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STUDY AND ANALYSIS OF ASA RIVER HYPOTHETICAL DAM BREAK USING HEC-RAS

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ABSTRACT
Impounded reservoirs provide beneficial functions such as flood control, recreation, hydropower and water supply but they also carry potential risks. Spontaneous dam break phenomenon can occur and the resultant flooding may cause substantial loss of life and property damage downstream of the dam. A hypothetical dam break on Asa Dam located in Ilorin, Kwara State, Nigeria was analyzed using United States Army Corps of Engineers (USACE), Hydrologic Engineering Center's River Analysis System (HEC-RAS) computer model. Unsteady flow simulation was performed using geometric data obtained from Digital Terrain Model (DTM) with 100-year, 24 hr flow event. The HEC-RAS was used in concert with HEC-GeoRAS to assess the flood hazard along the Asa River channel starting from the dam axis and approximately 12 km towards the downstream as a result of the dam break. The highest discharge Q (1913.66 m^3/s) and the highest peak stage (277.35 m) just below the dam were produced with breach width of 130.86 m and time of failure of 1.45 hours. The outcome of the analysis showed that in the event of such failure of Asa dam, some areas which include industrial and residential sections along the river channel are at very high risk of being inundated due to the significant difference in the value of the produced water surface elevation and existing ground elevation affecting thousands of people living along the channel immediate vicinity.

Key words: *Asa dam, Dambreak, Water level, HEC-RAS, River channel*

1. INTRODUCTION

Dam provides many benefits to the society, but floods resulting from the failure of constructed dams have also produced some of the most devastating disasters of the last two centuries [1]. Dam failures raise particular concern because it has the potential to cause more deaths and destruction than the failure of any other man-made structure [2]. This is due to the inherent destructive power of the flood wave that would be released as a result of the sudden collapse of the dam. According to [3], dam failure is defined as a collapse or movement of part of the dam or its foundations, so that the dam cannot retain water. In general, a failure results in the release of large quantity of water, imposing risks on the people and/or property downstream [4]. Failure of a dam (dam-break) can result in a major disaster with devastating losses of both human life and property. The phenomenon is time-dependent, multiphase and non-homogeneous. Erosion of an earth-dam can be primed by low or weak points on the crest or on the downstream face, by piping or overtopping. Progressive erosion then widens and deepens the breach, increasing outflow and erosion rate [5].

The geometric description of a dam break needs to be estimated to simulate the resultant flood wave and downstream consequences. Some readily available computer models that have been used for performing dam breach outflow hydrograph computation and downstream routing are HEC-RAS [6], HEC-HMS [7], NWS-BREACH model [8], NWSDAMBRK [9], NWS-FLDWAV [10] and a few others. These models require that the potential breach characteristics should be estimated outside of the model. Several "process" models are also available or being developed, that attempt to simulate the progression of a dam breach using sediment transport equations to estimate erosion rates and soil mechanics relations to predict mass slope failures [11, 26]. Availability of terrain data has improved the proficiency which hydraulic models capable of simulating a dam breach scenario and evaluating the resultant flood wave can be developed using geographic information systems (GIS) [12].

This paper describes how a flood wave created as a result of a hypothetical dam break propagates and attenuates along the Asa River valley from the dam axis to approximately 12 km downstream of the river. The Hydrologic Engineering Center's River Analysis System

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(HEC-RAS) in concert with HEC-GeoRAS was used for the computer analysis. HEC-GeoRAS was used to extract the geometric information from a digital terrain of the geographic area and then imported into HEC-RAS for unsteady flow hydraulic simulation.

2. DESCRIPTION OF THE STUDY AREA

Asa River has its source in Oyo State, South-West Nigeria and it flows through Ilorin, capital of Kwara State, Nigeria in a South-North direction forming a dividing boundary between the eastern and western parts of Ilorin metropolis. The major tributary of Asa River is River Awon, which continue to form one of the tributaries of River Niger at approximately 12.2 km North of Ilorin. River Asa is joined by River Oyun to the East and to the West by River Imoru. Afidikodi, Ekoro, Obe are among the earliest tributaries of Asa River while its tributaries in Ilorin include River Agba, Aluko, Atikeke, Mitile, Odota, Okun and Osere [13, 14]. The Asa Dam is located between latitudes $8^0 36'$N and $8^0 24'$N and longitudes $4^0 36'$E and $4^0 10'$E in Ilorin.The River is approximately 56 km long with a maximum width of approximately 100m within the dam site. Its total catchment area is approximately 1037 km^2 lying within Kwara State and Oyo State of Nigeria with about one third of the basin area located in Oyo State [15].

Asa Dam constructed in 1984 is a composite dam with earth embankment at its extreme ends. The dam is 597 m long and 27 m high at its deepest section and a crest width of 6 m. There is a spillway centrally located with a stilling basin spanning the entire width of the spillway dissipating the energy of the spill flow to prevent erosion of the stream bed. The intake chamber is located in the wing wall which also supports the main earth embankment while the superstructure of the low lift pumping station is located on the top of the wing wall. There are three vertical spindle submersible pumps, each rated 1150 m^3/hr against a total head of 29 m for the treatment plant (located at the head works) and two similar pumps each rated 300 m^3/hr against a total head of 56 m for the old treatment plant (6 km away from the Asa Dam). Raw water is admitted into the intake chamber on opening one of the three penstocks installed at three different levels [16].

The Asa River channelization corridor is characterized by many significant features, among which include the downstream of the Asa Dam. Generally, the Asa river channelization can be divided into six (6) main consistent sections with about four significant features of water reservoir, bridges and culverts and the extent of urbanization. The various segments are:

(i) From Asa Dam axis to Asa Dam Road/Dangote Factory Crossing,

(ii) River Course from the Dam Crossing to the Bridge at Geri Alimi/Offa Garage Bye Pass,

(iii) The Stretch between Geri Alimi Bye pass and Unity Road Bridge (Coca Cola Axis)

(iv) Stretch between Unity Road Bridge and Emir's Road (Behind the Railway station)

(v) Emir's Road/Amilegbe Stretch and

(vi) The stretch from Amilegbe and beyond to Duma.Asa River is a very significant source of water in terms of economic, agricultural and environmental purposes in the city as it is used in homes and industries [17].

There are farmlands, residential and industrial buildings along the banks of the river upstream and downstream of the dam.

3. MODEL DEVELOPMENT AND CALIBRATION

HEC-RAS model simulation for unsteady-flow requires six major data input which are:
(i) topographic/cross-section data,
(ii) roughness coefficient (manning n-values),
(iii) bridge geometry,
(iv) inline structure
(v) unsteady flow and
(vi) initial and boundary conditions.

The geometric data were derived from the Digital Terrain Model (DTM) using HEC-GeoRAS and the flow data from hydraulic and hydrologic study results previously conducted [18] in the study area.

3.1 CREATION OF THE GEOMETRIC DATA

The geometry data contains technical information about the cross-sections, hydraulic structures, river bank elevations and other physical attributes of the river channels [19]. The pre-processing was done through the use of HEC-GeoRAS to create the physical attributes in ArcGIS before being exported to HEC-RAS geometry file. In HEC-GeoRAS, each attribute was stored in a separate feature group referred to as RAS Layer [19]. The RAS Layers used are: River, Banks, Flowpaths, XsCutLines, Bridges, Inline Structures and Storage. The geometry data required for the computer model are Cross-sections, Bridge/Culvert, Inline structures and Storage areas. Figure 1 shows the Snapshot of Geometric Data window with the georeferenced river system.

3.1 Cross sections

HEC-RAS requires cross sections along the channel for the computation of water-surface elevations. Up to 200 cross-sections were manually drawn perpendicular to the stream flow along the river centerline using HEC-GeoRAS. The cross-section spacing varies between 50-100 meters except at the bridge and inline structure boundary cross-sections which need smaller spacing for accurate computation. Values varying between 5-35 meters were used for all boundary cross-sections. Additional (approximately 30) interpolated cross-sections were inserted in areas with major changes in cross-section configurations. Figure 2 shows an example of a typical cross-section.

3.2 Roughness coefficient (Manning's n)

Selection of the appropriate Manning's n value is very important for an accurate computation of water surface profiles. The value of Manning's n is highly variable and depends upon a number of factors including: surface roughness, channel irregularities, channel alignment, size and shape of channel, scour and deposition, vegetation, obstructions, stage and discharge, seasonal change, temperature, suspended materials and bed load [20]. The information gathered during field visits was used as a guide and base reference. Manning's n values of 0.035 for channel and 0.045 for overbanks were chosen for all the cross sections as contained in Chow's table [21] except at the inline structures where n value of 0.1 on the downstream cross section for overbanks and bridges with n value of 0.2 on the boundary cross-sections for overbanks in the simulation for marginal increase in flood profile and stability purpose [22]. The contraction and expansion coefficients were left at default values of 0.1 and 0.3 for all cross-sections since the flow is a gradual transition except at the bridges where the values are 0.3 and 0.5 respectively [20].

3.3 Bridge structures

Goggle earth was used to locate each bridge and a line was drawn along the centerline of the bridge without intersecting the cross section. The bridge line was drawn with a high degree of accuracy to ensure that the sectional topography is well represented. The bridge cross-sections (four for each bridge) were placed appropriately and the bridge bounding cross-sections 2 and 3 are as shown in Figure 3.

HEC-RAS automatically adds two more cross sections, immediately inside the upstream (BU for bridge upstream) and downstream (BD for bridge downstream) bridge faces. These two new cross sections appear in the Bridge/Culvert Data Editor window.

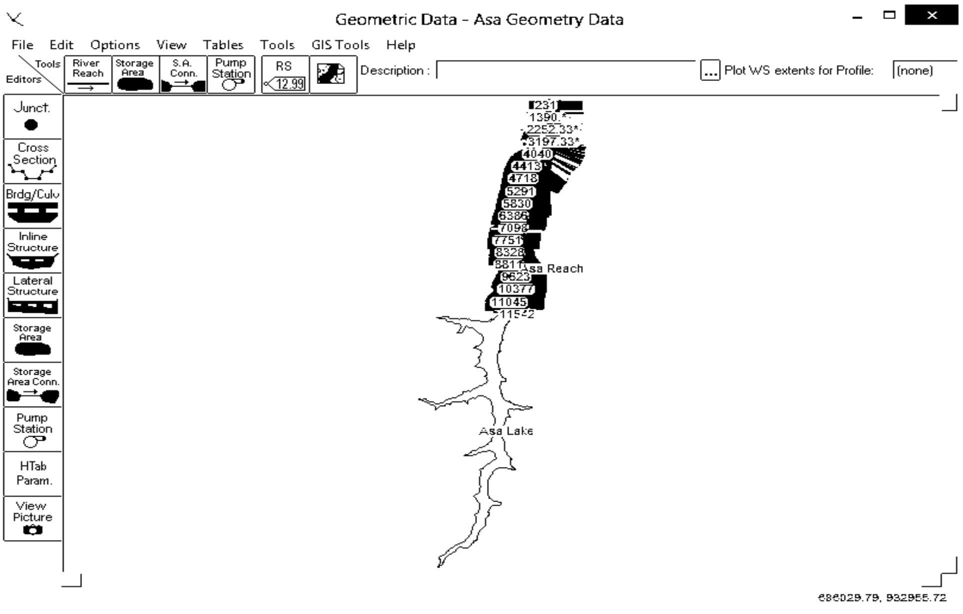

Figure 1: Snapshot of Geometric Data Window

Figure 2: Typical River Cross-Section

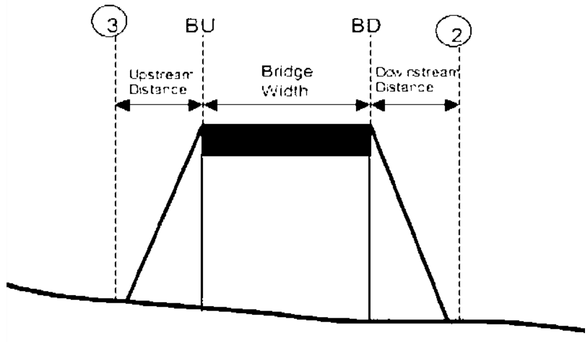

Figure 3: Bridge Bounding Cross Sections [23]

The bridge deck editor is used to describe the area that is blocked out by the bridge deck and road embankment. A total of five (5) bridge data were added at the following locations:

a. Bridge 1 (Asa Dam) at RS 10173
b. Bridge 2 (Unity) at RS 6253
c. Bridge 4 (Emirs Road) at RS 5385
d. Bridge 5 (Amilegbe) at RS 4402
e. Bridge 6 (Royal Valley Estate) at RS 400

Ineffective flow areas provide little or no conveyance of flow in the downstream direction and are used in bounding cross sections of bridge. The ineffective trigger height is set to an appropriate elevation and when flow depths reach this trigger height, the ineffective flow areas become areas of effective flow [24]. Figure 4 shows an example of upstream and downstream of a bridge with ineffective flow area.

3.4 Inline structure

The Asa dam structure was modeled as an inline structure. From the field visit, it was observed that the dam is ungated. In modeling a dam failure in HEC-RAS, the failure mode, breach size, and breach time are entered. HEC-RAS supports both overtopping and piping failure modes with the failure trigger being a target water surface, water surface and duration or specific time. The breach size is defined by a trapezoid and the duration over which the breach occurs. In simulating the hypothetical dam failure, breach parameters were estimated based on Asa dam structure and reservoir parameters as contained in [16]. Figure 5 shows the dam model and estimated breach parameters which are the breach width, breach height, time of formation and slope.

3.5 Unsteady flow

Dam break is most appropriately modeled in HEC-RAS using unsteady flow condition. Flow hydrograph is used as either an upstream boundary or downstream boundary condition but generally it is most commonly used as an upstream boundary condition while normal depth can only be used as downstream boundary condition [22]. For a flood induced dam break, a flood hydrograph is developed external to HEC-RAS. It is common to use hypothetical floods such as 100-year return period flow [25]. The flow hydrograph adopted for this study was developed by [18].

3.6 Initial and boundary conditions

Initial flow values, input hydrographs, downstream boundary conditions were set in HEC-RAS model. For this study, the initial flow was set at 347.84m^3/s which is initial flow value in the flow hydrograph. The input hydrograph of 100-year 24-hour and boundary cross section set as normal depth with a friction slope value of 0.0008 was obtained from [18].

4. MODEL CALIBRATION

The HEC-RAS computer model has been widely used for simulation of real and hypothetical dam break. The model was first calibrated using known flow event and observed water surface elevations at some key locations. The results indicated that the model produced results that are very close to the observed data.

5. SIMULATION RESULTS

HEC-RAS results consist of water surface elevations generated for flow of 100 year return period. In addition to water surface elevations, values of other hydraulic parameters such as flow rate, flow velocity, flow area and critical water surface elevation are available for each prescribed cross section. HEC-RAS outputs are available in both graphical forms. HEC-RAS output can be viewed as water surface profiles, general profiles, rating curves, stage and flow hydrographs, and X-Y-Z perspective plots. Figures 6 to 8 show the results of the stage and flow hydrographs at some selected cross sections (that is, cross section at the dam, immediate cross section downstream of the dam and at the end of the river channel) as typical results.

The dam break was simulated using estimated breach parameters with breach width of 130.86 m and breach time of 1.45 hours. It can be observed that at the location of the reservoir, the water surface elevation suddenly rises as a result of the dam break occurrence and then drops to a level of approximately 277 m after about eight (8) hours. The stage remains at this magnitude for a period of 84 hours and beyond. On the other hand, the magnitude of the flow rate increases correspondingly from a value of 370 m^3/s to a maximum value of 1900 m^3/s during a period of approximately 18 hours before reducing to a value of almost zero after a period of 76 hours indicating the process of emptying of the reservoir immediately after the dam break occurred.

At the location of cross section below the dam structure, the water surface elevation rises to a magnitude of 277.3 m after about 18 hours as a result of occurrence of dam break before gradually dropping to a level of approximately 276.2 m after about 72 hours and beyond. It is pertinent to note that the shape of the flow rate remains virtually the same from the upstream portion that is, the dam axis towards this location.

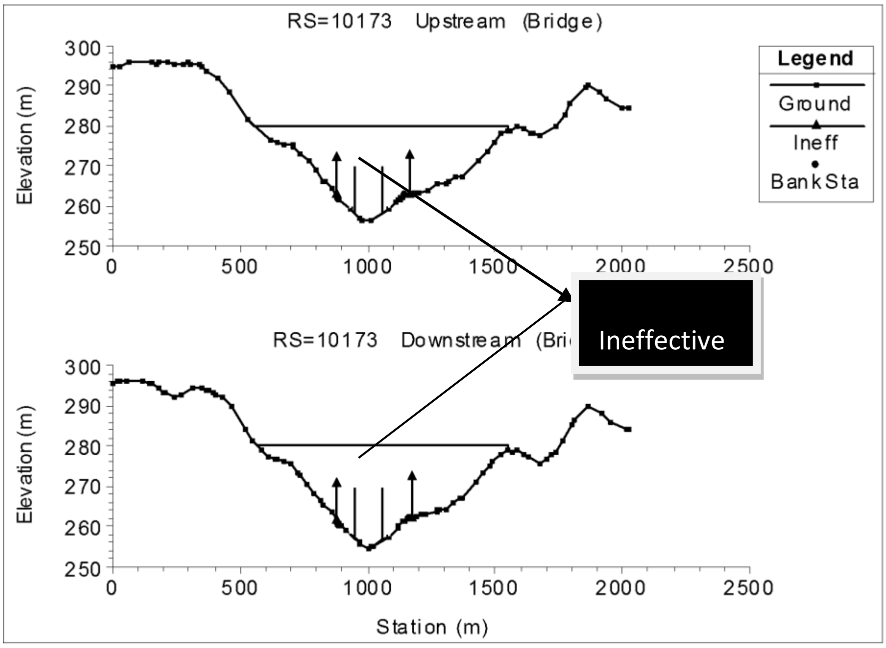

Figure 4: An Example of Bridge Bounding Cross Sections with Ineffective Flow Areas

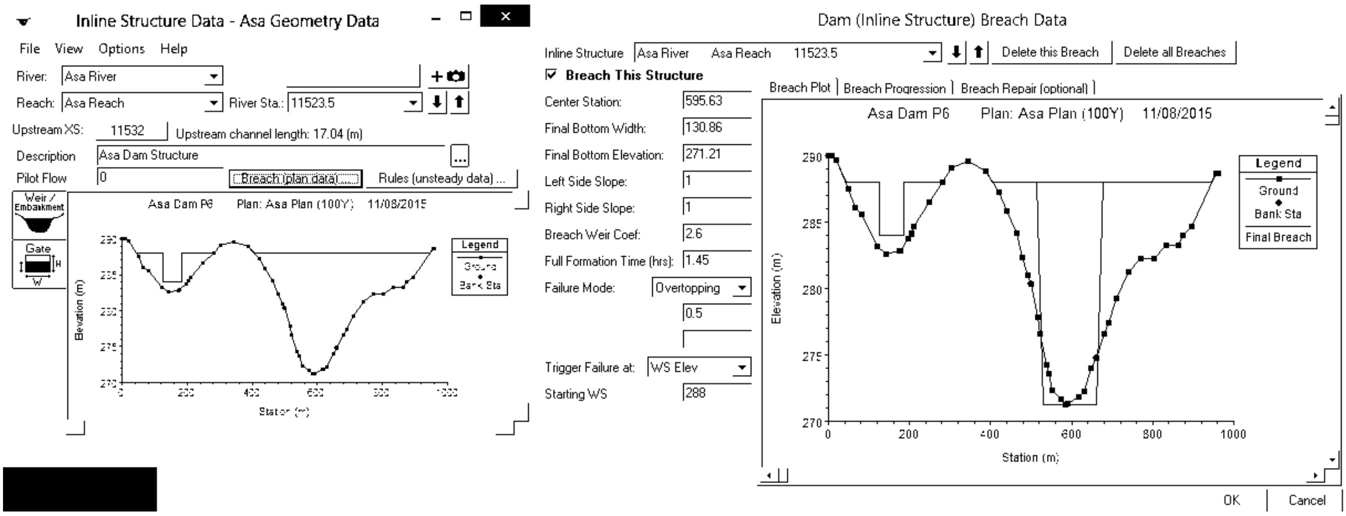

Figure 5: Asa Dam Model and Estimated Breach Parameters Figure

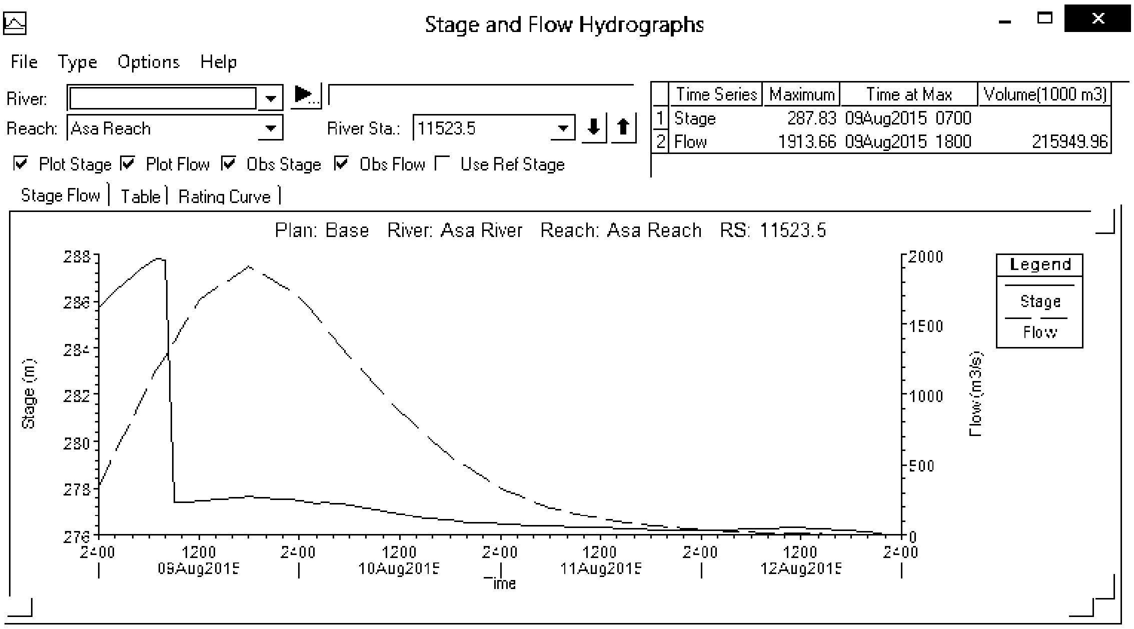

Figure 6: Plot of Water Level and Discharge versus Time at the Reservoir Location

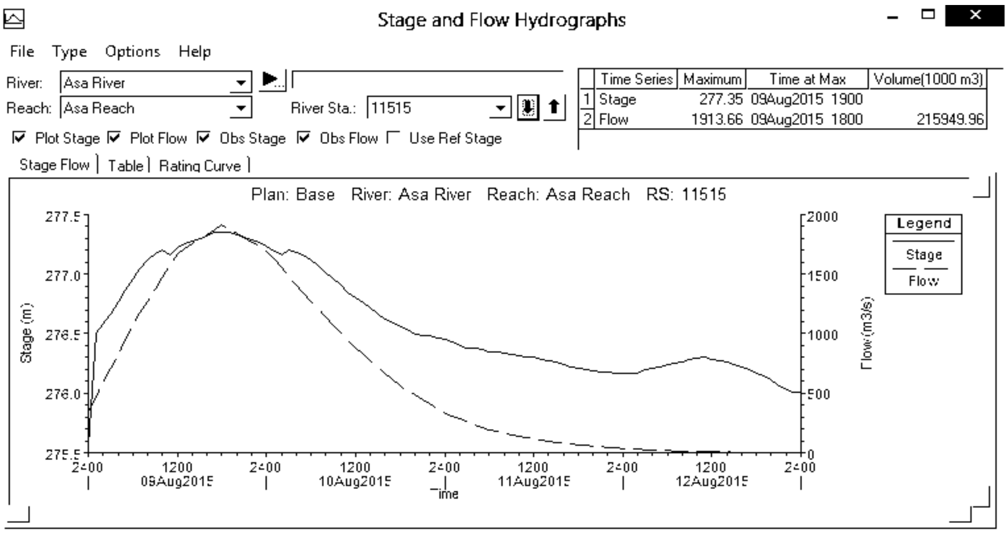

Figure 7: Plot of Water Level and Discharge versus Time at the Cross Section Immediately Below the Dam Structure

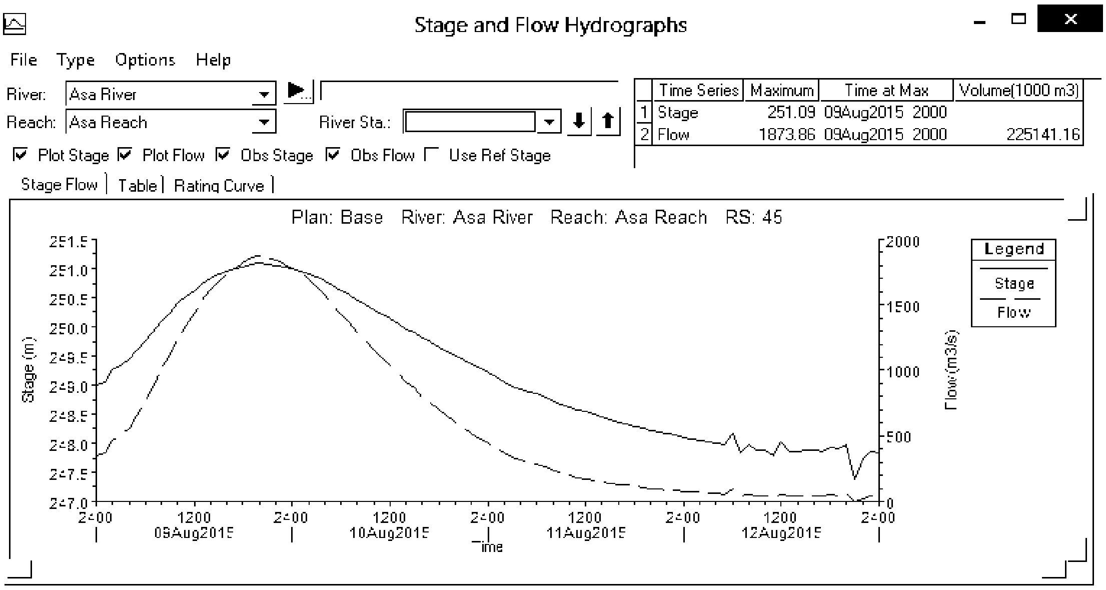

Figure 8: Plot of Water Level and Discharge versus Time at the Downstream End of the River

However, the magnitude of the peak flow maintains a value of 1900 m^3/s which does not show any significant difference in the flow rates. At the location of cross section downstream end of the river, the water surface elevation rises to a magnitude of 251 m after about 20 hours as a result of occurrence of dam break before gradually dropping to a level of approximately 248 m after about 72 hours and beyond. It is pertinent to note that the shape of the flow rate remains virtually the same from the upstream portion that is, the dam axis towards all locations within the channel. However, the magnitude of the peak flow reduces from 1900 m^3/s to 1800 m^3/s. The difference in the flow magnitude results in the spread of water with these two (2) locations.

The simulated results reached peak discharge of 1913.66 m^3/s with a flow velocity of 3.45 m/s at the immediate cross section after the dam. The maximum discharge at the lower end, 11.5 km away from the dam was 1873.89 m^3/s with a velocity of 1.67 m/s. It is very obvious that there is a small reduction in the peak discharge and it is caused by the steep river slope and the narrow cross sections. A milder slope, an increased roughness or a widening of the cross sections would have increased the flood wave attenuation and the difference in value approximately 39.77 m^3/s or 2.08 % reduction accounts for the spread of water within the area under consideration.

6. CONCLUSION

In this study, complete hydraulic simulation and analysis for a hypothetical dam break of Asa dam was performed using United States Army Corps of Engineers (USACE), Hydrologic Engineering Center's River Analysis System (HEC-RAS) computer model. The simulation was analysed with 100 year return period flow event which was selected to illustrate severe event scenario. The highest discharge Q (1913.66 m^3/s) and the highest peak stage (277.35 m) just below the dam were produced by breach width of 130.86 m and time of failure of 1.45 hours. The outcome of the analysis showed that in the event of failure of Asa dam, some areas which include industrial and residential areas were identified to have very high risk of being inundated due to the significant difference in the value of water surface elevation and ground elevation. The proper analysis of the hazards associated with dam failure will assist in land use planning and in developing emergency response plans to help mitigate catastrophic loss to human life and property.

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