PREDICTING THE LEVEL OF AKOSOMBO DAM USING MATHEMATICAL MODELING

BY

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ABSTRACT

Hydroelectric power is one of the cheapest renewable sources of energy in the world and its generation depends on the management of four major factors which are rainfall, inflows, and outflows of water resources as well as evaporation in dams. The main aim of the thesis seeks to utilize a differential equation model for Akosombo Dam's water level prediction. The model was tested on a data covering the past twenty eight years. In the testing process the first model produced a result which was about 65% accurate, the modified model gave a result with an accuracy of 86%. The results show that it is possible to use the model to predict the level of the water in the Akosombo dam for any month in a year with some acceptable level of accuracy.

DECLARATION

I hereby declare that this submission is my own work towards the M Sc., and that to the best of my knowledge, it contains no material previously published by another person nor material, which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Finally, my deepest gratitude goes to the Almighty God who has seen me throughout my academic life till now.

DEDICATION

This piece of work is dedicated to the Amfo-Otu, and Amoonu family at Abakrampa and Ammisa-Krom respectively.

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CHAPTER ONE

INTRODUCTION

1.01 BACKGROUND TO THE PROBLEM

The Akosombo dam provides electricity to Ghana and its neighbouring West African countries, including Togo and Benin. The idea for the dam was originated in 1915 with the Geologist Albert Ernest Kittson but it was only in the 1940s that plans for the dam began to be drawn up. The development of the Volta River Basin was initially proposed in 1949, however the then Gold Coast did not have sufficient funds, and had to seek a loan from American company Valco for the construction of the dam, under the British Colonial Administration (GHP 2007), formerly known as the Gold Coast until 1957, when Ghana became the first sub-Saharan nation to gain its independence from colonial rule (Fobil 2003). At that time, Ghana's limited economy was sustained solely by the country's cocoa production (Zakhary 1993). As a newly independent country, Ghana became motivated to expand the economy through industrial development. The elected Prime Minister of independent Ghana, Dr. Kwame Nkrumah, adopted the Volta River hydropower project to grandly represent the beginning of a new and growing economy. Although the Volta river development plan initially involve the construction of the Akosombo hydroelectric plants which comprises the power generating station and the Akosombo dam, the Kpong hydroelectric plant was later constructed downstream the Akosombo dam as a result of the creation of the Volta Lake. The Volta River is the main fresh water source for Ghana. The Volta is formed by the confluence of the Black and white Volta River at Yeji in the central part of the country. The river flows in the southerly course through Lake Volta to Ada on the Gulf of Guinea. The total length of the river including the Black Volta is 1500km

(930miles). Lake Volta which serves as the head pond of the Akosombo dam has a surface area of $3500km^2$ and a live storage capacity of 148 by $109m^3$. The first stage of the construction began in 1961 with the establishment of Volta river project and work started on the construction of the Akosombo dam and the hydroelectric power station. During that period a four unit plant with a total installed capacity of 588MW (mega watt) was completed in the year 1965, setting an important stage for industrialization and economic growth for the newly independent state of Ghana. The plant was formally commissioned by the Ghana's first President Osagyefo Dr Kwame Nkrumah in January 1966. Figure 1.1 shows the picture of the Akosombo dam as viewed from the Volta Hotel.

Figure 1.1 shows the picture of Akosombo dam

In the same year (1961), the Volta River Authority was established by the act of parliament (Volta river development act 46) to be responsible for the generation of electric energy in the country by the development of hydro potential of the Volta River and also the operation of the transmission systems. The VRA is responsible for the lake reservoir behind the dam, the fishing available within the lake, lake transportation and communication, and the welfare of those in the neighbourhood of the lake.

The construction of the Akosombo dam required the flooding of the Volta River Basin and its upstream fields, resulting in the creation of Lake Volta which covers 3.6% of Ghana's total land area.

In 1972 the second stage of the project was completed with the addition of two generating units with installed capacity of 324MW to the Akosombo generating station bringing the total number of generation units to six and total generating capacity of 912MW. In that very year (1972) the transmission system was completed to link Togo and Benin's power station to Ghana's hydro electric power station enabling power to be transmitted to these countries. Since 1987 the VRA, has been responsible for the distribution of electricity to customers in Brong Ahafo, Northern, Upper East and Upper West regions of Ghana. However, Ghana's industrial and economic expansion triggered an even higher demand for power, beyond what could be provided by the Akosombo HEP. By 1981, a smaller dam was built at the town of Kpong, downstream from Akosombo. Further upgrades to Akosombo have become necessary for maintaining hydropower output and to meet demand. The country's energy requirement has grown beyond what can be provided by the Akosombo dam. Power demand in correlation with unforeseen environmental trends has resulted in the experience of rolling out of blackouts and major power outages. A trend of decreasing lake levels has been observed, which sometimes results in level below what's required for the minimum operation of the Akosombo dam.

In response, the Takoradi Thermal Power Station was developed to add an additional capacity of 550MW to the country's electricity Capacity in 1996. Recently, the construction of Bui Dam has also commenced whiles further Thermal Power Stations (Tema Thermal 1 Project and Kpong Power) Projects are also being developed.
The addition of the Thermal component gave the country a reliable generation mix, the Thermal component is used to manage the water level of the Akosombo dam. However the souring crude oil prices coupled with the low state of the electricity tariffs has rather contributed to the over reliance on the Hydroelectric power.

According to the Akosombo retrofit project, after 30 years of successful operation of the generating units at Akosombo, VRA in looking ahead to the next 30 years of trouble-free reliable and economic operations embarked on the retrofit project in 1992. The project was suspended after the first unit retrofit in 1993, and resumed again in1999, with a new scope to replace the existing turbine runners. The objective of the project was to modernize, upgrade and improve the performance, reliability, maintenance and operation of the plant.

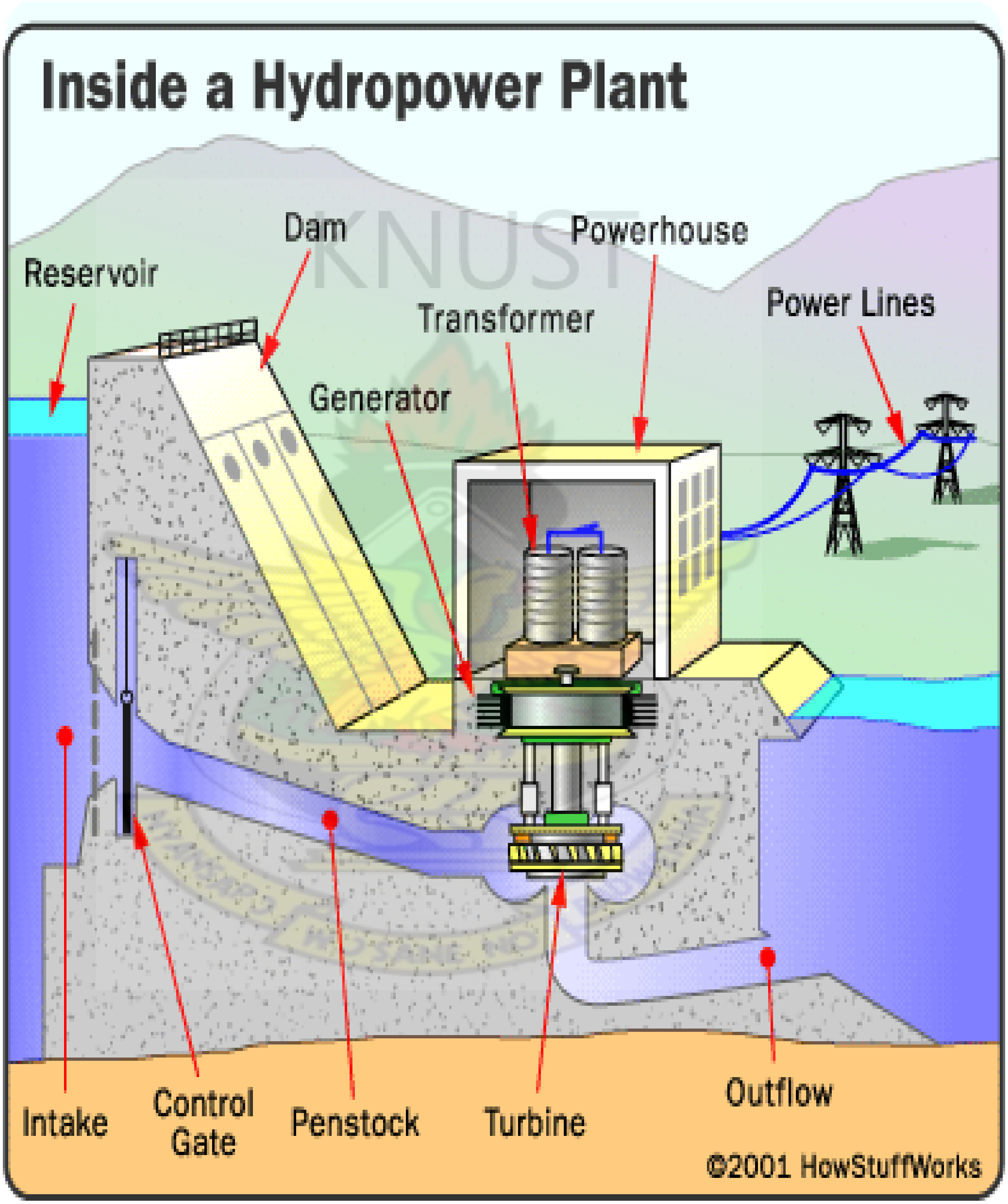
The major activities were:

- Replacement of the existing runners with a more efficient ones;
- Modification in the water passages to improve flow (i.e. stay vanes, wicket gates and insertion of a splitter vane in the draft tube);
- Rewinding of the generators with higher class insulation to up rate and restore their integrity;
- Replacement of the electromechanical governors with electronic governors;

- The rotary exciters were replaced with static exciters;
- The station auxiliaries were also replaced and/or refurbished.

Guaranteed peak efficiency of 93.5% was met during efficiency test after the retrofit of the first Unit. One of the major aims of the Akosombo retrofit project was to modernize the water way to enhance inflow of water which actually shows that the inflow is very important since it has a direct impact on the amount of electricity that is being generated by the plant.

Figure 1.2 shows the flow of water into and out of the hydropower plant which serves as the prime mover of the turbine.



1.02 STATEMENT OF THE PROBLEM

The security of the Ghana's electric power supply depends largely on the future of annual water inflow pattern into the Volta Lake Basin or the dam over seasonal to multiyear time scales. Hydroelectric power contributes about 65.58% of the countries firm annual average energy supply of 7,300GWh, the remains energy supply comes from thermal sources. However, depending on the water inflows, the two hydroelectric Generation Stations, Akosombo and Kpong can produce 6.100 GWh per annum.

With the mixture of hydroelectric and thermal power, the economics of the hydroelectric plants has become dependent upon the reservoir height and the inflow into the reservoir for several days into the future. The amount of water available for hydro production, i.e. energy value of the water reservoir, can vary much from one year to another. As hydropower is a major source of electricity in Ghana, availability of the water is the most important factor that affects electricity supply to consumers. Production decisions of hydroelectric power management are driven by water reservoir level and expectations of inflow. Even though a guaranteed peak efficiency of 93.5% was achieved after the first retrofit program on the first plant unit was carried out, the year 2006 came with its series of power outages because of the level of the Akosombo dam. The problem seems to suggest that there is no model or a simple equation that will help the ordinary Ghanaian or the economist to determine the level of the water in the dam. Since the level of water in the dam has a direct impact on the amount of electricity generated, and the consequent effect on the people of the country, there is the need to obtain a model of such nature which is the goal of this thesis.

1.03 OBJECTIVES

The major aim of this thesis is to develop a model that will seek to achieve the following objectives.

- To determine the level of the Akosombo dam anytime within the year,
- To help determine the month in which low schedules are bound to happen and finally
- To help test the application of that model since there are so many method and models that could have been used.

1.04 METHODOLOGY

This thesis will use differential equation concept in the modeling process (modeling through differential equation). Data for the work is obtained from the office of the Volta River Authority (Akosombo). It consists of data on the inflow, rainfall, and evaporation occurring on the surface of water in the dam from the year 1980 to August 2009. Data on the water levels, the flow rate at each period of the year, the outflows and the other factors (rainfall, temperature) and the size of the dam will be relevant to the modeling process Critical levels (maximum and minimum level s) of the dam for the chosen years will also be an important factor that will help in determining the month of low schedule and vice – versa.

1.05 JUSTIFICATION

This work is worth doing because it seeks to help solve the problem of low power outages in electricity generation since it will develop a model that will help to determine the level of water in the Akosombo dam and its consequence effect. It is justified once again because it will develop a relation that will help every interested person to determine the level of water in the dam at any time since the level of water have direct impact on the power generated.

Economically, it is important, because the level of water in the dam is the energy value of the country, it help the government to draw his budget on energy expenses (the higher the water level the higher the energy produce and the lower the level, the smaller the amount of power produced). Also it help the workers and the Volta River Authority (VRA) to make their plans and budget for the year or the month since they are usually paid based on the level of the water in the dam (they have less bonus and pay if the level is low and vice-versa).

Socio-economically, the work is worth doing because if the ordinary Ghanaian knows the level of the water in the dam, it will help the individual to plan on how to use electricity wisely in the house and at the work places. It will also help the business men involve in the importation of electrical goods to import less energy consuming product since they will know its effect on the power produced.

1.06 LIMITATIONS

There are a number of factors which will limit this piece of work to some level of accuracy. The first factor is based on the access to information from the office of the Volta River Authority, since one is required to apply through the dean of school of distance learning to the Chief executive officer of Volta River Authority.

The next factor has to do with the time span within which the work is being carried out. One is supposed to do continuous study for one whole year in order to easily determine the pattern of the inflow and the outflow of the water in the dam accurately.

One other factor which may account for some possible error is the use of already collected data. This is because the collected data may have been taken under certain limitations and conditions that are not available to the researcher.

The final problem has to do with funds and resources needed to practically check the inflow rate and outflow rate of the water since the river has not got a constant volume.

1.07 ORGANISATION

The first chapter of this thesis talks about the introduction to the topic. The chapter two discusses literature review (work done by other researchers on the same or similar field and the method applied). The third chapter deals with the methodology applied by the researcher in dealing with the problem or the topic (it is the actual work done by the researcher). The forth chapter is titled discussion; it is the one which explains the meaning of the result obtained from the work and its relevance and application. The final chapter which is the fifth is given the heading conclusion. It is the summary of the piece of work done by the researcher. It also gives recommendation to areas that can be researched in the near future by other researchers and some techniques that can help others to do good work in the same or similar area of research.

CHAPTER TWO

LITERATURE REVIEW

2.0.1 INTRODUCTION;

This chapter reviews research works done in the same field or related field of studies. It considers some basic principles that are to be considered when modeling and simple method used in a modeling process and give some report about some methods that were used in controlling some Dams and water levels through the use of differential equations and other mathematical modeling process.

According to Howard Perlman (2009), hydroelectric and coal-fired power plants produce electricity in a similar way. In both cases a power source is used to turn a propeller-like piece called a turbine, which then turns a metal shaft in an electric generator, which is the motor that produces electricity. A coal-fired power plant uses steam to turn the turbine blades; whereas a hydroelectric plant uses falling water to turn the turbine. The results are the same. From the figure 1.2, the theory is to build a dam on a large river that has a large drop in elevation. The dam stores lots of water behind it in the reservoir. Near the bottom of the dam wall is the water intake which is caused by gravity, and it falls through the penstock inside the dam. At the end of the penstock there is a turbine propeller, which is turned by the moving water. The shaft from the turbine goes up into the generator, which produces the power. Power lines are connected to the generator which carries electricity to any part of the country that is needed. As to how this generator works, the Corps of Engineers explains it this way: "A hydraulic turbine converts the energy of flowing water into mechanical energy. A hydroelectric generator converts this mechanical energy into electricity. The operation of a generator is based on the principles discovered by Faraday. He found that when a magnet is moved past a conductor, it causes electricity to flow. In a large generator, electromagnets are made by circulating direct current through loops of wire wound around stacks of magnetic steel laminations. These are called field poles, and are mounted on the perimeter of the rotor. The rotor is attached to the turbine shaft, and rotates at a fixed speed. When the rotor turns, it causes the field poles (the electromagnets) to move past the conductors mounted in the stator. This, in turn, causes electricity to flow and a voltage to develop at the generator output terminals. It could also be seen once again that the level of water will actually account for the speed at which the turbine will run and the consequence production of electricity.

2.0.2 DIFFERENTIAL EQUATION MODELING

Modeling is one of the ways by which formulae are used or deduced to help solve a real life situation, occurrence or a problem. Mathematical models are like other types of models. The aim of every model is not to produce exact copy of 'real' object but to give a representation of some aspect of the real thing. For example, a portrait of a person, a store mannequin and a pig can all be a model of human beings; none of them is a perfect copy of human beings but each has certain aspect in common with a human.

According to Anderson et al, model building is a tool frequently used by planners, scientists, mathematicians etc in developing government policies and in making private decisions. A try and error approach can be disastrous. To anticipate the ultimate result without the real, we use something else that look like or act like the real thing or object to model. A photograph can be a real model in communication- one picture is worth a thousand words. Sketches are used by architect and blueprint by carpenters. If boards are cut like drawings on a manila card, a home can be built that will look like the drawing. Other changes in living systems can be modeled by mathematical equations; by varying the input on one side of the equation, one can predict the outcome symbolized by the other side. Game biologist use such models to determine how fawn production might vary if the hunting of doe is allowed in the fall. Also to find downstream oxygen levels and species diversity, a biologist needs a more complicated model using temperature, flow of water, use of oxygen by wastes and organisms, rate of replenishing oxygen and the availability of nutrient in rivers.

Model building is not only predictive but can also be descriptive; the important thing, for one to remember is that, the less complicated the system and the more information available, the greater the likelihood of a successful model.

Model could also be referred too as a formula used by planers and mathematicians etc to predict or give information about a future value or effect of any interacting object or items. Every mathematical model follows simple assumption or some basic principles. The first step is to clearly state the assumptions which are relevant to the model. It usually describes the relationship among the quantities to be studied. The next step involves completely describing the variables and parameters to be used in the model and the last step is the use of the assumption formulated in step one to derive the equation relating the quantities in step two. Quantities in every model may fall into three basic categories; that is the, dependent variable, the independent variable, and the parameters. The independent variable in this study is time. The dependent variables are quantities that are functions of time. Parameters are quantities that don't change with time (or with the independent variable) but can be adjusted (by natural causes or by scientists conducting the experiment).

2.3.1 MALTHUSIAN MODEL

According to the Malthusian model (Unlimited population growth) an elementary model of population growth is based on the assumption that; the rate of growth of the population is proportional to the size of the population. This implies that the rate of change of a population depend only on the size of the population and nothing else. The quantities evolving from the assumption are as follows;

$t = \text{time(independent variable)}$

$p = \text{population (dependent variable)and}$

$k = proportionality\ constant$ (parameter)between the rate of growth of the population and the size of the population

Based on the assumption the rate of growth of population p is the derivative $^{dp}/_{dt}$.

i.e $\frac{dp}{dt} = kp$ (2.01)

This is a simple differential equation of first order with a solution given as

$p(t) = Ce^{kt}$ (2.02)

The model was used in calculating the US population census from the year 1790 to 1920. From the data of the real system the model worked for the first fifty years and started deviating there after thereby giving room for some modification to the model in order to fit the data collected. It could be seen that the assumption (first) made for the modeling process accounted for the deviation after the first fifty years. Population growth does not depend solely on the size of the population but on other factors like the land size, the health statute of a given population and the death and birth rate of the given population. To adjust the exponential model to account for the limited environment and other limited resources;

- If the population is assumed to be small; the rate of growth of the population is proportional to its size.
- If the population is too large to be supported by its environment and other resources, the population will decrease, that the growth rate is negative. From these assumptions we have t: time, P: population, k: growth-rate coefficient for small population (parameter) and N: usually called the carrying capacity introduced by the second assumption. In this condition, it is assumed that P(t) is increasing if P(t) < N. however if P(t) > N, we assume that P(t) is decreasing . Using the above notation, the assumption could be formulated as

$^{dp}/_{dt} = kP$ if P is small (first assumption) (2.03)

$If \;\; P \geq N, {}^{dp}/_{dt} < 0$ (secondassumption). (2.04)

To make the model algebraically simple, the exponential model is modified a little.

$^{dp}/_{dt} = k\,(something)P$ (2.05)

that is the "something" factor is made close to 1 if P is small, but if $P > N$,the term "something" is made to be negative. This gives the expression.

(something) = $1 - \frac{P}{N}$.

This expression equals 1 if $P = 0$ and negative if $P > N$. Thus the model is

$$dp/_{dt} = k\,(1 - \frac{P}{N})P \qquad (2.06)$$

The differential equation 2.06 is called the Logistic population model with

K: growth rate

N: carrying capacity of the system.

The equation 2.06 was obtained from the Malthusian model through some added assumption and modification. This is used to determine a real life occurrence and to predict future occurrence more correctly than the exponential growth model.

2.3.2 THE PREDATOR- PREY MODEL

According to C. Jost et al (1999) working on the deterministic extinction in Ratio-dependent predator-prey model, it came out that predator–prey system that incorporates conservation of mass and division of population rates of change into birth and death processes has the following canonical form:

$$\frac{dN}{dt} = f(N)N - g(N,P)P \qquad (2.07)$$

$$\frac{dP}{dt} = eg(N,P)P - \mu P \qquad (2.08)$$

with prey abundance $N(t)$, and predator abundance $P(t)$, conversion efficiency *e* and predator death rate μ. they used the traditional logistic form for the growth function f with maximal growth rate *r* and carrying capacity *K*:

$$f(N) = r(1 - \frac{N}{K}) \qquad (2.09)$$

The functional response g (prey eaten per predator per unit of time), that in general depends on both prey and predator density, was considered as a (bounded) function of the ratio prey per predator,

$$g \coloneqq g\left(\frac{N}{p}\right) = \frac{aN/P}{1+ahN/P} = \frac{aN}{P+ahN} \qquad \forall (N,P) \in [0,+\infty)^2 \setminus (0,0) \tag{2.10}$$

with total attack-rate μ and handling time h. The second equality is strictly correct only for $P > 0$. In the case of $P = 0$ and $N > 0$ we can define $g(N,0) \coloneqq 1/h$ (the limit of $g(x)$ for $x \to \infty$).

In a first step they simplify this model by non-dimensionalization. Let

$$\check{N} = \frac{ahN}{eK}, \qquad \rho = \frac{ahP}{e^2K}, \qquad R = \frac{rh}{e},$$

$$Q = \frac{h\mu}{e}, \qquad S = \frac{ah}{e}, \text{ and }, \qquad t = \frac{et}{h}$$

In these variables the system becomes

$$\frac{d\check{N}}{dt} = R\left(1 - \frac{\check{N}}{S}\right)\check{N} - \frac{S\check{N}}{p+S\check{N}}\rho \tag{2.11}$$

$$\frac{d\rho}{dt} = \frac{S\check{N}}{p+S\check{N}}\rho - Q\rho \tag{2.12}$$

with initial conditions $N(0) = n_0$, $\rho(0) = p_0$ for simplicity the hat is not written in this script but could be seen that the system has at most three equilibria in the positive quadrant: $(0,0)$, $(S,0)$ and a non-trivial equilibrium $(\check{n}, Þ)$ with

$$\check{n} = \frac{S(R+(Q-1)S)}{R} \qquad Þ = \frac{S(1-Q)}{Q}\check{n}$$

A simple calculation shows that $n?$ is positive for all $s < \frac{R}{1-Q}$. which implies $Q < 1$ and therefore ensures the positivity of Þ.

For $S > R$, the prey isocline is a humped curve through the origin and the point $(S, 0)$ For $S < R$, the denominator of the prey isocline can become 0 for some $N \in (0, S)$. The part of the isoclines that remains in the positive quadrant becomes in this case a strictly monotonically descending curve through the point$(S, 0)$. The predator isocline is always a straight line through the origin by Arditi and Ginzburg (1989)[12]. In this model the survival of the predator depend on the availability of the prey, whose live also depend on the birth rate and the food available to the prey.

2.3.3 HYDRAULIC MODELING OF AUTOMATIC UPSTREAM WATER- LEVEL CONTROL GATE

According to Litrico et al, an automatic upstream control gates are applied in various countries as a cheap and efficient way to control water levels in open channel networks. They came out with a specific type of gate initially described by Vlugter (1940) and more recently mentioned by Brouwer (1987), Brants (1996), de Graaff (1998), and Burt et al. (2001). Such gates are installed in several irrigation projects located in various countries (United States, Nigeria, Indonesia,etc.).

The considered automatic gate (called a Begemann or flap gate) is a weir equipped with a steel plate rotating around a horizontal axis located above the upstream water level. The water flows freely on the sides when the gate is opened. A counterweight on the top of the plate compensates for the hydraulic pressure exerted by the water. When the water level increases, the pressure also increases and the moment exerted by the water tends to open the gate. When the water level decreases, the opposite occurs. The equilibrium is obtained when the closing moment compensates for the opening moment. When properly designed, such a gate can maintain upstream levels (Vlugter 1940; Burt et al. 2001). The gate is designed to function properly under free-flow conditions (no downstream influence). A modified version of the Begemann gate is the Vlugter gate, which is equipped with a round back and is designed to function under submerged conditions. Their present study was restricted to the case of a gate functioning at free flow ,the Begemann gate. Such gates were primarily installed in Indonesia, where they were described and studied by Vlugter (1940). More recently, Begemann and Vlugter gates were installed in two Nigerian irrigation schemes built in the 1970s (Brouwer 1987). Similar gates have also been installed more recently on irrigation canals in California, following the design method proposed by Burt et al. (2001)

Most available studies focus on the design part of these gates. But, in order to correctly simulate the hydraulic behaviour of a canal equipped with such gates, it is necessary to have an accurate mathematical model of the gates. Such a model for the gate could be included in a classical hydraulic simulation model solving Saint-Venant equations (e.g., SIC, the model developed by Cemagref). They were interested in computing the upstream water elevation h_0 and the gate opening angle ∂ for any given discharge Q. For this purpose, it is necessary to have two formulas: a discharge law, giving the discharge for given opening angle ∂ and upstream water elevation h_0; and an equilibrium law, specifying the force exerted by water on the gate, and the application point (in order to compute the opening moment). This paper proposes an efficient mathematical model of the Begemann or flap gate with two such formulas. These gates were observed in the field during two missions in Nigeria, and a small-scale laboratory gate has been designed and used for experimental data acquisition. This reduced-scale experimental gate was built in the laboratory canal of Ecole Nationale Supérieure d'Agronomie de Montpellier (ENSAM), in France.

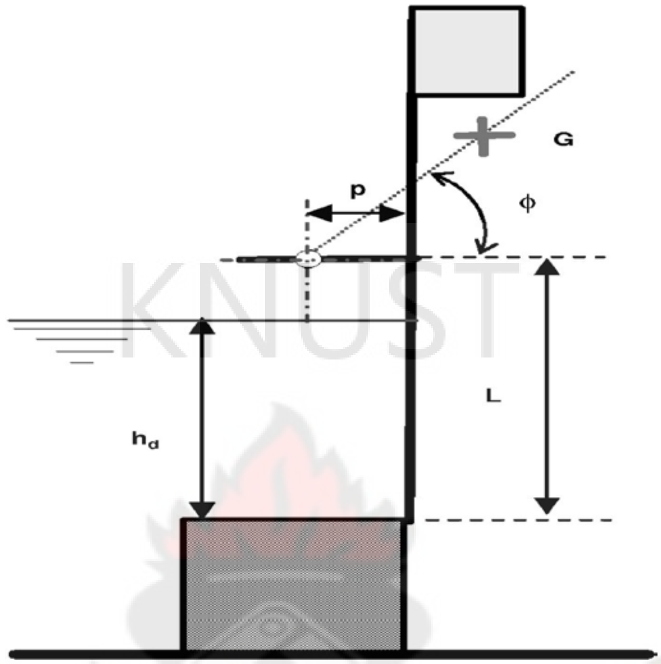


Fig. 2.1 Gate description in closed position

The control of water levels in distributary channels with automatic mechanical gates has received interest for a long time:Stickney (1912) proposed a design of automatic dam crest for regulating the flow over dams, and Neyrtec GEC-ALSTHOM has manufactured the well-known AVIS/AVIO and AMIL automatic gates since the 1950s (GEC-Alsthom [1975]; Goussard[1987]; Goussard [personal communication, 1993]). Jiong (1990) described a flap gate to control water levels in China. They described the Begemann gate as follows;

Gate Description

The gate dimensions are denoted by L, the gate height (m)p the distance from pivot to the gate (m), and B_g the gate width (m).

Let $(X_G Y_G)$ denote the coordinates of the center of gravity G with horizontal and vertical axis originating from the pivot point. Φ is the angle between the horizontal axis and the line joining the pivot to the center of gravity G:

$$\Phi = \arctan\left(\frac{Y_G}{X_G}\right) \tag{2.13}$$

The gate opening U and the vertical and horizontal openings Uv

and U_h for a given angle of opening d are obtained by standard trigonometry (Fig.2.1)

$$U = \sqrt{L^2} + P^2\sqrt{2}(1 - cos\delta) \tag{2.14}$$

$$U_v = Ls(1 - \cos\delta) + p\sin\delta \tag{2.15}$$

$$U_h = p(\cos\delta - 1) + L\sin\delta \tag{2.16}$$

These variables was useful in determining the discharge law.

The design upstream level h_d corresponds to the hydrostatic equilibrium when the gate is closed. In this case, the pressure is hydrostatic, and it is easy to compute the opening force. Since the opening moment compensates for the closing moment, one gets the equation describing the equilibrium

$$\frac{1}{2}pgB_g h_d^2\left(L - \frac{h_d}{3}\right) = M_c(0) \tag{2.17}$$

where $Mc(0)$ = closing moment at δ=0, given by $Mc(0) = MgX_G$; M = total mass of the gate and counterweight; p = water density and g = gravitational acceleration. Solving this equation leads to the equilibrium upstream level h_d for zero flow. The gate functioning is much more difficult to predict when the gate opens, since the pressure distribution is no longer hydrostatic. The gate was designed with a mathematical model to control the level of the dam.

2.3.4 DETERMINATION OF CONTROLLED-RELEASE CAPACITY FROM TRINITY DAM

According to Tony L Wahl and Elizabeth A Cohen (199) working on the trinity dam came out that the recent studies of alternatives for restoring anadromous fisheries on the Trinity River have recommended increased releases from Trinity Dam. To support these operations, the river outlet works, powerplant, and auxiliary outlet works at Trinity Dam were analyzed to determine the maximum possible controlled release. This analysis used a mathematical model of the combined operation of the river outlet works and powerplant, which share a common tunnel and penstock system; previously, the capacity of these components had only been analyzed for their separate operation. The model was calibrated using data collected from two field tests. The result of the analysis is a new set of discharge curves for the Trinity Dam outlet works and powerplant system. Curves were developed for the separate operations of the river outlet works and for combined operation of the outlet works and powerplant, using either the low-head or highhead turbine runners. Since the completion of Trinity Dam in 1962, up to 90 percent of the reservoir's inflow has been exported to the Central Valley.

Decline of the fishery became apparent within the first decade of operation. Today, the restoration and improvement of the fisheries and habitats associated with western rivers is a significant water resources management goal.

The Trinity River Flow Evaluation study considered alternatives for improving the habitat and environment of the Trinity River below Trinity Dam. One recommendation of that study was to increase controlled releases from Trinity Dam to as high as 11,000 ft^3/s at specific times during the year. This raised significant operational issues because it required combined releases from the various outlet works and the powerplant, a mode of operation not considered by the original designers. The studies described in this case were performed to determine the maximum possible controlled release, considering the performance of both the outlet works and powerplant systems during combined release operations. The spillway was an uncontrolled 54-ft diameter morning glory concrete structure with crest elevation 2370.0 ft and a design discharge of 22,400 ft3/s at water surface elevation 2388 ft. In addition to the uncontrolled spillway, there were three controlled outlet facilities, which are as follows;

· 7,000 ft3/s river outlet works controlled by two 84-inch hollow-jet valves

· 140 MW powerplant containing two Francis turbines

· 2,490 ft^3/s auxiliary outlet works controlled by one 84-inch jet-flow gate

The river outlet works system consists of a concrete lined 28-ft diameter tunnel, an intermediate gate structure with a 10´20-ft fixed-wheel gate, and a 16-ft diameter (15-9.) steel penstock with branches to both the powerplant and the outlet works control structures. The outlet works branch is an 11-ft diameter conduit that bifurcates into a pair of 7-ft diameter conduits, each leading to an 84-inch ring-follower gate and an 84-inch hollow-jet valve. The outlet works has a design discharge of 7,000 ft^3/s at El. 2370.0 ft. Designers anticipated significant variation of water levels in the reservoir, and thus the turbines are equipped with both low-head and high-head turbine runners that can be interchanged on a seasonal basis to control the variation.

CHAPTER THREE

METHODOLOGY

3.0.1 INTRODUCTION

This chapter, as already stated is going to use differential equation to model an expression to determine the level of the Akosombo dam. The method will employ the idea of accumulation, that is the total inflows and the total outflows on the dam, Rainfall calculations and evaporation as some of the factors will also considered on a simple form and how these could be calculated.

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3.0.2 PREDICTING METHODOLOGY

Predicting or forecasting methodology is generally understood as a collection of approaches, methods, and tools for collection of (differential equation) data to be used for the forecast or prediction of future values of the water levels, based on past values. The forecasting methodology includes the following operational steps:

Data preparation for predicting, formulating of the model, testing the model and evaluating the model

3.0.3 DATA

The data used for the model are the past inflow data into the Volta Lake basin, the outflows through the penstocks recorded at the Akosombo Power Station. Inflow data from the major tributaries of the Volta River recorded at Bui, Saboba and Nawuni. Also rainfall data and temperature for Yendi, Tamale, Bole, Saboba, and Bui were also collected for the same period of time. The data used were the monthly recordings from 1980-2009. Inflows were recorded in cubic metres per second , Rainfall was recorded in mm and temperature in degrees Celsius (°C).

The data for the model was pre-processed before using it in the model.

3.0.4 MODEL DEVELOPMENT

In this study, monthly rainfall, temperature and inflow at the tributaries of the Dam and the outflows through the penstocks and evaporation were selected for calibrating of the model.

- There are three major inflow channels into the dam each with different flow rate. Hence the equation from this could be written as

$$\frac{dU_1}{dt} + \frac{dU_2}{dt} + \frac{dU_3}{dt} \tag{3.01}$$

So the total inflow rate could be denoted by $\frac{dV_i}{dt}$, and $10 \leq \frac{dV_i}{dt} \leq 10^{15}$ where V is the total volume of water passing through all the channel at a time and t is the time of flow of the water.

- There are six outflows through the penstock which operate at a maximum when all the turbine are operating and two outflow with a minimum flow rate when the turbine are operating at minimum level. Hence we can have

$$\frac{dV_1}{dt} + \frac{dV_2}{dt} + \frac{dV_3}{dt} + \frac{dV_4}{dt} + \frac{dV_5}{dt} + \frac{dV_6}{dt} \tag{3.02}$$

The total outflow can be denoted by $\frac{dV_o}{dt}$ and $24.82 \leq \frac{dV_o}{dt} \leq 74.46$ where V_o is the total volume flowing out of the dam, and t is the time of flow.

- All inflows and outflows which have no effect on the level or the volume of the dam are negligible

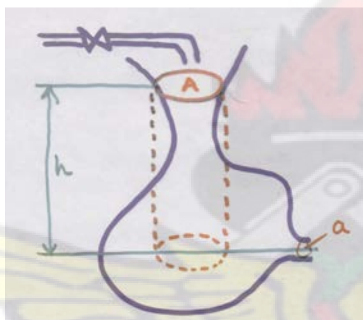
- The force, energy and the momentum of the water are assumed to be negligible in this case since it doesn't have much effect on the volume of water in the dam.

As a result of the first two assumptions and the mass law, the net flow is determined as

$$\frac{dV}{dt} = q_{in} - q_{out} \qquad (3.03)$$

i.e $\frac{dV}{dt} = \frac{dV_i}{dt} - \frac{dV_o}{dt}$

- By taking the height of the dam and the cross-sectional area of the inflow channel



leads to

$$V = \int_0^h A(h)dh \quad \text{(from Geometry)} \qquad (3.04)$$

So the volume of water in the dam could be determined at any time by integrating the expression $\frac{dV}{dt}$ and determining the constant at the initial period of the day or at any giving time with respect to an early time.

$$\int dV = \int Mdt + C, \qquad (3.05)$$

where C : volume at the start of the experiment or when time, t= 0 , and M : net flow.

Mathematically, the outflow through the penstock is given as follow (values are from the data obtained from VRA office). The volume of cylinder is given by $V = \pi r^2 l$

i.e $$V = 3.142 \times 3.6^2 \times 0.3048$$

$$V = 12.41\text{m}^3/\text{s}$$

Since there are six of these when the system is operating at a maximum, the maximum outflow through the penstock is $\frac{dV_o}{dt} = 6 \times 12.41 = 74.46$m^3/s (which is constant for all operation).

Figure 3.2 shows a picture of the six penstocks with four up and two down.

3.0.5 TESTING THE MODEL

Testing the model based on the data collected over the years.

Inflows And Predicted Volumes Based On The Model (for 1980)

Month	Saboba $\frac{dU_1}{dt}$	Nawuni $\frac{dU_2}{dt}$	Bui $\frac{dU_3}{dt}$	Sum $\sum_1^3 \frac{dU}{dt}$	Netflow $\frac{dV}{dt}$	Flow for month (Mt)	Predicted Volume (M^3)
JANUARY	10.3	14.4	20.9	45.6	-28.9	-74908800	1.3059E+11
FEBRUARY	8.0	6.0	10.0	24.0	-50.5	-13896000	1.30459E+11
MARCH	4.6	3.4	6.1	14.1	-60.3	-156297600	1.30303E+11
APRIL	3.3	2.4	4.8	10.5	-64.0	-165888000	1.30137E+11
MAY	17.1	9.7	23.5	50.3	-24.2	- 62726400	1.30074E+11
JUNE	37.0	40.3	69.3	146.6	72.1	186883200	1.30261E+11
JULY	40.6	80.6	113.2	234.4	159.9	414460800	1.30675E+11
AUGUSTS	485.0	462.5	458.8	1406.3	1331.8	3452025600	1.34127E+11
SEPTEMBER	1406.3	1407.5	1128.9	3942.7	3868.2	10026374400	1.44154E+11
OCTOBER	349.5	204.8	542.9	1097.2	1022.7	2650838400	1.46804E+11
NOVEMBER	73.4	64.4	238.5	376.3	301.8	808341120	1.47613E+11
DECEMBER	15.6	23.3	56.8	95.7	21.2	56782080	1.4767E+11

Inflows And Predicted Volumes Based On The Model (For 1981)

Month	Saboba $\frac{dU_1}{dt}$	Nawuni $\frac{dU_2}{dt}$	Bui $\frac{dU_3}{dt}$	Sum $\sum_1^3 \frac{dU}{dt}$	Netflow $\frac{dV}{dt}$	Flow for month (Mt)	Predicted Volume(M^3)
JANUARY	13.2	9.4	21.2	43.8	-30.7	-79574400	1.27995E+1
FEBRARY	4.3	6.2	10.6	21.1	-53.4	-138412800	1.27856E+11
MARCH	2.9	7.7	7.4	18.0	-56.4	-146188800	1.2771E+11
APRIL	4.3	10.1	9.1	23.5	-51.0	-132192000	1.27578E+11
MAY	21.6	49.3	37.7	108.6	34.1	88387200	1.27666E+11
JUNE	56.6	91.0	48.8	196.4	121.9	315964800	1.27982E+11
JULY	121.6	185.8	168.2	475.6	401.1	1039651200	1.29022E+11
AUGUSTS	596.9	607.1	356.9	1560.9	1486.4	3852748800	1.32875E+11
SEPTEMBER	779.4	1279.4	480.0	2538.8	2464.3	6387465600	1.39262E+11
OCTOBER	199.8	443.4	266.1	909.3	834.8	2163801600	1.41426E+11
NOVEMBER	71.6	129.7	75.4	276.7	202.2	541572480	1.41968E+11
DECEMBER	18.6	35.9	25.4	79.9	5.4	14463360	1.41982E+11

Inflows And Predicted Volumes Based On The Model (For 1990)

Month	Saboba $\frac{dU_1}{dt}$	Nawuni $\frac{dU_2}{dt}$	Bui $\frac{dU_3}{dt}$	Sum $\sum_1^3 \frac{dU}{dt}$	Netflow $\frac{dV}{dt}$	Flow for month (Mt)	Predicted Volume (m^3)
JANUARY	45.9	12.7	31.0	89.6	15.1	3913200	132504E+11
FEBRUARY	20.2	30.5	14.2	64.9	-9.6	-24883200	132479216800.0
MARCH	7.3	18.0	7.3	32.6	-41.8	-108456430	132370760370.1
APRIL	13.3	14.6	6.9	34.8	-39.7	-102858418	132267901951.9
MAY	14.8	14.7	20.7	50.2	-24.3	-62987503.4	132204914448.4
JUNE	28.0	59.4	53.6	141.0	66.5	172418845.5	132377333293.9
JULY	160.7	172.6	108.1	441.4	366.9	951000320.3	133328333614.2
AUGUSTS	595.7	503.2	317.4	1416.2	1341.7	3477724692.0	136806058305.8
SEPTEMBER	617.8	466.0	303.7	1387.4	1312.9	3403130721.0	140209189026.9
OCTOBER	153.4	125.3	137.3	416.1	341.6	885300300.9	141094489327.8
NOVEMBER	30.9	25.7	33.0	89.6	15.1	40529109.54	141135018437.3
DECEMBER	10.2	15.6	13.8	39.6	-34.9	-93546812.0	141041471625.4

Inflows And Predicted Volumes Based On The Model (For 1995)

Month	Saboba $\frac{dU_1}{dt}$	Nawuni $\frac{dU_2}{dt}$	Bui $\frac{dU_3}{dt}$	Sum $\sum_1^3 \frac{dU}{dt}$	Netflow $\frac{dV}{dt}$	Flow for month (Mt)	Predicted Volume (M^3)
JANUARY	63.2	48.5	8□.7	194.4	119.853	310660708.8	125408600000.0
FEBRUARY	42.4	46.2	63.3	151.9	77.4	200630295	125609230295.0
MARCH	38.3	65.1	53.5	156.9	82.5	213874931.3	125823105226.3
APRIL	44.0	65.5	21.2	130.7	56.2	145747946	125968853172.4
MAY	49.0	67.7	36.1	152.9	78.4	203149670	126172002842.3
JUNE	53.5	94.9	98.2	246.6	172.1	446211764.4	126618214606.7
JULY	138.5	127.9	215.0	481.4	406.9	1054699278	127672913885.2
AUGUSTS	1275.5	990.4	433.6	2699.5	2625.0	6803976965	134476890850.2
SEPTEMBER	1723.7	1241.9	543.0	3508.7	3434.2	8901338543	143378229393.4
OCTOBER	1095.0	302.4	446.6	1844.0	1769.5	4586642542	147964871935.0
NOVEMBER	203.6	53.8	112.3	369.6	295.1	790513135.6	148755385070.5
DECEMBER	53.4	30.3	29.7	113.4	38.9	104202515.9	148859587586.5

Inflows And Predicted Volumes Based On The Model (For 2000)

Month	Saboba $\frac{dU_1}{dt}$	Nawuni $\frac{dU_2}{dt}$	Bui $\frac{dU_3}{dt}$	Sum $\sum_1^3 \frac{dU}{dt}$	Netflow $\frac{dV}{dt}$	Flow for month (Mt)	Predicted Volume (m^3)
JANUARY	62.6	14.7	76.1	153.4	78.89331	2044914584	1.23484E+11
FEBRUARY	9.1	58.6	35.0	102.7	28.2	73181981.96	1.23558E+11
MARCH	54.5	49.6	25.0	129.1	54.7	141891223.2	123699473205.1
APRIL	48.0	4.5	12.2	124.7	50.2	130161725.9	123829634931.0
MAY	60.1	68.9	16.5	145.5	71.0	184088374.7	124013723305.7
JUNE	85.4	153.0	108.4	346.8	272.3	705921045.5	124719644351.2
JULY	159.0	175.6	241.0	575.6	501.1	1298779718	126018424069.4
AUGUSTS	691.6	508.4	527.2	1727.1	1652.6	4283606958	130302031027.7
SEPTEMBER	848.5	735.1	981.2	2564.8	2490.3	6454857153	136756888180.8
OCTOBER	739.1	402.3	780.3	1921.7	1847.2	4788003389	141544891569.7
NOVEMBER	210.5	74.1	219.4	504.0	429.5	1150292034	142695183603.6
DECEMBER	36.0	26.0	76.3	138.3	63.8	170899528.3	1.24049E+11

Inflows And Predicted Volumes Based On The Model (For 2006)

Month	Saboba $\frac{dU_1}{dt}$	Nawuni $\frac{dU_2}{dt}$	Bui $\frac{dU_3}{dt}$	Sum $\sum_1^3 \frac{dU}{dt}$	Netflow $\frac{dV}{dt}$	Flow for month (Mt)	Predicted Volume (m^3
JANUARY	37.6	22.0	11.6	71.2	-3.3259	-8620739.47	123890500000.0
FEBRUARY	20.9	□2.3	6.7	69.9	-4.6	-11987293.2	123878512706.8
MARCH	15.2	24.6	4.2	44.1	-30.3	-78551167.8	123799961539.0
APRIL	17.6	44.8	6.2	68.6	-5.9	-15241720.8	123784719818.1
MAY	39.5	76.9	27.3	143.8	69.3	179524882.5	123964244700.6
JUNE	30.6	77.4	96.2	204.3	129.8	336314219.2	124300558919.8
JULY	89.8	152.1	166.6	408.5	334.0	865698692.6	125166257612.4
AUGUSTS	390.9	208.3	254.7	853.9	779.4	2020179116	127186436728.3
SEPTEMBE	848.6	854.9	824.5	2528.0	2453.5	6359557228	133545993956.7
OCTOBER	878.1	640.9	850.2	2369.2	2294.7	5947910164	139493904120.4
NOVEMBE	270.8	114.9	195.3	581.0	506.5	13566174301	153060078420.9
DECEMBER	42.7	56.2	60.5	159.5	85.0	2276515018	155336593439.2

Inflows And Predicted Volumes Based On The Model (For 2009)

Month	Saboba $\frac{dU_1}{dt}$	Nawuni $\frac{dU_2}{dt}$	Bui $\frac{dU_3}{dt}$	Sum $\sum_1^3 \frac{dU}{dt}$	Netflow $\frac{dV}{dt}$	Flow for month (Mt)	Predicted Volume (m^3)
JANUARY	67.8	46.0	54.8	168.6	94.0623	243809623.6	12280200000
FEBRUARY	6□.0	74.8	39.6	174.3	99.8	258721130.1	12538921130
MARCH	55.9	58.0	44.5	158.4	84.0	217855109.6	12756776239.6
APRIL	53.7	66.3	42.3	162.2	87.7	227343650.6	12984119890.2
MAY	60.5	71.0	57.7	189.2	114.7	297206375.4	13281326265.6
JUNE	139.73	107.6	129.0	376.3	301.8	782278356.2	14063604621.8
JULY	345.7	142.6	241.3	729.6	655.1	1698131163	15761735784.6
AUGUSTS	1462.7	971.0	861.2	3294.9	3220.4	8347199221	24108935005.7
SEPTEMBE	2414.8	1984.7	2098.4	6498.0	6423.5	16649621185	40758556190.8
OCTOBER	1290.4	1034.0	1306.7	3631.1	3556.6	9218595102	49977151293.1
NOVEMBER	392.4	180.6	405.7	978.8	904.3	24219931192	74197082485.4
DECEMBER	392.4	77.0	80.5	549.9	475.4	12732414815	86929497300.9

It could be seen from the tables 3.1 to 3.7 that, within the real values and the predicted values that, there is a slight difference between the result and hence this call for the modification of the model Again the rainfall has about forty percent contribution to the volume of the dam as a result, the equation can be modified as

$$\rightarrow \frac{dV}{dt} = \frac{dV_i}{dt} + R - \frac{dV_o}{dt}, \tag{3.06}$$

where the R is the rainfall recorded.

Notwithstanding the rainfall, the evaporation of the sun also lead to the decrease in the volume or the level of the dam. Hence the model becomes

$$\frac{dV}{dt} = \frac{dV_i}{dt} + R - \frac{dV_o}{dt} - ET, \tag{3.07}$$

Where ET is the evaporation caused by the temperature variations. Fortunately the rainfall does exist as rate in volume per unit surface area per unit time; hence the total volume per unit time can be obtained by multiplying the rainfall by the total surface area of the dam. Hence the following equation can be obtained as

$$\frac{dV_r}{dt} = R \times total\ surface\ area\ of\ dam, \tag{3.08}$$

Hence the model becomes

$$\frac{dV}{dt} = \frac{dV_i}{dt} + \frac{dV_r}{dt} - \frac{dV_o}{dt}. \tag{3.09}$$

(V_r): the volume of water added due to rainfall and t is the time span of the rainfall.

Also the sunshine causing the evaporation exists as volume per unit surface area per unit time, of liquid loss based on the suns intensity and other factors; hence the volume of liquid evaporated as a result of the sunshine can be obtained by the product of the total dam surface area and the rate of evaporation.

$$. \frac{dV_s}{dt} = ET \times total\ surface\ area\ of\ dam) \qquad (3.10)$$

Based on this effect the model changes to the form

$$\frac{dV}{dt} = \frac{dV_i}{dt} + \frac{dV_r}{dt} - \frac{dV_o}{dt} - \frac{dV_s}{dt} \qquad (3.11)$$

Where V_s is the volume of water lost due to evaporation.

Hence equation (3.11) will now be tested and calibrated based on real values from the dam's inflow and outflow values collected.

Putting all the inflows together and the outflows together and the mass law gives the relation

$$\frac{dV}{dt} = q_{in} - q_{out} \qquad (3.12)$$

$$\frac{dV}{dt} = \frac{dV_i}{dt} - \frac{dV_o}{dt} \qquad (3.13)$$

Again the total volume of water can be obtained by the integration of the differential equation and finding the constant at a given time.

i.e $\int dV = \int Mdt + C,$ (equation 3.05)

In the subsequent section 3.0.6, and 3.0.7 rainfall and evaporation, factors affecting them as well as the method of measuring are discussed.

3.6.0 RAINFALL

3.6.1METHODS OF DATA COLLECTION AND INSTRUMENTATION

Methods for data collection and compilation of precipitation data vary among the agencies. The primary types of rainfall data in a region are daily totals and rainfall intensity (depths accumulated at various times) data. Daily measurements commonly used are collected in simple volumetric gages located throughout the region and provide general information about the spatial variation of daily, monthly, and annual precipitation. Each day at a prescribed time (usually 8:00 am local time) the station observer records in a data log the height of a water column in a fixed rain gage. The gage is then emptied and prepared for the next day's value. The value read at 8am is identified as the daily rainfall amount for the previous day. The daily totals of the volumetric gages are used for quality assurance of the rainfall intensity data.

3.6.2 RIANFALL MEASUREMENT DEVICES

Rainfall-intensity data in the region have most commonly been measured using mechanical strip-chart recorders, also known as weighing bucket recorders. These instruments record rain depth with time on a paper strip chart that is wrapped around a slowly and uniformly revolving cylindrical drum. As the instrument bucket is filled with rain, it slowly descends and a pen records the corresponding depth of rain on the paper chart. The result is a graph showing the amount of rainfall (vertical movement of pen) over time (rotational movement of drum). Chart recorders are serviced daily, weekly, or monthly, depending on the design of the instrument and the length of the chart in the recorder. Less commonly used recording rain gages include tipping-bucket gages, that digitally record the times that a small bucket (usually designed to hold 0.1 or 0.2 mm) fills and tips its contents, and weighing bucket rain gages equipped with digital data loggers rather than paper strip charts. Although digital data collection devices are expected to replace many of the older mechanical, strip chart recording devices, virtually all intensity data used for this study were from paper strip chart recorders.

The rainfall intensity data include measurements of both rainfall depth and time and are used to construct depth-duration frequency curves. The depth-duration frequency (or probability) curves are used to design culverts and storm drains. The curves also are used as input to rainfall runoff models that are used to simulate large floods for bridge and spillway design. Soil erosion prevention practices, water levels in dam and irrigation management procedures also are based on reliable predictions of rainfall intensities.

3.6.3 AVAILABILITY AND LIMITATIONS OF RAINFALL DATA

Rainfall intensity data were analyzed for 5 sites in and near the study area. The periods of data collection at these sites vary from about 20 years to more than 40 years. Although these at-site measurements of rainfall provide key information about the temporal and spatial characteristics of rainfall in the region, their usefulness is limited by the highly variable nature of rainfall. For example, heavy storms often cover relatively small areas and have widely varying intensities within the those areas. At-site, rain gages are commonly located outside the areas of highest rainfall intensity and inferences about real intensities and depths ,thus there may be an error. The limitations of at-site data collection may be at least partially compensated for by using radar analysis of rainfall to assess a real variability. Even though at-site rain data have limitations, they are essential in analyzing long-term statistical characteristics of rainfall. In this regard, the longer the period of record, the more reliable are the analyses. For example, determination of the daily rainfall having an annual exceedance probability of 1 percent (100-year recurrence interval) is more reliably estimated from a 50-year period of daily rainfall data collection than from a 20-year period.

3.6.4 EVAPORATION OR (EVAPOTRANSPIRATION)

It is difficult and of little value, to separate evaporation (from the soil surface or from water surface) and transpiration (the loss of water by plants to the atmosphere) for vegetated surfaces; thus, they are often lumped together and termed evapotranspiration (ET). Sometimes, terms such as consumptive use or crop water requirement are used instead of evapotranspiration. The rate of evapotranspiration is expressed as the volume of water evaporated per unit area per unit time: (in a unit of mm^3 mm^{-2} d^{-1} = mm d^{-1})

Thus, it is measured in the same units as rainfall.

3.6.4 FACTORS INFLUENCING THE RATE OF EVAPOTRANSPIRATION (ET)

3.6.4.1 Weather

For evaporation to take place we must have,

- An input of energy (mainly solar energy) depends on the amount of sunshine and its intensity;
- A vapour pressure gradient between the evaporating surface and the air. This depends on the relative humidity and temperature;
- Movement of air, otherwise the layer immediately above the evaporating surface would become saturated and no more evaporation would take place (allowing for movement of vapour in the air).

3.6.4.2 Surface area of water body

- Most evaporation takes place on the surface of the water body or the dam therefore actual evaporation can be said to depend on the total surface area of the dam or the water.

3.6.5 MEASUREMENT OF ACTUAL EVAPOTRANPIRATION (ET).

All methods of measurement are estimates which involve simplifying assumptions or inaccuracies that limit their applicability and reliability. The most commonly used methods of measuring actual evapotranspiration are based on water balance methods.

Consider the storage equation, Inputs - Outputs = Change in storage

P: effective precipitation

R: runoff,

ET : evaporation

ΔS: soil and groundwater storage

We can express the storage equation as,

$$P - R - ET = \Delta S. \tag{3.14}$$

Changes in storage (or assume $\Delta S = 0$ over a long period) and inputs, can be used to estimate actual evaporation from

$$ET = P - R - \Delta S. \tag{3.15}$$

Notwithstanding equation (3.15) for the ET, it is measured directly by the use of the instrument called the Lysimeter.

Also the evaporation can be calculated from the Penman-Montieth equation given by

$$\boldsymbol{ET = \left[\left(\frac{\Delta}{\Delta+\gamma}\right)(R_n - G) + \left(\frac{\gamma}{\Delta+\gamma}\right) f(u)(e_o - e_d)\right] / L} \tag{3.16}$$

where

Δ: slope of the saturated vapour pressure-temperature curve at mean daily temperature [kPa^oC^{-1}]

γ: Psychometric constant [kPa^oC^{-1}]

R_n : Net radiation energy [$MJm^{-2}day^{-1}$]

G: Ground heat flux (positive when direction of flux is into the ground[$MJm^{-2}day^{-1}$]

f(u): wind function of the form f(u)= a+b(U) where a and b are constant and U(km day^{-1}) is wind run [$MJm^{-2}kPa^{-1}day^{-1}$]

$e_{o:}$ mean daily saturated vapour pressure at mean dry bulb temperature [kPa]

e_d: Actual mean daily vapour pressure [kPa] and

L: Latent heat of vaporization of water [$MJkg^{-1}$]

3.0.7 TESTING THE MODIFIED MODEL

The modified model is tested using the data collected (for the year 2006)

Month	Net-flow $\frac{dV}{dt}$	mt	Rainfall	Sum of inflow and rainfall	Evaporation rate, $\frac{dV_s}{dt}$	Predicted volume ($m^3 \times 10^{11}$)
JANUARY	-30.567	-79229664	19155.71	-79210508.3	8576.8	1.238905
FEBRUARY	-56.4	-146188800	14155.42	-146174645	47740.9	1.001054
MARCH	-65.7	-170294400	23938.6	-170270461	38555.32	0.99552
APRIL	-46.8	-121305600	82082.09	-121223518	38360.7	0.8314
MAY	69.3	179625600	114282	179739882	5.47E+03	0.974994
JUNE	129.8	336441600	96092.57	336537692.6	37260.44	0.9691559
JULY	334	865728000	93121.38	865821121.4	528.32	0.9640122
AUGUSTS	779.4	2020204800	68941.22	2020273741	934.1	0.96
SEPTEMBER	2453.5	6359472000	127640.3	6359599640	2237.9	0.965592
OCTOBER	2294.7	5947862400	105030.3	5947967430	2294.7	0.9871125
NOVEMBER	5066.5	13132368000	265.716	13132368266	7056.1	0.93552
DECEMBER	85	220320000	0	220320000	2099.33	0.9921378

Table 3.8 present a result of the adjusted model which shows a similar pattern to that presented by the first model.

CHAPTER FOUR

DISCUSSION OF RESULT

4.0.1 INTRODUCTION

This chapter will seek to analyze and assign interpretation to the data obtained from the third chapter. It will also explain and discuss the results from the model and compare with the result of existing models. Again this section will assign reasons to certain adjustment or modification that occurred during the modeling process in an attempt to predict the level of the dam.

4.0.2 RESULT

As already stated in the second chapter, a mathematical model is an equation or a formula which is developed to solve or help solve a real life problem. In this work four main assumptions in section 3.04 were made and their corresponding equation (3.01) and (3.02) obtained, the formula is based on the behaviour of the system and the first model of the form

$$\frac{dV}{dt} = q_{in} - q_{out} \qquad (3.03)$$

$$\frac{dV}{dt} = \frac{dV_i}{dt} - \frac{dV_o}{dt} \qquad (3.04)$$

whose integration gave

$V = mt + C$. (equation 3.05)

Equation 3.05 was used to predict the volume of the water in the dam which gave the following results.

Table 4.1 Shows the Netflow, Predicted Volume and Actual Volume for the 1980

MONTH		Net-flow ($\frac{dV}{dt}$)	Predicted Volume ($m^3 \times 10^{11}$)	Actual Volume(m^3)
JANUARY		-28.9	1.3059	1.31E+11
FEBRUARY		-50.5	1.30459	1.07E+11
MARCH		-60.3	1.30303	.63E+10
APRIL		-64	1.30137	1.06E+11
MAY		-24.2	1.30074	1.05E+11
JUNE		72.1	1.30261	1.05E+11
JULY		159.9	1.30675	1.04E+11
AUGUSTS		1331.8	1.34127	1.04E+11
SEPTEMBER		3868.2	1.44154	1.06E+11
OCTOBER		1022.7	1.46804	1.04E+11
NOVEMBER		301.8	1.47613	1.09E+11
DECEMBER		21.2	1.4767	1.08E+11

Table 4.2 Shows the Netflow, Predicted Volume and Actual Volume for the year 1981.

MONTH		Net-flow ($\frac{dV}{dt}$)	predicted Volume ($m^3 \times 10^{11}$)	ActualVolume($m^3 \times 10^{11}$)
JANUARY		-30.7	1.27995	1.073718
FEBRUARY		-53.4	1.27856	1.066261
MARCH		-56.4	1.2771	1.062602
APRIL		-51	1.27578	1.052361
MAY		34.1	1.27555	1.046363
JNE		121.1	1.27982	1.040081
JULY		401.1	1.29022	1.036596
AUGUSTS		1486.4	1.32875	0.987923
SEPTEMBER		2464.3	1.39262	1.019818
OCTOBER		834.8	1.41426	1.048227
NOVEMBER		202.2	1.41968	1.051226
DECEMBER		5.4	1.41982	1.047052

Table 4.3 Shows the Netflow, Predicted Volume and Actual Volume for 1990

MONTH		Net-flow ($\frac{dV}{dt}$)	Predicted Volume ($m^3 \times 10^{11}$	Actual Volume(m^3X10^{11})
JANUARY		15.1	1.32504	1.325041
FEBRUARY		-9.6	1.324792	1.094103
MARH		-41.8	1.3237076	1.091016
APRIL		-39.7	1.322679	1.01175
MAY		-24.3	1.322049	1.07619
JUNE		66.5	1.323773	1.070881
JULY		366.9	1.333283	1.067801
AUGUSTS		1341.7	1.36806	1.067842
SEPTEMBER		1312.9	1.402091	1.072259
OCTOBER		341.6	1.41094	1.075945
NOVEMBER		15.1	1.41135	1.0723
DECEMBER		-34.9	1.41041	1.06618

Table 4.4 Shows the Netflow, Predicted Volume and Actual Volume for1995

MONTH		Net-flow ($\frac{dV}{dt}$)	predicted Volume($m^3 \times 10^{11}$)	Actual Volume($m^3 \times 10^{11}$)
JANUARY		119.8537	1.254086	1.254086
FEBRUARY		77.4	1.256092	1.018075
MARCH		82.5	1.258231	1.012724
APRIL		56.2	1.259688	1.002067
MAY		78.4	1.26172	0.996028
JUNE		172.1	1.2661821	0.9897062
JULY		406.9	1.276729	0.9860993
AUGUSTS		2625	1.344768	0.9946505
SEPTEMBER		3434.2	1.433782	1.022573
OCTOBER		1769.5	1.479648	1.045998
NOVEMBER		295.1	1.48755	1.042391
DECEMBER		38.9	1.48859	1.043445

Table 4.5 Shows the Netflow, Predicted Volume and Actual Volume for the year 2000

MONTH		Net-flow ($\frac{dV}{dt}$)	Predicted Volume ($m^3 \times 10^{11}$)	Actual Volume ($m^3 \times 10^{11}$)
JANUARY		78.89331	1.23484	1.234844
FEBRUARY		28.2	1.23558	1.050415
MARCH		54.7	1.236994	1.046057
APRIL		50.2	1.238296	1.036272
MAY		71	1.24013	1.029625
JUNE		272.3	1.247196	1.024032
JULY		501.1	1.2601842	1.0231
AUGUSTS		1652.6	1.30302	1.026018
SEPTEMBER		2490.3	1.367568	1.041297
OCTOBER		1847.2	1.415448	1.056089
NOVEMBER		429.5	1.42695	1.064154
DECEMBER		63.8	1.24049	1.062492

Table 4.6 Shows the Netflow, Predicted Volume and Actual Volume for the year 2006

MONTH		Net-flow ($\frac{dV}{dt}$)	Predicted Volume ($m^3 \times 10^{11}$)	Actual Volume ($m^3 \times 10^{11}$)
JANUARY		-3.3259	1.2389	1.238905
FEBRUARY		-4.6	1.23878	1.001054
MARCH		-30.3	1.23799	0.99552
APRIL		-5.9	1.23784	0.8314
MAY		69.3	1.23964	0.974994
JUNE		129.8	1.243005	0.9691559
JULY		334	1.25166	0.9640122
AUGUSTS		779.4	1.27186	0.96
SEPTEMBER		2453.5	1.33459	0.965592
OCTOBER		2294.7	1.39493	0.9871125
NOVEMBER		5066.5	1.5306	0.93552
DECEMBER		85	1.55336	0.9921378

Table 4.7 Shows the Netflow, Predicted Volume and Actual Volume for the year 2008

MONTH		Net-flow ($\frac{dV}{dt}$)	Predicted Volume ($m^3 \times 10^{11}$)	Actual Volume ($m^3 \times 10^{11}$)
JANUARY		94.0623	1.22802	1.258561
FEBRUARY		99.8	1.25389	1.02233
MARCH		84	1.275677	1.016951
APRIL		87.7	1.29841	1.006282
MAY		114.7	1.328132	1.000122
JUNE		301.8	1.40636	0.995136
JULY		655.1	1.576173	0.993921
AUGUSTS		3220.4	0.241089	1.041986
SEPTEMBER		6423.5	0.4075855	1.008267
OCTOBER		3556.6	0.499771	1.071327
NOVEMBER		904.3	0.7419708	1.07769
DECEMBER		475.4	0.869294	1.071287

4.0.3 DISCUSSION

From the above (and previous pages) table of result and the graph which came from the first model, it could be seen that the first relation which gives the net-flow of the Dam have both negative and positive values which indicate that at times there are more outflows than the inflow, hence a negative net-flow. This is accounted for by the fact that the penstocks do operate at a peak rate or maximum level. The negative values of the net-flow can be removed or adjusted by making the penstocks to operate at their minimum level. This has been corrected (calculated) by using the least operating values of the penstocks. Again from the first model (equation 3.05) it could be seen that the results for some month are minimal which show a direct relation or a clear correlation with the original data from the V.R.A.

Again, the first model (equation3.05) does predict the volume or the corresponding level for some month and then failed along the year; despite that, the model also give values which suggest that some month such as December, January, February, March, and April have the least net-flow or small volume of water with April being the month with the least volume of water or least water level in the dam.

Further more, the modified model (equation3.15) seeks to give a better prediction than the first one since this takes other factors such as the rainfall or the rate of rainfall which contribute about 22% increase to the inflow and volume of the water. Also the modified model seeks to be the best because it also takes account of evaporation which add up to the outflow of the water within the dam or decrease in the water level of the dam. Equation 3.15 was tested based on the rainfall, evaporation and the net flow of the dam which gives a better result than the first relation or model.

Table 4.8 present the result from the modified model compared with the actual volume for 2006

Month	Predicted volume ($m^3 \times 10^{11}$)	Actual volume ($m^3 \times 10^{11}$)
JANUARY	1.238705	1.238905
FEBRUARY	1.001054	1.001045
MARCH	0.99552	1.000007
APRIL	0.8314	0.8314
MAY	0.974994	0.974994
JUNE	0.9691559	0.9691559
JULY	0.96401220	0.95602
AUGUSTS	0.96	0.95895
SEPTEMBER	0.965592	0.965586
OCTOBER	0.9871125	0.978665
NOVEMBER	0.93552	0.93443
DECEMBER	0.9921378	0.98786

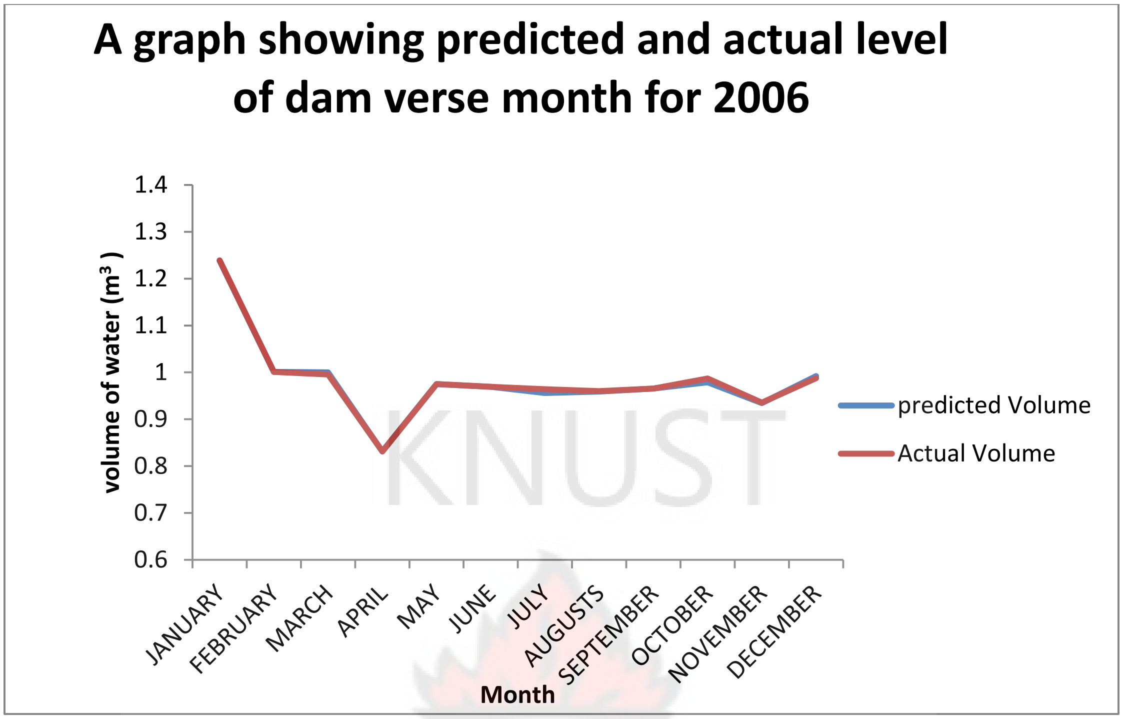


Figure 4.08 shows a graph of actual and predicted volumes from the modified model

It could also be seen from the table 4.8 that from December to April the volume of the water decreases gradually with April being the month with the minimum water content or level. This goes to prove the fact that the first model gave a good pattern of the water levels. Again it shows that March and April are the month in which low schedules are possible even with April being the month with least inflow and hence low power generation. The small volume of water in the month of April could be attributed to the fact that, March has a lot a sunshine (a month with a highest temperature over the past forty years) which causes a lot of evaporation in the dam and hence its consequential effect on the month of April.

Further more, the model suggest that the month of May to November have high net-flow with September being the month with the highest; hence a highest level of the dam within the year.

The result may have some slight deviation from the actual values due to the fact that, the meandering of the water as it approaches from the various tributaries was not considered. Again the velocity as well as the energy of the flowing river was not considered and evaporation that occurs as the tributaries enter the dam were not accounted for which seem to suggest that there is an error of about 15% which may be associated with the model.

CHAPTER FIVE

CONCLUSION

Several factors do affect the dam causing fluctuations in its water level. The basic procedures in modeling were adopted using differential equation. During the modeling process, several assumptions were made and their corresponding differential equations deduced. The model was tested against data values collected from the Volta River Authority (VRA). The model was modified again to reflect on other factors which were not accounted for in the first process. The modified model was also tested using data values and proved to predict the accurate levels of the water in the dam. The results from both tested models are shown in table 4.01 and 4.02 respectively over years. The full result could be seen on Appendices B. Tables showing the rainfall and temperature from the five sites close to the study area are in Appendices C and D. The appendix A has the table of the data of net-flows for the year 1980 to 2009. Appendix E present the meaning of some terms used and Appendix F shows the graph for the result from

the first model and Appendix G shows the summary of features of the Akosombo Dam.

The aim set out in this study has been successfully achieved with the model described by equation 3.05

i.e $V = mt + C$

In particular, the model predicted March and April as the month with the lowest water levels with a corresponding low power generation and September with the highest water level and hence maximum power generation within the year.

Finally the model presented a result which is within an accuracy of 86%, and this show that the model could be adopted and used (from the graph of the result).

5.0.2 Recommendation.

Though the model presented a result which is about 86% accurate, there exist a wider field in this area of studies which could still be worked on to achieve the best model for a system of this nature. The use of differential equation in modeling, present a very challenging way of looking at the behaviour of a system, It is therefore recommended that

- Students and researchers consider looking into this area to develop a model that will give as the best mathematical expression (formulae) needed for systems with such characteristics.
- study models for predicting inflows and outflows using differential equation
- The VRA should consider adopting other new models such as this one which is simpler.
- The V.RA should get involve in educating the public about the importance of the water level in the dam and how to calculate.

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APPENDICES

APPENDIX A

Inflows from the three major tributaries into the dam and their corresponding netflows for the year 1980 to 2009

YEAR	Saboba	Nawuni	Bui	SUM	netflow $\frac{dV}{dt}$
1980	10.3	14.4	20.9	45.6	-28.9
1981	13.2	9.4	21.2	43.8	-30.7
1982	13.4	16.5	11.2	41.1	-33.4
1983	33.7	14.6	12.5	60.8	-13.7
1984	8.1	4.5	1.5	14.1	-60.4
1985	5.6	4.7	2.2	12.5	-62
1986	11.0	4.2	12.0	27.2	-47.3
1987	12.5	5.9	12.7	27.9	-46.5952
1988	9.3	4.9	9.3	23.5	-51
1989	46.0	5.2	35.9	87.1	12.6
1990	45.9	12.7	31.0	89.6	15.1
1991	11.7	4.8	5.4	21.9	-52.6
1992	20.4	12.6	32.0	65.0	-9.5
1993	10.6	10.7	17.4	38.7	-35.8
1994	31.3	11.4	15.1	57.8	-16.698
1995	63.2	48.5	82.7	194.4	119.8537
1996	33.6	57.7	13.8	105.2	30.67865
1997	45.3	26.9	13.7	85.9	11.41189
1998	20.2	11.9	14.2	46.4	-28.1235
1999	67.2	50.2	14.3	131.7	57.19949
2000	62.6	14.7	76.1	153.4	78.89331
2001	13.7	21.9	26.9	62.5	-12.0424
2002	42.6	24.6	8.9	76.1	1.607557
2003	48.6	17.6	7.1	73.4	-1.12011
2004	52.6	20.8	41.3	114.8	40.26751
2005	30.8	38.3	20.2	89.3	14.76839
2006	37.6	22.0	11.6	71.2	-3.3259
2007	54.2	18.4	44.6	117.2	42.74311
2008	50.9	45.7	67.7	164.3	89.76572
2009	67.8	46.0	54.8	168.6	94.06235

MAY

YEAR	**Saboba**	Nawuni	**Bui**	SUM	Netflow $\frac{dV}{dt}$
1980	3.3	2.4	4.8	10.5	-64.0
1981	4.3	10.1	9.1	23.5	-51.0
1982	18.8	8.6	20.5	47.9	-26.6
1983	4.2	2.7	4.6	11.5	-63.0
1984	8.6	3.0	5.9	17.5	-57.0
1985	4.1	1.3	0.4	5.8	-68.7
1986	2.9	3.6	0.4	6.9	-67.6
1987	1.7	6.1	6.6	14.4	-60.1
1988	1.6	5.4	8.4	15.4	-59.1
1989	2.5	18.0	14.3	34.8	-39.7
1990	13.3	14.6	6.9	34.8	-39.7
1991	4.0	19.7	5.2	28.9	-45.6
1992	20.5	13.7	4.5	38.7	-35.8
1993	19.0	16.2	5.2	40.4	-34.1
1994	19.3	45.3	1.5	66.1	-8.4
1995	44.0	65.5	21.2	130.7	56.2
1996	29.5	36.3	13.1	78.9	4.4
1997	37.9	44.9	8.6	91.4	16.9
1998	20.6	25.1	2.6	48.3	-26.2
1999	51.7	74.2	22.8	148.6	74.1
2000	48.0	64.5	12.2	124.7	50.2
2001	51.3	33.7	10.6	95.6	21.1
2002	40.4	59.1	10.3	109.7	35.2
2003	45.3	53.1	10.9	109.4	34.9
2004	46.9	71.9	36.8	155.6	81.1
2005	39.6	45.7	8.9	94.2	19.7
2006	17.6	44.8	6.2	68.6	-5.9
2007	24.8	61.5	37.1	123.5	49.0
2008	64.6	56.2	25.0	145.8	71.3
2009	53.7	66.3	42.3	162.2	87.7

JULY

YEAR	**Saboba**	Nawuni	**Bui**	SUM	netflow $\frac{dV}{dt}$
1980	40.6	80.6	113.2	234.4	159.9

1981	121.6	185.8	168.2	475.6	401.1
1982	76.1	44.2	109.5	229.8	155.3
1983	174.1	136.9	129.8	440.8	366.3
1984	193.2	66.8	167.1	427.1	352.6
1985	153.2	438.2	335.2	926.6	852.1
1986	73.8	186.7	124.5	385.0	310.5
1987	137.0	150.3	87.1	374.4	299.9
1988	161.9	198.1	264.7	624.7	550.2
1989	229.8	393.4	358.8	982.0	907.5
1990	160.7	172.6	108.1	441.4	366.9
1991	733.5	323.6	439.7	1496.8	1422.3
1992	220.1	89.9	145.4	455.4	380.9
1993	178.0	205.2	78.6	461.8	387.3
1994	169.5	131.4	165.2	466.1	391.6
1995	138.5	127.9	215.0	481.4	406.9
1996	158.6	92.3	157.7	408.7	334.2
1997	254.8	104.1	169.7	528.6	454.1
1998	461.3	135.8	91.9	689.0	614.5
1999	186.4	267.0	227.4	680.8	606.3
2000	159.0	175.6	241.0	575.6	501.1
2001	178.8	85.6	245.0	509.4	434.9
2002	106.5	87.1	204.1	397.6	323.1
2003	270.2	451.3	376.8	1098.3	1023.8
2004	348.8	245.9	217.9	812.6	738.1
2005	436.5	265.2	214.3	916.0	841.5
2006	89.8	152.1	166.6	408.5	334.0
2007	152.9	273.3	92.3	518.5	444.0
2008	683.6	422.5	582.9	1688.9	1614.4
2009	345.7	142.6	241.3	729.6	655.1

OCTOBER

years	**Saboba**	Nawuni	**BUI**	**SUM**	netflow $\frac{dV}{dt}$
1980	349.5	204.8	542.9	1097.2	1022.7
1981	199.8	443.4	266.1	909.3	834.8
1982	331.5	726.1	191.4	1249.0	1174.5
1983	165.4	150.2	87.2	402.8	328.3
1984	874.4	195.7	685.6	1755.7	1681.2
1985	469.5	517.0	510.0	1496.5	1422.0
1986	300.7	353.3	474.6	1128.6	1054.1
1987	432.6	276.4	337.4	1046.4	971.9
1988	792.0	694.2	606.5	2092.7	2018.2

1989	748.3	1138.3	831.2	2717.8	2643.3
1990	153.4	125.3	137.3	416.1	341.6
1991	466.8	456.4	431.1	1354.3	1279.8
1992	277.9	159.5	195.6	632.9	558.4
1993	384.3	362.3	284.0	1030.6	956.1
1994	1845.9	1403.0	973.5	4222.5	4148.0
1995	1095.0	302.4	446.6	1844.0	1769.5
1996	697.6	1026.0	657.2	2380.8	2306.3
1997	471.6	167.6	449.0	1088.2	1013.7
1998	1847.5	1018.1	473.0	3338.6	3264.1
1999	2164.2	1422.6	1244.7	4831.6	4757.1
2000	739.1	402.3	780.3	1921.7	1847.2
2001	714.4	485.4	379.8	1579.6	1505.1
2002	591.7	266.4	355.9	1214.0	1139.5
2003	1159.1	1123.1	909.4	3191.7	3117.2
2004	454.1	211.9	344.9	1010.9	936.4
2005	639.1	263.6	613.9	1516.6	1442.1
2006	878.1	640.9	850.2	2369.2	2294.7
2007	766.4	700.2	448.7	1915.3	1840.8
2008	848.8	1074.0	1850.0	3772.7	3698.2
2009	1290.4	1034.0	1306.7	3631.1	3556.6

APPENDIX B

Water levels in feet, meter and corresponding volume from 1980 to 2009

	JANUARY			FEBRUARY			MARCH		
	Feet	meters	Volume 10^10			meters	volume in m X10^10		
1980	322.23	97.94225	13.05897	264.94	80.52888	10.73718	163.16	49.7439	6.63
1981	320.2194	97.33112	12.97748	263.1	79.9696	10.66261	261.4	79.69512	10.62
1982	313.0965	95.16611	12.68881	255.67	77.71125	10.3615	254.15	77.48476	10.3
1983	302.2745	91.87675	12.25023	244.55	74.33131	9.910841	243.09	74.1128	9.881
1984	295.4655	89.80714	11.97429	238.17	72.3921	9.65228	237.34	72.35976	9.647
1985	301.8997	91.76283	12.23504	244.62	74.35258	9.913678	243.4	74.20732	9.894
1986	312.8619	95.0948	12.67931	255.67	77.71125	10.3615	254.43	77.57012	10.34
1987	308.0726	93.63909	12.48521	250.4	76.10942	10.14792	248.63	75.80183	10.10
1988	310.0242	94.23228	12.5643	252.43	76.72644	10.23019	250.69	76.42988	10.19
1989	313.3432	95.24109	12.69881	255.79	77.74772	10.36636	254.1	77.46951	10.32
1990	326.9539	99.37809	13.25041	269.97	82.05775	10.94103	268.39	81.82622	10.91
1991	317.3145	96.44818	12.85976	259.62	78.91185	10.52158	257.71	78.57012	10.47
1992	327.5265	99.55213	13.27362	270.32	82.16413	10.95522	268.51	81.8628	10.91
1993	315.9816	96.04304	12.80574	258	78.41945	10.45593	256.02	78.05488	10.40
1994	310.1174	94.26061	12.56808	251.58	76.46809	10.19574	249.17	75.96646	10.12
1995	309.4458	94.05647	12.54086	251.21	76.35562	10.18075	249.13	75.95427	10.12
1996	311.6719	94.7331	12.63108	253.39	77.01824	10.2691	251.14	76.56707	10.20
1997	309.9045	94.1959	12.55945	251.39	76.41033	10.18804	248.8	75.85366	10.11
1998	300.0255	91.19316	12.15909	241.38	73.36778	9.782371	239.73	73.08841	9.745
1999	304.6977	92.61328	12.34844	246.32	74.8693	9.982573	244.59	74.57012	9.942
2000	304.6977	92.61328	12.34844	259.19	78.78116	10.50415	257.33	78.45427	10.46
2001	314.6397	95.63517	12.75136	256.32	77.90881	10.38784	254.13	77.47866	10.33
2002	303.1652	92.14748	12.28633	244.37	74.2766	9.903546	242.42	73.90854	9.854
2003	299.9755	91.17796	12.15706	241.51	73.40729	9.787639	239.78	73.10366	9.747
2004	310.0413	94.23748	12.565	252.1	76.62614	10.21682	250.43	76.35061	10.18
2005	309.7855	94.15973	12.55463	251.23	76.3617	10.18156	249.15	75.96037	10.12
2006	305.6997	92.91784	12.38905	247.01	75.07903	10.01054	244.9	74.66463	9.955
2007	299.6329	91.07383	12.14318	240.44	73.08207	9.744276	238.28	72.64634	9.686
2008	310.55	94.3921	12.58561	252.26	76.67477	10.2233	250.17	76.27134	10.16
2009	318.999	96.96018	12.92802	260.72	79.2462	10.56616	258.96	78.95122	10.52

	APRIL			MAY			JUNE		
	Feet	meters	volume 10^10		feet	meters	volume 10^10		
1980	261.42	79.45897	10.59453	259.82	78.97264	10.52969	258.58	78.59574	10.47
1981	259.67	78.92705	10.52361	258.19	78.4772	10.46363	256.64	78.00608	10.40

1982	252.3	76.68693	10.22492	250.81	76.23404	10.16454	249.44	75.81763	10.10
1983	241.74	73.4772	9.79696	240.45	73.08511	9.744681	239.7	72.85714	9.714
1984	236.79	71.97264	9.596353	236.18	71.78723	9.571631	235.89	71.69909	9.559
1985	242.28	73.64134	9.818845	241.11	73.28571	9.771429	239.88	72.91185	9.721
1986	253.21	76.96353	10.2618	252	76.59574	10.21277	250.74	76.21277	10.1
1987	246.85	75.0304	10.00405	245.09	74.49544	9.932725	243.59	74.03951	9.871
1988	248.98	75.67781	10.09037	247.18	75.1307	10.01743	245.73	74.68997	9.958
1989	242.33	73.65653	9.820871	250.71	76.20365	10.16049	249.09	75.71125	10.09
1990	266.78	81.08815	10.81175	265.55	80.71429	10.7619	264.24	80.31611	10.70
1991	256	77.81155	10.37487	254.81	77.44985	10.32665	255.35	77.61398	10.34
1992	266.9	81.12462	10.81662	265.43	80.67781	10.75704	264.19	80.30091	10.70
1993	254.01	77.20669	10.29422	252.23	76.66565	10.22209	250.59	76.16717	10.15
1994	246.96	75.06383	10.00851	244.77	74.39818	9.919757	242.89	73.82675	9.843
1995	247.26	75.15502	10.02067	245.77	74.70213	9.960284	244.21	74.22796	9.897
1996	248.88	75.64742	10.08632	246.89	75.04255	10.00567	245.49	74.61702	9.948
1997	246.62	74.96049	9.994732	244.53	74.32523	9.91003	254.69	77.41337	10.32
1998	238.23	72.41033	9.654711	237.42	72.16413	9.621884	237.03	72.04559	9.606
1999	243.06	73.87842	9.850456	241.61	73.43769	9.791692	240.31	73.04255	9.739
2000	255.7	77.72036	10.36272	254.06	77.22188	10.29625	252.68	76.80243	10.24
2001	252.16	76.64438	10.21925	250.48	76.13374	10.15117	248.71	75.59574	10.07
2002	240.67	73.15198	9.753597	239.3	72.73556	9.698075	238.06	72.35866	9.647
2003	238.35	72.44681	9.659574	237.16	72.08511	9.611348	236.58	71.90881	9.587
2004	248.84	75.63526	10.0847	247.52	75.23404	10.03121	246.42	74.8997	9.986
2005	247.82	75.32523	10.04336	346.26	105.2462	14.03283	244.8	74.40729	9.920
2006	242.59	73.73556	9.831408	240.58	73.12462	9.749949	239.14	72.68693	9.691
2007	236.8	71.97568	9.596758	236.07	71.7538	9.567173	235.73	71.65046	9.553
2008	248.3	75.47112	10.06282	246.78	75.00912	10.00122	245.55	74.63526	9.951
2009	257.46	78.25532	10.43404	256.05	77.82675	10.3769	254.3	77.29483	10.30

	JULY			AUGUSTS			SEPTEMBER		
	Feet	meters	volume10^10		feet	meters	volume		
1980	257.25	78.19149	10.42553	257.48	78.2614	10.43485	261.92	79.61094	10.61
1981	255.78	77.74468	10.36596	256.67	78.0152	10.40203	259.05	78.7386	10.49
1982	248.48	75.52584	10.07011	247.59	75.25532	10.03404	248.26	75.45897	10.0
1983	239.64	72.83891	9.711854	239.73	72.86626	9.715502	240.48	73.09422	9.745
1984	236.48	71.87842	9.583789	239.56	72.81459	9.708612	243.71	74.07599	9.876
1985	240.1	72.97872	9.730496	243.77	74.09422	9.87923	251.64	76.48632	10.19
1986	249.79	75.92401	10.1232	249.4	75.80547	10.1074	251.36	76.40122	10.18
1987	242.5	73.70821	9.827761	243.13	73.8997	9.853293	250.02	75.99392	10.13
1988	245.41	74.59271	9.945694	246.92	75.05167	10.00689	252.42	76.7234	10.22
1989	249.47	75.82675	10.11023	251.71	76.5076	10.20101	261.34	79.43465	10.59

1990	263.48	80.08511	10.67801	263.49	80.08815	10.67842	264.58	80.41945	10.72
1991	256.76	78.04255	10.40567	261.41	79.45593	10.59412	268.98	81.75684	10.90
1992	263.38	80.05471	10.67396	262.48	79.78116	10.63749	263.13	79.97872	10.66
1993	249.23	75.7538	10.10051	249.69	75.89362	10.11915	254.22	77.27052	10.30
1994	241.08	73.2766	9.770213	239.9	72.91793	9.722391	243.55	74.02736	9.870
1995	243.32	73.95745	9.860993	245.43	74.59878	9.946505	252.32	76.69301	10.22
1996	245.54	74.63222	9.950963	245.54	74.63222	9.950963	249.66	75.8845	10.11
1997	241.69	73.46201	9.794934	241.07	73.27356	9.769807	243.21	73.92401	9.856
1998	237.38	72.15198	9.620263	238.4	72.46201	9.661601	241.97	73.54711	9.806
1999	239.58	72.82067	9.709422	240.28	73.03343	9.737791	247.07	75.09726	10.01
2000	252.45	76.73252	10.231	253.17	76.95137	10.26018	256.94	78.09726	10.41
2001	247.35	75.18237	10.02432	246.5	74.92401	9.989868	247.66	75.2766	10.03
2002	27.42	8.334347	1.111246	238.28	72.42553	9.656738	241.95	73.54103	9.805
2003	237.5	72.18845	9.625127	239.12	72.68085	9.69078	244.75	74.3921	9.918
2004	245.4	74.58967	9.945289	246.56	74.94225	9.9923	251.24	76.36474	10.18
2005	244.22	74.231	9.897467	245.47	74.61094	9.948126	247.86	75.33739	10.04
2006	237.87	72.30091	9.640122	236.88	72	9.6	238.26	72.41945	9.655
2007	235.17	71.48024	9.530699	236.61	71.91793	9.589058	245.59	74.64742	9.952
2008	245.25	74.54407	9.93921	248.79	75.62006	10.08267	257.11	78.14894	10.41
2009	253.95	77.18845	10.29179						

	OCTOBER			NOVEMBER			DECEMBER		
	Feet	meters	Volume	feet	metres	volume	feet	metres	volur
1980	257.46	78.25532	10.43404	267.88	81.42249	10.85633	266.58	81.02736	10.80
1981	261.11	79.36474	10.58197	260.59	79.20669	10.56089	259.03	78.73252	10.49
1982	249.6	75.86626	10.1155	249.13	75.7234	10.09645	247.76	75.30699	10.04
1983	241.65	73.44985	9.793313	240.9	73.22188	9.762918	240	72.94833	9.726
1984	247.28	75.16109	10.02148	247.9	75.34954	10.04661	246.92	75.05167	10.00
1985	258.65	78.61702	10.48227	259.39	78.84195	10.51226	258.36	78.52888	10.47
1986	254.66	77.40426	10.32057	254.94	77.48936	10.33191	253.68	77.10638	10.28
1987	256.35	77.91793	10.38906	257.08	78.13982	10.41864	255.68	77.71429	10.3
1988	259.89	78.99392	10.53252	260.39	79.1459	10.55279	259.08	78.74772	10.4
1989	272.09	82.70213	11.02695	274.08	83.30699	11.1076	272.91	82.95137	11.06
1990	265.49	80.69605	10.75947	264.59	80.42249	10.723	263.08	79.96353	10.6
1991	274.19	83.34043	11.11206	274.91	83.55927	11.14124	273.64	83.17325	11.08
1992	264.62	80.43161	10.72421	263.75	80.16717	10.68896	262.03	79.64438	10.61
1993	258.38	78.53495	10.47133	258.02	78.42553	10.45674	256.22	77.87842	10.38
1994	251.88	76.55927	10.2079	256.19	77.8693	10.38257	255.14	77.55015	10.34
1995	258.1	78.44985	10.45998	257.21	78.17933	10.42391	257.47	78.25836	10.43
1996	256.28	77.89666	10.38622	257.71	78.33131	10.44417	255.72	77.72644	10.36

1997	247.9	75.34954	10.04661	248	75.37994	10.05066	245.72	74.68693	9.958
1998	248.91	75.65653	10.08754	251.74	76.51672	10.20223	250.2	76.04863	10.13
1999	259.27	78.80547	10.5074	263.67	80.14286	10.68571	262.5	79.78723	10.6
2000	262.17	79.68693	10.62492	262.58	79.81155	10.64154	260.59	79.20669	10.56
2001	251.55	76.45897	10.19453	250.51	76.14286	10.15238	248.4	75.50152	10.06
2002	245.27	74.55015	9.94002	246.55	74.93921	9.991895	244.96	74.45593	9.927
2003	253.36	77.00912	10.26788	255.89	77.77812	10.37042	254.86	77.46505	10.32
2004	255.96	77.79939	10.37325	256.43	77.94225	10.3923	255.05	77.5228	10.33
2005	251.79	76.53191	10.20426	252.95	76.8845	10.25127	251.04	76.30395	10.17
2006	243.57	74.03343	9.871125	245.16	74.51672	9.935562	244.81	74.41033	9.921
2007	255.19	77.56535	10.34205	256.222	77.87903	10.38387	255.27	77.58967	10.34
2008	264.35	80.34954	10.71327	265.92	80.82675	10.7769	264.34	80.3465	10.71

APPENDIX C

Data on temperature for five location close to the study area (1960 to 1996)

Bole Monthly Average Temperature (°C)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961												
1962	25.1	28.1	29.2	28.6	27.2	25.2	25.1	23.8	24.5	25.5	26.3	24.6
1963	26.1	29.0	28.0	27.7	27.7	26.5	25.5	25.2	25.4	25.8	25.5	24.8
1964	25.9	27.3	29.3	28.3	27.2	25.8	24.5	23.9	24.5	25.8	25.8	25.5
1965	25.5	28.0	28.8	28.1	26.9	25.6	25.2	24.7	25.1	26.4	26.0	23.9
1966	25.3	27.2	28.9	28.2	27.9	25.8	25.7	25.2	25.3	26.1	26.5	24.9
1967	25.5	28.3	29.3	28.2	27.3	25.8	24.5	24.6	24.8	26.0	25.6	25.2
1968	25.2	28.6	28.7	27.5	27.0	25.6	25.0	25.1	29.9	26.1	26.2	25.4
1969	25.0	29.2	29.2	28.1	28.4	26.6	25.2	24.5	25.1	25.8	25.6	25.7
1970	26.4	28.0	30.3	29.9	27.6	26.6	25.2	25.1	24.8	26.7	26.3	25.6
1971	25.1	27.9	28.5	28.3	27.8	25.8	24.7	24.5	25.0	25.9	26.0	25.1
1972	25.4	28.4	28.9	28.4	26.9	26.0	25.6	24.7	25.4	26.1	25.6	25.7
1973	26.7	29.4	29.9	29.1	28.1	26.4	25.5	30.3	25.4	26.5	25.7	25.1
1974	25.5	27.6	29.4	29.2	27.6	26.5	24.8	24.8	24.7	26.2	25.3	23.6
1975	25.2	27.7	28.8	27.7	27.1	25.9	24.7	24.5	24.9	25.6	26.5	25.9
1976	25.8	28.0	28.9	28.7	27.4	25.2	25.0	24.9	25.7	25.3	25.6	24.3
1977	26.5	27.3	29.7	29.5	28.0	26.3	25.7	24.7	25.5	26.3	25.6	25.0
1978	26.0	29.3	28.7	27.4	27.1	25.7	24.8	25.3	25.3	26.0	25.8	26.2
1979	27.1	27.7	30.2	29.7	27.7	25.8	25.2	26.2	25.3	26.4	26.5	24.4
1980	27.1	28.5	30.2	29.7	27.5	26.4	25.0	25.0	26.6	26.1	26.1	23.5
1981	24.5	28.9	29.1	28.3	27.1	26.6	25.1	25.0	25.6	27.1	26.2	25.9
1982	25.8	28.3	28.6	28.2	27.5	26.4	25.6	24.9	25.7	26.4	25.7	25.1
1983	25.0	29.4	31.0	30.5	28.3	26.4	25.3	25.3	25.8	27.2	27.2	26.3
1984	26.4	28.6	30.1	29.0	27.6	26.8	25.3	25.4	25.4	26.7	27.0	25.0
1985	27.3	28.1	30.0	28.6	27.4	26.1	25.4	25.2	25.1	26.7	26.9	25.3
1986	25.9	29.3	29.4	29.0	28.4	26.2	25.1	24.8	25.4	26.2	25.9	24.0
1987	26.8	29.2	29.7	30.1	29.2	27.3	26.4	25.8	26.2	27.1	27.2	26.1
1988	26.8	29.4	31.0	29.4	28.5	26.1	25.0	24.9	25.7	27.0	26.8	25.2
1989	25.9	27.8	29.4	29.9	28.5	25.9	25.5	25.0	25.3	26.3	26.7	25.5
1990	27.1	28.3	30.1	29.1	28.0	26.3	25.2	25.3	25.7	26.7	27.5	26.8
1991	27.3	29.7	29.9	28.9	26.3	26.7	25.3	25.1	25.9	25.8	26.3	25.2
1992	25.7	28.5	30.1	30.1	28.7	26.3	25.1	24.5	25.3	26.6	25.5	25.3
1993	25.8	28.7	29.2	28.7	27.9	27.1	25.5	25.3	25.5	27.1	27.5	25.1
1994	26.4	29.0	30.4	29.9	28.3	26.4	25.8	25.3	25.8	26.1	25.5	24.4
1995	26.0	28.3	30.3	29.5	28.4	26.8	25.5	25.4	26.1	26.8	26.1	26.3
1996	27.2	29.1	30.3	28.5	28.2	26.1	25.2	25.2	25.4	26.2	25.1	26.4
1997	27.3	28.2	30.0	28.8	27.6	26.3	25.1	25.3	25.9	27.4	27.0	26.0
1998	27.3	29.6	30.9	31.0	29.4	27.2	25.9	25.1	25.4	26.7	27.1	26.3
1999	27.2	28.3	30.5	28.9	28.2	26.7	25.5	25.0	25.1	19.5	27.1	25.3
2000	27.2	26.7	29.1	28.9	28.3	25.9	24.8	24.7	24.8	26.7	27.1	25.2
2001	25.9	27.7	29.9	28.9	27.8	26.7	25.9	25.1	25.2	27.2	27.6	27.1
2002	27.2	28.5	31.1	29.3	28.6	26.4	25.7	24.8	25.5	26.4	27.5	25.5
2003	26.6	29.1	29.9	28.9	27.8	25.6	25.3	25.4	25.8	27.1	26.9	25.3
2004	26.5	28.5	27.9	28.7	27.7	26.3	25.4	25.4	26.1	27.6	27.7	27.3
2005	26.4	30.2	31.4	30.2	28.3	26.5	25.7	25.4	26.5	27.1	27.3	26.7
2006	27.8	29.5	31.1	30.6	27.7	27.1	26.3	25.6	26.1	27.1	25.7	25.1

APPENDIX D

Rainfall data from five site close to the study area

Bole Monthly Rainfall Total (mm)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	0.6	8.6	57.3	94.9	130.0	145.0	168.8	145.9	143.3	48.8	0.0	0.0
1962	0.0	2.5	42.2	127.5	156.5	223.3	124.0	151.6	223.5	209.3	44.7	5.3
1963	0.0	57.1	20.3	155.2	107.4	129.0	318.0	120.7	279.4	146.3	36.3	0.0
1964	0.0	0.5	95.0	72.1	78.2	218.7	99.1	116.6	238.8	72.6	60.2	75.7
1965	0.0	9.1	44.2	84.3	130.8	230.4	266.7	133.4	121.9	78.7	0.0	0.0
1966	0.0	0.0	73.2	117.6	81.5	160.8	56.9	89.2	170.4	94.0	16.3	0.0
1967	0.0	2.5	46.7	124.2	130.6	144.5	102.1	80.5	131.8	89.4	10.7	0.5
1968	0.0	3.8	68.1	146.3	133.9	270.0	289.3	228.6	344.4	164.3	112.3	57.9
1969	0.0	21.6	94.0	175.8	42.2	129.0	211.3	238.3	141.5	256.3	56.1	0.0
1970	3.8	0.0	27.4	66.0	167.4	81.3	53.1	137.4	225.0	55.4	0.0	1.3
1971	0.0	54.9	98.3	61.5	105.7	120.9	189.7	156.7	247.1	41.1	0.0	18.5
1972	0.0	20.1	45.2	74.9	229.4	95.8	147.1	165.6	239.3	87.6	0.0	0.0
1973	0.0	0.0	39.6	85.3	138.2	73.2	229.6	199.9	156.7	119.9	0.0	2.0
1974	0.0	0.0	20.1	115.3	136.1	95.3	231.1	136.7	237.7	194.6	0.0	0.0
1975	0.0	4.6	67.3	133.9	152.7	196.6	319.3	85.6	95.3	15.2	7.9	20.3
1976	0.0	1.0	21.0	72.5	125.0	55.5	111.5	101.6	132.8	144.4	100.6	0.0
1977	8.2	17.0	50.3	40.9	99.4	104.1	114.9	172.2	191.9	50.1	0.0	0.0
1978	0.0	3.1	170.9	144.1	69.8	91.7	107.3	65.8	139.9	104.4	8.9	14.3
1979	0.5	0.0	27.0	80.2	153.9	199.7	289.6	188.4	204.1	143.0	11.2	14.5
1980	6.1	17.5	21.2	49.7	169.9	90.1	207.3	121.7	207.3	209.3	5.8	2.3
1981	0.0	1.0	155.9	67.2	183.7	132.9	160.2	182.3	301.3	63.8	0.0	tr
1982	0.0	20.4	85.8	88.2	124.1	134.0	195.4	195.7	219.0	119.9	30.0	0.0
1983	0.0	0.3	37.5	69.3	127.0	90.6	68.3	130.5	151.2	31.9	6.6	48.8
1984	0.0	0.0	71.7	134.1	140.5	108.2	240.8	219.9	96.0	64.8	8.7	0.0
1985	0.0	0.0	59.7	77.9	132.2	150.4	192.1	155.4	361.0	47.2	18.0	0.0
1986	0.0	3.8	59.2	60.6	152.7	147.2	156.9	126.8	189.8	124.1	13.3	0.0
1987	0.0	8.4	51.6	50.4	81.1	176.9	105.0	192.0	211.9	68.4	1.3	0.0
1988	0.0	0.0	36.0	80.2	163.9	295.5	83.7	95.7	151.8	71.4	12.8	1.3
1989	0.0	0.0	34.0	53.2	108.2	304.7	144.9	158.4	348.0	179.2	tr	0.0
1990	0.0	2.3	0.0	143.5	149.9	124.9	219.8	87.2	208.8	82.6	19.1	13.6
1991	0.0	4.8	69.0	189.1	390.4	110.3	197.0	268.6	123.6	185.3	TR	23.9
1992	0.0	0.0	9.6	17.0	92.9	95.0	116.6	90.2	294.6	45.0	61.0	0.0
1993	0.0	0.0	79.3	146.8	100.9	48.0	150.6	194.3	247.7	84.6	74.0	0.0
1994	4.8	0.0	38.4	42.2	109.7	91.7	103.9	98.7	249.2	260.5	0.0	0.0
1995	0.0	2.8	60.3	94.1	38.7	138.8	23.4	82.3	228.0	119.0	26.2	7.4
1996	0.5	39.9	33.5	125.6	187.4	123.2	130.4	143.5	136.4	109.6	0.0	0.0
1997	0.0	0.0	5.4	175.1	73.4	211.3	114.9	128.0	256.6	44.1	55.0	0.0
1998	0.0	59.7	0.0	90.8	75.7	186.5	116.4	165.0	163.5	83.4	6.9	0.3
1999	12.5	25.1	44.8	142.6	129.7	149.8	104.6	243.4	235.3	73.7	1.5	0.0
2000	50.8	0.0	59.2	65.1	177.9	139.3	159.0	182.8	276.0	92.0	24.3	0.0
2001	0.0	0.0	19.1	145.0	69.8	203.6	80.3	94.2	207.5	47.9	37.0	0.0
2002	0.0	0.0	31.9	96.0	145.7	137.7	244.4	252.7	157.7	68.8	17.6	0.0
2003	0.0	30.8	28.8	124.3	190.4	235.1	49.6	128.9	304.1	102.3	56.0	1.0
2004	1.4	8.1	118.2	148.5	173.4	75.7	162.0	268.4	118.6	95.8	54.0	21.1
2005	0.0	4.7	18.1	95.7	169.9	159.8	186.8	116.2	239.0	151.6	0.0	55.0
2006	3.9	15.4	23.5	170.7	156.2	121.3	178.9	167.8	134.6	134.9	1.1	0.0

Bui Mean Monthly Rainfall (mm)

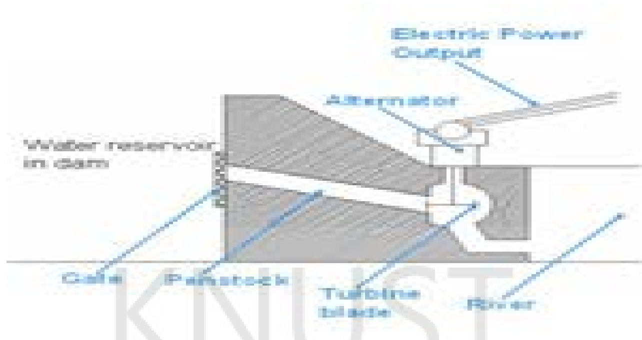
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961	0	0	2.75	3.08	6.11	8.68	4.12	0.19	6.09	2.22	0.65	0
1962	0	0.16	2	6.17	7.64	7.01	2.26	2.12	7.51	3.68	4.43	0.63
1963	0.02	2.63	5.31	5.75	10.41	6.95	11.13	12.5	1.82	15.59	0.33	0
1964	0.69	0.71	3.46	3.86	6.07	7.09	4.63	1.39	9.33	4.39	1.29	1.36
1965	0.21	3.7	2.47	10	7	6.25	3.89	6.16	4.96	5.18	0.05	
1966		0.04	3.67	4.47	5.85	9.99	4.98	1.98	9.6	8.36	0.03	0.64
1967	0	0.9	2.41	4.16	3.89	4.86	3.46	7.3	3.75	5.3	1.42	0.14
1968		1.37	2.19	5.78	11.33	7.19	7.45	7.09	10.19	8.53	0.94	
1969	0	0.93	3.66	6.6	6.95	3.35	4.24	2.85	5.02	5.4	2.28	0.11
1970	0.23	0.43	1.28	3.4	9.82	4.42	3.16	1.21	10.42	2.3	0	0
1971	0	1.23	4.02	3.48	5.02	9.32	4.45	4.18	7.22	2.3	0.49	0.27
1972	0	2.61	4.72	5.22	4.57	8.9	6.88	1.84	6.68	7.41	0	1.29
1973	0	0.07	2.38	2.8	9.57	2.74	2.77	3.57	5.17	3.3	0	0
1974	0	0.69	1.58	2.99	6.05	4.58	5.06	4.47	11.2	6.7	0	0
1975	0	0.3	2.87	4.57	5.73	5.55	5.3	2.52	4.79	5.68	0.22	0.41
1976	0	51.1	4.12	68.5	107.9	195.7	104.1	84.4	169.6	219.2	53.8	0
1977	2.9	0	44.2	114.7	180.4	80.6	47	115.4	256.9	111.3	0	0
1978	0	53.8	108.2	109	181.6	147.6	49.7	42.9	228.4	115.2	18	0
1979	11.7	19.1	89.6	166.8	169.7	193.6	326.2	73.7	221.1	130.6	22.9	0
1980	42.7	63	65.1	112.2	96.7	78.6	137.9	119.3	179	162.4	33.1	0
1981	0	21.6	239.9	34.8	260.2	141.1	101.8	120.8	308.3	120.2	0	0
1982	0	40.2	58.4	126.7	125.4	128	60.5	123.5	103.9	86.7	14.5	0
1983	0	0	47.4	154.5	287.6							
1984												
1985	0	0	0	0	0	0	256.2	168.8	286	110.7	0	0
1986	0	46.4	151.2	76.2	91.1	181.1	150.2	139.6	185.9	162.6		0
1987	0	7.8	121.4	132.5	130.5	79.8	103.7	264.6	265.4	175.7		
1988	0	0	54.1	81.6	98.1	116.8	140.5	38.3	253.4	47.9	9.2	0
1989	0	0	62.4	96.2	111.1	305.8	268.8	138.6	257.1	210	0	0
1990	15.2	32.3	5.4	204.7	66.1	168	61.1	201.1	80.5	99.4	46.7	48.4
1991	0	79.4	228.9	73.4	407.5	128.3	219	108.8	101.5	205.3	0	1.7
1992	5.4	2	33.3	135.9	121.1	208.7	77.3	42.8	149.1	96	57.2	0
1993	0	7.4	144	50.2	122.7	125.4	84.8	77	308.7	48.9	24.5	19.7
1994	0	tr	67.4	56.1	191.6	153.6	68.5	94.4	95.7	238.3	4.1	0
1995	0	10.2	92.5	108.4	168.2	142.2	72.2	76.8	250.6	195.2	12.2	8.8
1996	6.3	31.5	107.6	55	222.6	186.3	102.6	125	167.1	192.7	0	tr
1997	15.3	0	8.7	93.5	161.3	225.5	20	105.1	190.9	142.8	1.8	0
1998	7.3	19.4	0.8	95.5	103.9	110.9	81.5	59.4	188.4	160	1.9	4.1
1999	1.2	72.8	47.9	128.2	98.4	163.1	116.6	128.3	164.9	291.8	6	0
2000	93.3	0	13.8	125.7	142.7	315.1	43.9	97.4	258.5	54.6	4.5	0
2001	0	0	32.3	179.9	154.4	190.2	211.7	65.6	167.7	42.2	6.3	1.7
2002	1.2	tr	139.4	151.1	142.1	163.7	222.6	196.6	161.4	114.2	12	tr
2003	7.2	40.5	102.1	189.5	150.5	128.5	101.1	65.3	218.6	61.4	32.8	12.9
2004	12.3	tr	18.9	210	141.4	82.3	84	75	156.3	141.9	17.4	40.2
2005	27.5	15.7	44.5	128.7	165.7	118	293.2	66.5	196.8	238.4	5.4	28
2006	74.2	36.1	73.5	74.3	152	135.9	63.1	46.5	160.3	231.6	0	0

Yendi Monthly Average Temperature (°C)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	27.7	28.5	30.8	29.6	28.4	26.4	25.1	25.1	25.6	27.3	27.8	26.6
1962	27.0	29.3	30.2	29.7	28.2	25.8	25.7	24.7	25.3	26.8	27.5	26.2
1963	27.8	29.8	29.3	28.6	27.6	26.7	26.1	25.6	26.5	26.9	26.7	26.4
1964	27.4	29.4	30.4	28.7	28.1	26.5	25.6	25.1	25.3	26.7	27.4	27.5
1965	27.5	29.7	30.2	29.6	27.2	25.7	25.8	25.4	25.5	26.9	26.7	26.1
1966	27.5	29.4	31.0	29.7	28.7	26.4	26.3	25.1	25.7	26.8	27.4	26.7
1967	26.6	29.8	29.9	28.8	28.2	25.8	25.3	24.8	25.5	26.7	27.1	27.2
1968	26.4	29.4	29.9	29.6	28.6	26.3	26.0	26.1	25.7	27.1	27.1	27.7
1969	27.2	30.8	30.7	29.9	28.9	27.4	25.9	25.4	25.7	26.7	25.9	26.5
1970	27.8	29.9	31.3	31.5	27.8	27.2	25.8	25.1	25.2	27.4	27.7	26.8
1971	26.8	29.3	30.2	29.1	27.8	26.5	25.4	24.9	25.6	26.9	27.5	26.9
1972	27.3	30.1	30.2	29.5	28.3	26.6	26.2	25.8	26.4	26.8	26.5	26.9
1973	28.4	30.8	30.9	30.7	29.1	27.1	26.3	25.7	25.6	27.3	27.1	26.9
1974	26.7	29.2	30.9	29.8	28.6	26.8	25.6	25.6	25.6	26.8	26.6	25.7
1975	26.4	29.1	30.4	28.7	28.2	26.7	25.1	25.6	25.5	26.8	27.5	26.9
1976	27.2	28.9	30.4	29.5	28.1	25.9	25.7	25.3	26.1	25.9	26.7	25.6
1977	27.4	29.3	30.9	31.6	28.7	26.6	25.9	25.3	25.8	26.7	27.3	25.6
1978	27.5	30.1	30.0	28.1	27.5	26.5	25.3	25.6	25.9	26.7	26.5	26.9
1979	28.2	30.0	31.3	30.1	27.8	26.3	25.6	26.1	26.1	27.1	27.9	26.9
1980	28.7	30.5	31.7	31.4	28.9	27.3	26.7	25.7	26.4	26.7	27.1	26.4
1981	26.9	30.5	31.3	30.7	27.9	27.7	25.5	25.6	26.2	27.3	27.3	27.5
1982	27.3	29.2	30.1	29.5	28.0	27.1	26.4	25.5	26.3	26.5	26.8	26.7
1983	25.5	30.7	32.0	31.0	28.9	26.9	26.1	26.1	26.5	28.0	28.5	28.0
1984	27.5	29.6	30.7	28.8	28.5	26.9	26.1	26.1	25.9	27.0	28.1	26.1
1985	28.5	29.1	31.1	29.5	28.5	27.3	25.1	25.3	25.7	27.3	27.9	26.2
1986	27.3	30.4	31.1	30.5	29.7	26.8	25.5	25.5	25.6	26.6	26.1	25.4
1987	28.5	30.6	30.8	32.1	30.5	27.4	26.7	26.2	26.7	27.1	27.9	27.5
1988	28.0	30.5	32.1	30.9	29.9	26.5	25.5	25.0	26.1	27.3	27.6	26.6
1989	26.7	29.0	29.9	31.3	29.7	26.5	26.0	25.5	25.7	26.7	27.7	26.9
1990	28.5	29.8	31.7	31.3	29.4	27.5	25.7	26.1	26.3	27.4	29.1	28.4
1991	28.5	31.1	30.5	29.0	27.5	27.4	26.1	25.8	26.5	26.7	27.1	26.7
1992	26.9	30.0	31.3	31.0	28.3	26.7	25.7	25.7	26.3	27.2	26.7	26.7
1993	26.7	30.2	30.5	31.3	29.1	27.5	26.3	26.1	26.3	27.3	29.2	27.7
1994	28.0	30.3	32.4	31.0	29.1	26.9	26.5	26.3	26.5	26.9	27.5	26.9
1995	27.4	29.5	31.6	30.7	28.8	27.7	26.6	26.3	27.0	27.4	27.2	28.0
1996	28.4	30.8	32.3	30.8	29.1	27.3	26.5	26.0	26.3	27.0	27.0	27.8
1997	28.8	29.2	31.5	30.7	28.2	26.8	26.2	26.8	26.9	27.9	28.2	27.7
1998	28.2	31.5	32.7	32.7	29.9	27.5	27.0	26.1	26.4	27.7	28.7	28.4
1999	28.5	29.6	32.1	30.7	29.7	27.9	26.3	26.1	26.3	26.8	28.3	27.4
2000	29.3	28.8	31.2	31.0	29.8	27.1	26.3	25.9	26.4	27.3	28.3	26.7
2001	29.2	29.4	31.9	30.9	29.1	27.5	26.3	25.7	26.4	27.9	28.8	27.5
2002	28.4	30.0	31.1	30.5	29.4	27.9	26.6	26.3	26.6	27.6	28.6	27.4
2003	29.4	30.2	31.3	29.6	29.4	27.0	26.6	26.1	26.4	28.2	28.7	28.1
2004	28.6	30.2	31.4	30.3	28.7	26.8	26.4	26.3	26.4	28.1	28.4	28.6
2005	27.5	31.8	32.3	31.1	29.3	27.5	26.5	26.1	26.9	27.3	29.1	29.1
2006	28.2	30.3	31.7	31.3	28.6	27.4	26.6	26.2	26.0	27.1	27.8	27.2

APPENDIX E

Working of a Hydroelectric Dam and definition of terms



A hydroelectric dam converts **potential energy** (and/or kinetic energy) to electrical energy by means of a turbine and **alternator**.

A typical hydroelectric dam has the following main parts:

Water reservoir: A large quantity of water is stored in a reservoir (or dam). The height or depth of the stored water determines how much electricity can be generated. As the depth increases, the generation of electricity also increases.

Gate: A control gate is used for releasing/blocking water from the dam. Depending upon the electricity requirements, the gate is opened.

Penstock: The released water from the dam reaches the turbine blade through the penstock. The proper slope and diameter of the penstock is important for the efficiency of the dam.

Turbine: The turbine consists of a number of large fan blades and a spindle. The spindle rotates when water strikes the blades. Thus the power of flowing water is converted to the rotational power of the spindle.

Alternator: The spindle of the turbine is connected to the alternator, where rotational power of the spindle is converted into electrical power. The produced electricity is then distributed to the grid.

River: The outflow of water from the turbine is released to a river.

Advantages of Hydroelectric Dams

Cheap electricity: The operating cost of a hydroelectric dam is very minimal as there is no costly fossil fuel required. Moreover, life of a hydroelectric dam is much more than that of a thermal power plant.

Less green house gas: A hydroelectric power plant produces lesser amounts of green house gases as compared to a thermal power plant.

Tourism value: The dam of a hydroelectric power plant can be used as a tourist spot.

Disadvantages of Hydroelectric Dams

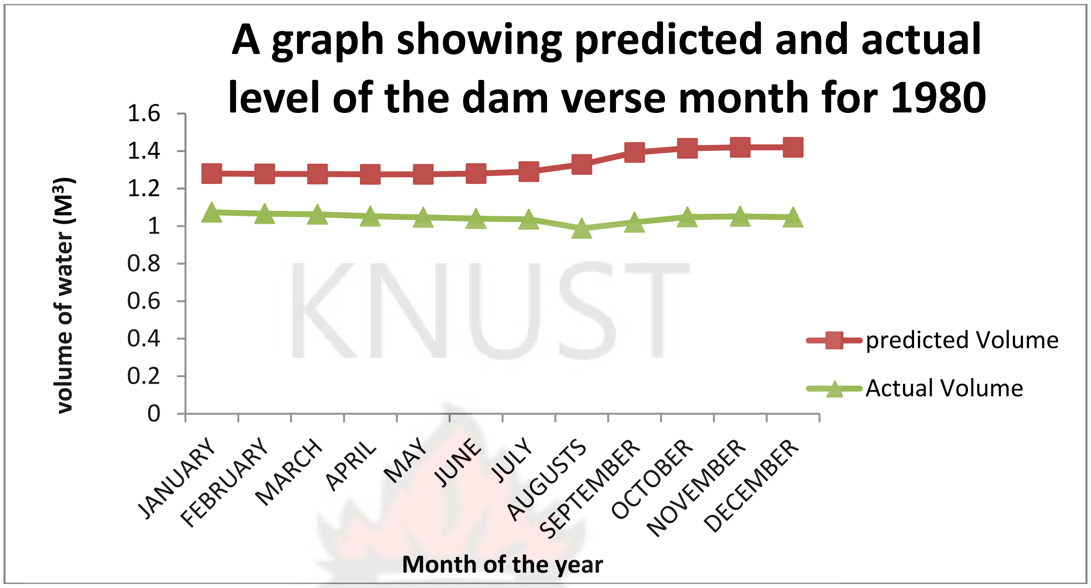
Effect on eco-systems: Construction of a dam affects the eco-system (especially water eco-system) of the surroundings. Some species of fishes cannot increase their population because of dams.

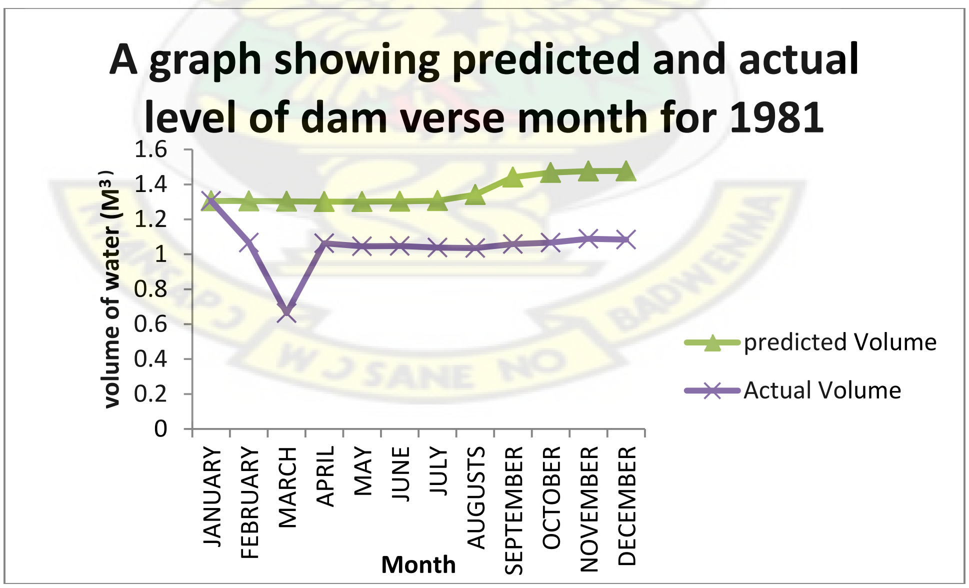
Relocation: For constructing a dam, relocation of the human and animal population of that area is required.

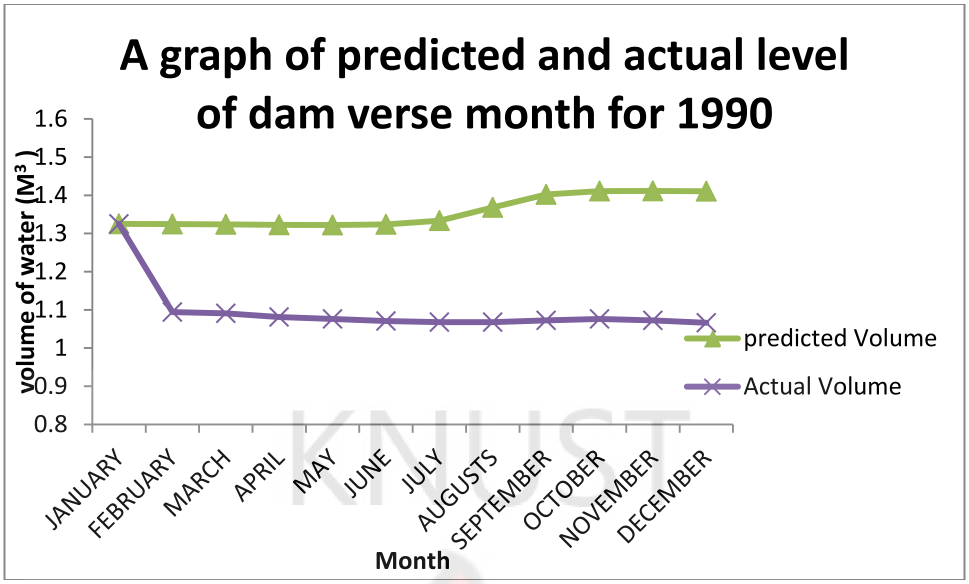
Green house gas emission: The blocked water in the dam causes generation of green house gas (**methane**).

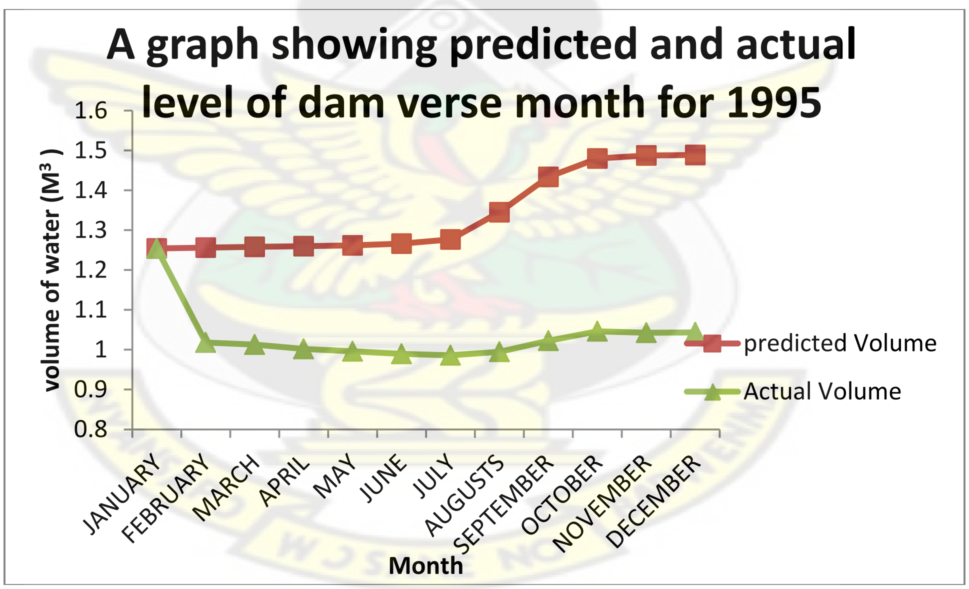
APPENDIX F

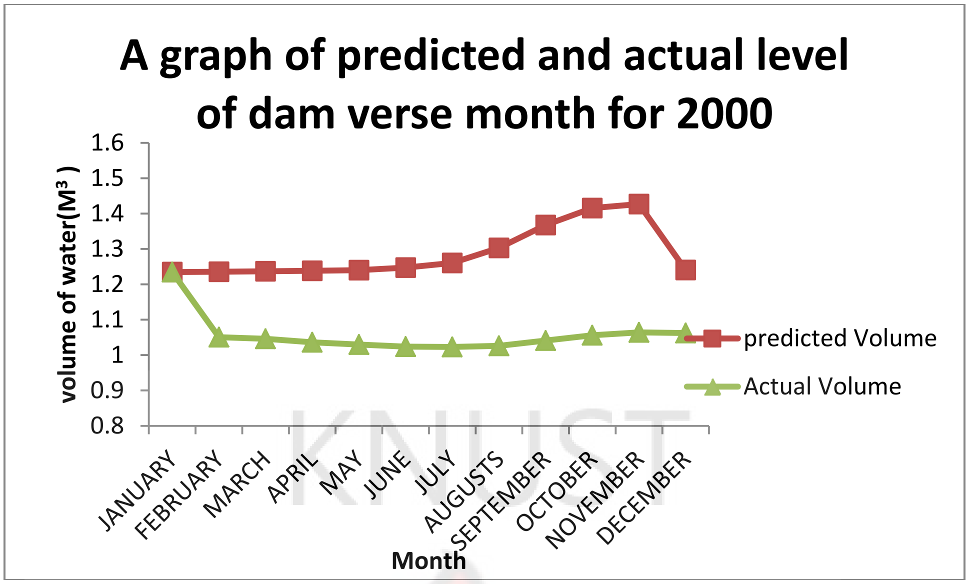
Graphs showing the result from the first model for six selected month

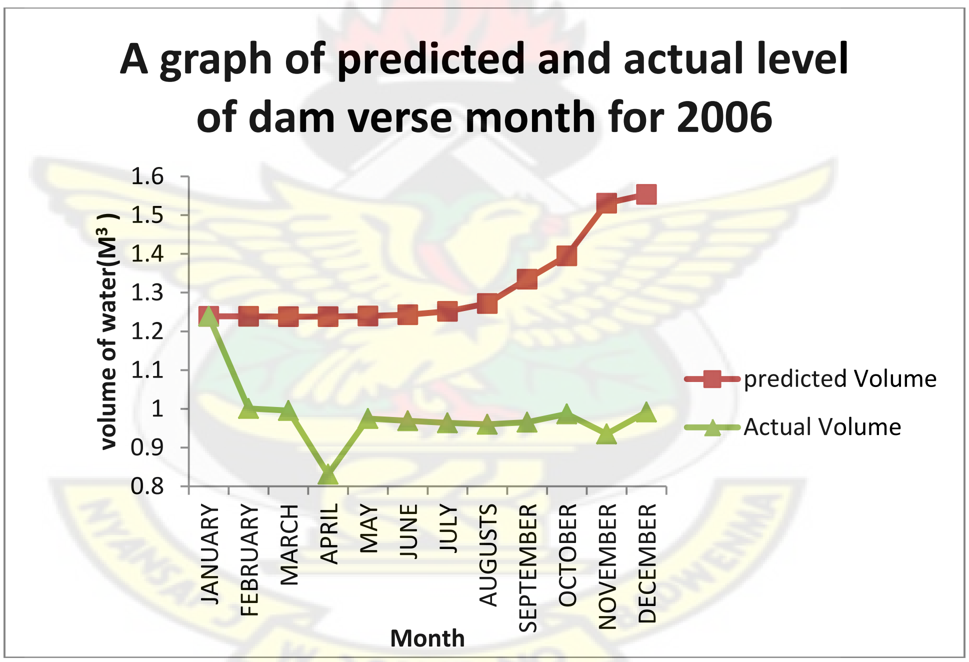





A graph of predicted and actual level of dam verse month for 1990
volume of water (M³)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUSTS
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Month
predicted Volume
Actual Volume


A graph showing predicted and actual level of dam verse month for 1995
volume of water (M³)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUSTS
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Month
predicted Volume
Actual Volume


A graph of predicted and actual level of dam verse month for 2000
volume of water(M³)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUSTS
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Month
predicted Volume
Actual Volume


A graph of predicted and actual level of dam verse month for 2006
volume of water(M³)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUSTS
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Month
predicted Volume
Actual Volume

APPENDIX G

Summary of Akosombo Dam and its features

Name:	Volta river
Location:	Akosombo, Ghana
Length:	660 m (2,165 ft)
Height:	111 m (364 ft)
Width (at base):	366 m (1,201 ft)
Construction began:	1961
Opening date:	1965
Construction cost:	£130 million
	Reservoir information
Creates:	Volta Lake
Capacity:	148 x 10^{12} litres
Catchment area:	8502 sq.km
	Power generation information
Installed capacity:	1020 MW
	Geographical Data

Coordinates:	6°17′59″N 0°03′34″E6.29972°N 0.05944°E
Maintained by:	Volta River Authority

PREDICTING THE LEVEL OF AKOSOMBO DAM USING MATHEMATICAL MODELING

A WORK PRESENTED
BY
AMFO-OTU WISDOM

SUPERVISER: DR. E. OSIE-FRIMPONG

ORGANISATION

- Introduction
- Problem statement
- Objectives
- Justification
- Methodology
- Result and Discussion
- Conclusion
- Recommendation

Background to the study

- The development of the Volta River Basin was initially proposed in 1949.
- The Volta was formed by the confluence of the Black and white Volta River at Yeji in the central part of the country. The river flows in the southerly course through Lake Volta to Ada on the Gulf of Guinea.
- The total length including the Black Volta is 1500km (930miles). Lake Volta which serves as the head pond of the Akosombo dam has a surface area of 3500km^2 and a live storage capacity of 148 by 109m^3

Background to the study

- The first stage of the construction began in 1961 when the Volta river project was established and work started on the Akosombo dam and the hydroelectric power station.
- During that period four unit with a total installed capacity of 588MW (mega watt) were completed in the year 1965, making an important step for industrialization and economic growth of the newly independent state of Ghana.
- Figure 1.1 shows the picture of the Akosombo dam and summary of its capacity and depth as viewed from the Volta Hotel

Akosombo dam

Akosombo Dam as seen from the Volta Hotel

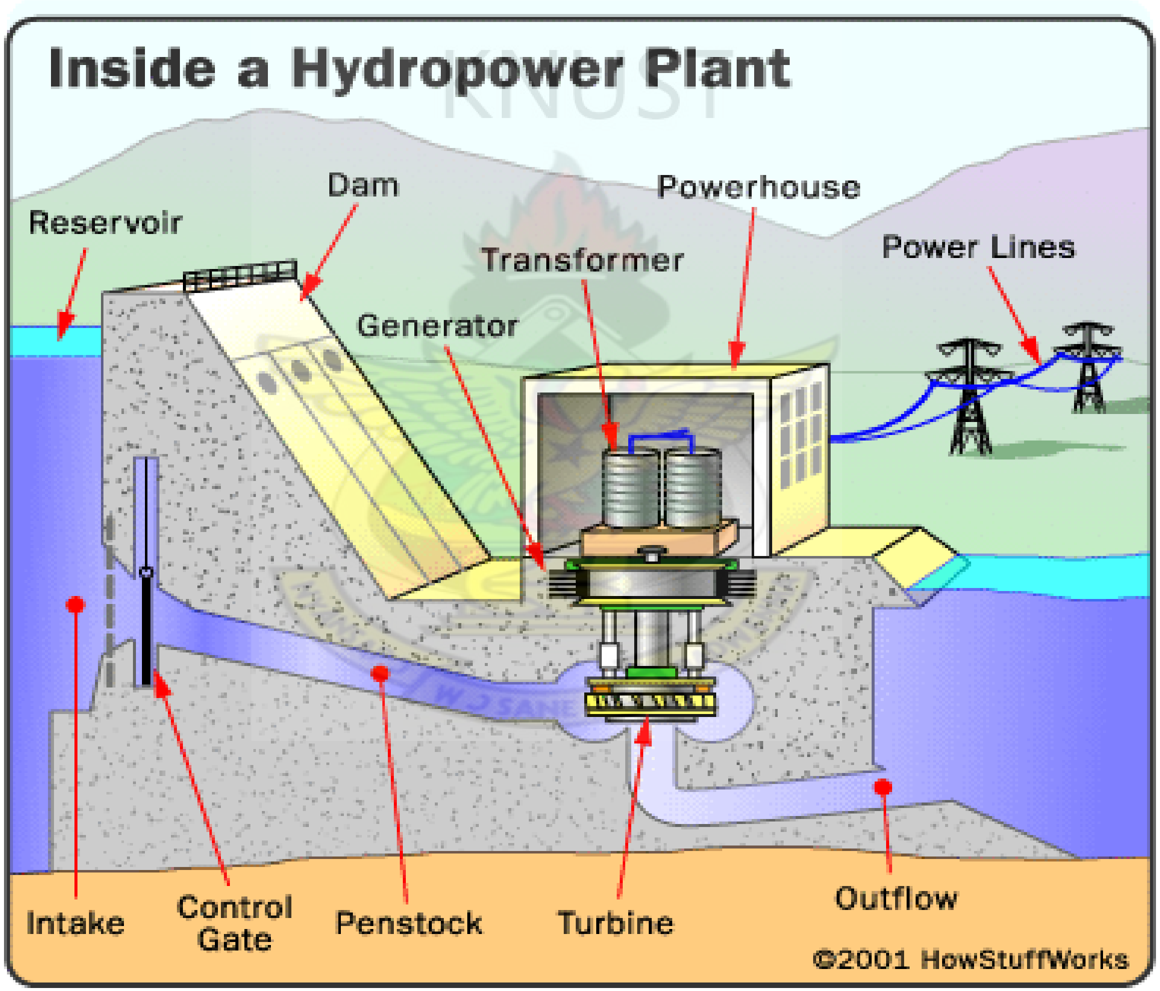
Summary of dams sizes

- **Official name** Akosombo Dam
  Name: Volta_river
- **Location:** Akosombo, Ghana
- **Length**: 660 m (2,165 ft)
- **Height** 111 m (364 ft)
- **Width (at base)** 366 m (1,201 ft)
- **Construction began** 1961
- **Opening date** 1965
- **Construction cost** £130 million

Reservoir information

- **Creates** Volta Lake
- **Capacity** 148 x 10^{12} litres
- **Catchment area** 8502 sq.km
- **Power generation information**
- **Installed capacity** 1020 MW
-
- **Geographical Data**
- **Coordinates**
- 6°17′59″N 0°03′34″E / 6.29972°N 0.05944°E / 6.29972; 0.05944
- **Maintained by** Volta River Authority

Figure1.2



Inside a Hydropower Plant
KNUST
Dam
Powerhouse
Reservoir
Transformer
Power Lines
Generator
Intake
Control Gate
Penstock
Turbine
Outflow
©2001 HowStuffWorks

Problem statement

- The year 2006 came with a lot power cut which seem to suggest that there is no lay down model or simple equation that will help the ordinary Ghanaian or the economist to determine the level of the water in the dam.
- Since the level of water in the dam has a direct impact on the amount of electricity being generated, and the consequence effect on the people of the country, hence there is the need to obtain a model of such nature which is the major concern of this thesis

Objective

- The major aim of this piece of work is to develop a model that will seek to achieve the following objectives.
- To determine the level of the Akosombo dam anytime within the year,
- To help determine the month in which low and high schedules are bound to happen and finally
- To help test the application of the model since there are so many method and models that could have been used.

Justification

- This work is worth doing because it seeks to help solve the problem of low power outages in electricity generation since it will develop a model that will help to determine the level of water in the Akosombo dam and its consequence effect.

- Furthermore it is worth doing because it will serve as one the requirement for obtaining a degree (second) in the program MSc. Industrial Mathematics

- So many method could have been used but the researcher choose to use the method of differential equation because it the area which is not widely recognized

Theory

- Modeling is one of the ways by which formulae are used or deduced to help solve a real life situation, occurrence or a problem
- According to Anderson, Model building is not only predictive but can also be descriptive; the important thing is for one to remember that, the less complicated the system and the more information available, the greater the likelihood of a successful model
- The first step is to clearly state the assumptions which are relevant to the model. It usually describes the relationship among the quantities to be studied.
- The next step involves completely describing the variables and parameters to be used in the model and the last step is the use of the assumption formulated in step one to derive the equation relating the quantities in step two

Methodology

- This thesis used differential equation concept in the modeling process (modeling through differential equation).
- Data concerning the work is obtained from the office of the Volta River Authority (Akosombo).
- It consists of inflow, outflow, rainfall and evaporation of water in the dam from the year 1980 to August 2009

- The forecasting methodology includes the following operational steps:
- Data preparation for predicting, Designing of the model, Testing the model and evaluating the model

Model Development

- 1. There are three major inflow channels into the dam each with different flow rate. Hence the equation from this could be written as $\frac{dU_1}{dt} + \frac{dU_2}{dt} + \frac{dU_3}{dt}$
- So the total inflow rate could be denoted by, $\frac{dV_i}{dt}$ where V is the total volume of water passing through all the channel at a time and t is the time of flow of the water
- All inflows and outflows which have no effect on the level or the volume of the dam are negligible
- The force, energy and the momentum of the water are assumed to be negligible in this case since it doesn't have much effect on the volume of water in the dam

Model Development

- . There are six outflows through the penstock which operate at a maximum when all the turbine are operating and two outflow with a minimum flow rate when the turbine are operating at minimum level. Hence we can have

$$\frac{dV_1}{dt} + \frac{dV_2}{dt} + \frac{dV_3}{dt} + \frac{dV_4}{dt} + \frac{dV_5}{dt} + \frac{dV_6}{dt}$$

The total outflow rate can be denoted by $\frac{dV_o}{dt}$ where V is the total volume flowing out of the dam, and t is the time of flow

- As a result of the first two assumptions, we can get the net flow determined as $\frac{dV}{dt} = q_{in} - q_{out}$
- Which yielded

$$\int dV = \int M dt + C,$$

Modified model

- Based on the third and forth assumption, the model changes to the form

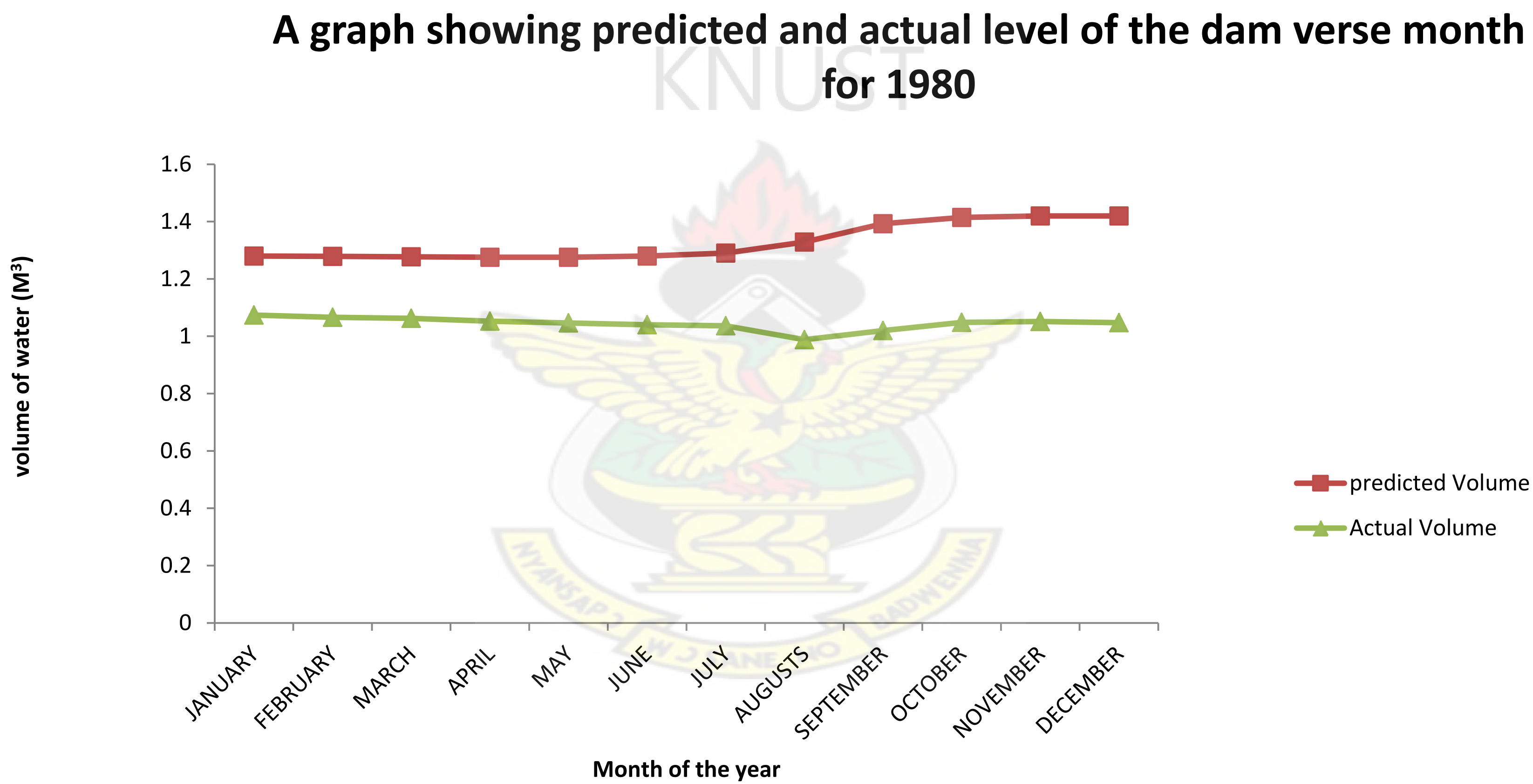
$$\frac{dV}{dt} = \frac{dV_i}{dt} + \frac{dV_r}{dt} - \frac{dV_o}{dt} - \frac{dV_s}{dt}$$

- Where,
- V_s is the volume of water lost due to evaporation,
- V_s is the volume of water due to rainfall
- by mass law; $\frac{dV}{dt} = q_{in} - q_{out}$ i.e $\frac{dV}{dt} = \frac{dV_i}{dt} - \frac{dV_o}{dt}$

Result and Discussion

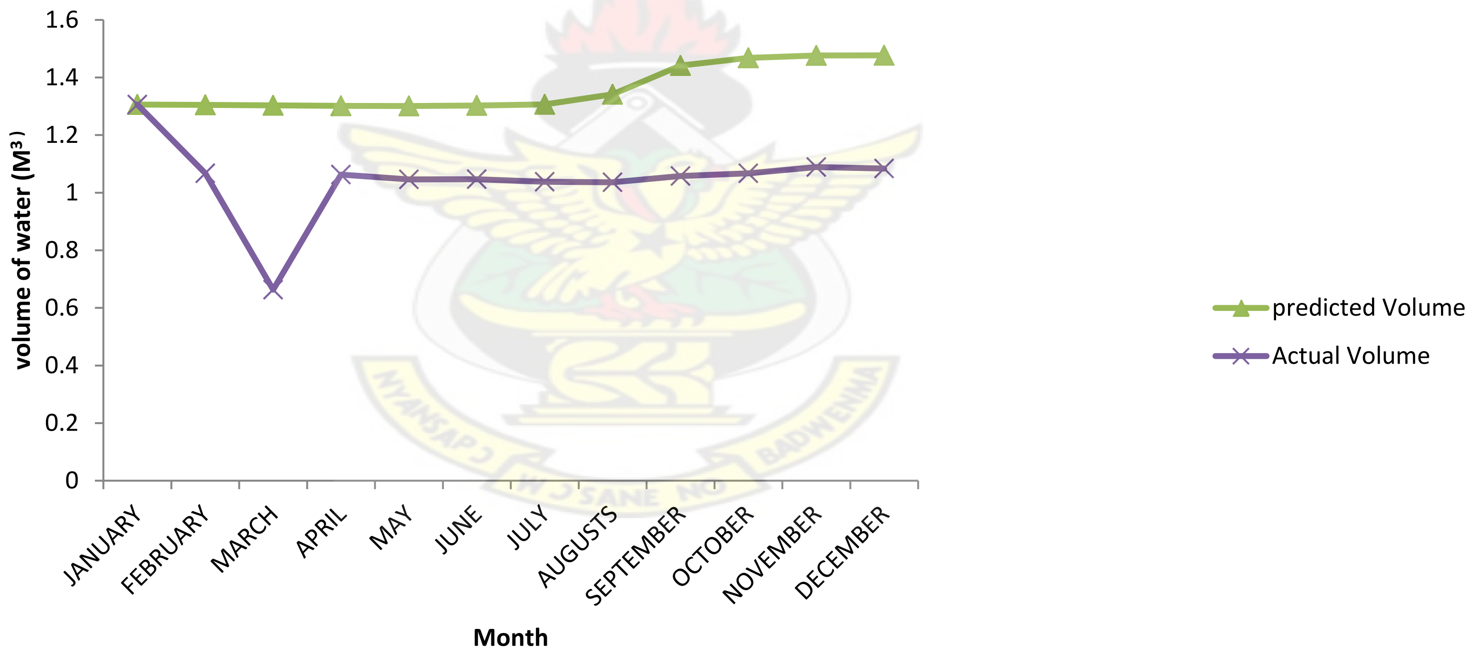
- From the tables of result and the graphs of the model,
- it could be seen that the first relation which gave the net-flow of the Dam have both negative and positive values which indicate that, at times there are more outflows than the inflow, hence a negative net-flow.
- This is accounted for by the fact that the turbine does operate at a peak rate or maximum level.
- The negative values of the net-flow is removed or adjusted by making the turbine to operate at their minimum level
- The modified model presented a result which is more valid and hence close to the data.

Result and Discussion

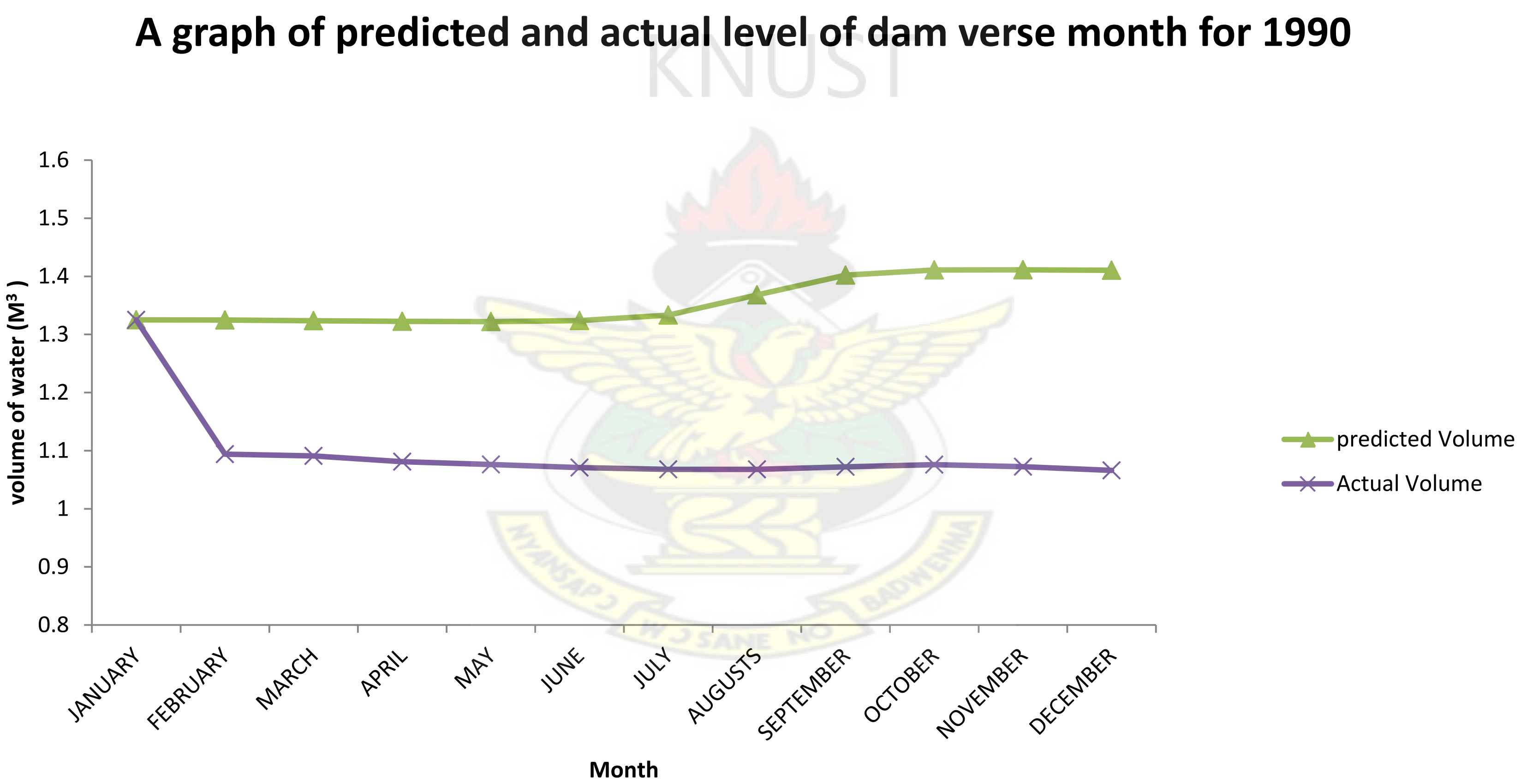


Result and Discussion

A graph showing predicted and actual level of dam verse month for 1981

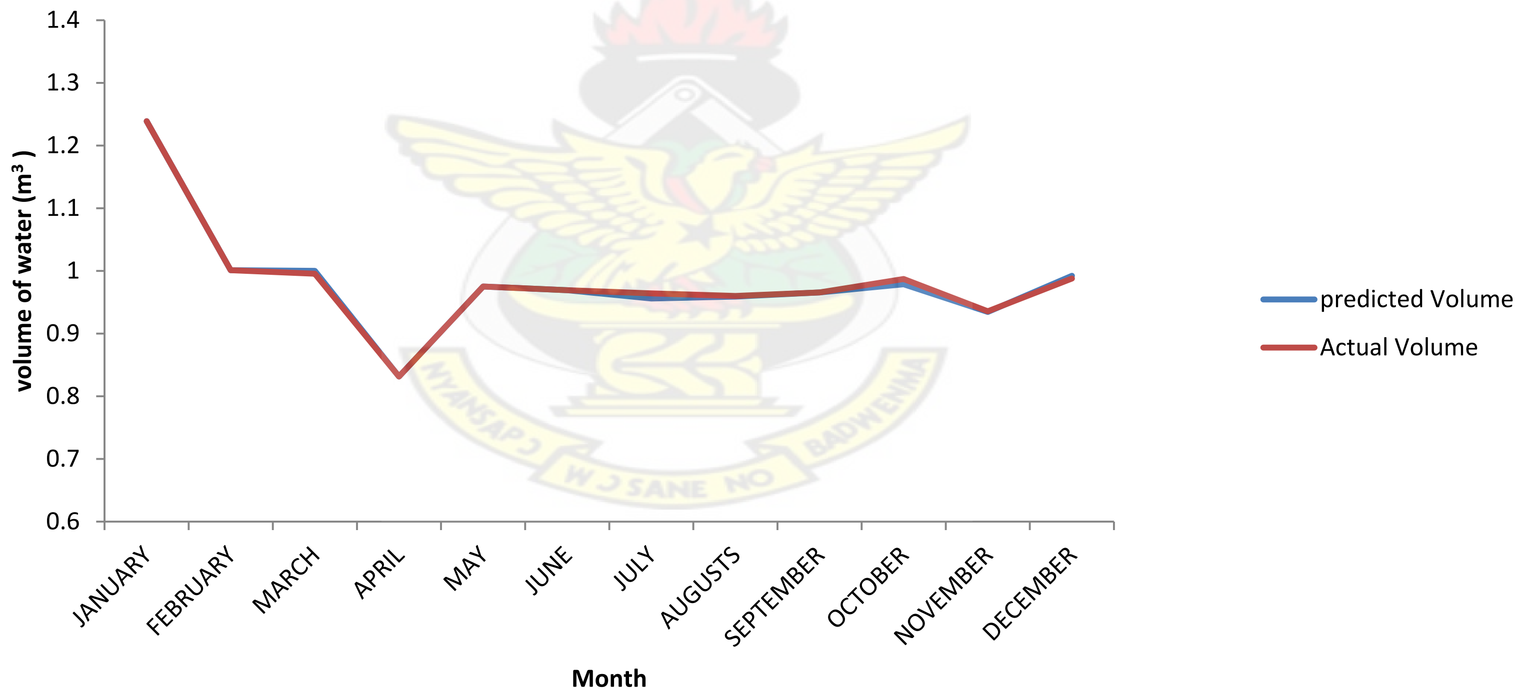


Result and Discussion



Result and Discussion modified model

A graph showing predicted and actual level of dam verse month for 2006



Conclusion

- It could be concluded that the aim set out in this piece of work has been successfully achieved with the model having the form as $V = mt + C$
- The model predicted March and April as the month with the least water levels and hence possible low power generation.
- September with the higher water level and hence maximum power generation within the year.
- Finally the model presented a result which is within an accuracy of 86% ,(from the graph) and this show that the modeled could be adopted and used.

Recommendation

- Students and researchers consider looking into this area to develop a model that will give as the best mathematical expression (formulae) needed for systems with such characteristics.
- study models for predicting inflows and outflows using differential equation