the lake. This means any changes to the tributary flow to the lake would result into small changes to the lake level and lake outflows. Because of this result, all the following scenarios had the full irrigation potential as the state of irrigation area and it was only the hydropower plants that were varied.

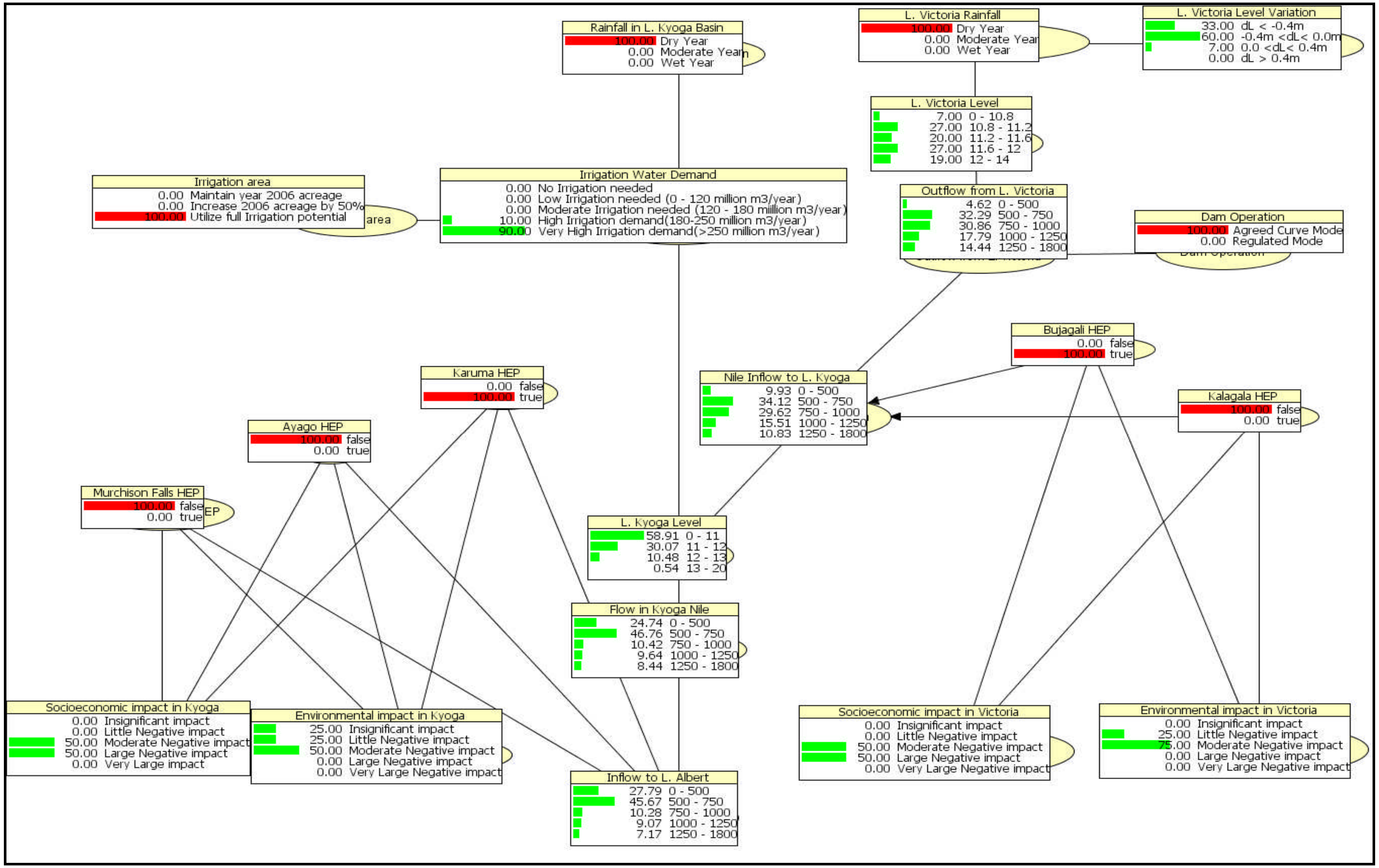


Figure 7.11 Bayesian Network for Karuma with full Irrigation potential scenario

Table 7.9 Description of states of variables and the results for the Karuma with full irrigation potential scenario

Variable	State/ Scenario			
	Baseline	**Karuma & 2006 Irrigation**	**Karuma & Full Irrigation**	**Highest water Demand**
Natural events				
Rainfall in L. Victoria	Moderate	Dry	Dry	Dry
Rainfall in L. Kyoga basin	Moderate	Dry	Dry	Dry
Decision events				
Irrigation area	Irrigation area of 2006	Irrigation area of 2006	Full Irrigation utilisation	Full irrigation utilisation
Dam operation mode	Agreed curve	Agreed curve	Agreed curve	Agreed curve
Hydropower plants in Victoria Nile	None	Bujagali	Bujagali	Bujagali & Karuma
Hydropower plants in Kyoga Nile	None	Karuma	Karuma	Karuma, Ayago and Murchison
Results				
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 3% • P (level is 10.8-11.6 m) = 24% • P (level > 12 m) = 50%	As for highest water demand	As for highest water demand	• P (level < 10.8 m) = 7% • P (level is 10.8-11.6 m) = 47% • P (level > 12 m) = 19%
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 25% • P (level is 11-12 m) = 28% • P (level > 13 m) = 7%	• P (level < 11 m) = 53% • P (level is 11-12 m) = 31% • P (level > 13 m) = 1%	• P (level < 11 m) = 59% • P (level is 11-12 m) = 30% • P (level > 13 m) = 0.5%	• P (level < 11 m) = 60% • P (level is 11-12 m) = 29% • P (level > 13 m) = 0.5%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 19% • P (flow >1,250 m^3/s) = 38%	• P (flow < 500 m^3/s) = 10% • P (flow is 500-750 m^3/s) = 34% • P (flow >1,250 m^3/s) = 11%	As for Karuma & 2006 Irrigation	• P (flow < 500 m^3/s) = 15% • P (flow is 500-750 m^3/s) = 31% • P (flow >1,250 m^3/s) = 10%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 11% • P (flow is 500-750 m^3/s) = 29% • P (flow > 1,250 m^3/s) = 29%	• P (flow < 500 m^3/s) = 25% • P (flow is 500-750 m^3/s) = 44% • P (flow > 1,250 m^3/s) = 9%	• P (flow < 500 m^3/s) = 28% • P (flow is 500-750 m^3/s) = 46% • P (flow > 1,250 m^3/s) = 7%	• P (flow < 500 m^3/s) = 34% • P (flow is 500-750 m^3/s) = 42% • P (flow > 1,250 m^3/s) = 6%
Irrigation water demand	Low (< 120 million m^3/year)	Moderate (120-180 million m^3/year)	As for highest water demand	Very high (>250 million m^3/year)
Social impacts in Kyoga Nile region	None	Moderate to large negative	Moderate to large negative	Large to very large negative
Environmental impacts in Kyoga Nile	None	Moderate negative	Moderate negative	Large to very large negative
Social impacts in Victoria Nile region	None	Moderate to large negative	Moderate to large negative	Large negative
Environmental impacts in Victoria	None	Moderate negative	Moderate negative	Moderate negative

An additional scenario is development of Kalagala in addition to Karuma. The results of this are not presented here, however the simulation shows that by developing Kalagala in addition to Bujagali and Karuma there is no significant change seen in the key variables of Lake Kyoga level and river flow exiting the basin.

The above scenarios in which Karuma is developed and other variable states change are very important because it is very likely that Karuma is indeed going to be developed soon. The highest water use situation when Karuma is the only hydroelectric plant developed in the Kyoga Nile occurs when Kalagala hydropower plant is developed and the full irrigation potential in the basin is utilized. It is shown that for this scenario compared to the baseline scenario there are no significant changes to lake levels and the amount of flow of the Nile leaving the basin.

7.7.3 Murchison Falls and Ayago Plants

This scenario occurs when, in addition to Karuma in the Kyoga Nile, either Ayago or Murchison falls hydropower plant is developed. A dry year is considered and full irrigation potential is utilized. Table 7.10 and figure 7.12 show the results of this scenario. Similar results are obtained with Ayago instead of Murchison.

The results in section 7.7 show that for a dry year the effect of developments is significant only when all hydropower plants and the full irrigation potential is utilised. By varying the number of hydropower plants or the irrigation area there is no significant change to lake levels and the river flow exiting the basin. This suggests that rainfall occurrence is the major factor in the basin rather than which combinations of developments are undertaken.

Table 7.10 Description of states of variables for the Murchison and Karuma with full irrigation potential scenario and the results

Variable	State/ Scenario			
	Murchison/Ayago & Karuma with full irrigation	**Karuma & 2006 Irrigation**	**Karuma & Full Irrigation**	**Highest water Demand**
Natural events				
Rainfall in L. Victoria	Dry	Dry	Dry	Dry
Rainfall in L. Kyoga basin	Dry	Dry	Dry	Dry
Decision events				
Irrigation area	Full Irrigation utilisation	Irrigation area of 2006	Full Irrigation utilisation	Full irrigation utilisation
Dam operation mode	Agreed curve	Agreed curve	Agreed curve	Agreed curve
Hydropower plants in Victoria Nile	Bujagali	Bujagali	Bujagali	Bujagali & Karuma
Hydropower plants in Kyoga Nile	Karuma & Murchison	Karuma	Karuma	Karuma, Ayago and Murchison
Results				
L. Victoria level (Jinja gauge)	As for highest water demand	As for highest water demand	As for highest water demand	• P (level < 10.8 m) = 7% • P (level is 10.8-11.6 m) = 47% • P (level > 12 m) = 19%
L. Kyoga level (Masindi gauge)	As for Karuma & full irrigation	• P (level < 11 m) = 53% • P (level is 11-12 m) = 31% • P (level > 13 m) = 1%	• P (level < 11 m) = 59% • P (level is 11-12 m) = 30% • P (level > 13 m) = 0.5%	• P (level < 11 m) = 60% • P (level is 11-12 m) = 29% • P (level > 13 m) = 0.5%
Victoria Nile flow to L. Kyoga	As for Karuma & 2006 Irrigation	• P (flow < 500 m^3/s) = 10% • P (flow is 500-750 m^3/s) = 34% • P (flow >1,250 m^3/s) = 11%	As for Karuma & 2006 Irrigation	• P (flow < 500 m^3/s) = 15% • P (flow is 500-750 m^3/s) = 31% • P (flow >1,250 m^3/s) = 10%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 30% • P (flow is 500-750 m^3/s) = 44% • P (flow > 1,250 m^3/s) = 7%	• P (flow < 500 m^3/s) = 25% • P (flow is 500-750 m^3/s) = 44% • P (flow > 1,250 m^3/s) = 9%	• P (flow < 500 m^3/s) = 28% • P (flow is 500-750 m^3/s) = 46% • P (flow > 1,250 m^3/s) = 7%	• P (flow < 500 m^3/s) = 34% • P (flow is 500-750 m^3/s) = 42% • P (flow > 1,250 m^3/s) = 6%
Irrigation water demand	As for highest water demand	Moderate (120-180 million m^3/year)	As for highest water demand	Very high (>250 million m^3/year)
Social impacts in Kyoga Nile region	Large negative	Moderate to large negative	Moderate to large negative	Large to very large negative
Environmental impacts in Kyoga Nile	Large negative	Moderate negative	Moderate negative	Large to very large negative
Social impacts in Victoria Nile region	Moderate to large negative	Moderate to large negative	Moderate to large negative	Large negative
Environmental impacts in Victoria Nile	Moderate negative	Moderate negative	Moderate negative	Moderate negative

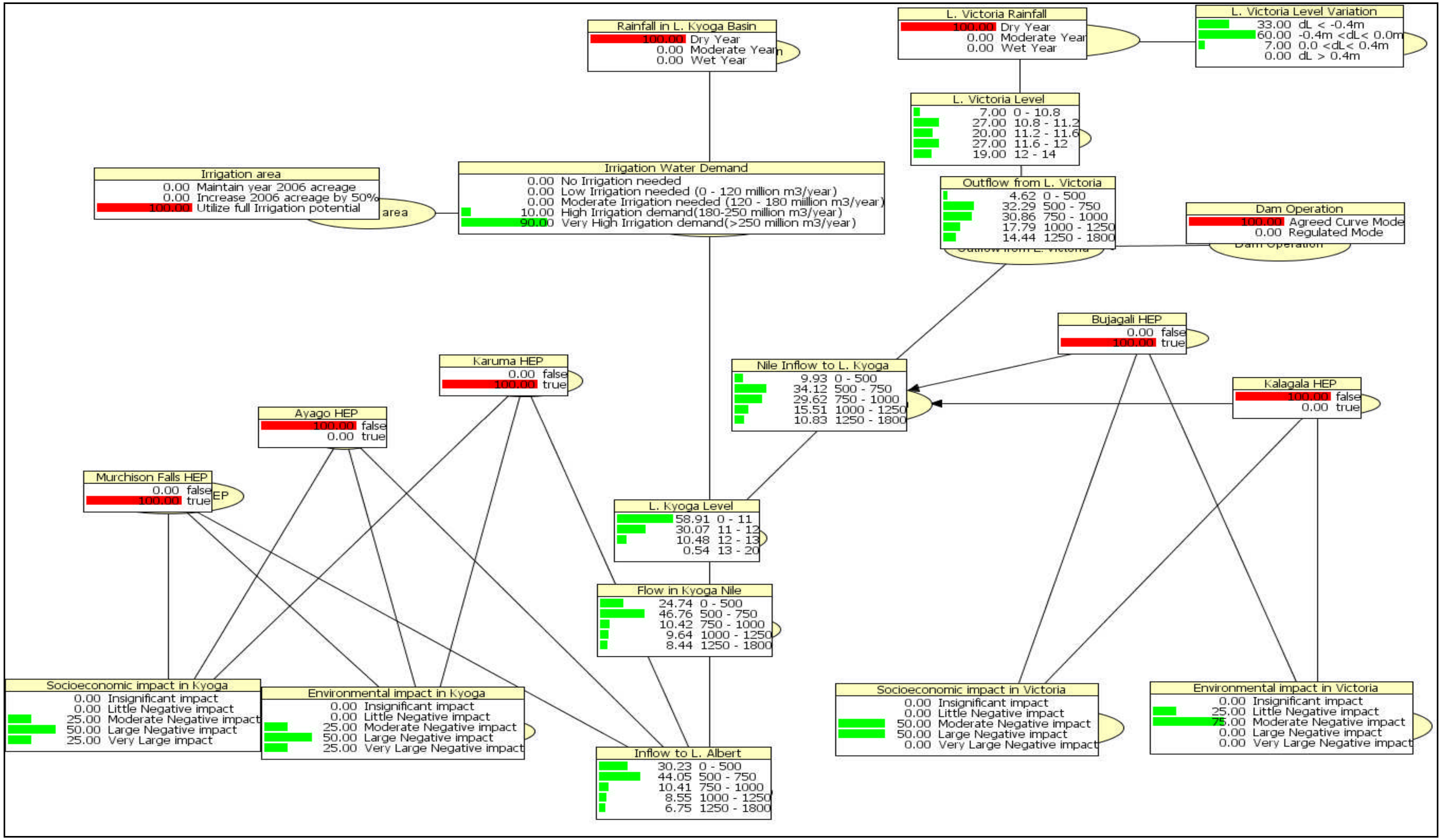


Figure 7.12 Bayesian Network for the Murchison and Karuma with full irrigation potential scenario

7.8 Low Water Use Scenario

The low water use scenario occurs during the wet years when irrigation water is not required. For wet years, changing the irrigation land area does not change the hydrology of the catchment because the crop water requirement is adequately supplied by the rainfall and therefore there is no need for irrigation water. For this scenario it is assumed that only the Bujagali and Karuma hydroelectric plants are developed. This is because at the time of writing, the Bujagali hydropower project was under construction while development of Karuma plant was in advanced stages and the Government of Uganda had secured part funding for its construction. Description of variable states and results of running the network for this scenario are presented in table 7.11 and figure 7.13.

River Nile flows out of the basin during wet years have a probability of 67% of being greater than1,000 m^3/s. The probability that the flows will be below 500 m^3/s is only 8%.

Table 7.11 Description of states of variables for the low water use scenario and the results

Variable	State/ Scenario		
	Low water use	**Karuma & full Irrigation**	**Highest water demand**
Natural events			
Rainfall in L. Victoria	Wet	Dry	Dry
Rainfall in L. Kyoga basin	Wet	Dry	Dry
Decision events			
Irrigation area	Full irrigation utilisation	Full Irrigation utilisation	Full irrigation utilisation
Dam operation mode	Agreed curve	Agreed curve	Agreed curve
Hydropower plants in Victoria Nile	Bujagali	Bujagali	Bujagali & Karuma
Hydropower plants in Kyoga Nile	Karuma	Karuma	Karuma, Ayago and Murchison
Results			
L. Victoria level (Jinja gauge)	• P (level < 10.8 m) = 0.01% • P (level is 10.8-11.6 m) = 11% • P (level > 12 m) = 67%	As for highest water demand	• P (level < 10.8 m) = 7% • P (level is 10.8-11.6 m) = 47% • P (level > 12 m) = 19%
L. Kyoga level (Masindi gauge)	• P (level < 11 m) = 14% • P (level is 11-12 m) = 23% • P (level > 13 m) = 10%	• P (level < 11 m) = 59% • P (level is 11-12 m) = 30% • P (level > 13 m) = 0.5%	• P (level < 11 m) = 60% • P (level is 11-12 m) = 29% • P (level > 13 m) = 0.5%
Victoria Nile flow to L. Kyoga	• P (flow < 500 m^3/s) = 2% • P (flow is 500-750 m^3/s) = 15% • P (flow >1,250 m^3/s) = 38%	• P (flow < 500 m^3/s) = 10% • P (flow is 500-750 m^3/s) = 34% P (flow >1,250 m^3/s) = 11%	• P (flow < 500 m^3/s) = 15% • P (flow is 500-750 m^3/s) = 31% • P (flow >1,250 m^3/s) = 10%
R. Nile flow from the system	• P (flow < 500 m^3/s) = 8% • P (flow is 500-750 m^3/s) = 23% • P (flow > 1,250 m^3/s) = 33%	• P (flow < 500 m^3/s) = 28% • P (flow is 500-750 m^3/s) = 46% • P (flow > 1,250 m^3/s) = 7%	• P (flow < 500 m^3/s) = 34% • P (flow is 500-750 m^3/s) = 42% • P (flow > 1,250 m^3/s) = 6%
Irrigation water demand	No irrigation needed	As for highest water demand	Very high (>250 million m^3/year)
Social impacts in Kyoga Nile region	Moderate to large negative	Moderate to large negative	Large to very large negative
Environmental impacts in Kyoga Nile	Moderate negative	Moderate negative	Large to very large negative
Social impacts in Victoria Nile region	Moderate to large negative	Moderate to large negative	Large negative
Environmental impacts in Victoria Nile	Moderate negative	Moderate negative	Moderate negative

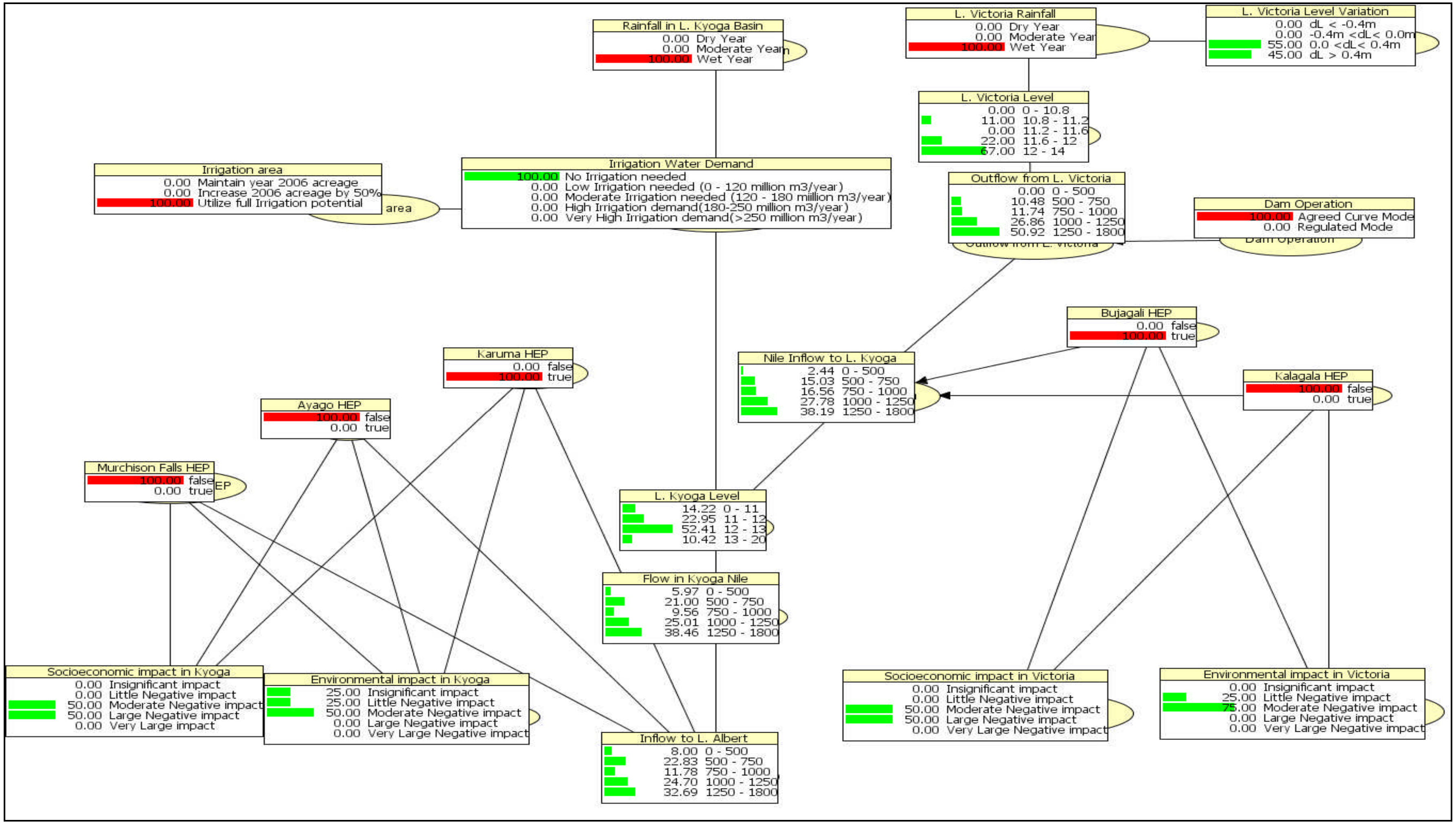


Figure 7.13 Bayesian network result for the low water use scenario

7.9 Effect of Outflow Operational rule on River Flow

The effect of outflow operational rule was investigated for the dry, moderate and wet year scenarios. This was done by applying the operation mode to the agreed curve then to the regulated mode in turns for each of the rainfall states. Changing the operation mode does not significantly change the characteristics of the Nile flow for the dry and moderate rainfall states, however for the wet years the effect is significant (figure 7.14).

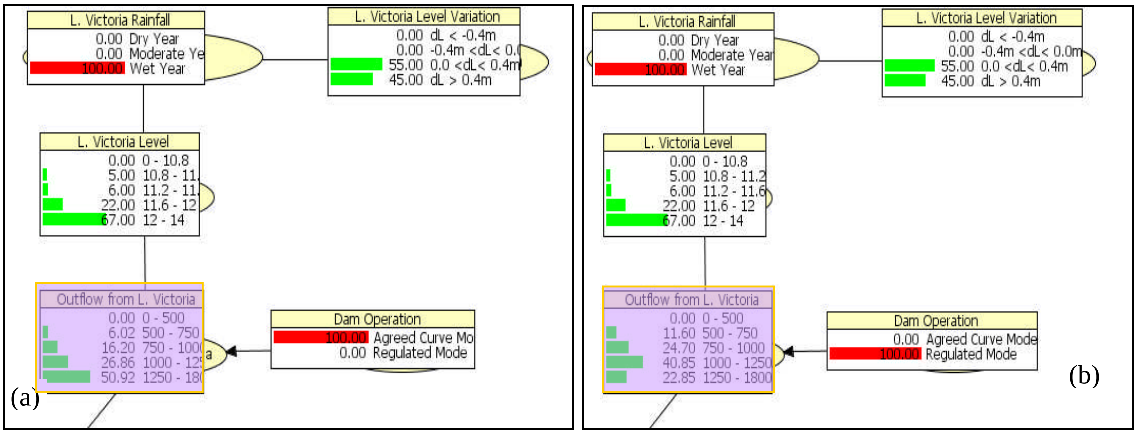


Figure 7.14 Effect of the operating mode on Lake Victoria outflows for a wet year (a) is when the agreed curve is applied and (b) is when the regulated mode is applied. The shaded nodes show the change in Lake Victoria outflows pattern.

For wet years applying the agreed curve operation would result into about 77% probability of outflows being above 1,000 m^3/s while the regulated mode would reduce this probability to 63 % (figure 7.14). This implies that for the wet years the regulated mode would have the effect of reducing the outflows as compared to the agreed curve.

For wet years the probability for having the annual lake Victoria level change being greater than 0.4 m is 45% (figure 7.14) and for dry years the annual lake Victoria level change has a probability of 33% of being less than 0.4 m (figure 7.12). This means the need for using the regulation mode will be more during the wet years than the dry years.

7.10 Socioeconomic and Environmental Impacts

The socioeconomic and environmental impacts arise from development of hydroelectric power plants. Results are obtained by entering probabilities obtained as described in 6.3.14 and running the program for each of the possible options for hydroelectric power developments in turn. The Bayesian networks showing results of socioeconomic and environmental impacts can be seen in the networks of the previous scenarios. The results obtained give answers to the question *"what would be the magnitude of socioeconomic and environmental impact caused in the vicinity of the project if combinations of projects are implemented"?* Results show that whereas impacts caused by single projects range from little to moderate, those for combinations of projects are significantly large. Running the programme with the option of all the three hydroelectric power projects in the lower Victoria Nile shows that the negative social and environmental impacts will be very large. The results of the impacts of the different possible combinations of hydroelectric power plants are summarised in table 7.12.

Table 7.12 Socioeconomic and environmental impacts of combinations of hydroelectric plants

	Magnitude of Negative impact	
Projects	**Socioeconomic**	**Environmental**
<u>Upper Victoria Nile reach</u>		
Bujagali	Moderate - large	Moderate
Bujagali and Kalagala	Large	Moderate
<u>Lower Victoria (Kyoga) Nile reach</u>		
Karuma	Moderate - large	Moderate
Ayago	Little - moderate	Moderate
Murchison Falls	Large	Large
Karuma and Ayago	Large	Moderate
Karuma and Murchison Falls	Large	Large
Ayago and Murchison Falls	Moderate	Large
Karuma and Ayago and Murchison Falls	Large - very large	Large to very large

Table 7.13 below is a summary of the impacts of different scenarios to show the relative difference and similarities between them.

Table 7.13 Summary of impact of developments to the water resources in the Victoria Nile

Summary Table				
Variables	**Scenarios**			
	Baseline (2006)	All HEP	Full Irrigation	Full Irrigation, All HEPs and Dry year (Highest water demand)
L. Kyoga Level P(Lake level ≤ 11m)	25%	33%	35%	60%
Nile Flow to L. Kyoga P(River flow ≤ 500 m^3/s)	2%	8%	2%	15%
Nile Flow from L. Kyoga P(River flow ≤ 500 m^3/s)	11%	21%	15%	34%

Note: P(X) is probability of X

Chapter 8 Discussions

8.1 Introduction

The limited knowledge of water resources distribution in the Victoria Nile basin amidst a complex occurrence of natural and anthropogenic events prompted this study. In the lower riparian states of the river Nile there is long hydrological record, but in the Victoria Nile headwaters there is a lack of such data. While the river Nile is well known for its long history, it was found that the Victoria Nile sub-basin is lacking in hydrological data. The gaps in the available water resources data in this river Nile sub-basin compared to the rest of the Nile basin played a key role in the selection of the methodology used. As such a review of available water resources in the basin was a starting point that had a large influence on the results of the study. Discussions on the occurrence of the available water resources in the basin and how they impact on development have been made in chapter 3. What is presented in this chapter is the discussion of the results of the Bayesian network and few points of emphasis on the water resources.

8.2 Findings

8.2.1 Water Resources in the Victoria basin

The observed difference between the Victoria Nile flows for the pre-1960 and post 1960 periods presented in section 3.3.2 is the most fundamental hydrological event that occurred in the recent history of the Victoria Nile and Lake Victoria. The increase in lake levels and river flows was so great that the maximum Victoria Nile flow for the pre-1960 period did not reach the average flow for the post 1960 period. The high correlation (correlation coefficient of 0.938) between Lake Victoria levels and river flows at Jinja shows how closely related these variables are. Because of the high rainfall in the region during the years 1960-1964, rainfall is considered to be a plausible cause of the increase in lake levels between 1960 and 1964. However, the low correlation found between Lake Victoria rainfall and lake levels (r^2=0.225) was suggestive of other factors affecting Lake Victoria levels. A key point to note in the lake level variations is that while the very high rainfall lasted only about five years, it took close to 40 years (until 2005) for the lake levels and outflows to return to the pre-1960 level. Such anomalies, if not well understood, have serious implications to infrastructure development in the basin. This long period of high Lake Victoria levels made some engineers believe that the lake levels and outflows would remain high and settle at the post 1960 levels. This belief was partly the cause of the over-design of the Kiira hydroelectric plant at Jinja which was designed for a larger capacity than is possible.

8.2.2 Lake Victoria Levels

Results show that Lake Victoria levels vary with the state of annual rainfall in the Lake Victoria basin. In dry years, lake levels are mostly in the range 10.8-12 m while for moderate and wet years lake levels are always greater than 11.6 m on the Jinja gauge. For dry years, the probability that the levels will be lower than 10.8 m is 7%. A lake level of less than 10.8 m has a negative implication for navigation on the lake and hydropower generation downstream of the lake. With only a 7% chance of occurrence it means there is little likelihood of concern on the mode of operation of outflows. To generate more electricity with low lake levels the hydropower plants would need more water flow (equation 8.1). This would cause departure from the agreed curve since the water level is virtually unchanged.

$$P = f(Q, H) \qquad \text{Equation 8.1}$$

Where P: Amount of electricity generated

Q: Water flowing to generation unit

H: Level of water above generation unit.

Lake Victoria levels averaged 11 to 12 m from about 1800 to 1960 (Nicholson et al., 2000). This period had low lake levels compared to the period 1960-2006. A lake level below 10.8 would therefore be low even for this low lake level period. The lowest end of year level recorded was 10.28 m and this occurred in 1922 while the highest recorded level was 12.94 metres which was reached in 1963.

For wet years lake levels are always greater than 11.6 m and have a high chance of 67% of rising above 12 m. This may cause flooding on the shores of the lake and will necessitate allowing more outflow from the lake.

Any significant change in the level of a lake will affect the physical and biological processes within the lake and its surroundings. Other effects include interference with navigation and abstraction of water for various purposes like domestic water supply. Navigation is key on Lake Victoria because there are steamers which transport people and cargo between the Ports of Mwanza in Tanzania, Kisumu in Kenya and Port Bell in Uganda. In Uganda the district of Kalangala is an island on Lake Victoria which can only be accessed by a ferry from the mainland. Navigation activities could be curtailed if lake levels were to fall. As the results show, the lake level is expected to reduce to catastrophic levels only 3.7% of the times and this can only be during dry or moderate years when the Lake Victoria basin annual rainfall is less than 1,398 mm. In recent times such a catastrophic reduction in levels was experienced in February 2006 when the lake level was as low as 10.48 meters on the Jinja gauge (Mubiru, 2006).

The above results notwithstanding, it should be noted that other contributing factors in the water balance of Lake Victoria such as tributary inflow and evaporation were not taken into account in this analysis, principally because they are outside the study area and it is expected that their effects would be manifested in the lake levels. Furthermore previous water balance estimates have considered evaporation variation from year to year as being relatively small (Sutcliffe and Parks, 1999) and therefore it was assumed that evaporation would not change between dry, moderate and wet years. Previous studies have also shown that tributary inflow to the lake is small compared to direct rainfall (Tate et al., 2004). These two variables (evaporation and tributary inflow) could be added to the network in order to refine the results. It is not expected that the results would change significantly.

8.2.3 Lake Kyoga Levels

It would be expected that increasing irrigation would lower Lake Kyoga levels since all the irrigation water in the basin is obtained from rivers and streams that drain into the lake. This is true from the results (section 7.5) but the effect of irrigation is minimal. This small effect on the lake level is due to the fact that lake levels are more dependent on the Victoria Nile inflow to the lake than rainfall in the basin on which irrigation demand depends. Rainfall in the basin has a lower influence on Lake Kyoga levels, as seen from a low correlation coefficient for average annual catchment rainfall in Kyoga basin and Lake Kyoga levels of only 0.56. Irrigation water demand as a cause of low lake levels is seen to be insignificant as compared to outflows from Lake Victoria and therefore cannot be considered a key factor in Lake Kyoga level changes. This could be due to the fact that rainfall in the Kyoga catchment is relatively high and even during dry years when the crop water requirement is highest (projected at 1,804 million m^3 per year), this would translate into only 38 cm of lake level change, considering that the lake area is about 4,700 km^2. It can be concluded that irrigation in the basin is not likely to have a significant impact on the lake levels.

Lake Victoria rainfall has a larger effect on Lake Kyoga levels (section 7.6). This is shown by the large change observed in lake levels between the low and high rainfall scenarios. The results show that while there is a 48% probability of lake levels being less than 11m and only 1% of being higher than 13 m for the low rainfall scenario, the level is mostly greater than 11 m and has a probability of only 8% of being less than 11 m for the high rainfall scenario. This large effect is explained by the increased Victoria Nile river flow from Lake Victoria that is a result of increased rainfall in the lake. The correlation coefficient for Lake Kyoga levels and Lake Victoria outflows is 0.76 showing a strong positive relationship between the two. Therefore, unlike Lake Victoria, since Lake Kyoga is not regulated, its level depends on the upstream regulation of Lake Victoria. Since the main source of Lake Kyoga is the outflow from Lake Victoria, it is expected that Lake Kyoga levels will show a similar trend to those of Lake Victoria. This is confirmed by the time series of lake levels in Figure 8.1.

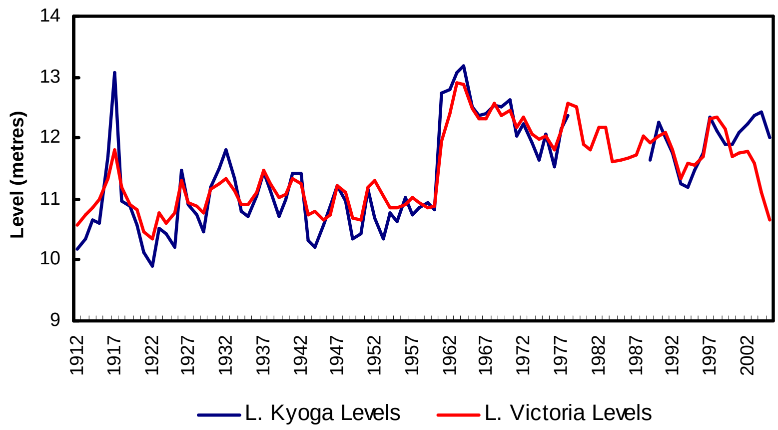


Figure 8.1 Comparison of Lake Kyoga and L. Victoria levels

Lake Victoria levels taken at Jinja gauge and Lake Kyoga levels taken at Masindi gauge. Data was obtained from Water Resources Department, Entebbe and Kennedy and Donkin Power Ltd, 1997

The results show that during dry years low lake levels can be attributed to reduced rainfall rather than irrigation. The lake is prone to flooding during high rainfall years, when lake levels can rise above 13 m. The records available for the 59 year period, 1947-2005, show an average end of year level of 11.77 m with a minimum level of 10.35 m recorded in 1949 and a maximum level of 13.2 m recorded in 1964.

8.2.4 Victoria Nile River Flow Exiting the Basin

The amount of water exiting the Victoria Nile basin can be deduced from the Kyoga Nile flow at the entry to Lake Albert. This result could be used to inform the Ugandan Government and the lower riparian states what would be the expected Victoria Nile flow exiting the basin. The results of hydropower development, irrigation and rainfall were shown in sections 7.4, 7.5 and 7.6 respectively. The results show that irrigation and hydropower development reduce the flow of the Nile exiting the basin but by small amounts only. A critical examination of the hydropower and irrigation results shows that the reduction in river flow arising from developing all hydropower plants is larger than that due to full irrigation. With all hydropower plants developed the probability of having river flows less than 500 m^3/s increases by 10% from the baseline level while that for having full irrigation increases by just 4%. Since irrigation consumes more water than hydropower development it would be expected that having full irrigation would cause more reduction in river flows than hydropower development. This result is surprising, but also revealing, because it could suggest that irrigation projects within the Nile basin do not necessarily reduce the Nile water flows significantly. Irrigation water in the Victoria Nile comes from rivers and streams that flow into Lake Kyoga. The contribution of this flow is small compared to the inflow from Lake Victoria. This explains why the irrigation component does not contribute as much as hydropower development which uses the water directly on the Nile.

Unlike irrigation and hydropower development, rainfall has a large effect on the flow exiting the basin. The probability of river flows being less than 500 m^3/s for the high rainfall scenario is only 3% but for the low rainfall scenario this probability is 20%. For the high rainfall scenario exit flows have a probability of 44% of rising above 1,250 m^3/s while for the low water scenario this probability is just 13%. This variation between the low rainfall and high rainfall scenarios suggests the need for storage to balance the flows.

8.2.5 Control of Outflows from Lake Victoria

The observed declining Lake Victoria levels, hydroelectric power development and persistent droughts have been the main reason that people have questioned whether Victoria Nile flows have followed the agreed curve model. Evidence that the agreed curve model was not strictly adhered to was presented earlier by other authors (Kull, 2006; Sutcliffe and Petersen, 2007). The analysis presented in section 3.3.3 and figure 3.13 shows that there is a clear relationship between departure from the agreed curve and rainfall occurrence. The departure from the agreed curve flow defined as actual river flow minus agreed curve flow, increases immediately after a low rainfall month. This trend is reversed whenever there is high rainfall. The introduction of more hydroelectric power generation units at the Kiira hydropower plant reduced the effect of increased rainfall because persistent over-abstraction was seen to occur after introduction of more generation units. This analysis confirms that the agreed curve has not been adhered to in the past but it further shows that it will be increasingly difficult for it to be followed amidst pressures of hydroelectric power demand and low rainfall. With hydroelectric power demand rising, the Government of Uganda will find it difficult to generate the required electricity during low rainfall periods when the lake level is expected to be low. This calls for an alternative operation mode for such extreme situations. The mode of operation of Lake Victoria outflows is likely to be an item on the agenda when negotiation talks on the Nile treaty commence under the Nile Basin Initiative.

The agreed curve principle was developed as a means to mimic the natural outflows from Lake Victoria before the Nalubaale hydroelectric power facility was constructed. Since the regulated mode is suggested in this study as an alternative operating mode when lake levels register an annual fall or rise of 0.4 m, it is seen as an adequate and flexible operation for the dry and wet years since it would confine lake outflows within the 500-1,250 m^3/s range most of the time which would otherwise affect hydroelectric power production. The limitations to the use of the agreed curve in extreme conditions of low or very high rainfall years was documented by Mubiru, (2006) who made an analysis of the Nalubaale dam operations during the El Nino event of 1997/98 and the severe drought of 2005/06. One of the key conclusions made in the analysis was that under cases of extreme rain/drought conditions the agreed curve has significant limitations. The findings here seem to concur with this conclusion.

8.2.6 Socioeconomic and environmental impacts

The methodology used in the study offers a quick way of assessing the overall socio-economic and environmental impacts in cases where there are more than one hydropower projects to be developed. Positive impacts of the proposed hydropower plants were identified as electricity generation to boost the Ugandan economy and creation of employment. The generation of electricity is seen as a benefit mainly to urban areas that will access the electricity through the electricity grid and little will be available to the local communities who live in the neighbourhood of the hydropower plants. Creation of employment is a benefit to the local communities, however, this is a short lived benefit because employment for the local communities is mostly unskilled labour that will be available only during the construction phase of the projects and is therefore not sustainable. Long term benefits are therefore felt by those away from the projects. Negative impacts on the other hand occur in the vicinity of the projects and are felt by the local communities. This shows that there is inequity between those living in the urban areas away from the projects and those living close to the projects. It is therefore a considered view that even with the large benefit from electricity generation, impact mitigation measures are necessary.

Results obtained here give decision makers a quick outlook of the consequences of implementing all the potential hydroelectric power plants in the basin. It is shown that even if individual impact assessments suggest low to moderate impacts, it is questionable whether combinations of more than one project could be implemented without causing serious impacts in the vicinity of the projects. Additionally, where social economics dictate implementation of such projects, it gives Government an early signal that such negative impacts exist and therefore early planning for mitigation measures can be made.

The difficulty of quantifying environmental variables and reliance on existing EIAs of projects provide problems in using the methodology. This is because, like any other modelling technique, errors from input data will create errors in the model results. It is important to exercise caution when using the approach, especially where other information is available that could be used to improve on the determination of probabilities. For instance, if the probabilities derived using simple proportions as described in this thesis do not make logical sense, then it is better to seek other information or take the worst case scenario. Use of participatory approaches has been emphasized in many decision support systems (Giupponi, 2007) and future improvement is directed towards use in negotiations and group discussions context (Matthies et al., 2007). It is highly recommended that use of this approach should be as participatory as possible. It should be used as a guide to determining likely impacts rather than a directive on what should be done.

8.3 Use of Bayesian Networks for decision support

The application of Bayesian networks in water and environment management was presented in chapter 5. The main benefit of using Bayesian networks lies in their potential to deal with uncertainty by attaching probabilities to the occurrence of uncertain events. The process of eliciting probabilities is a critical one because it determines the validity of outcomes of the decision making. The frequency distribution is an important approach that can be used in cases where there are some data available otherwise probabilities can be elicited from domain experts or through interviews with communities or by logical reasoning done by the network developer. All these approaches except interviews with communities were used because of the variability of data available in the study area. Some variables had data spanning long periods of time for instance Lake Victoria outflows, while others had no data at all for instance the impacts of combinations of hydroelectric power plants to the environment.

Developing the networks into logical cause-effect graphs such as that presented in figure 5.1 requires time and clear understanding of the system. A network developed for a particular purpose can be improved and updated to include additions whenever this is necessary. For this study some key variables such as fish catch and tourism were left out principally because of scope but these can be added at any time to have a comprehensive system of connected variables. This provides an easy way to update and expand a network.

The Bayesian Network for the Victoria Nile presented in chapter 6 is a useful source of information to guide decision making in the basin. It can inform the decision makers the likely impacts of implementing multiple projects. Furthermore it can be used as a means to encourage dialogue and debate among stakeholders, specifically on the use and management of the Nile. Supporting organisational decision making involves designing tools that provide relevant information (McIntosh et al., 2009). In this regard, this tool is seen as an information source rather than an optimisation tool. The information obtained can be used as an initial step in decision making and provoking discussions on developments in the Nile. The principal stakeholder in the Victoria Nile basin is the Government of Uganda through the ministry of Water and Environment, the ministry of Agriculture, Animal Industry and Fisheries and the Ministry of Energy. These are the potential users of the tool since there are no other known organised stakeholders except peasant farmers and local fishermen who may not be in position to use the tool. With information on the impacts of irrigation and hydropower developments obtained from this tool the government of Uganda is in a better position to negotiate its stake on the Nile and inform other riparian states that these developments do not significantly reduce the flow of the Nile contrary to the popular belief. The Ministries can individually use the tool to find out how their activities; irrigation and hydropower development can impact on the water resources in the basin.

8.4 The Conceptual Framework

This study was based on the conceptual framework presented in chapter 1. A framework for decision making presented in this study was seen as one response that would avert the prevailing state of the water resources in the Victoria Nile basin. The study provides key information on the likely consequences of implementing irrigation and hydropower developments in the Victoria Nile basin under different rainfall regimes. This information can support decision makers whenever a need for additional developments arises.

Climate variability and change and high population growth will continue to put pressure on the water resources. By providing information on the state of the water resources for different rainfall scenarios and irrigation demands the study attempts to give an indication of the consequences of developments. The decision maker can therefore choose whether to proceed with a planned development or not. For hydroelectric power development, should the demand for energy necessitate development of all plants, the information obtained here provides an early warning that certain impact mitigating factors need to be carried out or planned.

Inadequate data in the basin was seen as one cause of poor planning. The approach used here considers this setback and attempts to provide information where data required for deterministic modelling is inadequate. While this framework does not exhaustively provide the required response to manage the water resources in the basin, it contributes to dealing with the pressures exerted on the basin.

8.5 Objectives

The research set out to achieve the objectives outlined in chapter 1. Overall the research aim was achieved.

Objective 1 was to review the knowledge of the water resources of the Victoria Nile basin. Chapter 3 presented analyses of the basin rainfall, Lake Kyoga, and the Victoria Nile River which are the main water resources in the basin. Although Lake Victoria is not part of the studied area, it has a large influence on the hydrology of the Victoria Nile basin.

Objective 2 was to establish the potential water resources development projects likely to be implemented in the Victoria Nile basin. The potential water using developments were discussed in chapter 4 and the development pressures and challenges in the basin in chapter 4. Hydroelectric power development is seen as the main development that the government of Uganda can benefit from the river Nile. There is a potential for five additional hydroelectric power plants on the Victoria Nile making a total of seven in addition to those already developed at Jinja. Given the fundamental role electricity is playing in the economic development of Uganda, it is likely that these plants will be developed.

Irrigation is the second highest water user in the basin. Irrigation has not been given much attention in the past but is it anticipated that given the high population growth in the region and the variable rainfall, it may become essential in meeting food needs for the country. The research has shown that irrigation water will not significantly reduce the water flows exiting the basin.

Objective 3 was to develop a decision support methodology for the basin. Chapter 5 and 6 discussed decision support methodologies for water resources and how a Bayesian Network for the basin was developed. The Bayesian network approach was chosen mainly because of its potential to deal with uncertainty and where data is scarce. The methodology has the added advantage of being easily updated whenever more data is obtained and whenever other important variables need to be considered. Caution should be exercised however in using the methodology as elicitation of probabilities is a challenging exercise. Coupling this with other modelling techniques is one area that is possible but was not tried in this research.

Objective 4 was to give an indication of the likely impacts of the key development decisions to the water resources in the basin. Using the Bayesian networks methodology, the results of assumed scenarios were obtained in chapter 7. The results showed what would be the likely effects of developing different combinations of hydroelectric power plants and undertaking different levels irrigation for different rainfall regimes.

Chapter 9 Conclusions and Recommendations

9.1 Conclusions

This chapter gives a summary of the main conclusions from the study, recommendations to policy makers and areas requiring further research. Detailed conclusions on the various areas studied are contained under the respective sections in previous chapters.

9.1.1 General

1 The Victoria Nile basin is well endowed with water resources except the north eastern part of Uganda that covers Karamoja and parts of the Teso region (figure 2.3). The Victoria Nile River flowing out of Lake Victoria is the largest source of water entering and leaving the basin. Its main influence on the hydrology of the basin is the changing levels in Lake Kyoga.

2. Rainfall occurrence in Lake Victoria and the Victoria Nile basins show similar tendencies; however the two rainfall seasons in the Victoria Nile are not as clearly distinguished as for Lake Victoria (figure 3.5). In most cases, however, the Victoria Nile basin has higher rainfall maxima while Lake Victoria has lower minima (figure 3.6). This pattern could be responsible for the common floods in the Victoria Nile basin.

3. The Victoria Nile flows are highly dependent on Lake Victoria levels. This close dependence of river flows on the lake levels means that any hydraulic structure development on the river should consider the long term behaviour of the lake as an essential factor.

4. There is a temporal relationship between Lake Victoria rainfall, Lake Victoria levels and Victoria Nile flows (figure 3.11). Seasonal changes of lake rainfall, lake level and lake outflows reveal that there is a time lag of approximately one month for the effect of rainfall over Lake Victoria to be observed in the changes in lake level.

5. High rainfall of 1960-64 lasted only five years whereas the Lake Victoria levels took about forty years to return to the pre-1960 levels. This could suggest that filling the lake is much faster than emptying it since there is only one outflow.

9.1.2 Effect of Rainfall

6. Rainfall has the largest effect on the water resources in the basin. The lake Kyoga level, the Lake Victoria level and the Victoria Nile flow are all highly influenced by the amount of rainfall over Lake Victoria. When the Lake Victoria annual rainfall is less than 1,186 mm Lake Victoria levels can fall below 10.8 m on the Jinja gauge thereby curtailing navigation and hydropower generation. Lake Kyoga levels are similarly low during such low rainfall years, with lake levels less than 11 m on the Masindi gauge and Victoria Nile flows exiting the basin could drop below 500 m^3/s.

7. River flows exiting the basin and Lake Kyoga level changes are dependent on rainfall changes in Lake Victoria and the subsequent changes in its outflows than Victoria Nile basin rainfall.

9.1.3 Effect of Irrigation

8. The full irrigation potential in the Victoria Nile basin estimated at 128,865 ha, would require a maximum of about 1,800 million cubic metres of water per year which is equivalent to only 7% of the annual Victoria Nile flow exiting the basin.

9. If the area available for irrigation in 2006 was increased by 50% there would be no significant effect on Lake Kyoga level and the river Nile flow exiting the basin. Increasing the irrigation area to the full potential would only reduce Lake Kyoga level and river flow exiting the basin by a small margin. This is due to the fact that Lake Kyoga levels and Victoria Nile river flows are more dependent on outflows from Lake Victoria than rainfall in the basin.

9.1.4 Effect of hydropower generation

10. The main effect of development of hydropower plants is manifested in the socioeconomic and environmental impacts caused by the plants. Even if individual hydropower projects are expected to cause little to moderate negative impacts combinations of projects are seen to cause large to very large impacts.

11. Having one hydropower plant developed in each of the two reaches of the Victoria Nile would not have any significant effect on Lake Kyoga levels and river flows. Developing all the five potential hydropower plants decreases river flow exiting the basin but by a small margin only.

9.1.5 High water demand

12. When all hydropower plants are developed and the full potential of irrigation is utilised the basin will experience the highest water demand during dry years. It is only this highest water demand situation that has a significant effect on Lake Kyoga levels and river flows, otherwise varying the number of hydropower plants and the irrigation area does not significantly change the lake levels and river flows exiting the system.

9.1.6 Control of Victoria Nile flows

13. The agreed curve mode is a sufficient means of controlling outflows from Lake Victoria during moderate rainfall and lake level regimes. For extreme conditions of lake levels outside the range 10.8-11.6 m the agreed curve may not be appropriate, especially under increasing demands of hydropower generation.

14. The regulated mode is suggested as an additional flexible outflow control mode for extreme conditions of rainfall and lake levels. It would come into operation for situations when lake levels are out of the range of 10.8-11.6 m which according to findings in the research is when Lake Victoria annual rainfall is less than 1,186 mm or above 1,398 mm. This operating mode would consider downstream demands, upstream demands and lake level.

9.2 Recommendations

Recommendations presented here are classified in two main categories. There are those targeting improvement in implementation of programs in the Victoria Nile basin which would serve to inform the policy makers and those that target further research on use of similar methodology and work in areas with similar characteristics.

9.2.1 The Victoria Nile development

1. The Victoria Nile basin contains about 70% of the irrigation potential in Uganda. This makes the region important in terms of water resources management and if the irrigation potential is fully exploited could become the highest water utilizing region in Uganda. Unfortunately there is lack of water resources data that is crucial for planning programs. It is recommended that further emphasis be put on collection of data and making it available for planning.

2. Irrigation and hydropower developments in the Victoria Nile basin are not seen to significantly reduce the flow of the Nile. This by far is the biggest fear of the lower riparian states. It is recommended that using a similar approach or otherwise, the entire water resource needs of Uganda and other riparian states be evaluated so that it is clear what the consequences of key water consuming developments would be. This would reduce the fears of the lower riparian states in cases where the amount of water used is not significant enough to change the Nile flow. At the international level this information would be important as a yardstick for negotiating rights over the use of the Nile water.

3. An important aspect of the Bayesian networks methodology is the ease with which updates to the network can be made. As an improvement to the work done in this research it is recommended that Bayesian networks for sub-basins of the Victoria Nile basin are developed with additions of other key variables that may be specific to the sub-basin. These may include for instance livestock

water consumption in Karamoja, fish catch in Lake Kyoga sub-basin and tourism in the Victoria Nile basin. These are seen as key activities in the region.

4. Roll-over of such work to all catchments in Uganda is recommended. This is important because there is likely to be bulk-water transfers from catchments of abundant supply to catchments of scarcity. Such a project was proposed in the Water for Production strategy of the Government of Uganda in 2005. Without knowledge of available water resources in a catchment and the effects of water consuming developments it is difficult to know what the consequences of large water transfers would be for the receiving and the donor catchments.

9.2.2 Further research

This research was initiated as a PhD study and was therefore constrained by time and scope. As a result of this, certain important areas were not adequately covered. Some recommendations to further research are presented below.

1. There was an attempt to translate the qualitative socioeconomic and environmental impacts into a quantitative format so that using probabilistic methods the effects of more than one project could be assessed. This was done for a maximum of eight combinations moreover with many assumptions such as similar impacts from several projects. It is my view that this approach if improved could be a great step in dealing with qualitative parameters.

2. This research and other studies showed that the agreed curve is becoming increasingly difficult to adhere to in extreme situations of rainfall. Given that upstream and downstream demands are likely to increase, a suggestion was made to have an additional operating mode for extreme situations. A review of the literature did not show any possible alternatives for operating outflows. It is recommended that further research be carried out to explore fully the use of the regulated mode and what would be the likely consequences.

3. The system studied includes several dynamic variables such as lake levels and river flows but the study considered them as static by using a long time scale of one year. This approach makes the short term changes in these variables to be lost. It is recommended that possibilities of incorporating dynamic modelling techniques be explored so as to capture short term changes in the dynamic variables.

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Appendix

Appendix 1 Rainfall Data

1.1 Annual Rainfall (mm) For the Kyoga Catchment at Four Stations

Data source: Data obtained from Uganda Meteorology Department, 2006; additional data from 1938 to 1959 and data filling-in up to 1967 got from Shahin Mamdouh, 1985.

Year	Soroti	Serere	Masindi	Tororo
1938	1224	1205	1045	1137
1939	920	938	1114	1079
1940	1096	1457	1396	1421
1941	1868	1496	1429	1527
1942	1642	1458	1252	1470
1943	983	997	1098	1214
1944	1170	481	1331	1331
1945	1125	1449	1371	1228
1946	1390	1485	1192	1653
1947	1411	1156	1190	1468
1948	1347	1480	1118	1247
1949	1010	1235	1030	1114
1950	1011	1147	1336	1330
1951	1570	1507	1459	1637
1952	1266	1437	1047	1539
1953	1261	1165	1263	1054
1954	1222	1223	1426	1283
1955	1312	1306	1141	1385
1956	1440	1422	1080	1419
1957	873	1306	747	1426
1958	1196	1273	1153	1267
1959	1267	1387	1262	1345
1960	1403	1500	1225	1637
1961	1645	1822	1629	1981
1962	1498	1510	1635	1753
1963	1364	1808	1489	1795

Year	Soroti	Serere	Masindi	Tororo
1964	1049	1472	1445	1637
1965	1145	1227	1318	1305
1966	1337	1670	1234	1529
1967	1684	1333	1186	1580
1968	1560	1561	1223	1685
1969	1309	1320	1455	1610
1970	1363	1458	1454	1702
1971	1364	1226	1443	1487
1972	1225	1699	1733	1698
1973	1206	1181	1339	1020
1974	1172	1267	1274	m
1975	1846	1538	1256	1614.5
1976	1620	1371	1176	1436.3
1977	1523	1661	m	m
1978	1726	1433	1706	1285.2
1979	1084.2	1112		m
1980	1158.3	1188	1230	1035.4
1981	1355.2	1390	m	1400.4
1982	1445.3	m	m	1558.5
1983	1373.1	m	1014	1480.7
1984	1175	1262	1192	1416.1
1985	1474	m	m	1509.5
1986	1162.4	m	m	1253.5
1987	1089	m	m	1337.8
1988	1548	m	m	1781.2
1989	1254.8	1287	m	m
1990	1519	m	1410	1504
1991	1776	m	1264	1485.6
1992	1245	m	1302	1401.9
1993	1112	m	1401	1048.4
1994	1372	1479	1311	m
1995	1402	m	1631	1588.4
1996	1771	2378	1329	1765.9
1997	1234	1365	1615	m

Year	Soroti	Serere	Masindi	Tororo
1998	1350	m	m	1839.9
1999	1221.6	m	m	1504.2
2000	1164.8	m	1565.3	1420.1
2001	1764.9	m	1345.3	1516.9
2002	1223	m	1354	1430.4
2003	1479.2	m	1293.5	1501.7
2004	1054.7	m	1242.2	1273.5
2005	m	m	1212	m
2006	m	m	m	m

m: Missing data

1.2 Monthly Rainfall (mm) for Jinja Station

Source: Uganda Meteorology department with gaps filled from Institute of Hydrology (1985)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1903	146	49	146	12	58	152	0	83	97	127	43	58	971
1904	48	47	145	151	77	62	22	125	73	88	147	131	1116
1905	62	18	98	100	104	12	87	69	77	137	231	76	1071
1906	5	138	254	202	90	88	24	144	74	120	26	30	1195
1907	49	74	6	215	184	39	84	99	21	81	79	101	1032
1908	18	125	13	151	142	65	29	61	97	94	99	67	961
1909	118	23	78	277	37	37	71	199	200	88	27	258	1413
1910	54	12	120	204	219	120	121	44	49	78	186	65	1272
1911	83	34	244	144	153	39	19	98	48	144	256	36	1298
1912	42	108	143	179	93	76	73	117	26	127	101	117	1202
1913	16	130	83	207	203	15	71	37	82	87	56	62	1049
1914	118	85	175	168	133	75	103	121	110	75	189	37	1389
1915	65	53	137	212	171	72	11	60	130	144	98	105	1258
1916	35	161	80	252	120	100	54	82	160	56	43	150	1293
1917	135	145	54	233	165	80	19	220	72	159	42	19	1343
1918	44	6	30	95	62	45	55	55	86	111	79	60	728
1919	20	181	204	116	111	17	82	83	121	41	211	16	1203
1920	39	17	208	124	84	74	47	84	47	56	89	97	966
1921	35	70	44	119	96	33	83	161	56	72	96	89	954

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1922	27	55	138	158	204	22	21	148	71	77	62	69	1052
1923	0	157	162	162	187	23	70	76	175	129	81	147	1369
1924	23	91	164	197	184	40	86	190	55	180	55	55	1320
1925	90	64	169	200	66	87	87	79	117	166	158	99	1382
1926	26	163	140	258	112	48	22	98	131	115	151	31	1295
1927	138	210	96	175	75	60	43	60	80	87	47	97	1168
1928	13	17	93	205	103	37	35	115	86	144	60	25	933
1929	8	28	69	98	56	118	106	90	109	125	52	279	1138
1930	156	46	78	148	96	100	30	84	85	138	44	9	1014
1931	34	45	281	218	235	45	86	56	66	41	58	42	1207
1932	27	14	225	111	146	46	42	71	61	15	85	21	864
1933	70	40	145	164	153	86	35	102	26	84	24	62	991
1934	7	54	131	113	133	35	59	138	36	121	83	105	1015
1935	0	114	104	185	167	104	14	38	78	118	73	133	1128
1936	193	82	125	183	62	164	18	56	93	49	36	124	1185
1937	23	59	87	151	161	13	30	50	71	113	247	88	1093
1938	25	13	108	267	131	32	18	105	99	149	50	83	1080
1939	1	98	119	175	167	45	88	124	129	89	135	8	1178
1940	82	108	77	161	88	35	59	56	125	59	150	20	1020
1941	39	65	82	157	181	141	72	128	9	74	244	287	1479
1942	57	26	202	303	231	64	3	195	35	40	90	90	1336
1943	78	87	70	206	85	82	14	108	40	70	4	60	904
1944	29	20	186	262	183	35	58	103	68	125	148	102	1319

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1945	26	28	68	69	255	55	49	196	70	38	139	17	1010
1946	14	0	35	234	284	55	72	71	101	104	81	96	1147
1947	104	67	105	293	284	39	115	78	140	21	13	63	1322
1948	87	76	115	197	167	113	85	100	202	86	151	57	1436
1949	2	39	33	124	102	32	78	78	70	83	117	143	901
1950	120	16	106	176	115	26	47	50	54	92	43	37	882
1951	66	98	155	251	160	53	34	27	85	102	73	250	1354
1952	14	133	165	130	80	83	75	57	42	10	107	0	896
1953	80	15	46	231	54	47	24	41	32	93	164	44	871
1954	17	26	33	186	100	103	69	48	80	107	38	140	947
1955	86	64	70	166	136	38	26	121	79	65	51	159	1061
1956	96	24	124	256	138	84	64	141	113	101	93	104	1338
1957	115	34	75	174	219	44	66	66	11	81	104	62	1051
1958	66	91	92	199	58	56	38	45	64	92	91	101	993
1959	88	92	75	182	67	72	64	110	69	217	196	32	1264
1960	107	43	218	208	58	2	108	41	181	149	78	37	1230
1961	18	64	181	143	100	33	66	113	93	368	431	120	1730
1962	59	20	128	199	201	67	82	86	128	278	151	51	1450
1963	137	114	169	233	258	25	39	78	46	121	218	209	1647
1964	23	240	122	247	93	149	109	29	120	113	169	121	1535
1965	4	31	55	117	75	13	55	27	122	197	153	151	1000
1966	44	224	184	203	117	134	42	93	104	105	210	20	1480
1967	8	34	127	116	265	76	58	46	87	159	294	110	1380

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1968	10	77	161	237	96	88	28	70	94	161	121	209	1352
1969	96	156	110	205	149	48	55	54	136	110	186	24	1329
1970	128	40	276	193	211	33	25	108	42	108	105	23	1292
1971	45	60	133	191	111	35	138	99	121	75	70	58	1136
1972	38	151	42	206	133	241	46	122	138	169	288	42	1616
1973	37	58	50	161	91	56	3	90	149	117	148	32	992
1974	72	43	137	179	117	67	132	58	131	85	48	59	1128
1975	33	33	244	241	226	59	59	92	163	115	48	128	1441
1976	126	131	150	177	115	76	152	102	83	37	173	58	1380
1977	86	35	227	226	122	39	109	156	30	184	218	95	1527
1978	27	171	159	183	197	94	60	91	83	88	111	152	1416
1979	m	m	m	m	m	m	m	m	m	m	m	m	m
1980	m	m	m	m	m	m	m	m	m	m	m	m	m
1981	27	104	183	125	204	44	74	119	104	53	144	100	1281
1982	41	62	115	147	217	35	9	45	89	159	228	84	1231
1983	33	20	61	208	166	64	58	128	91	168	94	38	1129
1984	73	19	37	118	77	21	73	127	60	75	179	56	915
1985	130	49	m	m	m	m	m	m	m	m	m	m	m
1986	2	12	97	264	165	55	49	36	44	131	131	m	m
1987	58	148	194	207	167	83	7	100	232	144	111	33	1484
1988	89	48	139	242	63	m	m	m	m	m	m	m	m
1989	m	m	m	m	m	m	85	m	118	136	178	148	m
1990	44	122	200	179	68	2	11	57	142	134	63	119	1141

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	40	132	122	176	198	63	130	33	122	101	70	65	1252
1992	25	12	4	m	m	94	113	92	135	128	198	140	m
1993	52	47	89	141	147	94	35	39	53	100	87	50	934
1994	62	16	220	187	280	73	91	74	85	114	153	54	1409
1995	10	54	189	251	149	56	103	22	170	198	119	30	1351
1996	131	108	239	200	155	171	88	117	108	60	171	18	1566
1997	107	5	80	195	88	39	m	73	35	191	291	259	m
1998	160	91	239	189	155	42	18	75	54	74	95	35	1227
1999	138.7	27.2	246.3	237.4	193.2	14.5	43	86.3	117.5	133.5	166.8	144.5	1548.9
2000	31.4	37	76.3	133.7	108.7	32.3	28.3	117.7	117.7	111.2	113.6	121.8	1029.7
2001	90.9	58.3	115.3	165.2	176.2	139.3	48.5	149.6	161.5	218.7	274.9	51.8	1650.2
2002	89.5	48.7	184.1	419	133.3	8.8	14	72.3	55	33.5	221.6	147.1	1426.9
2003	129.1	20.2	118.4	108.9	149.4	163.5	9.8	69	70.8	210.8	110.8	144	1304.7
2004	89.8	55.9	91	281.4	44	12.4	47.1	132.1	175.5	119.7	245.7	126.8	1421.4
2005	35.5	30.5	112	202.2	162.4	31.6	150.8	210.4	100.1	119	71	98	1323.5

m: Missing

1.3 Monthly Rainfall (mm) at Key Stations in Lake Victoria Basin 1956-1978

Source: Piper et al., 1986

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Jinja	64	85	141	195	140	69	70	83	100	141	161	87	1336
Entebbe	88	101	179	260	235	121	69	79	72	126	179	111	1620
Kalangala	135	137	239	340	322	162	96	94	114	159	210	208	2216
Bukoba	150	180	254	398	316	89	51	66	102	153	195	193	2147
Kagondo	119	152	219	362	234	47	26	40	94	115	201	161	1770
Mwanza	102	114	156	177	71	16	15	21	25	99	158	146	1100
Musoma	59	84	123	182	101	24	21	22	31	53	117	78	895
Kisumu	71	98	155	234	175	79	63	90	84	87	139	102	1377
Monthly Mean	99	119	183	269	199	76	51	62	78	117	170	136	1558

1.4 Average Monthly Rainfall (mm) for Lake Victoria Basin 1948-2001

Average rainfall for Lake Victoria basin; average for the regions in Uganda, Tanzania and Kenya
Regions: Uganda- Busoga, North Buganda, South Buganda and Central; Tanzania- Mara, Mwanza and Ziwa Magharibi; Kenya- Nyanza and Western
Source: ARTES World Bank, 2003

Year	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
Jan	92	40	72	86	45	78	50	93	114	98	53	82	122	44	96	145	64	38
Feb	58	57	51	121	90	42	70	102	74	70	85	83	120	124	45	110	151	71
Mar	125	45	196	177	159	119	73	121	127	139	140	131	203	155	151	149	163	141
Apr	194	218	209	240	219	202	240	173	211	235	179	171	240	176	203	248	296	189
May	153	93	159	172	187	113	195	146	129	181	135	110	112	141	196	200	128	115
Jun	65	53	50	69	39	72	55	39	47	64	85	51	38	50	69	46	63	31
July	57	64	57	41	39	28	68	62	38	38	44	39	29	64	36	32	51	41
Aug	69	79	79	60	75	51	56	67	66	50	56	66	47	75	73	43	67	49
Sep	95	76	75	65	99	95	84	103	84	42	60	83	97	134	94	53	82	81
Oct	98	74	85	120	73	105	65	74	82	75	69	109	84	196	145	62	101	135
Nov	84	67	70	208	110	135	79	78	109	116	75	168	101	379	114	240	100	177
Dec	90	141	89	264	30	85	118	137	113	127	119	71	51	171	87	180	133	127

Year	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Jan	89	53	33	126	130	77	98	86	65	48	60	133	63	119	64	51	88	53
Feb	120	45	160	144	91	55	120	104	70	95	130	64	133	138	58	63	51	49
Mar	193	130	195	139	219	78	89	74	164	177	104	147	204	137	143	201	121	85
Apr	228	198	297	135	233	228	172	220	235	182	184	230	214	195	180	182	188	171
May	78	203	162	180	156	160	173	143	110	155	161	148	139	158	192	155	202	164
Jun	62	67	86	52	39	38	97	64	84	63	59	60	52	68	37	28	59	63
July	29	50	28	43	46	78	29	17	95	85	52	35	32	27	29	61	37	50
Aug	71	49	41	44	79	69	61	65	41	61	80	65	58	52	58	69	59	76
Sep	108	105	63	79	66	82	81	110	75	128	80	72	64	58	79	88	76	91
Oct	104	131	128	104	85	77	147	91	63	104	65	116	120	55	83	97	181	118
Nov	132	236	201	165	106	107	232	146	96	64	135	195	147	121	162	95	222	97
Dec	77	81	162	74	121	77	114	66	85	107	104	107	158	124	94	94	103	98

Average rainfall for Lake Victoria basin; average for the regions in Uganda, Tanzania and Kenya
Regions: Uganda- Busoga, North Buganda, South Buganda and Central; Tanzania- Mara, Mwanza and Ziwa Magharibi; Kenya- Nyanza and Western
Source: ARTES World Bank, 2003

Year	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Jan	61	112	54	105	127	65	71	98	85	108	45	53	98	103	263	86	73	242
Feb	67	70	97	106	97	71	139	87	52	138	64	88	120	65	112	17	48	70
Mar	84	155	140	146	151	141	204	166	78	121	189	130	237	144	85	215	111	149
Apr	218	227	223	191	250	174	204	228	160	163	182	222	180	229	202	202	165	168
May	108	193	153	186	128	167	121	263	127	177	199	152	127	168	146	139	142	125
Jun	52	62	46	72	49	66	22	72	74	80	57	84	68	75	96	66	58	65
July	65	49	26	25	53	44	20	49	60	22	52	43	52	36	30	50	43	82
Aug	66	42	33	45	107	66	52	64	52	52	77	30	57	52	55	82	75	70
Sep	61	74	70	95	135	97	64	59	89	62	41	106	135	12	69	92	79	159
Oct	92	70	139	85	96	113	131	189	132	76	91	211	88	158	117	115	102	129
Nov	207	130	132	162	128	148	114	94	134	107	341	111	142	242	112	171	144	160
Dec	104	124	167	54	115	194	127	61	150	68	62	91	61	308	74	114	143	85

Appendix 2 Lake Level Data

2.1 Lake Victoria End of Month Levels (Metres above Jinja Gauge) and Mean Annual Outflows

Source: Institute of Hydrology (1993) as supplemented by Kennedy and Donkin Power Ltd. (1997)
Data from 1996 - 2006 sourced from Directorate of Water Development, Ministry of Water &Environment, Uganda

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1896	11.57	11.50	11.51	11.53	11.53	11.50	11.41	11.40	11.28	11.22	11.40	11.36	835.4
1897	11.41	11.41	11.42	11.54	11.55	11.58	11.56	m	m	m	m	m	866.3
1898	m	m	m	m	m	m	m	11.48	11.47	11.45	11.48	11.44	857.7
1899	11.40	11.40	11.36	11.38	11.52	11.41	11.31	11.07	10.94	10.86	10.83	10.90	734.2
1900	10.89	10.90	10.91	10.90	10.92	10.95	10.97	10.91	10.74	10.59	10.59	10.72	568.9
1901	10.70	10.76	10.94	11.26	11.30	11.13	11.02	10.88	10.80	10.72	10.71	10.64	598.4
1902	10.62	10.65	10.62	10.71	10.76	10.69	10.68	10.64	10.58	10.57	10.69	10.82	497.6
1903	10.90	10.90	10.94	11.07	11.32	11.43	11.41	11.34	11.33	11.35	11.36	11.34	725.0
1904	11.31	11.32	11.37	11.53	11.59	11.49	11.39	11.30	11.24	11.17	11.24	11.31	793.3
1905	11.32	11.26	11.37	11.46	11.51	11.38	11.23	11.15	11.07	11.04	11.13	11.30	753.1
1906	11.27	11.34	11.62	11.91	11.92	11.91	11.77	11.74	11.69	11.62	11.57	11.55	931.2
1907	11.48	11.45	11.33	11.55	11.69	11.60	11.45	11.35	11.26	11.23	11.23	11.23	822.5
1908	11.18	11.15	11.07	11.09	11.24	11.21	11.16	11.13	11.06	11.03	11.11	11.18	691.9
1909	11.10	11.03	11.02	11.18	11.32	11.17	11.03	10.89	10.93	10.89	10.83	10.93	650.5

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1910	10.91	10.87	10.85	11.01	11.14	10.99	10.90	10.89	10.86	10.77	10.79	10.83	595.3
1911	10.79	10.66	10.71	10.89	10.92	10.85	10.71	10.63	10.63	10.47	10.50	10.48	513.5
1912	10.49	10.51	10.56	10.82	10.87	10.78	10.69	10.62	10.60	10.57	10.57	10.57	486.5
1913	10.59	10.66	10.74	10.85	11.08	11.09	10.99	10.85	10.74	10.70	10.71	10.75	555.3
1914	10.67	10.68	10.79	10.82	10.91	10.90	10.84	10.80	10.79	10.75	10.86	10.86	553.5
1915	10.80	10.82	10.94	11.04	11.17	11.14	11.02	10.89	10.88	10.84	10.89	11.00	612.5
1916	11.00	11.08	11.11	11.35	11.51	11.45	11.31	11.27	11.33	11.30	11.30	11.34	751.4
1917	11.37	11.45	11.45	11.76	11.89	11.91	11.81	11.79	11.86	11.88	11.87	11.82	963.7
1918	11.79	11.70	11.67	11.77	11.78	11.67	11.46	11.32	11.29	11.22	11.21	11.18	876.1
1919	11.09	11.12	11.15	11.32	11.34	11.21	11.15	11.04	11.03	10.96	10.94	10.91	684.2
1920	10.91	10.81	10.89	11.12	11.12	11.09	10.92	10.84	10.76	10.74	10.77	10.82	594.7
1921	10.83	10.82	10.83	10.81	10.85	10.77	10.73	10.71	10.59	10.55	10.45	10.45	518.8
1922	10.39	10.55	10.46	10.60	10.64	10.57	10.38	10.48	10.35	10.33	10.35	10.34	416.1
1923	10.22	10.34	10.34	10.58	10.82	10.82	10.80	10.73	10.65	10.62	10.65	10.76	470.3
1924	10.72	10.79	10.77	10.87	10.99	10.94	10.71	10.69	10.61	10.63	10.60	10.59	532.9
1925	10.69	10.68	10.76	10.76	10.80	10.83	10.70	10.61	10.53	10.50	10.68	10.76	506.9
1926	10.75	10.76	10.88	11.07	11.38	11.36	11.27	11.26	11.26	11.29	11.29	11.29	694.4
1927	11.29	11.34	11.37	11.51	11.54	11.41	11.27	11.17	11.09	11.00	10.93	10.93	746.9

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1928	10.87	10.82	10.82	11.02	11.28	11.24	11.12	11.04	10.98	10.93	10.91	10.89	633.0
1929	10.79	10.74	10.78	10.87	10.95	10.87	10.85	10.78	10.68	10.65	10.65	10.78	547.8
1930	10.83	10.85	11.03	11.29	11.41	11.36	11.23	11.18	11.20	11.20	11.18	11.15	697.8
1931	11.11	11.12	11.22	11.39	11.47	11.42	11.40	11.35	11.34	11.24	11.26	11.26	764.1
1932	11.21	11.19	11.33	11.39	11.59	11.52	11.46	11.36	11.37	11.35	11.31	11.33	797.2
1933	11.35	11.39	11.42	11.44	11.51	11.43	11.28	11.21	11.19	11.15	11.12	11.14	772.1
1934	11.05	10.98	10.97	11.11	11.17	11.08	11.01	10.97	10.87	10.85	10.87	10.92	632.8
1935	10.82	10.92	10.94	11.02	11.18	11.22	11.08	10.94	10.89	10.81	10.81	10.90	619.0
1936	10.99	11.06	11.17	11.39	11.43	11.41	11.29	11.21	11.15	11.08	11.03	11.12	715.3
1937	11.13	11.19	11.31	11.57	11.73	11.65	11.56	11.45	11.39	11.37	11.48	11.47	827.3
1938	11.41	11.38	11.50	11.58	11.61	11.57	11.46	11.40	11.32	11.30	11.28	11.26	828.8
1939	11.21	11.19	11.26	11.40	11.39	11.29	11.23	11.13	11.09	11.05	11.04	11.03	660.8
1940	11.04	11.08	11.22	11.38	11.46	11.38	11.33	11.24	11.13	11.07	11.11	11.09	687.3
1941	11.06	11.06	11.09	11.19	11.32	11.30	11.19	11.12	11.05	11.03	11.16	11.34	684.4
1942	11.37	11.30	11.50	11.69	11.83	11.75	11.60	11.54	11.43	11.33	11.30	11.25	864.2
1943	11.13	11.15	11.13	11.28	11.35	11.26	11.12	11.04	10.96	10.90	10.83	10.75	680.6
1944	10.70	10.68	10.74	10.87	10.96	10.85	10.75	10.69	10.67	10.63	10.74	10.79	527.7
1945	10.75	10.73	10.67	10.67	10.90	10.87	10.83	10.83	10.73	10.70	10.69	10.66	543.4

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1946	10.59	10.51	10.46	10.60	10.67	10.71	10.63	10.67	10.64	10.63	10.66	10.74	496.7
1947	10.80	10.84	10.95	11.27	11.50	11.45	11.43	11.37	11.34	11.30	11.23	11.22	720.6
1948	11.19	11.17	11.20	11.26	11.32	11.31	11.26	11.23	11.18	11.13	11.12	11.10	733.2
1949	11.03	10.98	10.89	10.98	11.01	10.92	10.86	10.82	10.74	10.70	10.63	10.68	590.8
1950	10.68	10.62	10.73	10.84	10.93	10.83	10.81	10.74	10.73	10.72	10.65	10.65	504.2
1951	10.62	10.67	10.70	10.95	11.02	10.95	10.84	10.78	10.68	10.68	10.87	11.18	554.4
1952	11.19	11.22	11.27	11.50	11.75	11.63	11.55	11.48	11.47	11.41	11.40	11.30	616.2
1953	11.25	11.16	11.15	11.29	11.32	11.25	11.11	11.04	11.01	10.97	10.99	11.05	587.7
1954	10.98	10.94	10.92	11.06	11.23	11.18	11.10	11.03	11.00	10.93	10.86	10.86	655.5
1955	10.86	10.89	10.89	10.97	11.00	10.86	10.77	10.73	10.76	10.77	10.74	10.84	578.5
1956	10.92	10.92	10.91	11.08	11.17	11.07	10.97	10.93	10.91	10.91	10.89	10.91	621.0
1957	10.90	10.90	11.00	11.19	11.34	11.35	11.24	11.15	11.03	10.96	10.96	11.02	637.4
1958	10.98	11.00	11.02	11.10	11.20	11.16	11.11	11.05	10.99	10.93	10.86	10.94	623.7
1959	10.93	10.95	10.97	11.05	11.09	11.00	10.85	10.78	10.75	10.78	10.85	10.84	584.5
1960	10.86	10.92	11.08	11.29	11.31	11.18	11.05	10.96	10.94	10.92	10.91	10.87	643.5
1961	10.80	10.83	10.89	11.03	11.08	11.01	10.91	10.90	10.90	11.01	11.56	11.94	651.8
1962	12.07	12.01	12.11	12.29	12.51	12.45	12.34	12.32	12.29	12.34	12.34	12.39	1226.9
1963	12.47	12.51	12.58	12.80	13.02	12.95	12.82	12.70	12.59	12.50	12.70	12.91	1304.3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1964	12.89	12.92	12.98	13.30	13.33	13.24	13.09	13.04	12.96	12.93	12.88	12.88	1595.8
1965	12.82	12.75	12.74	12.84	12.85	12.67	12.55	12.42	12.33	12.34	12.43	12.48	1488.0
1966	12.45	12.49	12.59	12.78	12.73	12.63	12.49	12.40	12.37	12.35	12.37	12.32	1362.0
1967	12.25	12.15	12.14	12.25	12.41	12.33	12.23	12.11	12.06	12.06	12.25	12.31	1199.4
1968	12.21	12.28	12.44	12.67	12.81	12.79	12.64	12.54	12.41	12.37	12.46	12.58	1368.8
1969	12.62	12.69	12.78	12.82	12.92	12.80	12.66	12.51	12.43	12.36	12.39	12.36	1458.7
1970	12.41	12.44	12.59	12.79	12.88	12.78	12.64	12.61	12.55	12.52	12.47	12.45	1404.1
1971	12.40	12.31	12.23	12.42	12.51	12.38	12.30	12.25	12.20	12.16	12.16	12.17	1253.1
1972	12.17	12.19	12.16	12.20	12.31	12.29	12.17	12.09	12.00	12.07	12.27	12.35	1187.1
1973	12.35	12.37	12.30	12.37	12.45	12.31	12.19	12.10	12.08	12.03	12.11	12.05	1219.8
1974	11.99	11.93	11.96	12.21	12.24	12.30	12.32	12.19	12.12	12.05	12.01	11.97	1111.1
1975	11.90	11.86	11.95	12.09	12.12	12.09	12.09	12.05	12.05	12.05	12.01	12.04	1056.2
1976	11.97	11.95	11.99	12.09	12.20	12.09	12.05	12.00	11.93	11.85	11.86	11.82	1101.7
1977	11.88	11.82	11.93	12.21	12.32	12.28	12.17	12.03	11.98	12.00	12.11	12.13	1140.8
1978	12.07	12.14	12.40	12.59	12.60	12.57	12.43	12.36	12.29	12.29	12.41	12.56	1248.5
1979	12.59	12.71	12.76	12.94	13.10	12.97	12.82	12.70	12.56	12.48	12.49	12.50	1406.3
1980	12.51	12.45	12.40	12.37	12.51	12.42	12.30	12.04	11.99	11.90	11.91	11.90	1462.8
1981	11.95	11.92	11.90	12.05	12.18	12.12	12.10	12.00	11.92	11.86	11.83	11.80	1014.7

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1982	11.80	11.79	11.78	11.80	11.88	11.97	12.00	11.92	11.88	11.90	11.92	12.18	1048.0
1983	12.13	12.07	12.03	12.07	12.04	12.03	12.04	12.08	11.98	12.13	12.16	12.17	1001.0
1984	12.14	12.04	12.05	12.10	12.09	11.95	11.83	11.78	11.62	11.58	11.70	11.60	987.3
1985	11.60	11.59	11.57	11.82	11.93	11.90	11.87	11.83	11.74	11.66	11.62	11.63	1034.1
1986	11.59	11.57	11.56	11.80	11.88	11.83	11.66	11.57	11.50	11.57	11.65	11.67	947.2
1987	11.57	11.83	11.67	11.78	12.08	12.16	11.87	11.66	11.62	11.66	11.66	11.73	953.8
1988	11.77	11.68	11.67	12.04	12.01	11.98	11.91	11.92	11.96	11.95	11.99	12.02	1033.4
1989	12.01	12.02	12.08	12.16	12.23	12.11	12.01	11.84	11.79	11.78	11.82	11.91	1158.1
1990	12.00	12.04	12.25	12.46	12.53	12.38	12.21	12.12	12.03	11.99	11.95	12.02	1100.7
1991	12.06	12.07	12.15	12.21	12.41	12.38	12.24	12.14	12.06	12.16	12.12	12.09	1175.6
1992	12.01	11.94	11.87	11.96	12.03	11.98	11.87	11.73	11.67	11.70	11.70	11.82	1042.6
1993	11.82	11.82	11.81	11.82	11.96	11.94	11.75	11.64	11.50	11.42	11.38	11.34	1008.7
1994	11.36	11.30	11.34	11.45	11.59	11.49	11.49	11.44	11.32	11.34	11.52	11.59	828.3
1995	11.55	11.57	11.58	11.74	11.86	11.80	11.74	11.60	11.55	11.57	11.59	11.57	914.3
1996	11.61	11.66	11.71	11.76	12.00	11.99	11.92	11.82	11.81	11.76	11.72	11.73	980.3
1997	11.70	11.62	11.52	11.61	11.70	11.76	12.05	11.56	11.41	11.32	11.51	12.36	923.1
1998	12.31	12.46	12.51	12.65	12.88	12.83	12.67	12.54	12.46	12.43	12.42	12.34	1229.5
1999	12.32	12.46	12.51	12.41	12.53	12.42	12.23	12.10	12.06	12.06	12.07	12.14	1158.4

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
2000	12.15	12.07	12.01	11.99	12.00	11.91	11.76	11.62	11.51	11.47	11.57	11.64	1119.3
2001	11.73	11.77	11.73	11.80	11.87	11.87	11.76	11.70	11.65	11.65	11.72	11.74	1096.3
2002	11.76	11.74	11.77	11.89	12.14	12.07	11.91	11.79	11.68	11.59	11.66	11.72	1179.8
2003	11.82	11.73	11.68	11.70	11.90	11.90	11.83	11.71	11.68	11.60	11.56	11.59	1203.2
2004	11.56	11.48	11.47	11.54	11.67	11.56	11.34	11.21	11.12	11.06	11.06	11.11	1329.2
2005	11.10	11.05	11.01	11.08	11.11	11.14	11.03	10.90	10.85	10.77	10.72	10.70	1177.2
2006	m	m	m	m	m	m	m	m	m	m	m	m	m

2.2 Lake Kyoga End of Month Levels (Metres above Masindi Gauge) and Mean Annual Outflows

Source: Directorate of Water Development, Ministry of Water &Environment, Uganda

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1947	10.72	10.60	10.56	10.75	11.02	11.28	11.46	11.54	11.58	11.54	11.34	11.22	784.1
1948	11.02	10.98	10.90	10.93	10.98	11.05	11.11	11.19	11.25	11.24	11.15	10.95	747.8
1949	10.82	10.70	10.57	10.57	10.60	10.58	10.57	10.57	10.71	10.59	10.48	10.35	549.9
1950	10.24	10.08	10.17	10.30	10.40	10.50	10.55	10.69	10.87	10.75	10.55	10.42	488.8
1951	10.34	10.34	10.40	10.60	10.82	11.02	11.06	11.06	10.94	10.93	10.96	11.14	618.2
1952	11.18	11.06	11.02	11.08	11.11	11.07	11.01	11.03	11.07	11.05	10.90	10.70	730.2
1953	m	m	m	m	m	m	m	m	m	m	10.52	10.36	m
1954	10.34	10.38	10.39	10.52	10.81	10.92	11.09	11.19	11.19	11.08	10.87	10.77	630.5
1955	10.65	10.60	10.58	10.60	10.66	10.60	10.64	10.69	10.75	10.81	10.71	10.62	574.7
1956	10.58	10.50	10.49	10.61	10.79	10.88	11.08	11.21	11.18	11.29	11.12	10.98	660.5
1957	10.77	10.65	10.64	10.79	10.95	11.21	11.21	11.23	11.10	10.95	10.85	10.76	686.2
1958	10.65	10.61	10.54	10.63	10.76	10.88	11.02	11.09	11.08	11.08	10.91	10.87	646.6
1959	10.77	10.73	10.75	10.80	10.92	10.94	m	11.02	11.12	11.10	11.06	10.95	681.1
1960	10.80	10.67	10.73	10.86	11.16	11.21	11.20	11.22	11.18	11.10	11.08	10.80	717.4
1961	10.70	10.50	10.47	10.52	10.60	10.64	10.66	10.84	11.00	11.31	12.30	12.75	700.2
1962	12.92	12.73	12.66	12.60	12.80	12.87	12.83	12.86	12.94	12.98	12.96	12.82	1589.5

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1963	12.74	12.73	12.72	12.92	13.26	13.40	13.39	13.34	13.18	12.94	12.92	13.12	1703.3
1964	13.09	13.00	12.94	13.02	13.19	13.30	13.32	13.39	13.37	13.49	13.26	13.20	1794.0
1965	13.10	13.06	13.09	13.07	13.10	13.06	12.87	12.69	12.53	12.60	12.53	12.50	1620.9
1966	12.43	12.45	12.47	12.65	12.71	12.97	12.77	12.67	12.67	12.69	12.64	12.37	1480.3
1967	12.23	12.12	11.84	11.95	12.01	12.15	12.20	12.26	12.22	12.30	12.24	12.42	1237.5
1968	12.32	12.30	12.30	12.49	12.80	13.03	13.00	12.94	12.80	12.76	12.59	12.57	1497.6
1969	12.53	12.59	12.63	12.59	12.81	12.85	12.77	12.66	12.57	12.57	12.51	12.50	1478.7
1970	12.25	12.19	12.27	12.44	12.69	12.83	12.85	12.89	12.89	12.90	12.78	12.62	1490.8
1971	12.44	12.32	12.11	12.22	12.33	12.29	12.30	12.33	12.37	12.34	12.22	12.01	1323.6
1972	11.92	11.86	11.84	11.87	11.90	11.99	11.98	12.01	11.94	12.03	12.14	12.17	1157.1
1973	12.19	12.04	11.99	12.03	12.24	12.21	12.13	12.11	12.09	12.08	12.05	11.91	1230.5
1974	11.74	11.50	11.57	11.65	11.74	11.80	11.93	12.06	12.13	12.00	11.78	11.60	1090.9
1975	11.47	11.46	11.26	11.29	11.23	11.17	11.38	11.63	12.09	12.43	12.25	12.03	1001.6
1976	11.95	11.82	11.67	11.70	11.80	11.78	11.80	11.87	11.82	11.72	11.61	11.50	1064.6
1977	11.42	11.34	11.31	11.50	11.66	11.71	11.87	11.98	12.00	11.99	12.17	12.13	988.5
1978	12.11	12.06	11.92	12.01	12.32	12.47	12.41	12.36	12.37	m	m	m	1255.1
1979	m	m	m	m	m	m	m	m	m	m	m	m	m
1980	m	m	m	m	m	m	m	m	m	m	m	m	m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1981	m	m	m	m	m	m	m	m	m	m	m	m	m
1982	m	m	m	m	m	m	m	m	m	m	m	m	m
1983	m	m	m	m	m	m	m	m	m	m	m	12.28	m
1984	12.12	m	m	m	m	m	m	m	m	m	m	m	m
1985	m	m	m	m	m	m	m	m	m	m	m	m	m
1986	m	m	m	m	m	m	m	m	m	m	m	m	m
1987	m	m	m	m	m	m	m	m	m	m	m	m	m
1988	m	m	m	m	m	m	m	m	m	m	m	m	m
1989	m	m	m	m	m	m	m	m	m	m	m	11.64	1064.6
1990	11.41	11.51	11.61	12.08	m	m	m	m	12.01	12.16	12.31	12.27	1086.6
1991	12.22	12.19	12.15	m	m	m	m	m	m	m	m	12.00	m
1992	11.96	11.77	11.85	11.74	11.76	11.77	11.82	11.87	11.75	11.72	11.72	11.75	1026.9
1993	11.53	11.34	11.43	11.50	11.57	11.80	11.76	11.63	11.52	11.42	11.25	11.25	885.3
1994	11.08	11.00	10.99	11.01	11.11	11.14	11.09	11.25	11.11	11.15	m	m	667.7
1995	m	m	11.24	11.26	m	m	m	m	m	m	m	11.48	m
1996	11.37	11.33	11.27	11.38	11.64	11.69	11.89	11.95	12.02	11.88	11.78	11.74	937.9
1997	11.60	11.44	11.35	11.39	11.49	11.49	11.51	11.51	11.35	11.49	11.77	12.34	884.2
1998	12.50	12.48	12.28	12.04	12.11	12.10	12.24	12.17	12.05	12.20	12.37	12.13	1261.9

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Outflows (m^3/s)
1999	12.08	11.89	11.95	12.10	12.28	12.28	12.16	12.00	11.94	12.04	11.96	11.89	1167.6
2000	11.74	11.51	11.46	11.52	11.64	11.67	11.72	11.83	11.93	12.09	12.04	11.88	1001.4
2001	11.74	11.71	11.73	11.80	11.90	11.96	11.99	12.01	11.97	12.18	12.30	12.08	1095.3
2002	11.92	11.89	11.88	12.04	12.20	12.16	12.05	12.00	11.94	12.10	12.25	12.24	1159.0
2003	12.15	12.00	12.00	12.19	12.26	12.30	12.28	12.32	12.41	12.38	12.39	12.38	1273.8
2004	12.25	12.20	12.14	12.32	12.35	12.36	12.39	12.50	12.58	12.62	12.61	12.43	1349.7
2005	12.36	12.23	12.23	12.22	12.25	12.18	12.16	12.18	12.30	12.20	12.23	12.00	1253.4
2006	11.66	11.60	11.46	11.41	11.40								

m: missing

2.3 Lake Kyoga end of month levels measured at Bugondo pier

Source: Directorate of Water Development, Ministry of Water &Environment, Uganda

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1947	m	m	m	m	m	m	m	m	m	m	m	m
1948	10.96	10.86	10.78	10.82	10.86	10.92	11.00	11.02	11.08	11.06	10.96	10.86
1949	10.72	10.58	10.46	10.50	10.54	10.54	10.50	10.54	10.62	10.56	10.40	10.36
1950	10.30	10.16	10.28	10.38	10.50	10.56	10.62	10.68	10.76	10.67	10.58	10.52
1951	10.48	10.44	10.50	10.66	10.84	10.90	10.92	10.88	10.86	10.82	10.86	11.08
1952	11.11	11.06	10.96	10.98	10.96	10.96	10.92	10.88	10.85	10.80	10.71	10.53
1953	10.46	10.36	10.38	10.50	10.44	10.55	10.50	10.54	10.50	10.56	10.54	10.40
1954	10.48	10.54	10.56	10.70	10.90	10.98	11.02	11.04	11.06	10.96	10.80	10.40
1955	10.64	10.62	10.52	10.60	10.62	10.56	10.58	10.66	10.68	10.68	10.62	10.60
1956	10.54	10.50	10.48	10.66	10.80	10.90	11.00	11.08	11.02	11.12	10.96	10.86
1957	10.76	10.68	10.64	10.82	10.98	11.09	11.13	11.12	10.98	10.88	10.74	10.71
1958	10.60	10.59	10.56	10.70	10.81	10.90	11.00	11.00	10.97	10.94	10.90	10.82
1959	10.72	10.75	10.78	10.82	10.80	10.91	10.91	10.89	10.95	10.90	10.93	10.82
1960	10.71	10.67	10.70	10.88	11.11	11.12	11.11	11.11	11.07	10.99	10.92	10.61
1961	10.51	10.35	10.31	10.42	10.50	10.53	10.59	10.72	10.88	11.20	11.93	12.46
1962	12.60	12.53	12.41	12.35	12.52	12.57	12.55	12.58	12.63	12.70	12.65	12.54

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1963	12.49	12.42	12.40	12.62	12.90	m	13.06	13.02	12.82	12.68	12.64	12.75
1964	12.71	12.62	12.60	12.75	12.90	12.96	13.05	13.02	13.06	13.11	12.94	12.76
1965	12.78	12.76	12.76	12.76	12.76	12.72	12.58	12.38	12.28	12.26	12.26	12.20
1966	12.12	12.13	12.20	12.28	12.41	12.54	12.44	12.42	12.35	12.36	12.35	12.14
1967	12.00	11.84	11.78	11.78	11.86	11.94	11.95	11.98	11.96	11.98	12.06	12.16
1968	12.22	11.93	12.02	12.14	12.52	12.72	12.72	12.58	12.58	12.43	12.32	12.26
1969	12.28	12.28	12.30	12.31	12.36	12.48	12.40	12.34	12.24	12.18	12.10	12.15
1970	11.90	11.84	11.92	12.06	12.26	12.42	12.40	12.43	12.44	12.47	12.42	12.23
1971	12.08	11.94	11.73	11.84	11.94	11.90	11.92	11.90	11.98	11.94	11.86	11.64
1972	11.61	11.56	11.48	11.48	11.60	11.62	11.62	11.63	11.58	11.61	11.76	11.69
1973	11.78	11.73	11.68	11.64	11.78	11.86	11.74	11.73	11.68	11.80	11.72	11.58
1974	11.49	m	11.21	11.34	11.34	11.46	11.51	11.63	11.72	11.52	m	11.21
1975	11.13	10.98	10.96	10.98	10.88	10.82	11.02	11.22	11.69	11.98	11.80	11.59
1976	11.46	11.30	11.20	11.24	11.28	11.38	11.30	11.40	11.38	11.28	11.22	11.06
1977	m	10.96	10.96	11.06	11.00	m	m	m	m	m	m	m
1978	m	m	m	m	m	m	m	m	12.00	11.98	11.88	11.88
1979	11.82	m	m	m	m	m	12.10	12.08	12.05	12.01	11.99	11.94
1980	11.84	m	m	12.00	11.96	11.86	11.88	12.03	11.96	11.97	11.97	m
1981	m	m	m	m	m	m	m	m	m	m	m	m

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982	m	m	m	m	m	m	m	m	m	m	m	m
1983	m	m	m	m	m	m	m	m	m	m	m	m
1984	m	m	m	m	m	m	m	m	m	m	m	m
1985	m	m	m	m	m	m	m	m	m	m	m	m
1986	m	m	m	m	m	m	m	m	m	m	m	m
1987	m	m	m	m	m	m	m	m	m	m	m	m
1988	m	m	m	m	m	m	m	m	m	m	m	m
1989	m	m	m	m	m	m	m	m	m	m	m	m
1990	m	m	m	m	m	m	m	m	m	m	m	m
1991	m	m	m	m	m	m	m	m	m	m	m	m
1992	m	m	m	m	m	m	m	m	m	m	m	m
1993	m	m	m	m	m	m	m	m	m	m	m	m
1994	m	m	m	m	m	10.51	10.61	m	10.62	10.57	10.77	10.74
1995	10.74	10.73	10.73	10.74	m	m	m	m	m	m	m	m
1996	m	m	m	m	m	m	m	m	11.45	11.47	11.44	11.42
1997	11.11	10.98	10.80	10.81	10.94	10.94	10.97	10.93	10.84	10.87	11.15	11.74
1998	11.94	11.97	11.88	11.90	12.24	12.71	12.98	12.98	12.97	12.98	13.02	12.95
1999	12.87	12.83	12.90	12.96	13.10	13.10	13.04	13.05	13.05	12.97	12.97	12.88
2000	12.74	12.63	12.58	12.55	12.60	12.65	12.71	12.83	12.86	12.90	12.85	12.73

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	12.64	12.52	12.54	12.57	12.60	12.61	12.66	12.68	12.65	12.72	12.74	12.61
2002	12.59	12.55	12.51	12.62	12.64	12.63	12.57	12.49	12.41	12.50	12.54	12.56
2003	12.49	12.41	12.33	12.45	12.48	12.53	12.53	12.54	12.59	12.54	12.54	12.46
2004	12.43	12.37	12.29	12.44	12.42	12.44	12.47	12.54	12.64	12.60	12.55	12.48
2005	12.38	12.12	12.22	12.20	12.20	12.08	12.08	12.08	12.12	12.08	12.02	m
2006	11.63	11.41	11.25	11.18	11.15							

m: Missing data

Appendix 3 River Flow Data

3.1 Extended outflows from Lake Kyoga

Kyoga outflows from Kamdini (1940-80), Masindi Port (1912-39), Jinja regression (1896-1912. 1980-95)
Source: Kennedy & Donkin Power Study, 1997

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total (MCM)	Year (m^3/s)
1896	2498	2336	2419	2301	2398	2335	2391	2302	2155	2132	1940	2090	27297	865.6
1897	2191	1986	2235	2170	2340	2355	2462	2469	2380	2450	2359	2429	27826	882.4
1898	2420	2175	2399	2313	2377	2292	2360	2350	2266	2332	2235	2317	27836	882.7
1899	2309	2032	2220	2120	2176	2220	2317	2162	1860	1676	1497	1480	24069	763.2
1900	1505	1437	1542	1504	1553	1509	1590	1621	1545	1456	1221	1170	17653	559.8
1901	1249	1189	1340	1439	1800	1981	1956	1767	1557	1474	1332	1321	18405	583.6
1902	1273	1100	1224	1184	1260	1303	1334	1285	1214	1193	1114	1218	14702	466.2
1903	1371	1353	1548	1521	1676	1866	2184	2250	2113	2125	2064	2155	22226	704.8
1904	2147	1975	2097	2071	2295	2376	2427	2280	2071	2032	1880	1942	25593	811.5
1905	2040	1894	2061	2030	2243	2272	2288	2082	1860	1813	1685	1780	24048	762.6
1906	1956	1855	2083	2264	2746	2865	2960	2854	2644	2675	2506	2504	29912	948.5
1907	2455	2160	2317	2134	2279	2458	2576	2406	2149	2083	1934	1977	26928	853.9
1908	1977	1817	1887	1755	1773	1827	1970	1915	1800	1793	1671	1760	21945	695.9
1909	1860	1674	1754	1647	1800	1940	1998	1800	1569	1559	1509	1499	20609	653.5
1910	1523	1420	1535	1450	1584	1710	1753	1603	1492	1517	1397	1401	18385	583.0

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total (MCM)	Year (m^3/s)
1911	1438	1299	1334	1244	1425	1504	1530	1401	1226	1218	1084	1041	15744	499.2
1912	1047	974	1059	890	960	970	1070	1110	1130	1180	1100	1120	12610	399.9
1913	1010	860	910	900	1050	1130	1320	1410	1320	1270	1270	1220	13670	433.5
1914	1140	950	1000	1015	1030	1040	1120	1160	1190	1230	1260	1300	13435	426.0
1915	1350	1100	1170	1160	1300	1300	1360	1330	1300	1360	1350	1370	15450	489.9
1916	1310	1190	1300	1290	1430	1490	1640	1710	1770	1980	2060	2100	19270	611.0
1917	2510	2190	2360	2380	2860	3270	3660	3750	3750	4220	4230	4120	39300	1246.2
1918	3810	3140	3190	2900	2980	2760	2720	2600	2320	2200	1960	1890	32470	1029.6
1919	1500	1290	1570	1570	1690	1680	1770	1740	1620	1620	1570	1580	19200	608.8
1920	1460	1300	1320	1330	1480	1540	1580	1580	1480	1490	1390	1360	17310	548.9
1921	1260	1090	1170	1100	1180	1180	1260	1270	1210	1200	1120	1070	14110	447.4
1922	960	810	880	870	970	960	990	980	990	1000	960	910	11280	357.7
1923	820	690	750	760	890	970	1110	1240	1240	1380	1380	1350	12580	398.9
1924	1240	1110	1120	1100	1250	1280	1320	1330	1360	1390	1290	1280	15070	477.9
1925	1160	970	1050	1030	1080	1060	1110	1100	1040	1060	1030	1070	12760	404.6
1926	1070	930	920	940	1370	1540	1700	1810	1800	1950	1870	1930	17830	565.4
1927	1870	1640	1740	1720	1900	1890	1940	1900	1800	1780	1630	1590	21400	678.6
1928	1510	1290	1290	1220	1400	1480	1580	1600	1540	1580	1500	1480	17470	554.0
1929	1390	1180	1220	1170	1360	1330	1360	1370	1320	1350	1270	1260	15580	494.0
1930	1250	1110	1240	1280	1500	1600	1730	1770	1730	1830	1780	1780	18600	589.8
1931	1670	1440	1560	1560	1750	1800	1920	1980	1950	2030	1960	1960	21580	684.3
1932	1890	1680	1830	1820	1940	1970	2070	2100	2090	2210	2090	2130	23820	755.3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total (MCM)	Year (m^3/s)
1933	2080	1830	1990	1910	2050	2000	2030	2030	1970	2000	1870	1850	23610	748.7
1934	1770	1510	1590	1500	1620	1590	1670	1660	1590	1580	1510	1490	19080	605.0
1935	1440	1240	1350	1310	1410	1440	1560	1560	1510	1560	1460	1430	17270	547.6
1936	1410	1320	1480	1520	1700	1750	1890	1930	1870	1890	1720	1670	20150	639.0
1937	1600	1400	1540	1530	1670	1720	1880	1960	1870	1900	1850	1930	20850	661.1
1938	2022	1715	1796	1755	1917	1925	1989	2010	1938	2013	1881	1805	22766	721.9
1939	1660	1404	1474	1458	1590	1589	1642	1662	1550	1522	1439	1408	18398	583.4
1940	1344	1205	1362	1379	1513	1560	1691	1772	1726	1704	1595	1621	18472	585.7
1941	1298	1055	1408	1360	1487	1544	1656	1677	1690	1748	1696	1908	18527	587.5
1942	2041	1837	2075	2121	2458	2696	2895	2886	2815	2688	2405	2323	29240	927.2
1943	2110	1773	1848	1723	1821	1801	1835	1882	1782	1746	1555	1452	21328	676.3
1944	1261	1084	1106	1073	1202	1197	1255	1254	1206	1218	1121	1153	14130	448.1
1945	1086	925	985	901	1001	1092	1236	1403	1541	1633	1491	1449	14743	467.5
1946	1317	1059	1044	949	1038	1056	1129	1274	1428	1588	1815	1886	15583	494.1
1947	1722	1451	1501	1467	1743	1909	2151	2325	2353	2466	2172	2221	23481	744.6
1948	2010	1762	1803	1709	1813	1838	1974	2062	2007	2032	1926	1897	22833	724.0
1949	1805	1371	1547	1404	1478	1441	1469	1472	1493	1544	1355	1269	17648	559.6
1950	1208	1019	1087	1083	1172	1172	1250	1309	1386	1453	1322	1223	14684	465.6
1951	1108	955	1038	1073	1249	1345	1473	1560	1520	1587	1562	1781	16251	515.3
1952	1938	1796	1872	1815	2005	1883	1919	1899	1900	1934	1779	1714	22454	712.0
1953	1586	1330	1387	1345	1445	1345	1421	1427	1350	1372	1327	1248	16583	525.8
1954	1306	1262	1500	1501	1663	1746	1851	2036	1952	1904	1740	1728	20189	640.2

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total (MCM)	Year (m^3/s)
1955	1556	1325	1409	1410	1536	1455	1466	1481	1491	1632	1515	1465	17741	562.6
1956	1373	1215	1241	1197	1336	1373	1490	1608	1668	1804	1880	1880	18065	572.8
1957	1588	1365	1445	1438	1658	1824	2023	2053	1975	1869	1715	1652	20605	653.4
1958	1534	1316	1408	1337	1464	1459	1613	1677	1663	1695	1493	1416	18075	573.2
1959	1423	1251	1368	1314	1409	1396	1459	1486	1533	1668	1600	1642	17549	556.5
1960	1734	1581	1693	1693	1953	2095	2189	2164	2127	2127	2030	1977	23363	740.8
1961	1848	1520	1594	1552	1660	1671	1753	1905	1992	2201	2768	3603	24067	763.2
1962	4050	3462	3728	3555	3791	3739	3862	3864	3773	3901	3783	3821	45329	1437.4
1963	3773	3404	3692	3691	4282	4420	4610	4660	4460	4230	3890	4150	49262	1562.1
1964	4250	3890	4190	4150	4540	4380	4550	5000	5160	5240	4777	4707	54834	1738.8
1965	4579	3984	4426	4393	4596	4412	4465	4195	3803	3814	3725	3808	50200	1591.8
1966	3628	3181	3603	3701	3990	3944	4218	4154	4008	4029	3895	3801	46152	1463.5
1967	3615	3048	3211	3068	3207	3253	3509	3515	3339	3542	3387	3739	40433	1282.1
1968	3768	3381	3694	3609	4290	4537	4728	4651	4274	4186	4032	4049	49199	1560.1
1969	4005	3651	4143	3978	4315	4338	4425	4292	4057	4004	3715	3824	48747	1545.8
1970	3689	3126	3428	3483	3923	4067	4397	4366	4353	4442	4234	4130	47638	1510.6
1971	3737	3237	3355	3134	3353	3315	3417	3457	3430	3484	3291	3180	40390	1280.8
1972	3077	2875	3023	2890	3117	3143	3277	3155	3053	3097	3210	3536	37453	1187.6
1973	3376	2973	3178	2950	3208	3239	3228	3325	3267	3370	3141	3121	38376	1216.9
1974	2997	2478	2571	2641	2721	2743	2991	3019	3186	3366	3058	2760	34531	1095.0
1975	2877	2527	2630	2415	2463	2282	2513	2828	3116	4207	3979	3661	35498	1125.6
1976	3473	3035	3129	2987	3196	3234	3340	3269	3282	3232	2983	2924	38084	1207.6

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total (MCM)	Year (m^3/s)
1977	2810	2506	2651	2282	2997	3039	3195	3344	3334	3526	3546	3677	36907	1170.3
1978	3456	3057	3314	3139	3661	3778	3888	3901	3886	3928	3959	3963	43930	1393.0
1979	3742	3363	3777	3744	3967	4027	4216	4185	4037	4105	3886	3944	46993	1490.1
1980	3858	3576	3782	3693	3850	3759	3805	4386	4398	4034	3704	3752	46597	1477.6
1981	3850	2593	2563	2701	2751	2855	3434	3463	3164	3258	2767	2292	35691	1131.8
1982	1504	2192	2286	2723	2904	3406	3505	2757	2657	2846	3098	3022	32900	1043.3
1983	3201	3179	3471	3384	2351	2635	2857	2939	2899	2328	2348	2186	33778	1071.1
1984	2210	2206	3001	2458	2328	2304	2363	3269	3473	2587	3473	2516	32188	1020.7
1985	2483	2161	2513	2855	3081	2855	2751	3042	2932	2999	2844	3528	34044	1079.5
1986	2540	1986	2815	3010	2928	2502	2857	2723	2348	2504	2436	2422	31071	985.3
1987	2449	2212	2311	2260	2328	2238	2563	3042	2789	3069	2976	2940	31177	988.6
1988	2472	2549	2690	2533	2875	2768	2817	3003	2865	2996	2920	3039	33527	1063.1
1989	3089	2645	3455	3635	3741	3557	3673	3430	3264	3168	3060	2890	39607	1255.9
1990	2005	2053	2556	2792	3348	3274	3309	3219	3166	3329	3271	3159	35481	1125.1
1991	3043	2827	3117	3003	3135	3335	3509	3581	3490	3541	3108	3283	38972	1235.8
1992	3233	2987	3156	3069	3007	2927	2967	3316	2662	2481	2465	2664	34934	1107.7
1993	2752	2438	2807	3050	3303	3086	3107	3183	2631	2555	2334	2314	33560	1064.2
1994	2350	2086	2268	2207	2303	2131	2123	2344	2200	2179	2119	2055	26365	836.0
1995	2655	2237	2389	2447	2508	2762	2888	2818	2382	2434	2262	2267	30049	952.8

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total (MCM)	Year (m^3/s)
This part of data is from Masindi Port Gauge (DWD, 2006) and is monthly flow in m^3/s														
1996	817.5	781.2	754.1	759.7	827.2	940.9	1028.3	1077.0	1123.9	1092.0	1036.7	1016.8		937.9
1997	953.4	875.0	792.2	793.7	847.2	861.9	868.7	874.5	827.5	820.3	916.1	1180.2		884.2
1998	1367.8	1406.0	1344.8	1230.6	1157.0	1198.1	1234.3	1229.8	1196.1	1202.6	1318.4	1257.5		1261.9
1999	1176.0	1131.6	1107.3	1128.0	1255.6	1294.6	1251.3	1169.6	1110.9	1143.5	1136.2	1106.4		1167.6
2000	1025.9	926.9	862.7	854.1	932.3	944.2	981.7	1006.6	1064.5	1122.8	1182.8	1112.8		1001.4
2001	1026.6	988.4	954.7	993.4	1047.7	1107.1	1091.7	1136.2	1131.7	1164.3	1267.0	1234.9		1095.3
2002	1119.0	1083.9	1078.7	1092.4	1218.8	1222.2	1186.9	1164.4	1111.4	1133.8	1234.2	1262.6		1159.0
2003	1250.1	1177.5	1130.8	1149.2	1258.5	1285.8	1305.9	1293.4	1351.8	1353.3	1361.7	1368.1		1273.8
2004	1313.2	1251.1	1208.7	1265.2	1328.8	1328.3	1336.9	1385.6	1418.6	1457.5	1483.8	1419.3		1349.7
2005	1345.7	1294.6	1258.4	1250.1	1262.8	1251.4	1212.4	1208.3	1259.1	1261.5	1252.0	1183.8		1253.4

3.2 Monthly Victoria Nile flows at Mbulamuti

Source: Directorate of Water Development, Ministry of Water &Environment, Uganda

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1956	m	m	m	m	m	m	m	550.2	568.6	664.9	570.8	570.9	585.1
1957	592.9	601.7	613.0	691.5	760.3	807.9	793.3	720.6	679.0	632.3	628.7	644.9	680.5
1958	651.9	654.6	642.5	659.7	731.2	739.2	729.0	694.2	670.9	645.5	611.4	627.5	671.5
1959	636.9	641.6	652.7	650.5	684.0	675.0	662.8	633.3	631.0	627.7	635.7	648.3	648.3
1960	662.1	670.6	707.7	802.9	839.2	816.0	747.7	706.3	681.1	654.2	653.3	629.3	714.2
1961	604.2	604.0	615.5	674.5	731.6	722.6	664.0	646.1	649.4	682.0	877.4	1154.2	718.8
1962	1285.9	1261.5	1251.7	1291.2	1295.4	1467.7	1417.2	1347.1	1329.7	1338.6	1319.6	1348.7	1329.5
1963	1358.3	1366.5	1415.3	1430.6	1545.8	1683.1	1691.3	1623.7	1508.5	1454.9	1437.2	1543.0	1504.8
1964	1626.0	1555.2	1587.7	1654.7	1732.5	1718.8	1767.4	1691.4	1696.0	1668.3	1576.9	1596.6	1656.0
1965	1709.4	1741.1	1733.6	1692.7	1681.1	1691.2	1423.9	1353.5	1295.0	1273.3	1312.5	1335.2	1520.2
1966	1354.2	1343.2	1379.3	1450.2	1639.9	1705.3	1386.3	1332.0	1295.5	1280.6	1314.2	1281.5	1396.8
1967	1265.6	1217.8	1137.2	1148.6	1227.9	1224.3	1219.2	1177.4	1150.5	1158.1	1159.5	1246.4	1194.4
1968	1216.4	1166.6	1234.8	1327.5	1491.0	1549.5	1484.6	1435.3	1360.1	1317.4	1289.3	1381.8	1354.5
1969	1404.4	1449.8	1488.2	1533.0	1619.3	1598.3	1480.8	1390.5	1345.2	1305.0	m	1495.7	1464.6
1970	1211.7	1290.0	1335.5	1429.7	1571.1	1553.4	1462.8	1412.1	m	m	m	1324.6	1399.0
1971	1302.7	1254.2	1177.8	1218.4	1307.3	1298.7	1238.5	1199.6	1191.7	1166.2	1146.7	1137.2	1219.9
1972	1142.5	1153.7	1131.0	1143.9	1194.3	1219.5	m	m	m	m	m	m	1164.1

Year	Month												Annual
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
1973	1232.1	1201.5	1291.8	1203.7	1251.5	1273.1	1183.5	1143.0	1109.8	1114.5	1084.6	1117.2	1183.9
1974	1093.1	1037.2	1033.2	1105.6	1173.3	1174.6	1151.5	1247.7	1280.1	1033.7	990.0	984.8	1108.7
1975	1092.5	919.0	906.0	906.4	767.0	826.7	1055.8	1113.7	1322.6	1290.5	1104.1	1027.5	1027.6
1976	1119.9	1092.6	1065.8	1116.7	1108.8	1134.1	1097.6	1145.5	1093.1	1028.7	985.6	1049.7	1086.5
1977	1097.8	1088.2	1025.3	1090.7	1194.6	1158.8	1215.4	1139.2	1216.9	1140.3	1210.0	1268.4	1153.8
1978	m	m	985.7	1200.9	1285.7	1264.5	1245.4	1178.0	1263.4	1248.3	1226.2	1200.1	1209.8
1979	1216.5	1297.1	1341.5	1344.2	m	1397.4	1374.2	m	1383.9	1323.9	1413.7	1398.4	1349.1
1980	1450.5	1486.4	1544.2	1547.9	1399.7	1411.5	1501.7	1559.5	1418.0	1349.7	1320.7	1361.7	1446.0
1981	1127.0	984.8	986.2	919.5	m	m	1193.9	1193.3	1175.5	1063.4	988.0	m	1070.2
1982	981.9	1071.9	1142.2	1102.0	1208.0	1205.3	1114.8	1106.5	1057.2	1143.0	1184.3	1160.7	1123.1
1983	1212.2	1219.5	1215.7	997.4	m	m	m	m	m	m	m	m	1161.2
1984	m	m	m	m	m	m	m	m	m	m	m	m	
1985	m	m	m	m	m	m	m	m	m	m	m	m	
1986	m	m	m	m	m	m	m	m	m	m	m	m	
1987	m	m	m	m	m	m	m	m	m	m	m	m	
1988	m	m	m	m	1062.8	1091.4	1102.6	1093.7	1188.2	1193.7	1079.2	942.6	1094.3
1989	1053.9	1103.4	1229.0	1261.8	1240.9	1250.3	1169.5	1156.8	1126.2	1125.7	1038.2		1159.6
1990	m	m	m	1152.9	1126.8	1132.6	1192.0	1127.7	1116.0	1121.8	1107.6	1067.6	1127.2
1991	1069.1	1082.7	1085.7	1097.1	1185.3	1191.6	1241.5	1259.8	1224.7	1227.1	1230.5	1152.9	1170.7

Year	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1992	1156.5	1142.8	1158.1	1114.1	1170.1	1203.7	1288.9	1075.6	974.3	984.4	970.1	952.9	1099.3
1993	920.7	964.6	1046.6	1052.9	1071.0	1049.5	1092.5	961.4	922.1	921.0	902.0	928.6	986.1
1994	923.2	976.2	766.3	798.3	692.0	663.6	m	m	m	746.8	721.4	882.2	796.7
1995	850.9	854.9	940.4	893.6	978.9	1019.8	998.3	879.1	830.0	799.7	780.6	854.0	890.0
1996	800.8	898.4	843.4	850.8	819.3	1080.7	1088.6	1016.4	961.6	973.5	967.3	969.7	939.2
1997	942.8	903.1	860.8	829.9	912.6	952.2	908.2	877.5	865.5	880.1	900.3	861.2	891.2
1998	1141.1	1119.7	1117.1	1163.2	1353.5	1575.2	1601.5	1169.0	1090.0	1089.4	1337.8	1191.5	1245.7
1999	1238.3	1293.0	1271.5	1334.0	1386.9	1350.0	1253.3	1002.8	1036.9	1058.4	1079.0	1090.2	1199.5
2000	1070.7	1054.3	1038.5	1037.6	1098.8	1198.5	1187.7	1269.5	1190.9	1220.2	1205.9	1129.0	1141.8
2001	1114.8	1097.4	1057.8	1070.0	1116.9	1097.8	1171.7	1159.1	1120.3	1160.8	1148.5	1097.7	1117.7
2002	1202.7	1273.8	1143.4	1218.1	1143.0	1162.5	1167.5	1107.0	1075.4	1152.1	1185.8	1152.5	1165.3
2003	1168.4	1196.6	1167.2	1166.3	1149.6	1155.9	1220.4	1243.5	1227.5	1225.0	1267.8	1252.6	1203.4
2004	1269.8	1281.0	1269.5	1265.6	1310.1	1352.7	1416.4	1374.2	1376.8	1359.0	1392.0	1386.0	1337.8
2005	1395.0	1301.2	1245.6	1242.7	1193.4	1176.7	1192.4	1177.0	1196.9	1180.8	1194.4	1175.7	1222.7
2006	1098.7	893.5											

3.3 Lake Victoria End of month Levels and Monthly Water Releases at Jinja for the Period 1997 - 2005

Data source: The electricity generation company, Uganda

Period	End of Month Level (m)	Discharge (x 10^6 m^3)
Jan-97	11.70	2558.930
Feb-97	11.62	2223.980
Mar-97	11.52	2329.350
Apr-97	11.61	2373.110
May-97	11.70	2710.330
Jun-97	11.76	2549.070
Jul-97	12.05	2516.100
Aug-97	11.56	2379.720
Sep-97	11.41	2126.500
Oct-97	11.32	2080.780
Nov-97	11.51	2249.230
Dec-97	12.36	2891.190
Jan-98	12.31	3368.740
Feb-98	12.46	3243.830
Mar-98	12.51	3666.200
Apr-98	12.65	3761.740
May-98	12.88	4281.370
Jun-98	12.83	4073.160
Jul-98	12.67	3930.130
Aug-98	12.54	3709.700
Sep-98	12.46	3475.200
Oct-98	12.43	3543.110
Nov-98	12.42	3404.850
Dec-98	12.34	3399.340
Jan-99	12.32	3368.740
Feb-99	12.46	3243.830
Mar-99	12.51	3666.200
Apr-99	12.41	3392.170

Period	End of Month Level (m)	Discharge ($\times 10^6$ m^3)
May-99	12.53	3696.760
Jun-99	12.42	3402.220
Jul-99	12.23	3238.350
Aug-99	12.10	3067.110
Sep-99	12.06	2907.680
Oct-99	12.06	3003.600
Nov-99	12.07	2928.130
Dec-99	12.14	3114.600
Jan-00	12.15	3118.740
Feb-00	12.07	2823.740
Mar-00	12.01	2941.200
Apr-00	11.99	2834.000
May-00	12.00	2935.650
Jun-00	11.91	2725.400
Jul-00	11.76	2617.750
Aug-00	11.62	2452.020
Sep-00	11.51	2239.620
Oct-00	11.47	2242.860
Nov-00	11.57	2246.170
Dec-00	11.64	2483.010
Jan-01	11.73	2594.710
Feb-01	11.77	2386.710
Mar-01	11.73	2592.290
Apr-01	11.80	2598.970
May-01	11.87	2774.360
Jun-01	11.87	2676.500
Jul-01	11.76	2635.480
Aug-01	11.70	2554.640
Sep-01	11.65	2413.660
Oct-01	11.65	2499.170
Nov-01	11.72	2507.010

Period	End of Month Level (m)	Discharge ($x\ 10^6\ m^3$)
Dec-01	11.74	2612.930
Jan-02	11.76	2640.500
Feb-02	11.74	2357.070
Mar-02	11.77	2644.100
Apr-02	11.89	2708.520
May-02	12.14	3116.650
Jun-02	12.07	2921.300
Jul-02	11.91	2826.730
Aug-02	11.79	2670.510
Sep-02	11.68	2451.810
Oct-02	11.59	2426.350
Nov-02	11.66	2429.510
Dec-02	11.72	2588.880
Jan-03	11.82	2705.610
Feb-03	11.73	2346.820
Mar-03	11.68	2495.520
Apr-03	11.70	2475.840
May-03	11.90	2813.250
Jun-03	11.90	2715.470
Jul-03	11.83	2718.480
Aug-03	11.71	2571.900
Sep-03	11.68	2450.430
Oct-03	11.60	2441.540
Nov-03	11.56	2309.030
Dec-03	11.59	2426.000
Jan-04	11.56	2381.230
Feb-04	11.48	2140.790
Mar-04	11.47	2272.180
Apr-04	11.54	2277.010
May-04	11.67	2444.900
Jun-04	11.56	2304.340

Period	End of Month Level (m)	Discharge ($x 10^6 m^3$)
Jul-04	11.34	2107.000
Aug-04	11.21	1945.630
Sep-04	11.12	1779.780
Oct-04	11.06	1765.800
Nov-04	11.06	1700.890
Dec-04	11.11	1817.170
Jan-05	11.10	1807.590
Feb-05	11.05	1585.190
Mar-05	11.01	1708.350
Apr-05	11.08	1725.700
May-05	11.11	1821.240
Jun-05	11.14	1799.970
Jul-05	11.03	1729.460
Aug-05	10.90	1586.630
Sep-05	10.85	1481.970
Oct-05	10.77	1444.510
Nov-05	10.72	1397.220
Dec-05	10.70	1376.280

Appendix 4 Socioeconomic and Environmental Impact Assessments

4.1 Overall impact assessment for Karuma Falls Hydropower Project

Parameter	Value	Magnitude of impact	Overall impact assessment
River flow	Not valued	Medium negative	Medium negative impact (++)
Water quality	Not valued	Insignificant/ Little	Small negative impact (+)
Soil degradation and erosion	Not valued	Insignificant/ Little	Small negative impact (+)
Terrestrial vegetation	Low to Medium	Medium Negative to little impact	Medium negative impact (++)
Mammals	Low to medium	Medium Negative to little impact	Medium negative impact (++)
Herpetofauna (reptiles and amphibians)	Low to medium	Medium Negative to little impact	Medium negative impact (++)
Avifauna (birds)	Low to medium	Little impact	Small negative impact (+)
Aquatic ecology	Low to medium	High negative to medium negative impact	Medium negative impact (++)
Conservation areas	Medium to high	High negative to medium negative impact	Medium negative impact (++)
Socioeconomics and culture	High	Medium negative impact	High negative impact (+++)
Health	High	Medium negative impact	High negative impact (+++)
Agriculture	Medium to high	Medium Negative to little impact	Medium negative impact (++)
Archaeology	Low to medium	Medium Negative to little impact	Medium negative impact (++)

Note: Table constructed from data from Norplan A.S, 1999

4.2 Overall impact assessment for Bujagali Falls Hydropower Project

	Issue/Parameter	Description
1.	Resettlement and land compensation	85 household displaced, 125 Ha of land take
2.	Effects on land	Loss of agricultural land
3.	Effects on hydrology	The project is not expected to significantly alter or affect the hydrology of L. Victoria or the Victoria Nile. The reservoir can only hold back a few hours. The significant concern related to hydrology is fluctuating water levels immediately downstream of the dam.
4.	Effects on water and aquatic life	Not expected to have any significant long term detrimental impacts on water quality or aquatic life. Significant erosion only on short term.
5.	Air quality and green house gases	No significant emissions anticipated. The project will generate about 250 times less greenhouse gas emissions compared to generating the same amount of electricity from burning fossil fuels.
6.	Environmental protection areas	The project will result in disturbance and loss of land that falls within the Jinja Wildlife sanctuary.
7.	Tourism, white water rafting and aesthetics	There will be flooding of Bujagali falls and associated rapids. Loss of white water rafting opportunity over 2.5 km reach of the Nile from Bujagali falls to Dumbbell island.
8.	Effects on cultural property	Project will result in flooding of household graves and amasabo (shrines).
9.	Community health, safety and security	Increase in risk of schistosomiasis in 388 ha reservoir area.

Note: Table constructed from data from Burnside et al., 1999

4.3 Overall impact assessment for Kalagala Falls Hydropower Project

	Issue/Parameter	Description*
1.	Resettlement and land compensation	More than 1500 people will be displaced, 1300 Ha of permanent land take
2.	Effects on land	Loss of access to agricultural land of some 30 ha. Land use impacts will be more significant here than for Bujagali.
3.	Effects on hydrology	The project is not expected to significantly alter or affect the hydrology of L. Victoria or the Victoria Nile. The reservoir can only hold back a few hours. The significant concern related to hydrology is fluctuating water levels immediately downstream of the dam.
4.	Effects on water and aquatic life	Not expected to have any significant long term detrimental impacts on water quality or aquatic life. Significant erosion only on short term.
5.	Air quality and green house gases	No significant emissions anticipated. The project will generate about 250 times less greenhouse gas emissions compared to generating the same amount of electricity from burning fossil fuels.
6.	Environmental protection areas	The project will result in disturbance and loss of land that falls within the Jinja Wildlife sanctuary.
7.	Tourism white water rafting and aesthetics	Loss of aesthetic value of Kalagala, Busowoko and Buyala falls. Loss of white water rafting opportunity over 15 km reach of the Nile below Dumbbell island.
8.	Effects on cultural property	Project will result in flooding of household graves.
9.	Community health, safety and security	Increase in risk of schistosomiasis in 1,900 ha reservoir area.

* The description is obtained from the comparison of schemes done by Norplan A.S, 1999

4.4 Overall impact assessment for Murchison Falls and Ayago Hydropower Projects

	Parameter/issue	Murchison Falls	Ayago South
1.	Physical and hydrological	Reduction in bypassed river section and over falls to an average minimum of 150 m^3/s. Bypassed river section only 2.9km but includes Murchison Falls. No long term water quality impacts.	As for Murchison although amenity flow provision would be 200 m^3/s. Bypass river section would be up to 10 km.
2.	Land and river use	No impacts identified	No impacts identified
3.	Landscape and tourism	Continuing adverse tourist impact, improved access and infrastructure may benefit tourism, continuing visual intrusion mainly from transmission lines.	As for Murchison but not to the same degree
4.	Socio-economy	Continuing security implications of development in remote area beset with terrorist activity; employment and improved infrastructure will boost economy; security likely to improve; ongoing social effects in rural communities; on-going reduction in community support programme.	As for Murchison
5.	Ecological impacts	Possibly lose of mist flora and associated faunal communities sustained by subsidiary falls.	As for Murchison but also barrier to fish movements.

Source: Kennedy and Donkin et al., 1997