KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
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FLOODPLAIN MODELLING ASSESSMENT: CASE STUDY OF WEIJA CATCHMENT, GA WEST DISTRICT

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This Thesis is submitted in fulfilment of the requirements for the Degree of Master of Science at the K.N.U.S.T for Water Resource Engineering and Management.

CERTIFICATION

I hereby declare that this submission is my own work towards the MSc 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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Dedication

I dedicate this work to my Lord and Master Jesus Christ for His Love and Mercy towards me.

Abstract

Many regions throughout the world have experienced severe river flooding during the recent years. The Weija catchment, which is located in the Ga West District of Ghana in West Africa, is no exception with over 5,000 people affected every year by floods in the area. When land development encroachments into river floodplains are permitted, the magnitude of flood peak discharge increases due to removal of floodplain storage.

This study approached the problem of flood modelling using HEC-RAS, which is a flexible 1-dimensional hydraulic model. The analyses made in this study provide indications of the effects of encroachments on flood characteristics; however, the problem is such that each individual case of the left and right channel distance are analysed separately to determine the land which must be allocated in the event of flood.

The results from this study revealed that removal of structures in the flood plain and hence subsequent widening of the existing narrow flood bank of the channels will help reduce the devastating effects of the floods whenever the spillways of the dams are opened.

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Abbreviations and Acronyms

DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
GIS	Geographical Information Systems
ITCZ	Inter-Tropical Convergence Zone
SPOT	Système Probatoire d'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
HEC-RAS	Hydrologic Engineering Center River Analysis System
GHA	Ghana Highway Authority
HSD	Hydrological Service Department
WRI	Water Research Institute
WRC	Water Resource Commission
CSIR	Council for Scientific and Industrial Research

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1 Introduction

1.1 Background

Flood, which is an inundation of land by the rise and overflow of a water body (USGS, 2006), occurs most commonly when runoff generated from heavy rainfall exceeds the capacity of the channel/storage system.

Flood modelling can help to understand the rainfall-runoff relationship and the extent of flooding in a catchment, consequently providing the required information to help in flood management. The modelling also provides information to mitigate damages caused by floods by giving early warning to communities downstream which will be affected, and can at the same time be used to evaluate various flood mitigating measures in order to determine which alternatives will be economically and environmentally feasible giving the prevailing conditions. On the other hand, studies and analysis have shown that damage reductions due to forecasts improvements can range from a few percentage points to as much as 35% of annual flood damages (UN ISDR, 2004).

In Ga West District of Greater Accra Region, floods are persistent particularly in the surrounding communities the downstream of the Weija reservoir.

The impact of flooding was not felt to the same extent in the past as it is now. This could be due to the rapid increase in population and consequent increase in human activities (Kron, 2003, Todini, 1999). The floodplains are being increasingly occupied to meet ever-increasing requirements for housing and consequently the flood problem is exacerbated.

Plate 1.1 Floods in Mallam (GNA 2007)

Flooding is a natural and variable phenomenon that can occur on any land surface, ranging from a street intersection, a home lot to the extensive rural floodplain areas inundated by large rivers as shown in Plate 1.1.

Flooding results in damage to property, crops and negatively impacts on human welfare as shown in Plate 1.2 and 1.3. Floodplain Management in Ghana for that matter aims at minimizing damages and reducing the threat to human life and welfare when a major flood event occurs. Along with these more traditional river engineering and flood defence tasks come also the requirements of applying new solutions. These should not only meet the stringent design requirements but also preserve and enhance the environment.

Plate 1.2 Effect of Floods on Residents (GNA 2007)

Plate 1.3 Effects of Floods on Housing (GNA 2007)

There is a growing realization about the importance of non-structural measures, including flood forecasting and early warning, in flood management. Establishing a flood forecasting system would enhance the effectiveness of all other mitigation measures by providing time for appropriate actions.

This has increased the importance of flood modelling for flood forecasts to issue advance warning in severe storm situations to reduce loss of lives and property damage. But the accuracy of operational hydrological models primarily relies on good rainfall data input in terms of temporal and spatial resolution and accuracy (Pathirana et al., 2005).

1.2 Problem Statement

Flooding has become annual occurrence in many urban settlements in Ghana. The Ga West District in the Greater Accra Region has over the years been hit by floods especially during the long rains. However, flooding is common along the 8km stretch of the Densu River below the Weija dam whenever there is release of water over the spillway. Changes in flood characteristics are often a result of human development actions and also of climate change. The frequent flooding of these areas have had devastating effects on the communities at the lower reach of the Densu river, displacing on average 3,300 people per year (Adinku, 1994; Gyau-Boakye, 1997), destroying property, and infrastructure running into billions of cedis and in some cases lost of lives. There is therefore the need to put measures in place to mitigate or help curb the recurring flood problems which has affected the lives of the people living in the communities in the Ga West District.

Modelling therefore can be used as a tool in assessing the floods in Weija and proposing possible mitigations measures.

1.3 Objective of Study

The main objective of this study is to assess the extent of flooding in the floodplain of Weija by using a model and propose mitigation measures.

Specific objectives of this study:

- Set up a hydraulic model for the study area to determine flooding,
- Map floodway to determine the width of land that must be allocated in the event of flooding,
- Propose flood mitigation measures based on output from model.

2 Study Area

The Ga West District is the second largest of the seven Districts in Greater Accra Region. It lies within latitude 5°48′ North 5°29′ North and longitude 0°08′ west and 0°30′ West. The District shares common boundaries with Ga East and Accra Metropolitan Assembly to the East, Akwapem South, Suhum Kraboa Coalter and West Akim to the North, Awutu Efutu Senya to the West and the Gulf of Guinea to the South. It occupies a land area of approximately 710.2 sq km with about 1028 communities (Ghana Web 2007). The land area consists of gentle slopes interspersed with plains in most parts and generally undulating at less than 76m above sea levels with a section shown in Plate 2.1. The slopes are mostly formed over the clay soils of the Dahomeyan gneiss with alluvial areas surrounding the coastal lagoons generally flat.

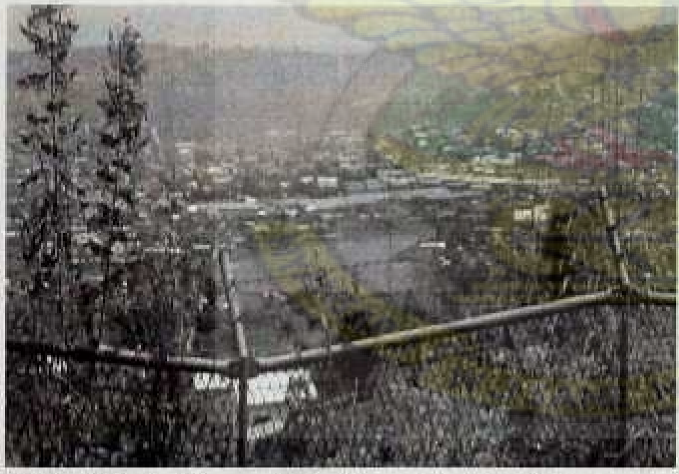

Plate 2.1 Section of Ga West District (Photograph taken on 17 September 2007)

The Akwapim range and the Weija hills rise steeply above the western edge. There are three major rivers namely the Densu, Nsaki and Ponpon that drain the district. The largest of the three is the Densu which drains down from the Eastern Region through the western portions of the district to Weija where it enters the sea. Other water bodies mostly tributaries of the Densu are the Adaiso, Doblo, Ntafafa and the Ponpon River.

The District lies wholly in the coastal savannah agro-ecological zone. The relief is generally undulating at less than 76m (250ft) above sea level except for the areas around the Akwapem and Weija hills. Only the alluvial areas surrounding the coastal lagoon could strictly be called flat. The Rainfall pattern is bi-modal with an annual mean varying between 790mm on the coast to about 1270mm in the extreme north. The annual average temperature ranges between 25.1°C in August and 28.4°C in February and March. February and April are the hottest months. Humidity is generally high during the year. Average humidity figures are about 94% and 69% at 6:00 and 15:00 hours respectively. The land area is underlain by shallow rocky soils and is extensively developed on the steep slopes of the Akwapim range and the Weija hills as well as the basic gneiss inselbergs. On the Akwapim range the soils are mainly pale and sandy with brushy quartzite occurring to the surface in most places. These soils are rich in sandstone and limestone that are good source of material for the construction industry. The red earths are usually developed in old and thoroughly weathered parent materials. They are typically loamy in texture near the surface, becoming more clayey below. The red soils are porous and well drained and support road development and also provide ample moisture storage at depth for deep-rooting plants. Nutrients supplies are concentrated in the humus top-soil. The Weija Dam was built across the River Densu at Weija in 1977 to satisfy the ever-increasing demand for water supply for domestic, industrial and agricultural purposes. The Weija Dam reservoir, hereafter called the Weija Lake, has a surface area of about 3,100,000 km^2 (Fig.2.2), and a depth ranging from 1 to 7 m, and is almost at the mouth of 116 km long River Densu. The river source is from the Atewa-Atwiredu mountain range in the Eastern Region of Ghana. It discharges into the Gulf of Guinea, partly through the Sakumo lagoon at Bortianor, 10 km from the mouth of the River Densu. Soils are sodium Vleisols, coastal savannah Ochrosols and Lithosols. However, the CSIR-Soil Research Institute (Ayibotele & Tuffour-Darko, 1979; Ahn, 1970) described the major soil types in the Weija area as belonging to the Ayensu-Chichiwere soil type. It is mottled grey in colour, heavy alluvial clay, coarse and fine sandy leaves.

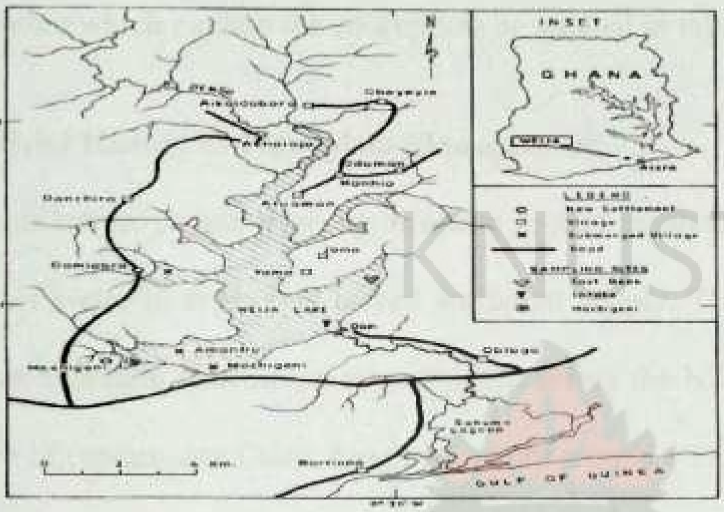

Figure 2.1 Weija Reservoir and surrounding towns

The area covered by the Weija Lake in the coastal savanna plain has a low (800 mm p.a.) erratic bi-modal peak rainfall in May–June and October. The hottest months are February–April, with the highest mean monthly temperature of 32 °C occurring in March. The lowest mean monthly temperature of 21.7 °C occurs in August. Information on the chemical quality of the lake water (Biney, 1987; Ansa-Asare, & Asante 1998; Ansa-Asare, et al, 1999) relates to the period prior to and after impoundment.

The main economic activities in the catchment of the reservoir are fishing and crop farming. Major crops include maize, cassava, sugar cane, pineapple and vegetables. Fertilizers (nitrate and phosphate based) are used in cultivating some of the cereals and pineapple. Domestic effluents are also discharged into the lake waters without treatment.

3 Literature Review

The available reports on the study area, the flood assessment in Weija in Ga West district is limited since not much work has been done in this area by researchers in relation to hydraulic modelling. However the limited literature available and other literature which explain the concepts to be applied in this study were reviewed.

3.1 Brief History of Floodplain Management

For millennia, people have attempted to protect inhabited areas from flooding and to deliver water to areas that lacked sufficient supply. There is evidence that the first major hydraulic structure, a masonry dam across the Nile River, located about 23 km south of present-day Cairo, Egypt, was built around 4000 B. C. (Dyhouse et al, 2003). The increased water level upstream of this structure enabled the diversion of flows through excavated canals to irrigate the arid lands near the Nile.

3.1.1 Floodplain Modelling

An engineer is called upon to determine the 100-year flood elevation at a certain location, or determine the adverse effect on flood levels from placing fill in the floodplain. Three methods are available for the engineer to address a floodplain hydraulics problem:

- **Engineering experience** – until 100 years ago the design of nearly all hydraulic structures was used on an engineer's experience and judgment, with minimal consideration of hydraulic computations. High water marks for a "flood of record" were commonly used to size a levee or to determine the necessary height of a roadway embankment. Today, even engineers with years of floodplain modelling background would not rely on their experience for floodplain solutions without using hydraulic modelling to confirm their assumptions and suspicions.

- **Physical modelling** – physical modelling was first used in the late 1800s and early 1900s, (Dyhouse et al, 2003) but was largely confined to flume studies at university hydraulic laboratories. The physical modelling performed then was not directly applicable to floodplain modelling. Today, physical modelling is mostly performed at large hydraulic laboratories and is not often applied when numerical models will suffice. Physical models are expensive to construct and operate, require a special engineering, expertise, and are typically only practical for major river systems or large river structures.
- **Numerical modelling** – analytical procedures for floodplain hydraulics were handled with hand computation in the first two-thirds of the twentieth century. These procedures were transferred to computer programs that have been consistently improved and expanded, and made progressively more user-friendly. Today, many programmes are available for modelling a variety of floodplain problems, with rare exceptions, numerical modelling with a computer programme is the most appropriate method to perform floodplain hydraulic studies.

The application of a standard riverine numerical model, such as HEC-RAS, enables the engineer to simulate the hydraulics of the floodplain, evaluate existing conditions, determine proper design of hydraulic structures, and assess the effects of the structures, performed by a competent engineer.

3.1.2 Floodplain Studies

Floodplain studies provide water surface profiles and floodplain maps for land-use planning for flood prone areas.

Floodplain studies often include the analysis of historic floods, which are used in model calibration to make sure the model can reproduce historic water surface elevations recorded during actual flood events. Floodplain studies also generally feature the computation of the water surface profile for at least the one-percent annual chance (100-year average return interval) flood. The 100-year flood elevations from this profile are then transferred to a topographic map, illustrating the portions of the floodplain that will be inundated by the 100-year flood. Structural solutions to flood problems are seldom, if ever, investigated as part of a floodplain study giving general flood information for a community, however, the reports do include the effects of any existing levees, reservoirs, bridges, culverts, and channelisation in the study area.

3.1.3 Structural Measures

Structural solutions to flood problems change the hydrology or hydraulics for a portion of the watershed under study; some examples include dams and reservoirs. Detention ponds, channel modifications, diversions, and levees. Diversions of flow, for example by dams, reservoirs, and detention ponds, change the downstream hydrology by diverting or storing some of the floodwater during a flood, thereby reducing the downstream peak discharge and delaying the time of peak discharge. Channel modifications such as levees; result in a change to the water surface elevations. A floodplain model is first developed to determine the base conditions for the stream or watershed. Structural measures are then incorporated into the model and analysed to determine their effect on flood levels.

3.2 Hydrologic / Hydraulic Modelling

Most models focus on particular land-water features; some are dominantly receiving water models, while others are primarily oriented to calculating watershed loading. Both receiving water and watershed models can incorporate the ability to simulate management techniques. Two major categories of models are recognized and used for evaluation and comparison:

Receiving water models (Hydrology, Water Quality). This group of models emphasizes description of hydrology and water quality of water conveyance systems, including rivers, canals, reservoirs, lakes and estuaries. Some include bi-directional flow, pumps, and operations in freshwater systems. Others include evaluation of tidal systems and the influences of wind, waves, and tides on mixing. Water quality simulation involves representation of sediment and pollutant transport and transformation. Some models include ecological processes, such as vegetative growth, aquatic organisms and aquatic productivity. Not all receiving water models address water quality. Sometimes, water quality functions are provided by linking hydrologic and water quality models. Kalin and Hantush (2003) and USEPA (1997)

Watershed models. This group of models emphasizes description of watershed hydrology and water quality, including runoff, erosion, and washoff of sediment and pollutants. Some models include surface-groundwater interactions and simplified groundwater transport. Some also include internally linked river transport and water quality processes and reservoirs. Table 3-1 provides a summary of currently available models for watershed, receiving water, and other key features. Some models simulate performance and treatment capabilities. Models continue to be expanded to address multiple categories of analysis, such as watershed models that include analysis (e.g., SWMM), or receiving water models that include hydrology and water quality (e.g. Environmental Fluid Dynamics Code [EFDC]). Some models are identified as "system," to recognize that these systems support multiple models (e.g. U.S. Environmental Protection Agency (EPA).

Total Maximum Daily Load (TMDL) Modeling Toolbox includes linkages between watershed models and receiving water models). Integrated systems are included in the list of models.

Table 3.1: Summary of some available models

Model Acronym	Full Model Name	Source
AGWA	Automated Geospatial Watershed Assessment	USDA-ARS
HEC-HMS	Hydraulic Engineering Center Hydrologic Modeling System	USACE
HEC-RAS	Hydrologic Engineering Center River Analysis System	USACE
DWSM	Dynamic Watershed Simulation Model	Illinois State Water Survey
GSSHA	Gridded Surface Subsurface Hydrologic Analysis	USACE
GWLF	Generalized Watershed Loading Functions	Cornell University
Mercury Loading Model	Watershed Characterization System—Mercury Loading Model	EPA
SWMM	Storm Water Management Model	EPA
TOPMODEL	—	Lancaster University (UK), Institute of Environmental and Natural Sciences
WMS	Watershed Modeling System (Version 7.0)	Environmental Modeling Systems, Inc.
MIKE 11	—	Danish Hydraulic Institute

The type, complexity and water quality simulation capabilities are identified for each model. Model type is categorized as follows:

Steady State. These models operate under a single non-variable flow condition. Steady state models are typically used to evaluate a design flow.

Quasi-dynamic. Quasi-dynamic models allow for limited variation, typically a variation in meteorologic conditions over the course of day, to examine variability.

Dynamic. These models allow for variations in both flow and meteorologic conditions on a small time-step, typically shorter than daily.

Level of complexity in receiving water models is also evaluated based on spatial detail described as one, two or three dimensions. Most three-dimensional models also have the ability to be applied in one- or two-dimensional modes.

Descriptions of water quality capabilities are based on support for specific pollutants or parameters.

For watershed models, the evaluation is based on five separate factors: type, complexity, time-step, hydrology, and water quality. Types of watershed models are generally classified as landscape only, simulating only land-based processes, and comprehensive models, including land and conveyance systems (e.g., rivers, pipes). Complexity in watershed models is classified on three levels:

Export functions are simplified rates that estimate loading based on a very limited set of factors (e.g., land use).

Loading functions are empirically based estimates of load based on generalized meteorologic factors (e.g., precipitation, temperature).

Physically based include more physically based representations of runoff, pollutant accumulation and washoff, and sediment detachment and transport. Most detailed models use a mixture of empirical and physically based algorithms.

Hydraulic Capabilities

HEC-RAS is designed to perform one-dimensional hydraulic calculation for a full network of natural and constructed channels.

Steady flow water surface profile. This component of the modelling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a single river reach, a dendric system, or a full network of channels. The steady flow component is capable of modelling subcritical, supercritical and mixed flow regime water surface profiles.

The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in the situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions).

Special features of the steady flow component include: multiple plan analyses; multiple profile computations; multiple bridge and/ or culvert opening analysis, and split flow optimization at stream junctions and lateral weirs and spillways.

Unsteady flow Simulation. This component of the HEC-RAS modelling system is capable of simulating one dimensional unsteady flow through a full network of open channels. This unsteady flow component was developed primarily for subcritical flow regime calculations.

Sediment Transport/Movable Boundary computations. This component of the modelling system is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods.

The hydrologic floodplain consists of the land adjacent to the baseflow channel residing below bankfull elevation. The topographic floodplain, on the other hand, is defined as the land adjacent to the channel including the hydrologic floodplain and other lands up to an elevation based on the elevation reached by a flood peak of a given frequency (Federal Interagency Stream Restoration Working Group, 1998). The two types of floodplains are illustrated in Figure 3.1.

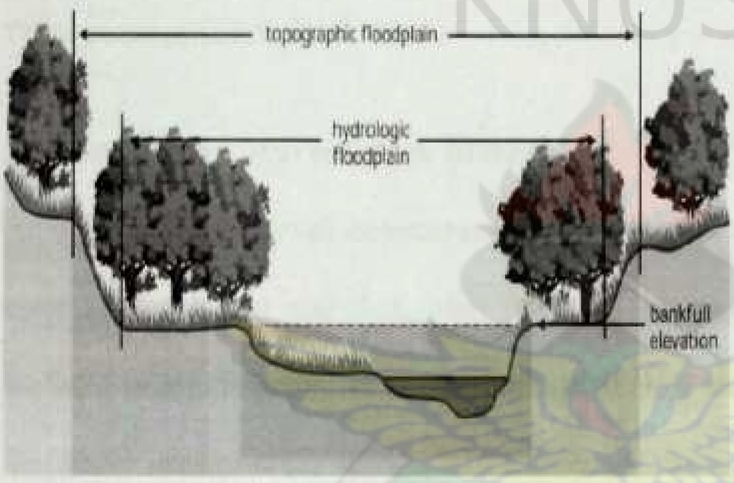

Figure 3.1 Hydrologic and Topographic Floodplain (Federal Interagency Stream Restoration Workgroup, 1998).

The floodway contains not only the channel, but also any adjacent floodplain areas, consisting of pools, riparian wetlands and temporary or permanent ponds. This flat floodway zone which surrounds the channel is flooded frequently, more specifically; research indicates that the floodplains of many streams of different sizes, flowing in diverse physiographic and climatic regions, are subject to flooding about once a year (Wolman and Leopold, 1957).

The floodway therefore, is the portion of the topographic floodplain not suited for development (building) due to the high flood risk of the region. If development is allowed to occur in the floodway, floodwater conveyance would be greatly impaired resulting in increasing flood stages and velocities which would ultimately subject the inhabitants of the floodway to flood damage (SEWRPC, 1986).

The high flow floodplain also contains the floodway fringe in addition to the stream channel and the floodway. The floodplain fringe is that portion of the regulatory floodplain located in the area between the floodway and the boundary of the 100-year flood. Floodwater depths and velocities are small in this regulatory area relative to the floodway and therefore, in a developed urban area, further development may be permitted, however development is restricted and regulated in attempt to minimize flood damage (SEWRPC, 1986)

3.3 Flood Wave Movement in Rivers

As a flood wave moves downstream in a river, it is perceived at a given point in the river as first a rise and then, after the peak has passed, as a lowering of the water surface. In all channels, as the magnitude of flow increases, the stage also increases, and water in temporary storage in the river will increase as well. Because some of the water entering a given reach of the river goes into storage, the rate of flow leaving the reach is decreased as the consequence of maintaining a balance between the volumes of water entering and leaving the reach and the volume stored in the reach at any given time. This decrease in flow is called the "attenuation" of the flood wave and occurs to some degree in all channels. As the flow decreases the river stage falls, the water stored in the channel and in the overbank areas is released from storage (Dutta et al., 2000). This lengthens the time base of the flood. Because the energy gradient is steeper on the rising side of a flood wave than on the falling side, the flow is greater on the rising side for a given stage. An important effect of storage on the flood hydrograph, therefore, is attenuation of the peak discharge. Removal of floodplain areas by fills, levees, buildings, road embankments, or other encroachments will reduce the volume of temporary flood storage, and thus there will be less attenuation of the flood peak. The resulting higher flows may significantly change flood flow-frequency relationships downstream from the encroached reach from those previously existing. The higher discharges may cause significant increases in water surface elevations. And, as mentioned above, problems related to changes in timing of the flood peaks may arise if combinations with tributary flows are significant

An encroachment can cause backwater effects (and hence an increase in channel and overbank storage) upstream from the encroachment. This can be as significant as the loss in storage due to the encroachment in some cases (Knebl et al., 2005).

3.4 Flooding in Ga West District in Greater Accra Region

The City of Accra lies on a flood-prone coastal area due to both heavy rainstorms and the relatively flat topography. Several problems have historically worsened this flooding. Heavy developments along floodplains, increasing urbanization, and rubbish in watercourses have been the three biggest determinants of recent flooding (Otui 1996). The main flood affected area in Weija is Ogblogo which lies below the Weija reservoir level. Previous encroachment in the floodplain has resulted in flooding in the towns in the area.

3.4.1 Densu River Catchment and Sakumo Lagoon

This is the largest coastal basins within the study area. It is divided into two sections above and below the Weija dam: the northern section of the basin, which extends inland along the Densu River and the southern section a low lying land comprising the Sakumo lagoon and Panbros salt pans. The Lafa stream flows into the lagoon and drains much of the western area of Accra including Dansoman, Kwashieman, McCarthy Hill and Awoshie. Much of this catchment is now urbanised.

Flooding is common along the 8km of the Densu River below the Weija dam whenever there is release of water over the spillway. As a result, there is heavy erosion of drainage channels - many of which flow down existing tracks and roads. Access to this area is often cut off and roads become impassable during heavy rains.

Densu River is the main source of the drinking water supply for the western part of the capital city of Accra because it flows into the Weija Reservoir, which is a major source of potable water for south western Accra (Ghana Districts, 2007).

The hydrological map of the basin is shown in the Figure 3.2. From an elevation of about 760m (2500ft) above sea level (Otui, 1996), the river flows generally southwards until it reaches the Weija reservoir (created by a dam at Weija).

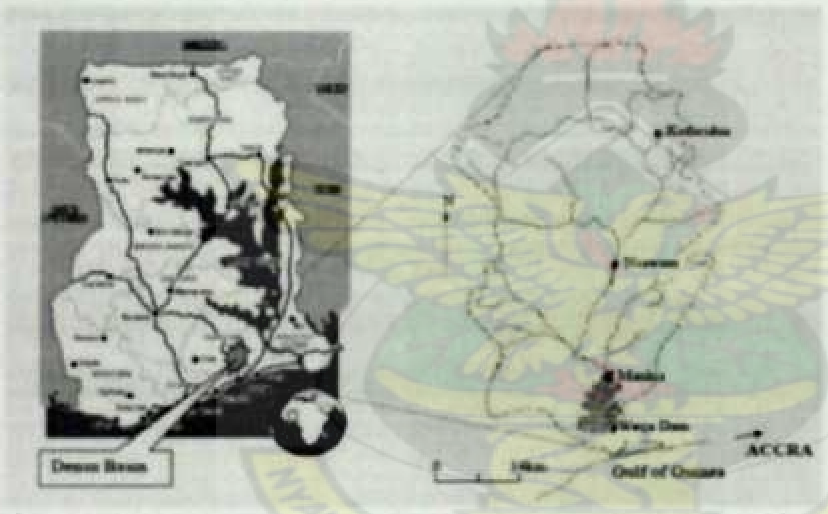

Figure 3.2 Sub-catchments of Densu Basin (Otui, 1996)

The upper reaches which include the upper part of Koforidua and surrounding towns feed into a middle reach that is Nsawam and surrounding towns below creating a "mainstem" of the river where vegetation is less dense than the headwater part thereby producing relatively lower interception losses. However, in the middle section of the catchment, the basin varies from higher altitude (175m) to just about 3m near Weija where in between these heights, its gradient over a considerable section of the river is virtually flat (0.0056; i.e. a fall of only about 9m run of the river course upstream of Weija) (Otui, 1996). Floodplains, lakes and swamps characteristically are found around the slow flowing river mainstem.

Below the mainstem is the lower reach between Weija and the sea where the river meets the ocean. In the lower reach saline and fresh water mix, silt settles, and a delta forms. The vegetation gradually turns from mostly derived savannah (due to exploitation by man) into predominantly highly productive mangrove forests and wetlands (Marchand and Tornstra, 1986).

4 Research Methodology

4.1 Introduction

The methodology performed in this study is to apply HEC-RAS a model capable of calculating the extent of the floodplain based on an input flow is described in this chapter. This information was utilized for the graphical representation of the floodplain boundary and corresponding flood risk based on a specified flow. The data analysis of the peak flow data and HEC-RAS model output data is discussed to determine the comparability of the data sets. This relationship is used to calculate the flow at each hydraulic reach based on the input flow. A summary of the methodology is shown in figure 4.1 below.

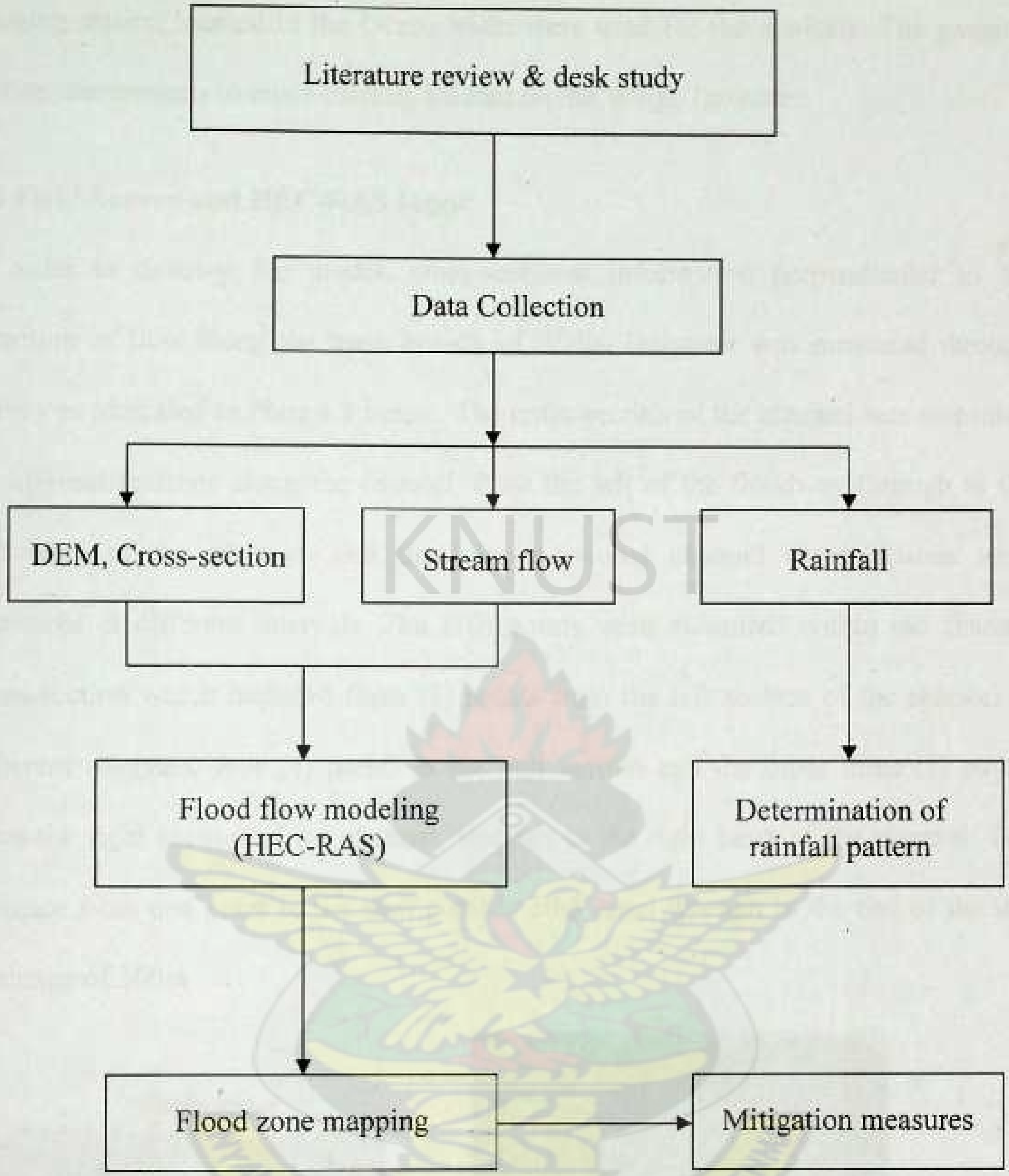

Figure 4.1 Flow chart of research methodology

4.2 Data Analysis

The study entailed determining the validity of the data set incorporate into the HEC-RAS model which is measured streamflow data from the HSD. This was achieved by examining the relationship of the rating curves developed from the two sources of information. Peak flow data collected between 1977 and 2006 from the catchments gauging station located in the Densu basin were used for the analysis. The gauging station corresponds to cross-section, located on the Weija Tailwater.

4.3 Field Survey and HEC-RAS Input

In order to develop the model, cross-sectional information perpendicular to the direction of flow along the main branch of Weija Tailwater was measured through survey as indicated in Plate 4.1 below. The cross-section of the channel was measured at different sections along the channel, from the left of the floodway through to the left bank of the channel, and then the individual channel cross-sections were measured at different intervals. Ten (10) points were measured within the channel cross-section which included three (3) points from the left section of the channel at different intervals, four (4) points at the mid section and the other three (3) points from the right section of the channel, through to the right bank of the channel. The distance from one point to the next point is 30m apart through to the end of the last chainage of 300m.

Plate 4.1 Measurement of cross section of the Weija Tailwater at various depths.

Next, the hydraulic cross-sectional information then was incorporated into HEC-RAS and the hydraulic simulation of the channel was developed. The hydraulic model (HEC-RAS) was used to model the common flood flows of the floodplain.

The primary component of the HEC-RAS modelling system utilized in this study was the steady flow water-surface profile component. Incorporated within this component is the capability of HEC-RAS to calculate water-surface profiles for steady gradually varied flow in a wide variety of channel and flow conditions, as well as provide cross-sectional data that can be used to characterize the flow-carrying capacity of the stream and the adjacent floodplain, the general hydrological sections from the Weija reservoir to the Sakumo lagoon is shown in Figure 4.2. In regard to the model output, each cross section detailed was assigned a particular river station identification number ranging from chainage 0 to 30 with a distance of 30 metres, which corresponds to the total length (in metres) of the main branch of Weija Tailwater. A total of 10 river stations were separated into hydrological sections (Figure 4.3): Tailwater from Weija reservoir.

Figure 4.2 General Division of a Stream into Hydraulic Reaches and Hydrological Sections.

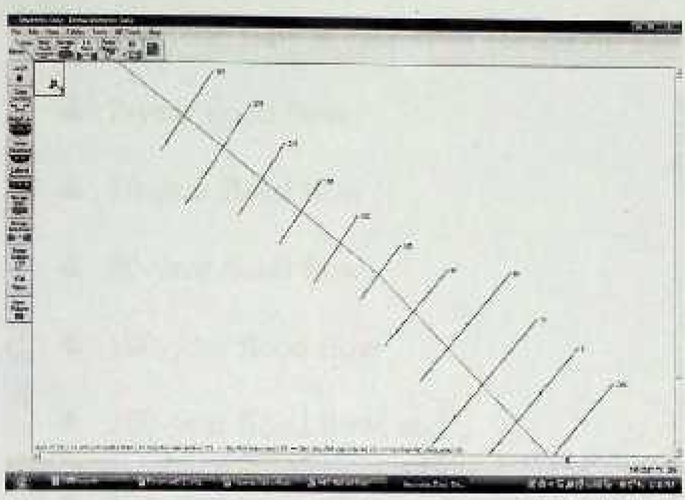

Figure 4.3 Hydraulic Reaches of Weija Tailwater of Study Area.

The cross-sectional data utilized in this study includes primarily station-elevation data and corresponding horizontal station information as well as graphical representations of the numerous cross sections in the model. Figure 4.3 is an example of the cross sectional information generated by HEC-RAS. The cross-sections are modelled to give the perspective plot which shows the arrangement of the channels and the shape of Weija Tailwater as shown in Figure 4.4 below.

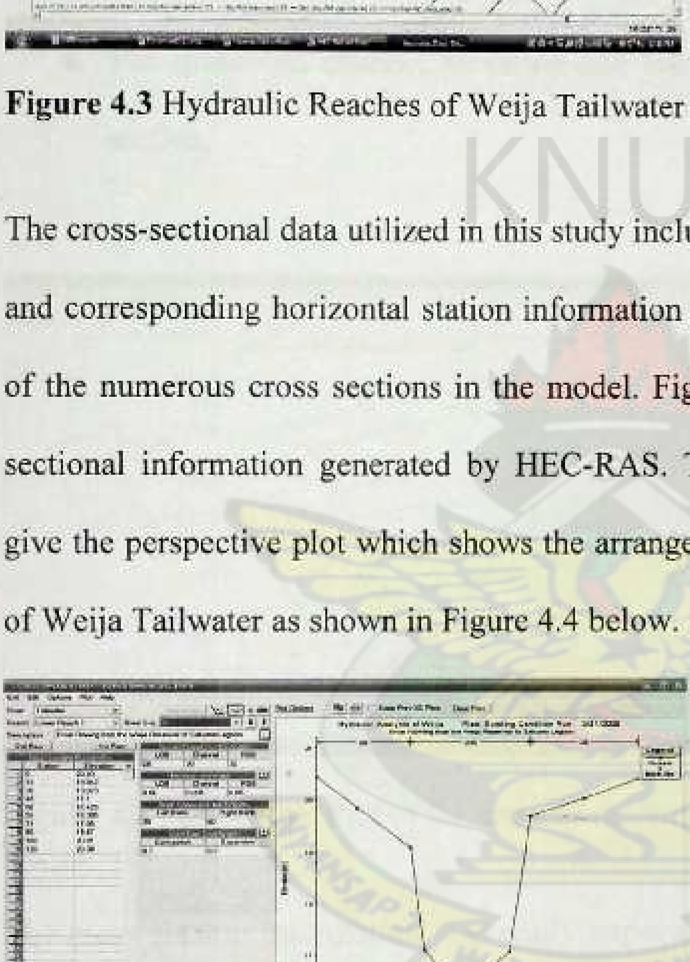

Figure 4.3 Example of Cross-Sectional Profile Generated in HEC-RAS.

In addition to cross-sectional data, profile data also were utilized in this study.

Profile data used includes:

- The name of the reach (i.e. Lower Reach T),
- The river station identification,

- The total flow at each river station for each return period examined,
- 2-year flood flow
- 10-year flood flow
- 50-year flood flow,
- 100-year flood flow
- 200-year flood flow, and,
- The minimum channel elevation and water-surface elevation for each cross section.

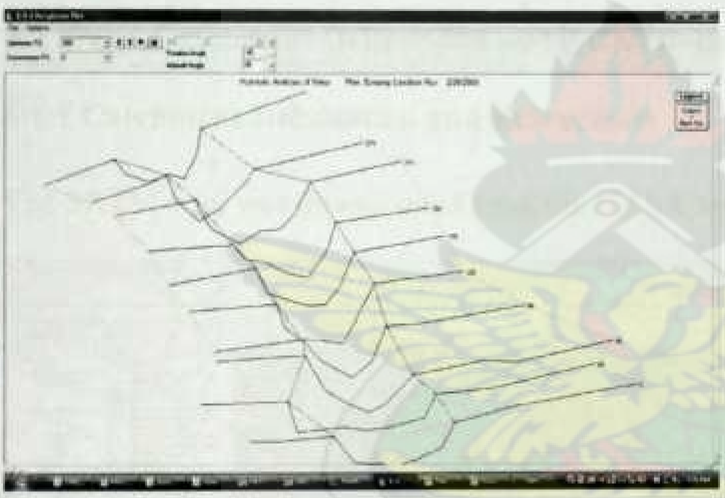

Figure 4.4 Perspective Plot of the channel showing the various cross-sections

The cross section information was easily exported from the model as a text file for computation of water surface elevation, velocity head and other parameters.

4.4 Floodplain and Flood Risk Representation

The final step of the methodology entails mapping the floodway and proposing mitigation measures for a variety of recurrence intervals and watershed conditions for the Densu basin.

5 Results and Discussion

This chapter presents the results from the various tasks performed as discussed in Chapter 4, and is organized as follows. First, the Weija catchment delineation is presented in Section 5.1. Next, data screening results with analysis of HEC-RAS Outputs are in Section 5.2, as well as design of hydraulic model is presented in Section 5.3. Flood frequency analysis is presented in Section 5.5 present the existing data and flood history in catchment area. The results of the estimated flood risk and encroachment analysis of various storms are presented in Section 5.6.

5.1 Weija Catchment Delineation and Extractions

5.1.1 Catchment Delineation and Extractions

The SRTM map was downloaded from the NASA website in Figure 5.1

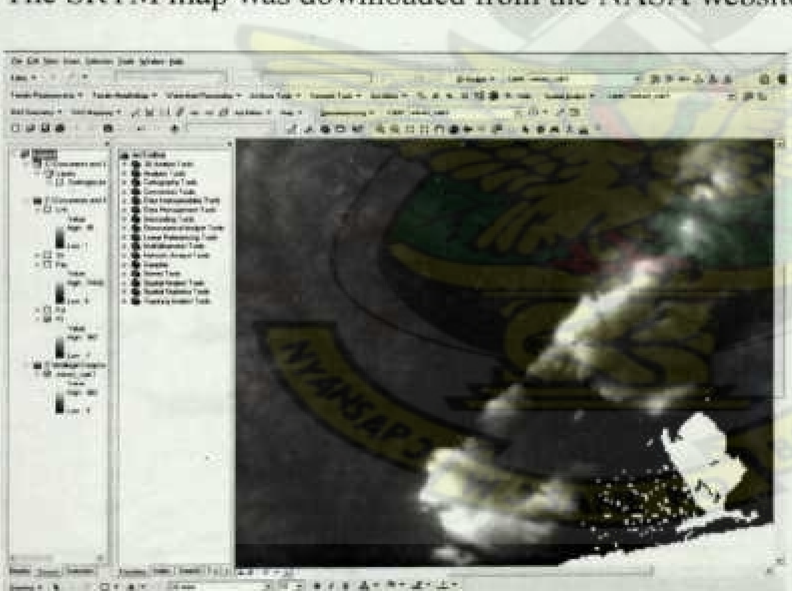

Figure 5.1 Map with sinks

Using the map in figure 5.1 above, the Arc Hydro Tool was applied for the Weija catchment for delineation and extraction of the Densu basin. Below is the delineated catchment of the Weija reservoir that was obtained from the DEM in Figure 5.2

below. The Dem was exported from Arc GIS as a GEO referenced TIF file to be used as the background map of the river network in the hydraulic model.

Figure 5.2 Delineated Weija catchment

The delineated catchment fitted well with what was reported in literature as derived from topographical maps as shown Figure 5.3 below.

Figure 5.3 A catchment derived from topographical map (WRI, 2007)

5.2 Data Screening

The streamflow data which was used for modelling of the floodplain was first screened and the purpose for the screening is to check for any missing data in the data set. This help to correct wrong input of values before it was used for the determination of return period which was incorporated into the model for analysis. The results from screening are shown in Figure 5.4 below.

5.2.1 Rough screening of Data

A rough screening of the data was done together with a computation of the annual totals for the hydrological year which starts from March to February. The screening of the data was done before modelling of the floodplain and the result of the data screening was used for the modelling exercise. From the initial streamflow data screening yearly data with missing values were rejected and wrongly entered values were noted and corrected.

5.2.2 Statistical Analysis

The yearly totals for the discharge of the hydrological water year (March to February) were computed to check if any discrepancies in the data could be observed.

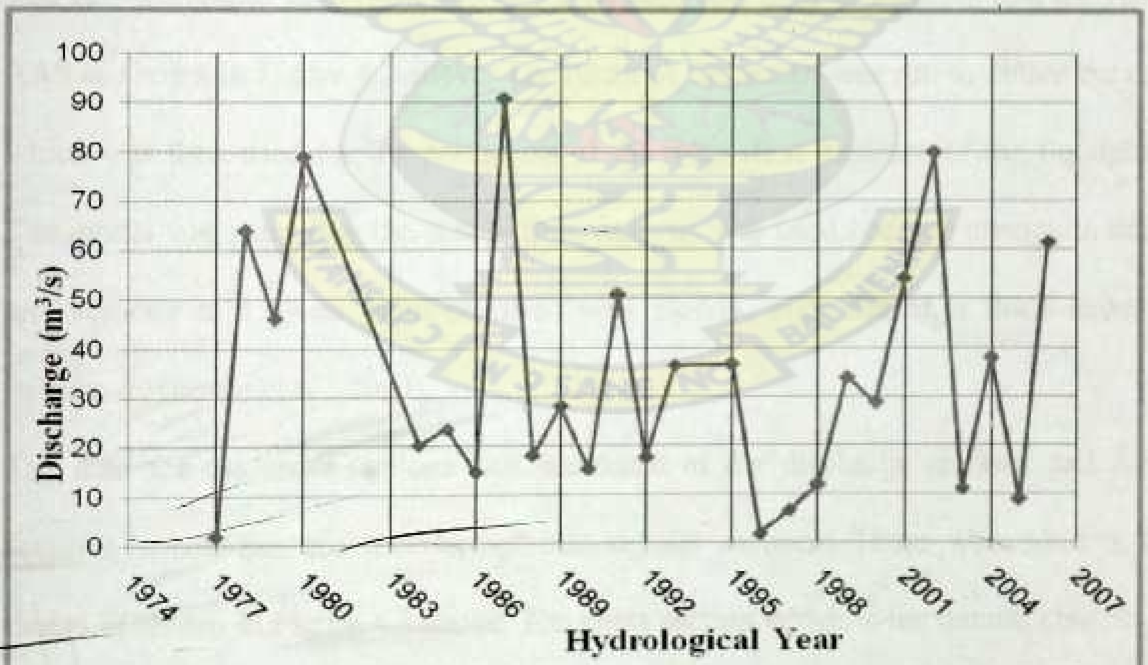

Figure 5.4 Plot of annual discharge (m^3/s)

From Figure 5.4 above it was observed that there were variations from the plotted annual discharge patterns. The differences will be observed from the early part of

1977 and 1995 which indicated drought which was experienced in the country. However Figure 5.5 shows consistency in the annual totals

5.3 Design of the Hydraulic Model Setup

The river network using the background map, as indicated in Figure 5.5.

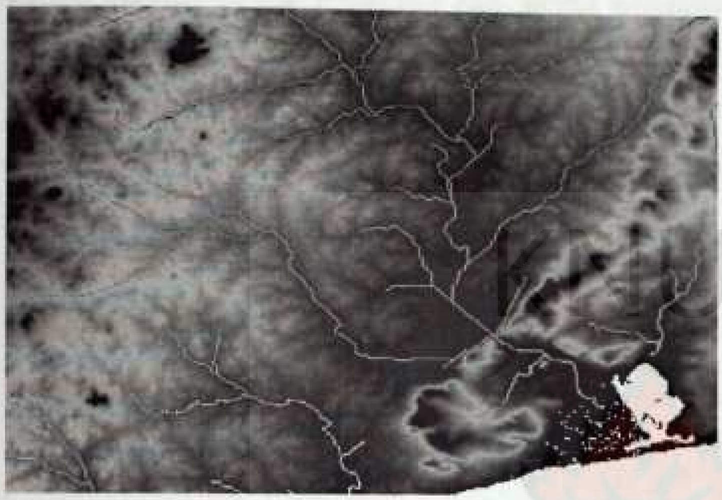

Figure 5.5 Geo-referenced map from ARC GIS used as Input into HEC-RAS

The geo-referenced map from Arc GIS generated was used as an input into the HEC-RAS as shown in Figure 4.2 above. The result of the model was run to obtain the data which was then used for the prediction of the mitigation measure of the floodplain. The model was run using the steady flow analysis was used because change in depth and velocity at a given point occurred very slowly, even during a flood event in streams (Dyhouse et al., 2003).

The data for the cross-sections was measured at the discharge stations and some sections in between and transformed into regular sections. These were used in the model as shown in Figure 4.3 above. The cross section which is the natural channel of the drain was used for the modelling for the true reflection of the outcome of the model which can be used for implementation. The perspective plot of the model cross sections derived from the data, output from model and stream networks from HEC-RAS as shown in Figures 4.4 above.

5.3.1 Model Calibration

The usefulness of hydrologic models depends both on how well the model is calibrated and how well it performs during validation (Ajami et al., 2004).

Calibration is the selection of model parameters to enable the model to simulate the gauge heights of the observed and model behaviour of the study site as closely as possible (Singh, 1995) as given by performance criteria which assess the difference between observations and model simulations. No matter how sophisticated the model structure, (Gupta et al., 1999) observed that if the parameters are poorly specified, simulated streamflows can be quite different from those actually observed and suggested therefore the calibration procedure must be conducted properly to maximise the reliability of the model.

The calibration for the current study was carried out during the period 2005 with the result shown in Figure 5.6 below. Calibration of the model was done using gauge height generated from the model, which was then compared with the gauge height measured from the field. The calibration was determined by adjusting the manning's value of the model for the output to be closer to the values measured from the gauging station.

Overall, good agreement between recorded and hydraulic model flood levels was obtained for the calibration events, indicating that the model is reliably predicting the flooding behaviour of the current floodplain.

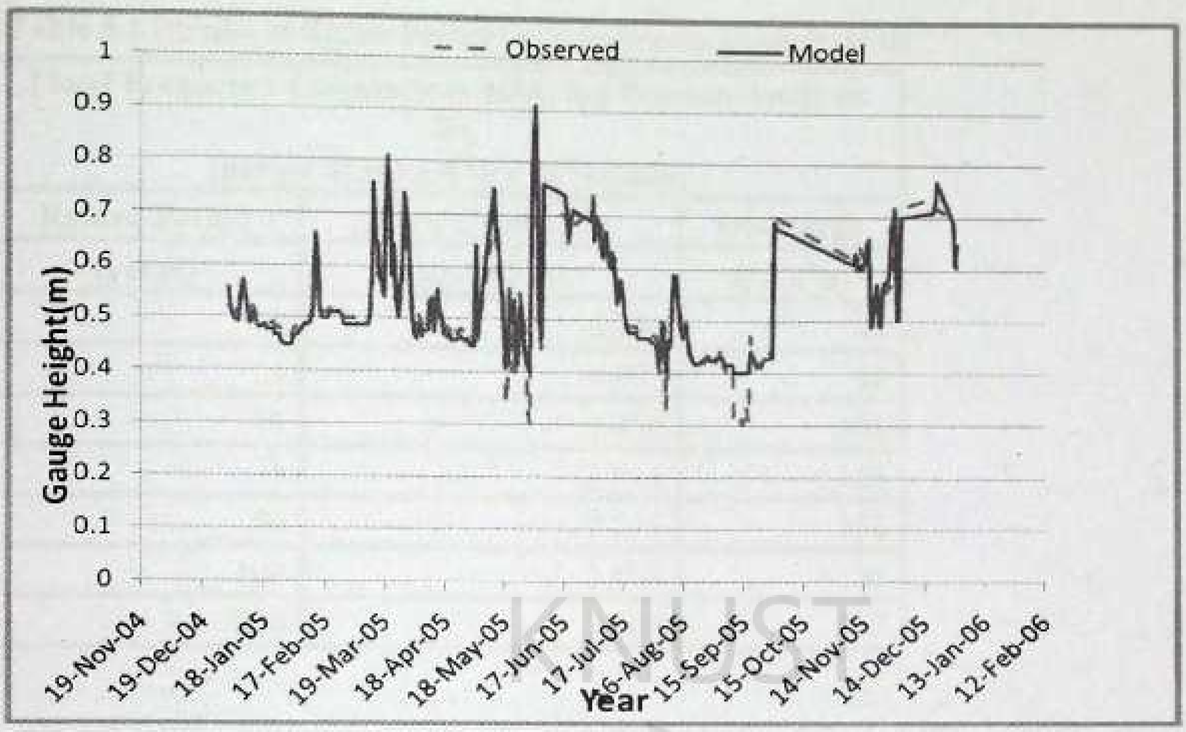

Figure 5.6 Modelled and observed results during calibration for the year 2005.

Testing the efficiency of the model with the Nash-Sutcliffe efficiency (E) gave a value of 0.63 for the year 2005. An efficiency of 1 (E=1) corresponds to a perfect match of modelled gauge height to the observed data. Essentially, the closer the model efficiency is to 1, the more accurate the model is. The model predicted low flows as well as high flows. However, since the interest of this study is in the high flow, the fit is said to be good according to efficiency criterion. Nash-Sutcliffe efficiencies ranges from -∞ to 1.

5.4 Flood Frequency Analysis

Using Excel, the annual maximum series approach was used in analysing the flood as shown in Figure 5.4 above and flood frequency calculations using Log-Pearson Analysis is used to determine the return periods which are shown in Table 5.2 below which were used in the model floodplain analysis.

Table 5.1 Results of Return Period using log-Pearson Analysis III

Flood Frequency Calculations using log-Pearson Analysis III (period of record WY 1977-2006)		
Return Period (years)	**Skew Coefficient K(-1.0735)**	**Discharge Q (m^3/s)**
2	-0.056	48
5	0.907	88
10	1.416	108
25	1.943	123
50	2.275	130
100	2.549	135
200	2.804	137

5. 5 Existing Data and Flood History in Catchment Area

The City of Accra lies on a flood-prone coastal area due to both heavy rainstorms and flat topography. Several problems have historically worsened this flooding. Heavy developments along floodplains and increasing urbanization have been the biggest determinants of recent flooding. The main flood affected area in Weija is Ogblogo which lies downstream of the Weija reservoir. Previous encroachment in the floodplain has resulted in flooding in the area.

Plate 5.1 Downstream of Weija Reservoir (Photograph taken on 17 September 2007).

Development of river floodplain results in removal of areas in which water is temporarily stored during the passage of floods as shown in Plate 5.1 above. Floodplain storage is an important factor in the attenuation of flood peak flows, and also in the reduction of flood levels. In-migrants to Accra frequently build accommodations within floodplains. There are many settlements of temporary and uncompleted housing being erected alongside drainage channels, under dire threat of flood damage.

5.5.1 Rainfall Analysis

The analysis of annual rainfall in the Weija reveal a decline in the rainfall pattern in the catchment, one will expect a decline in flooding with the decrease in rainfall pattern as shown in Figure 5.7 below but this is not the case, since the issue of flooding has become an annual event in the catchment. This shows that not only rainfall causes the flood but also water from Weija dam when the spill gate is opened for the release of excess water from the dam also contribute to flooding in the area.

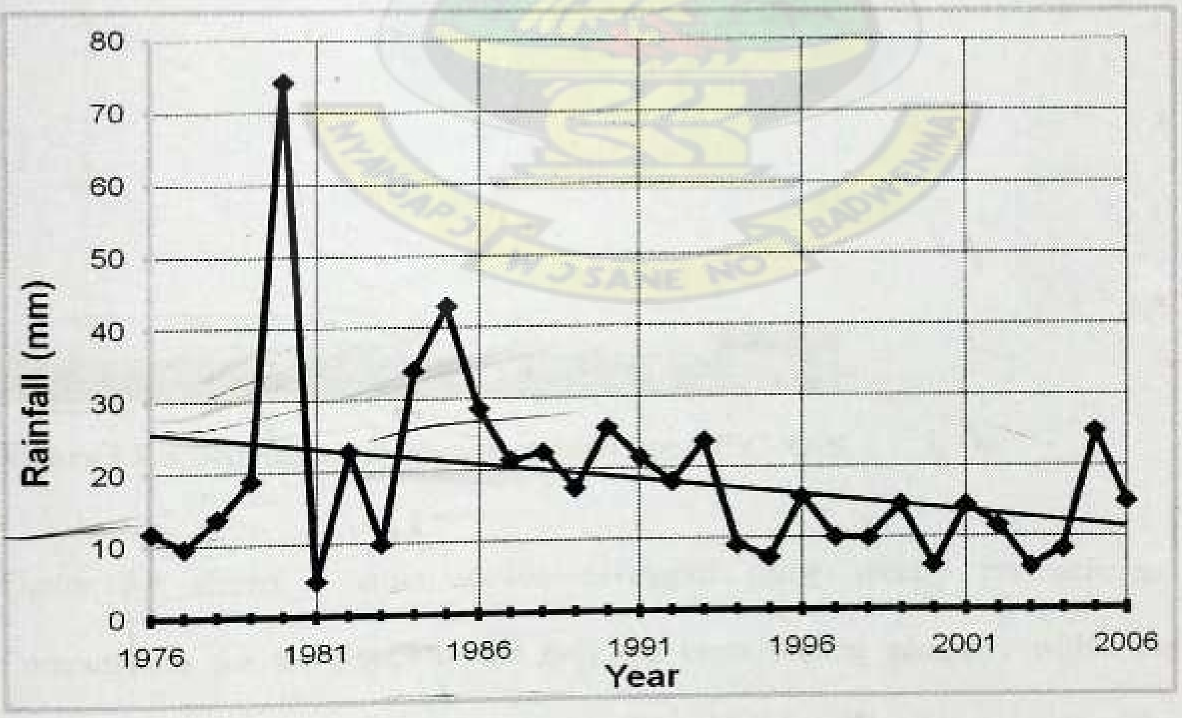

Figure 5.7 Plot of annual total precipitation (mm/year) for 1976 to 2006.

5. 6 Flood Risk Estimation and Encroachment Analysis

In the encroachment analysis, computation of left and right encroachment station was used to develop a floodway width less than or equal to the unencroached cross sectional area available for 5-year discharge, water surface elevation for the floodway profile is greater than the unencroached 5-year flood profile in other words to determine the adverse effect on flood levels from placing fill in the floodplain. The 5-year profile is important because it is the basis for creating the floodway limit to prevent encroachment into the floodplain.

In the encroachment analysis, (specify encroachment stations) is used for analysis because actual encroachment stations at selected cross sections can be easily increased or decreased for a specific amount. This specifies the exact location of the encroachment stations on either side of the channel so that small adjustments to individual cross sections better defining the floodway.

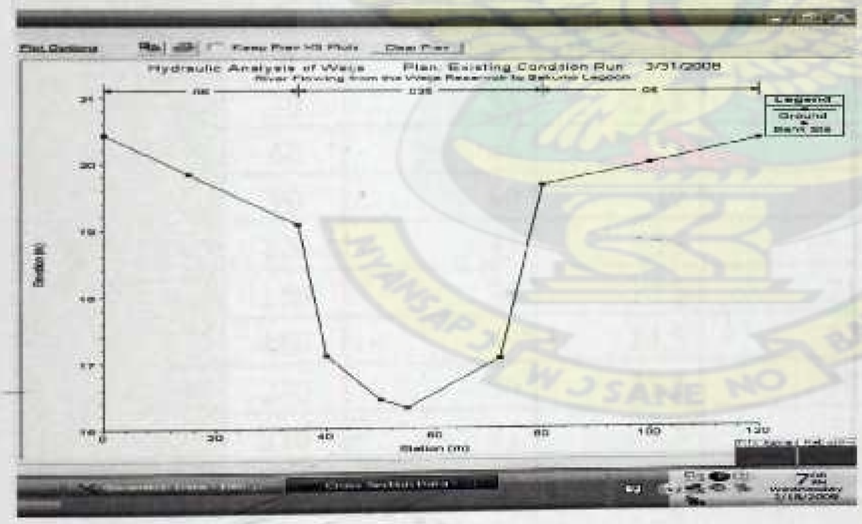

Figure 5.8 Specifying encroachment stations from HEC-RAS.

Figure 5.8 shows a cross section developed using specify encroachment. Computations for the floodway use only the cross section geometry within the floodway. The "vertical walls" that bound either side of the floodway is part of the wetted perimeter computations which was then used for encroachment analysis of the floodplain.

5.6.1 Mapping the Floodway

The resutls from encroachment as shown in Table 5.2 below is used to plot the floodway using data, a standard table in the model which is the base scenerio i.e. the intiail condition. Encroachment width is used to determine the level of encroachment in the floodplain and the extent of the floodplain which is reserved in the event of flooding. From the analysis of the initial condition, the encroachment width for the floodplain due to encroachment had been reduced and this had resulted in flooding in the study area whenever there is release of water over the spillway of the Weija dam.

Table 5.2 Flooding resulting from Encroachment for the Initial Scenario

Reach	River Sta	Top Wdth Act	Dist Center L	Center Station	Dist Center R	Encr WD
		(m)	(m)	(m)	(m)	(m)
Lwr Rch T	0	52	28	31	28	56
Lwr Rch T	30	55	27.5	30.5	27.5	55
Lwr Rch T	60	46	23	25	23	46
Lwr Rch T	90	40	19	21	21	40
Lwr Rch T	120	45	18	19	27	45
Lwr Rch T	150	36	17.5	21.5	18.5	36
Lwr Rch T	180	49	24.5	32.5	24.5	49
Lwr Rch T	240	50	28.5	58.5	21.5	50
Lwr Rch T	270	71	35.5	51.5	35.5	71
Lwr Rch T	300	65	32.5	57.5	32.5	65

River Sta – River Station

Top Wdth Act – Top Width Action

Dist Center L – Distance from Center Left

Dist. Center R – Distance from Center Right

Encr WD – Encroachment Width

Lwr Rch T – Lower Reach Tailwater

The variables "Dist. Center L" and "Dist. Center R" are the left and right floodway limits, respectively, measured from the center station of cross section. The center station is defined by HEC-RAS as the average of the left channel bank station and right channel bank station. The encroachment width is equal to the sum of the " Dist. Center L" and "Dist. Center R" values. The resulting computation is used to plot floodway map as shown in Figure 5.9 below, to determine the width of land that must be allocated for flooding event. From the map, there was no adquate land allocated for flooding which had resulted in the water destroying properties closer to the floodplain.

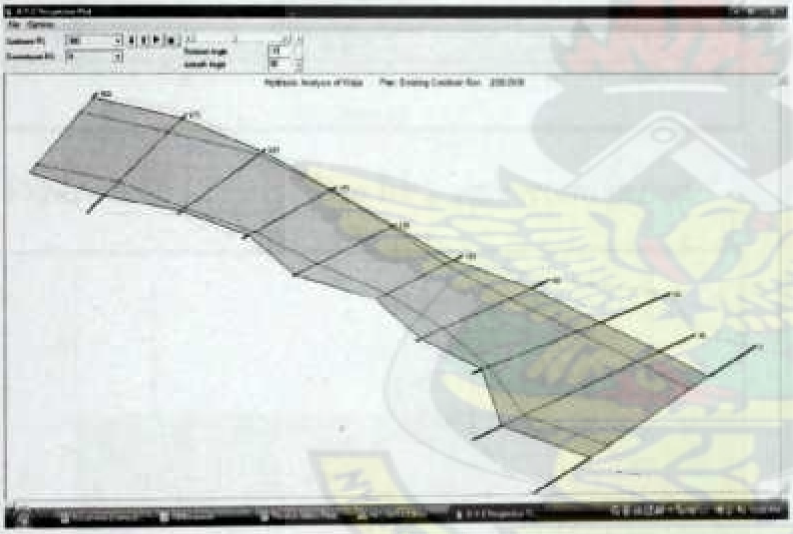

Figure 5.9 Floodway mapping of Weija downstream

The "Encr. WD" (encroachment width), is used as the flooway width for the flood insurance studies in order to discourage people from building in and "Top Width Act" (top width active), represents the water surface within the channel.

In order to map the floodway, the geometric data collected at the study area were then entered into the model to generate the shape of the cross-section of the channel. The 2 year return period and 5 year return period are shown in the Figures 5.10 and 5.11 below. For the 2 year return period the water was at an elevation of 3 meters with a depth of 6.5metres deep for each of the cross-sections. In this case the boundary of the channel is considered as a levee which causes the accumulation of water to have such a height because of the level of encroachment on floodway of the study area. With the 5 year return period, the elevation of the water level is 7 meters which will result in flooding of the encroached floodplain which is similar to the condition of 2 year return period.

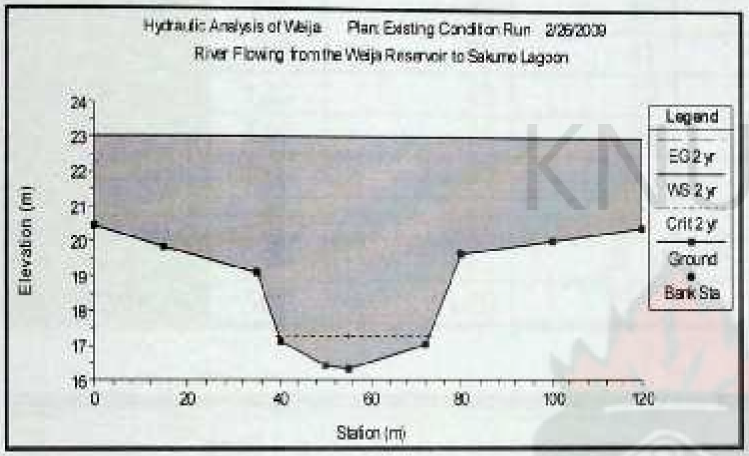

Figure 5.10 Cross-section for 2 year return period

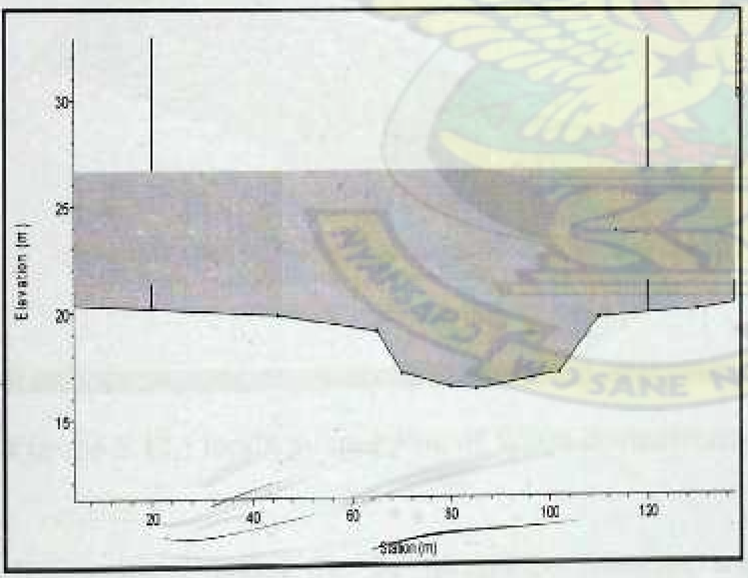

Figure 5.11 Cross-section for 5 year return period

5.6.2 Mitigation Measure

The mitigation measure adapted in this study is widening the floodway of the channel by 10 metres on both sides of the channel to cope with the amount of water released from the Weija dam since the introduction of obstruction will result in the decreasing the floodway.

Table 5.3 Final Scenario when flood bank is increased by 10 metres

Reach	River Sta	Top Wdth Act (m)	Dist Center L (m)	Center Station (m)	Dist Center R (m)	Encr WD (m)
Lwr Rch T	0	89	51	61	38	89
Lwr Rch T	30	88	50.5	60.5	37.5	88
Lwr Rch T	60	86	45	55	41	86
Lwr Rch T	90	79	41	51	38	79
Lwr Rch T	120	48	39	49	37	76
Lwr Rch T	150	75	38	48	37	75
Lwr Rch T	180	77	52.5	62.5	24.5	77
Lwr Rch T	240	117	78.5	88.5	38.5	117
Lwr Rch T	270	117	71.5	81.5	45.5	117
Lwr Rch T	300	120	77.5	87.5	42.5	120

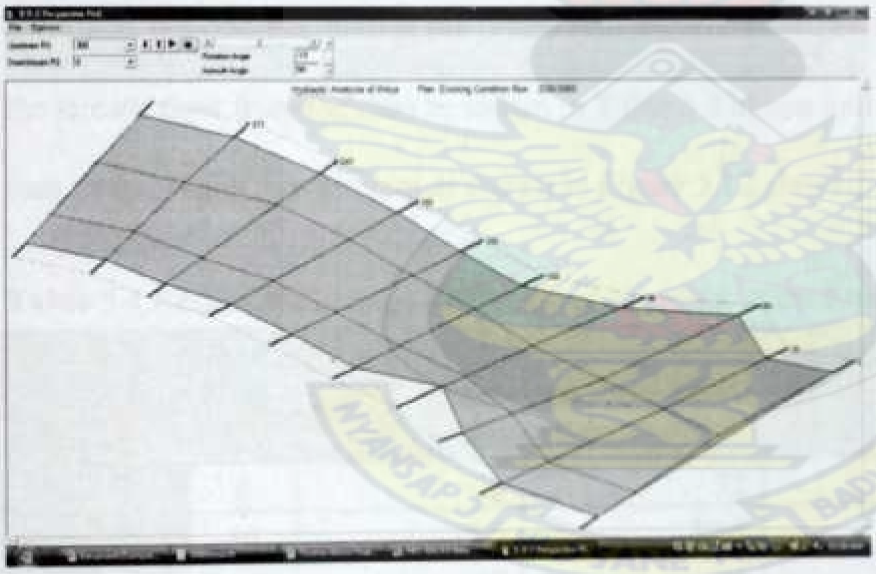

Figure 5.12 Floodway mapping of Weija downstream for wider channel

The measure taken for the mitigation measure was to extend the encroachment distance to 10 meters on both side of the channel. The percentage reduction in flood was computed by finding the difference between the mitigation approached and the current approached, the resulting value was divided by the current approached, i.e.

$\left(\frac{M_t - C_t}{C_t}\right)*100$ the averages of the various river stations were computed to determine the percentage reduction in the study area. The same procedure was used to determine percentage increase in the top width of the channel.

By means of mitigation, widening the encroachment width of the channel is used in this case which resulted in an average reduction of 51% in flooding with an additional increase in an average Top width of 77% to cope with the release of water from Weija dam as shown in the Table 5.4 below. The Table is an indication of the percentage reduction in flooding that will be achieved when the channel floodway is widened. Widening the width involves expanding the narrow section of the flood bank of the channel to cope with the amount of water that is released from the dam with this approach, the distance both at the centre Left and centre Right is increased to cater for the stream flow from the dam as shown in Table 5.3 above and the resulting floodway map of the Weija downstream as shown in Figure 5.12 above.

Table 5.4 Results of Average Reduction of Flooding in the Study Area

Reach	River Sta	Dist Center R Ct	Dist Center R Mt	% Reduction in flooding	% Increase in Top Wdth
		(m)	(m)	(%)	(%)
Lwr Rch T	0	28	38	36	71
Lwr Rch T	30	27.5	37.5	36	60
Lwr Rch T	60	23	41	78	87
Lwr Rch T	90	21	38	81	98
Lwr Rch T	120	27	37	37	7
Lwr Rch T	150	18.5	37	100	108
Lwr Rch T	180	24.5	24.5	0	57
Lwr Rch T	240	21.5	38.5	79	134
Lwr Rch T	270	35.5	45.5	28	65
Lwr Rch T	300	32.5	42.5	31	85
			Average	51	77

Dist Center R Ct – Distance Center Right of Current Situation

Dist Center R Mt – Distance Center Right of Mitigation

Top Wdth – Top Width

6 Conclusions and Recommendations

Conclusions

The following conclusions were drawn from the findings:

- From analysis channel with flood bank of 10m wide, the extent of flooding was reduced to 51% whiles channel with narrow or no flood bank, the extent of flooding was severe.
- The floodway map helps to know the extent of land areas which must be allocated in event of flooding.
- Mitigation measure, to avoid flooding there is the need to widen the narrow flood bank of the channels to cope with the amount of water released at the upstream of the Weija dam.

Recommendations:

- With regard to the current rate of encroachment at the downstream, there is the need for the government to institute policy which will prevent people from building at the floodway because of the devastation aftermath of flooding in the area.
- The community should be educated to know the distance from which to develop away from the channel to avoid flooding.

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Appendix

Cross – Section Data of Channel

BACK SIGHT	INTER MEDIATE	FORE SIGHT	RISE/ FALL	REDUCED LEVEL	DISTANCE (M)	REMARKS
1.210			21.210	20.000		**TBM1 U/S of Bridge LB Toe**
	0.780			20.430	0.0	**Cross-section 1 CHO LB**
	1.368			19.842	15.0	
	2.132			19.078	35.0	**Bank LB**
	4.110			17.100	40.0	
	4.785			16.425	50.0	
	4.905			16.305	55.0	
	4.160			17.050	72.0	
	1.540			19.670	80.0	
	1.200			20.010	100.0	
	0.830			20.380	120.0	
	0.850			20.360	0.0	**Cross-section 2 CHO + 30 LB**
	2.040			19.170	6.0	
	2.081			19.129	18.0	
	2.045			19.165	26.0	**Bank LB**
	4.040			17.170	30.0	
	4.560			16.650	42.0	
	4.660			16.550	50.0	
	4.250			16.960	58.0	
	4.350			16.860	74.0	
	1.755			19.455	77.0	
	1.352			19.858	100.0	
1.455		2.035	20.630	19.175		**CP**
	1.071			19.559	0.0	**Cross-section 3 CHO + 60 LB**
	2.210			18.420	3.4	
	1.825			18.805	15.0	
	2.505			18.125	40.0	
	3.820			16.810	45.0	
	4.980			15.650	50.0	
	5.550			15.080	55.0	
	4.840			15.790	62.0	
	3.576			17.054	70.0	
	0.515			20.115	77.0	

	0.732			19.898	84.0	
1.255		1.052	20.833	19.578		**CP**
	0.615			20.218	0.0	**Cross-section 4 CHO + 90 LB**
	1.583			19.250	7.0	
	1.600			19.233	18.0	**Bank LB**
	4.480			16.353	23.0	
	5.780			15.053	30.0	
	4.040			16.793	41.0	
	2.245			18.588	47.0	
	2.647			18.186	59.0	
1.294		0.980	21.147	19.853		**CP**
	0.925			20.222	0.0	**Cross-section 5 CHO + 120 LB**
	1.292			19.855	1.0	
	4.555			16.592	8.0	
	6.220			14.927	12.0	
	5.720			15.427	20.0	
	5.520			15.627	27.0	
	4.330			16.817	32.0	
	2.270			18.877	35.0	
	2.290			18.857	40.0	
1.350		1.600	20.897	19.547		**CP**
	0.617			20.280	0.0	**Cross-section 6 CHO + 150 LB**
	1.318			19.579	2.0	
	4.100			16.797	7.0	
	5.570			15.327	12.0	
	5.468			15.429	18.0	
	4.848			16.049	25.0	
	4.110			16.787	32.0	
	1.878			19.019	36.0	
	2.680			18.217	47.0	
1.090		1.745	20.242	19.152		**CP**
	0.805			19.437	0.0	**Cross-section 7 CHO + 180 LB**
	1.100			19.142	3.0	**Bank LB**
	3.390			16.852	6.0	
	5.540			14.702	13.0	

	4.940			15.302	20.0	
	3.790			16.452	28.0	
	3.325			16.917	35.0	
	2.045			18.197	39.0	
	1.700			18.542	45.0	
2.560		2.600	20.202	17.642		**CP**
	0.346			19.856	0.0	**Cross-section 8 CHO + 240 LB**
	0.712			19.490	4.0	
	3.312			16.890	10.0	
	4.360			15.842	15.0	
	4.200			16.002	22.0	
	4.940			15.262	30.0	
	3.430			16.772	40.0	
	1.390			18.812	45.0	
	0.600			19.602	46.0	
	0.695			19.507	50.0	
	2.285			17.917	0.0	**Cross-section 9 CHO + 270 LB**
	2.350			17.852	13.0	
	3.420			16.782	17.0	
	4.160			16.042	22.0	
	4.940			15.262	26.0	
	5.660			14.542	35.0	
	4.600			15.602	39.0	
	3.425			16.777	44.0	
	1.000			19.202	48.0	
	1.380			18.822	56.0	
	1.755			**18.447**	70.0	**Metal Anchor in farm (cassava) TBM2**
2.615		2.485	20.332	17.717		**CP**
	0.813			19.519	0.0	**Cross-section 10 CHO + 300 LB**
	1.563			18.769	13.0	**Bank LB**
	3.745			16.587	15.0	
	5.420			14.912	20.0	
	4.720			15.612	26.0	
	4.800			15.532	35.0	

	3.525			16.807	45.0	
	2.100			18.232	49.0	
	2.580			17.752	55.0	
		1.885		**18.447**	**Closure**	**Metal Anchor in farm (cassava) TBM2**