



HYDRAULIC ASSESSMENT FOR SIGHTING A CONCRETE WEIR ON OGBESE RIVER FOR IRRIGATION

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Abstract

Weirs are constructed along river channels to create sufficient head for water pumps or diversion. Weir location requires gorge section with steep channel side slopes to prevent overtopping of the section during peak river flows. Hydraulic investigations were conducted to determine the capacity of an existing failed weir section and new weir location to accommodate a 2-year, 25-year, and 50-year return period flood. Aeronautical Reconnaissance Coverage Geographic Information System (ARC-GIS) and Hydrological Engineer Center - Hydrological Modeling System (HEC-HMS) were used for rainfall-runoff modeling to generate peaks river flows. Hydrological Engineer Center – River Analysis System (HEC-RAS) was used to simulate river flow cross-sections. Watershed area was delineated in Digital Elevation Model (DEM) and ARC-GIS. The predominant land use/cover is forested area which is 64.8% of the watershed area. Built-up area contributed 13.1% of the watershed area. Sandy clay loam is the predominant soil type. 2-year return period river flow was accommodated in the banks of the new weir location but breached the right bank at the failed weir section. 25-year return period flood was accommodated within its banks of the new weir location but breached both banks at the failed section. 50-year return period flood minimally breached both banks of the new weir location. The new weir location was therefore recommended with rip-rap construction 10 m from both the left and right bank new weir location.

Keywords: Weirs, irrigation, return period, watershed, flood

Introduction

Irrigation is critical to both food production and food security and in the recent decades, significant advances have been made in irrigation efficiency in the sub-Saharan African region (Darko et al, 2020). Irrigation development is considered one of Nigeria's critical choices for agricultural growth. In Sub-Saharan Africa (SSA), food production is almost entirely rain-fed with irrigation playing very little role (Kadigi *et al.*, 2013). Most of Nigeria's crop production is rain-fed; irrigated agriculture only makes up about 1% of the nation's total area under cultivation. Because of this rain-fed agriculture, crop production in Nigeria is susceptible to intra-annual and inter-annual climatic variations (Xie *et al.*, 2017). There is need for irrigation reservoirs created by dams and weirs. According to Singh & Kumar (2022), dams are versatile structures that provide water for irrigation, transportation, hydroelectric power generation, industrial use, and flood control. Weirs are special types of dams; they are smaller and are often constructed over a river to regulate the upstream

water level. A weir is a structure built across a river to raise the water level so that it can be channeled into off-taking canals. Weirs are typically built on perennial rivers that flow adequately throughout the year, eliminating the need to build a storage reservoir (Doko *et al.*, 2016). According to Vanishree & Manjula (2018), weir structures are used in channel flow, and storage applications for flow estimates, flow redirection, and discharge management, and they are frequently designed for flow conditions. The Benin-Owena River Basin Development Authority built a weir on the Ogbese River at Iju town Ondo State in 2012. The weir's features included a height of 1.2 metres, a length of 12 meters, and a crest width of 1 meter. This weir, which has since failed, is about 8 kilometers from the Iju main town. The failed weir was intended to supply water for farm irrigation especially during dry-season farming. It is crucial to note that hydraulic factors contributed to the failure of the weir. It is pertinent to avoid the same mistakes while appraising to determine the causes of failure at existing weir section and designing a new weir.

The aim therefore is assessment of concrete weirs on Ogbese River in Iju town to determine the capacity to contain overtopping during extreme river flows. This was achieved through rainfall-runoff simulation and hydraulic design of weir locations.

Materials and Method

Description of Study Area

The proposed reinforced concrete weir is at Iju, Akure North LGA of Ondo State. The town is about 19 km from the capital city of Ondo State, the town falls under southern Nigeria's tropical savanna climate, characterized by two distinct wet and dry seasons of six months each. The wet season usually begins in April and lasts until November. While the dry season span from October to March of each year. The major economic activity of the proposed project host community is agriculture. The farmers in the community are mostly peasant farmers, mainly engaged in arable crops and some cash crops farming. Some of the arable crops grown include; Tomato, Yam, Cassava, Maize and Cocoyam. Their major cash crops are; Cocoa, Cola-nut, Tobacco and Coconut. Other economic activities include lumbering and rearing of domestic animals. The town is an underdeveloped community with a few social amenities. There is no pipe-borne water. The major sources of their domestic water supply are; shallow wells, few deep

Resources Conservation Service Number (NRCS-CN) NRCS-CN was used to determine the maximum expected flood of the stream for return periods of 2, 25 and 50 years of the river. The curve number (CN) model is very popular for simulating rainfall-runoff. It is the simplest globally tested model with rich literature and well-documented use that accounts for the essential runoff-generating characteristics of watersheds, such as LULC, soil type, hydrologic soil group, and antecedent soil moisture condition (Oliveira *et al.*, 2016, Walega *et al.*, 2020, Zhang *et al.*, 2018, Ajimal *et al.*, 2023).

Watershed Delineation

The watershed area drained by the reach of the weir location was delineated as a lumped hydrological response unit. A 30m Digital Elevation Model (DEM) - the ALOS Global Digital Surface Model (AW3D30) - processed on the Arc-Geographic Information System (ArcGIS) interface was used to delineate the watershed area and generate the stream network. The weir locations were the outlets of the watershed. An outlet is a pour point from which water flows out of the watershed area. This is usually the lowest point along the boundary of the drainage basin. The drainage divide defines the boundary of the watershed and the area within this boundary contributes runoff to the outlet (see Figure 1).

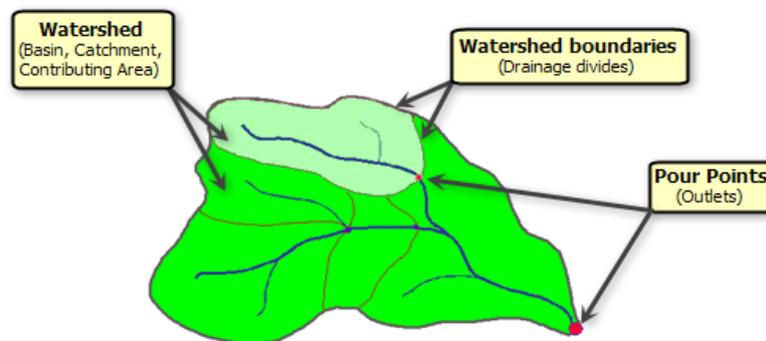


Figure 1: Watershed Components; Boundary and Pour Points

wells and streams. The irrigation farm is located between $5^{\circ} 26'0''$ and $5^{\circ} 29'0''$ latitude and $7^{\circ} 9'0''$ and $7^{\circ} 11'0''$ longitude, and about 8 km away from the center of Iju Township. The weirs are located on river Ogbese and adjacent to the irrigation farm.

Hydrologic Analysis

The watershed drained by the streams in the area was delineated using ArcGIS software. In addition, the maximum flood was determined to design the head work capable of withstanding any disaster that could be caused by the peak flood, which may come in 25 and 50-years return period. The United States Department of Agriculture (USDA) Natural

HEC-HMS Model

HEC-HMS has three input components: (i) a basin component, which describes the different elements of the hydrologic system (sub-basins, channels, junctions, sources, sinks, reservoirs and diversions) including their hydrologic parameters and topology, (ii) a meteorologic component, which describes space and time, of the rainfall event to be simulated, and consists of time series of rainfall at specific points or areas and their relation to the hydrologic elements, (iii) control specifications component, which defines the time boundary for the rainfall event and for the calculated flow hydrograph (Olivera and Maidment, 1999;

USACE, 2000). HMS model requires hydrological data, background maps (sub-basin and river network), LULC map, Soil map, curve number grid map, base flow, routing parameters and meteorological data. The Curve Number (CN) parameter of the Soil Conservation Service (SCS) was computed from soil and LULC classifications of the Ogbese river watershed. The CN parameter is dependent on LULC, hydrologic soil group based on the soil texture, and antecedent moisture condition.

Bathymetric survey

Bathymetric survey was conducted at an average interval of 250 m from new weir location. The selected weir cross-section for design was benchmarked Section1 and it is a suitable gorge, 274 m downstream of the failed weir section (Section 2). The underwater depth profile of the river was taken at transverse lines drawn perpendicular to river alignment. The banks are steeper than the floodplains with ground bank stations marked with red dots. Floodplains plot limits are 25 m from river channel centre line on left and right bank.

Hydraulic Analysis

Geometric data in HEC-RAS model was generated from Arc-GIS. The flow path center line was established for the river. The flow path center line defines the central flow direction of the river. Five sections (including the failed weir section and new weir location) called river stations were established along these center lines and were given altitude

from bathymetric survey data. The limits of the flood plains were established as offsets on both sides of the center line. Transverse lines were drawn on the river stations and across the river. The lines were drawn perpendicularly to the river's flow direction (from upstream, to downstream). Flood plain cross-sections were extracted from the altitude values of these transverse lines spaced at interval of 250 m. Manning value were associated to land use and land cover classification the transverse lines intercepts (ranging from 0.025 – 0.035). Peak discharge values were generated for the river stations using HEC-HMS model. In order to run the flood simulation HEC-RAS, steady flow analysis was used for hydraulic analysis. The resulting cross-sections of flow generated were verified.

Results and Discussion

Watershed Delineation

The watershed with outlet at the new weir location in Iju is shown in Figure 2. The watershed is a sub-watershed of Ogbese river. The area delineated is 1224 m². The highest elevation at the divide is 747 m and lowest at pour point is 298 m. The average slope of watershed is 3.2% and river bed slope is 0.27%.

Geospatial datasets of Sentinel-2 10m Land Use and Land Cover map was generated for the watershed drained at the weir location and shown in Figure 3. Five LU/LC classifications were generated as shown in the legend. Forested area was the predominant LU/LC with 64.8% and built

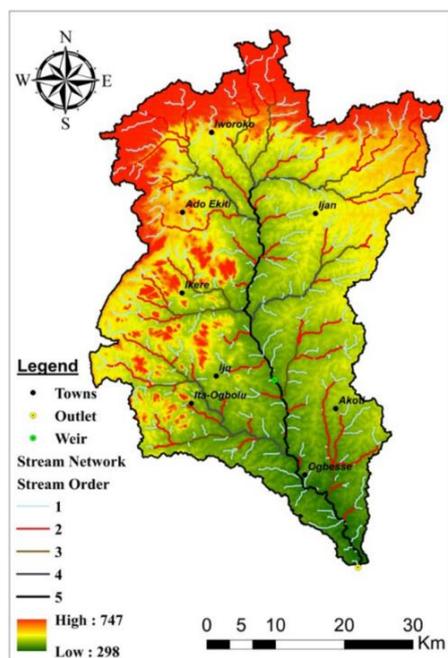


Figure 2: Ogbese Watershed with Outlet at New Iju Irrigation Weir

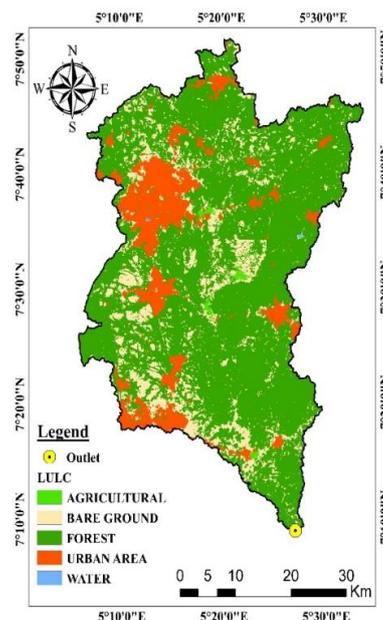


Figure 3: Land Use and Land Cover Map for New Iju Irrigation Weir Watershed

area of 13.1%. A high forested area and low built-up area implies lower surface runoff value and low curve number value in HEC-HMS model.

Food and Agriculture Organization of the United Nations digital (FAO) soil map was overlaid on the watershed and was extracted for the soil map of the watershed. This map shown in Figure 4 indicates that Sandy Clay Loam soil type is predominant. This soil type has an average infiltration rate of 12 mm/hr. This moderate infiltration rate implies relatively lower curve number and low surface runoff.

Hydrology and Hydraulic redesign of weir

The weir for irrigation water head has to be relocated in a river cross-section that has stable and steep abutment that will guarantee overtopping does not occur for a flood hydrograph of 25 and 50

years return period. Steady flow analysis in HEC-RAS model was used to generate the geometry of flow. 0.02 and 0.035 manning’s values were assigned for the channel and floodplains respectively. The channel is of earth material with rock outcrops in some places while the floodplains are low-height vegetation. The depth of flow should be below the bank depth for 25 and 50 years return periods floods.

Over-Topping at failed section using 2 years Return Period Flood

Figure 5 shows the 24 hours duration of 2 years return period flood hydrograph. The peak river flow simulated was 60 m/s³. The simulated river flow rate was routed through river reach and the river stage generated is 3.4 m cross-section at Failed Weir Section (see Figure 6).

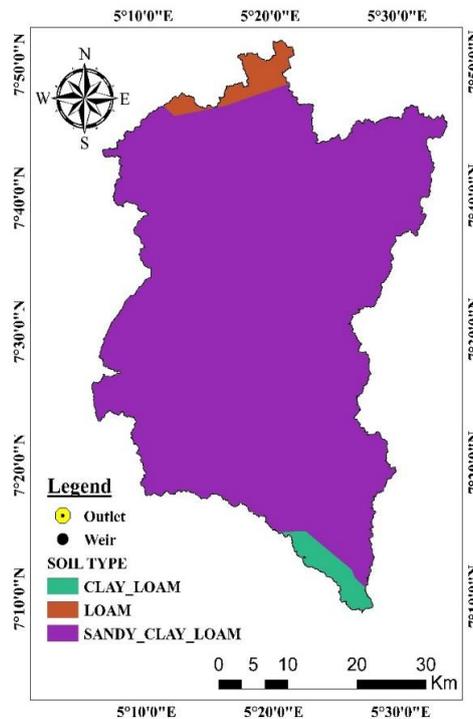


Figure 4: Soil Map for New Iju Irrigation Weir Watershed

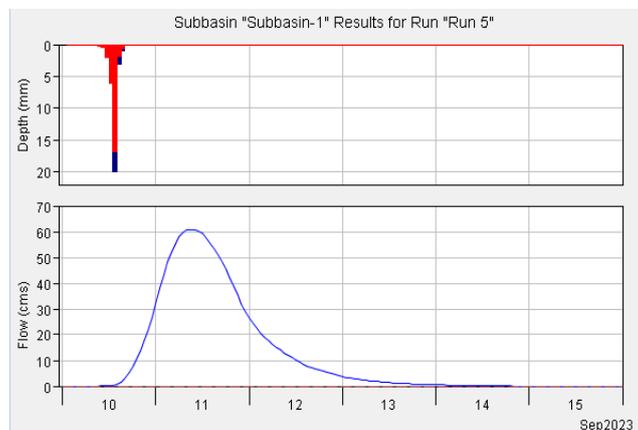


Figure 5: River Hydrograph for 2-year return period rainfall

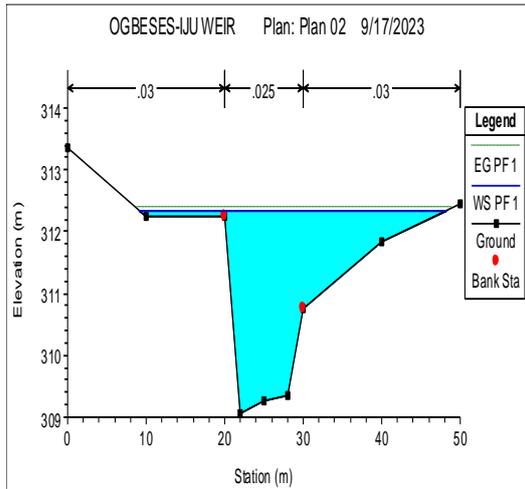


Figure 6: River Cross-section at Failed Weir Section for Regular 2-year Return Period Rainfall

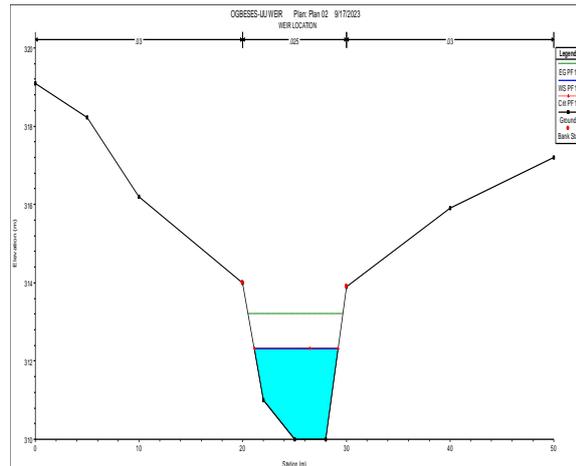


Figure 7: River Cross-section at New Iju Weir location for Regular 2-year Return Period Rainfall

The ground bank stations of the river marked with red dots were overtopped. The right bank was the most vulnerable with 18 m length from the bank inundated. The existing weir failed due to flat floodplains and over-topping from low-intensity 2-year return period rainfall. Provision of protective materials of rip-rap, gabions or geo-grids for the floodplains will be extensive and expensive as the length to be covered will be too long especially at the right bank. Flow was well within the banks for new weir section with stage height of 2.1 m (see Figure 7).

Check for Over-Topping using 25 years Return Period Flood

Figure 8 shows the 24 hours duration of 25-years return period hyetograph and consequent flood hydrograph. The peak river flow is 148 m³/s. The simulated river flow rate is routed through river reach. The river stage indicates a flow depth of 3.82 m at the new weir cross-section in Figure 9. River flow is within the ground bank limit. The failed weir section has both banks overtopped by 25 years return period flood as shown in Figure 10. It has an inundation height of 1.6 m at the floodplain plot limit of 25 m from the centerline of river. Bank and floodplain protection for cross-section that will

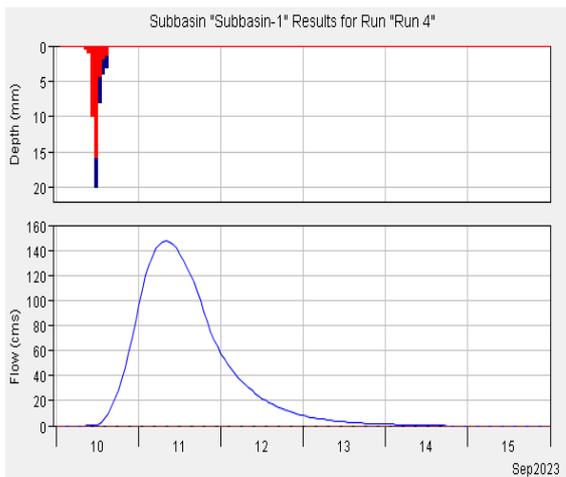


Figure 8: River Hydrograph for 25-year Return Period Rainfall

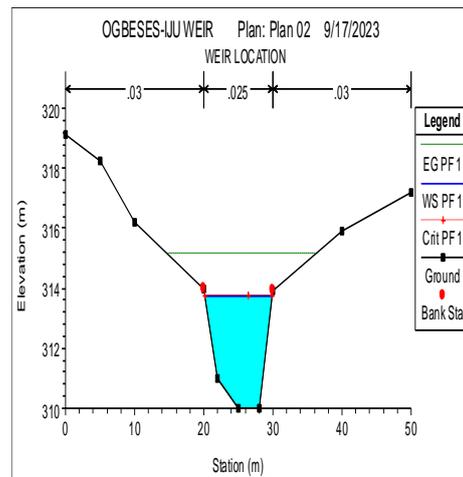


Figure 9: River Cross-section at New Iju Weir Location for 25-Year Return Period Flood

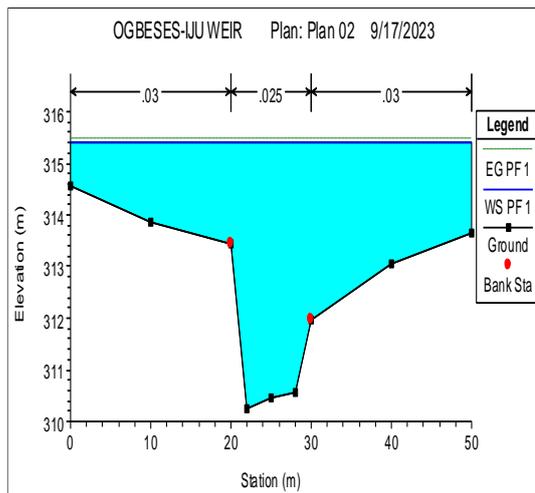


Figure 10: River Cross-section at Failed Weir Section for 25-Year Return Period Flood

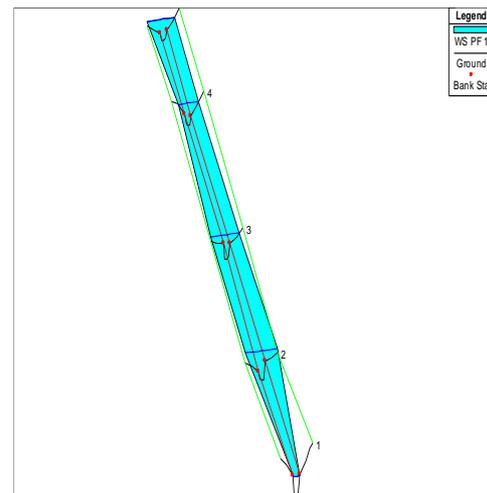


Figure 11: X-Y-Z perspective plot for 25-Year Return Period Flood

accommodate the flow would not be cost efficient hence the siting of a new weir location. Figure 11 shows the X-Y-Z perspective plot for 25-Year Return Period Flood. The banks were breached for all other sections with exception of the newly selected weir location.

Check for Over-Topping using 50 years Return Period Flood

Figure 12 shows the 24 hours duration of 25 years return period hyetograph and consequent flood hydrograph. The peak river flow simulated was 326.6 m/s³. The simulated river flow rate was routed through river reach. The river stage indicates a flow depth of 5.9 m at the new weir cross-section in Figure 13. River flow breaches the ground bank limit. The new weir section has its bank overtopped by 50 years return period flood as shown in Figure 13. The steep flood plains can still accommodation

flow at a distance of 9.8 m and 10.15 m from both left and right respectively. It has an inundation height of 2.1 m and 2.3 m at both left and right banks respectively. Bank and floodplain protection for 50 years return period flood would not extensive and costly. Figure 14 shows the X-Y-Z perspective plot for 50-Year Return Period Flood. All the banks were breached with limited inundation at new weir location.

Conclusion

- a. The watershed delineation generated an area of 1224 m² with predominant LU/LC classification of forests, and predominant soil type of sandy clay loam. The LU/LC classifications and soil types generated curve number of 75 for the watershed river flow simulation. Average watershed slope is 3.2 % while average longitudinal bed slope is 0.27%.

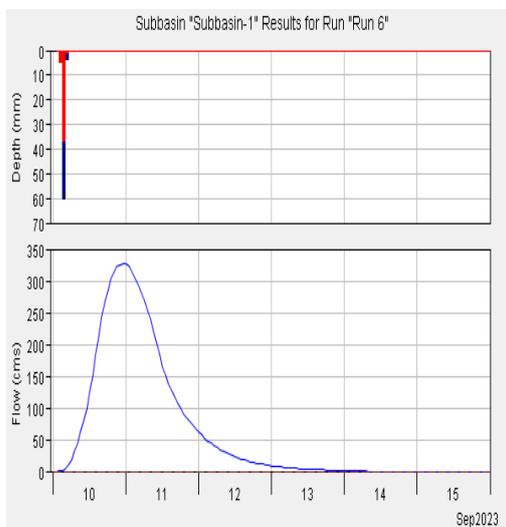


Figure 12: River Hydrograph for 50-year Return Period Rainfall

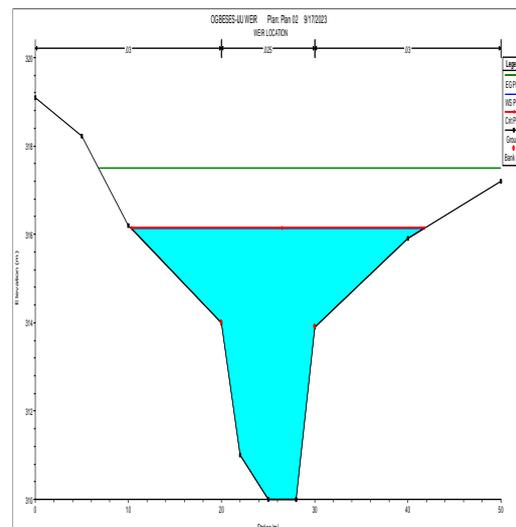


Figure 13: River Cross-section at New Iju Weir Location for 50-Year Return Period

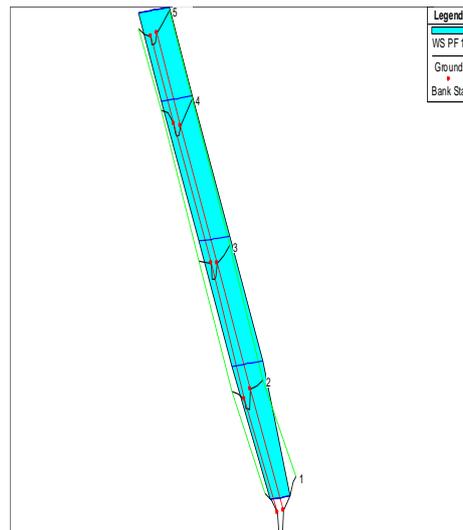


Figure 14: X-Y-Z perspective plot for 50-Year Return Period Flood

- b. Peak discharge generated for regular rainfall of 2 years return period was $60 \text{ m}^3/\text{s}$. For 25 and 50-years return periods, 24-hour duration rainfall $147.7 \text{ m}^3/\text{s}$ and $326.6 \text{ m}^3/\text{s}$ was simulated as peak discharge. This peak flow was used to perform hydraulic analysis at new weir river reach to check for bank overtopping at both the failed section and newly sited weir location. The banks of the failed weir section were breached for 2 years, 25 years and 50-years return period floods. The new weir location cross-section accommodated the 2 years and 25 years return period floods but had its banks breach nominally with 50-years return period flood. The new weir location was therefore recommended.

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