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Hydrological Analysis of Stream Flow, Velocity, and Cross-Sectional Dynamics of River Benue at Jimata Bridge

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Abstract

This study examines the stream turbulence, stream power, and cross-sectional dynamics of the River Benue at Jimeta Bridge over three dates: May 12, 2024, July 27, 2024, and August 25, 2024. The aim was to assess the river's hydrological behavior, focusing on stream flow, velocity, and cross-sectional characteristics, and to understand their implications for river management and ecological stability. The study employed a quantitative approach involving field measurements and calculations. The research integrates secondary data to explore the river's hydrological behavior. Field data were collected using equipment such as the SK 100 suspended Derrick and current meter, measuring stream flow discharge, velocity, and cross-sectional profiles. Discharge was calculated using the formula $Q = A \times v$, velocity, and depth were measured using a flowmeter and depth gauges at specified intervals. The Froude number was calculated to classify the flow regime as sub-critical, super-critical, or critical. Stream power was computed using the formula: $\omega = \rho gdvs$. Cross-sectional measurements were taken to determine changes in flow depth and velocity over the study period. On May 12, 2024, the Froude number was 0.72284, indicating a sub-critical flow regime with a moderate stream power of 891.59667 J/m²/s. The flow depth was 1.56875 m, and the velocity was 0.289 m/s. By July 27, 2024, the Froude number decreased to 0.1844, suggesting a continued sub-critical flow. The stream power increased significantly to 152,224.54 J/m²/s, with a flow depth of 62 m. On August 25, 2024, the Froude number was 0.1406, confirming sub-critical flow. The stream power was high at 12,819.47 J/m²/s, with a flow depth of 2.296 m and a velocity of 0.660741 m/s. The study reveals a consistent sub-critical flow regime throughout the observation period, suggesting stable and calm river conditions. However, significant variations in stream power highlight the river's potential for geomorphic changes and erosion, especially during periods of high stream power. Cross-sectional dynamics demonstrate how variations in flow depth and velocity affect stream power and sediment transport capabilities. Continuous monitoring of stream flow, velocity, and cross-sectional dynamics is essential for understanding the river's behavior and predicting potential changes. Regular data collection will allow for timely adjustments to management practices and infrastructure maintenance. Establishing a real-time monitoring system for stream power and flow conditions provide valuable information for flood forecasting and response.

INTRODUCTION

Stream flow, or discharge, is the volume of water moving past across-section of a stream over a set period of time (Volunteer monitoring facts series 2016). It is usually measured in cubic feet per second or meter cube per second (Chen, 2023). The channel discharge is the volume of water flowing through a given channel cross-section in a given time (Robert, Hirsch & john 2024). The flow rate or discharge of a river is the volume of water flowing through a cross-section in a unit of time and is usually expressed as m^3s^{-1} (Kuusisto 1996). It is calculated as the product of average velocity and cross-sectional area but is affected by water depth, alignment of the channel, gradient and roughness of the river bed (Jamie & Richard, 2023).

Stream flow is affected by the amount of water within a watershed, increasing with rainstorms or snowmelt, and decreasing during dry periods (Xinzhong, Greg & Monireh, 2020). Measuring the flow of water is an easy task when you have a controlled environment such as a pipe or a flume (Smith, 2020). There are precision instruments that measure flow in these controlled environments such as venture meters (Jones & Davies, 2021). These situations involve steady, uniform flow, and idealized conditions (Brown et al., 2022). In real-world situations, there is the added complication that flows can be no uniform and unsteady Peters & Rogers, 2019).

A number of different methods have been developed to measure discharge. These can be grouped into instantaneous measurements, where discharge is measured at a particular point in time (Anderson, 2021), and continuous measurements for a record of discharge variations through time (Evans & Clark, 2023). Discharge increases with the area of the channel cross section and with the velocity of flow (Nelson & Baker, 2024). Fall (2015) remarked that, hundreds of thousands of stream flow measurements are done every year. They can be done on a wide array of water body discharges, from still waters to floods. Since the flow velocity varies at different points in a stream cross section, calculating the average velocity at many points within that cross section is highly recommended. He also said that, there are numerous methods for measuring volumetric flow rate/discharge and linear flow velocity in a water body. These include: - Floating markers, Tracer dilution, Mechanical current-meters, Drogues, Acoustic current meters and Laser Doppler meters. According to Thomas and Goudie (2020), stream power is the rate of energy expenditure inflowing water. The energy possessed by flowing water is held virtue of elevation above some base level towards which the water can flow, and the elevation of water above this in turn is derived from the solar-driving atmospheric processes that left water vapour and delver precipitation over the land. Along a stream potential energy is progressively transformed in to other forms, notably the kinetic energy of the flowing mass, together with energy dissipated as fractional heat, sound, and in moving sediment particles.

Flow is important because it defines the shape, size and course of the stream (Nelson & Baker, 2024). It is integral not only to water quality, but also to habitat (Johnson & Lee, 2016). Food sources, spawning areas and migration paths of fish and other wildlife are all affected and defined by stream flow and velocity (Gibson & Williams, 2020). Velocity and flow together determine the kinds of organisms that can live in the stream (some need fast-flowing areas; others need quiet, low-velocity pools) (Parker & Lewis, 2023). Different kinds of vegetation require different flows and velocities, too (Clark, 2016). Discharge data enable populations to distribute and manage finite water supplies (Chan 2023). Effective water management requires accurate discharge measurements (Jones & Johnson, 2022). Discharge is a critical parameter necessary for designing hydraulic structures, evaluating aquatic habitat, and any general river or stream studies (Caliente 2019).

Hydraulics is the study of water flow in a channel. Water flow is subject to two main forces: gravity, which causes downstream flow, and fractional resistance with the bed and bank, which opposes the flow downstream (Nagle 2020). In addition, the volume of water within a channel and the shape of the channel affect the amount of energy a stream has to do its work (Barnes & Mitchell, 2018). In addition, water flow is not steady or uniform (Stone, 2017). It is turbulent, chaotic and eddying (Williams, 2020). Turbulence provides the upward motion in the flow which allows the lifting and support of fine particles (Harris, 2019). By contrast, laminar flow is the movement of water in a series sheets or laminae (Kendrick, 2021). It is common in groundwater and in glaciers, but not in river. The conditions necessary for turbulent flow to occur are: complex channel shapes such as meandering channel and alternating pools and riffles, high velocity, cavitation in which pockets of air explored under high pressure (Fletcher, 2022). When water velocities are low, turbulence is reduced and not readily visible to the eye (Martin, 2020). As water level rise, mean velocity increases, the hydraulic increases, and the stream appear more turbulent (Spencer, 2024). Turbulence is therefore the product of channel roughness and velocity (Jackson & Moore, 2015). Moreover, fraction creates an uneven distribution of velocity in a stream (Hughes, 2019). Water closest to the bed and bank travels slowest; water nearest the center travels fastest (Sutherland, 2021).

METHODOLOGY

The Study Area

Yola, the headquarters of Adamawa state comprised of Yola North and South Local Government Areas. It is located between latitudes 09°15′ N and 09°20′ N and longitudes 12° 25′ E and 12°29′ E (Figure 1) with an elevation of 135m above sea level (Figure 1). It covers a land area of about 2189km^2 (Adebayo, Tukur & Zemba, 2020).

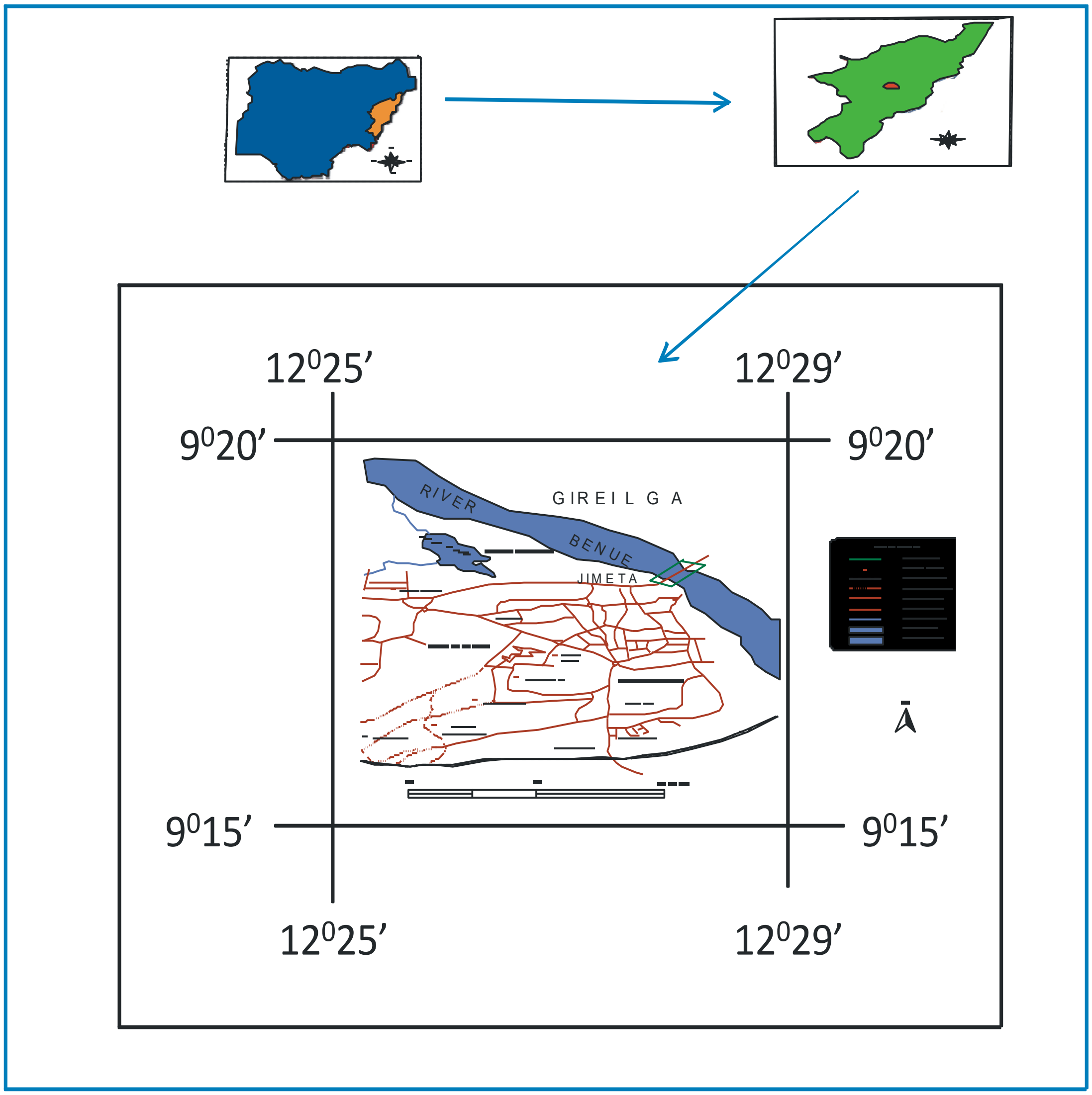

Figure 1: The Study Area

Data Type and Sources

For the purpose of this study, the quantitative data were obtained from the field at the river site which included data on current morphometric properties of the river channel at selected stations.

Materials/Equipment Used

Equipment required for field measurements of stream flow discharge included complete instrument for discharge measurement (SK 100 suspended Derrick, sinker weight, revolution counter, Bray Stock, fish tail and tools) (plate 1), Inventory checklist, Sample ID forms (sampling information and identification) and labels, G. P. S., Camera, Protective clothing, Tools (hammer, spanner, axe, knife, etc.), First aid kit, Boat, and Personnel.

Plate 1: SK 100 suspended Derick, Sinker weight, Revolution counter, Fish Tail, Winch, Rod and thread, Boat and Braystock. Source: Fieldwork 2024

Sample Procedure for Discharge Measurement

The sampling technique used was area sampling technique through equal increment of width (IIL), using the same transit rate for all verticals and the same bill along the same cross-section (Gilbert, 1987). Stratification was used where the cross-section of the river was divided in to 32 sections (5m) each with their distinct boundaries because the width of the river that contained water was 160m. After dividing the cross-section into 32 sections or units, the use of systematic sampling technique was adopted for the whole cross-section. Using the above discharge procedure, river discharges at the Benue Bridge were obtained in both dry and rainy seasons of the 2024 hydrological year.

Method of Data Collection for Discharge Measurement

River discharge measurements at sample stations were carried out using the Boat Method (plate 2). This method is normally suitable in situations where there is no bridge, where the bridge is too high from the river, or when the flow depth is in excess of 2m. The channel's cross section at the sampled station was divided into 32 sections at 5m interval. Then at each section, flow velocity and flow depth were measured using the current meter and sinker weight. The discharge was then determined from the measurement note as provided in section.

Plate 2 Boat method
Source: Fieldwork 2024

Methods of Data Analysis

Cross-sectional area (A) was obtained by taking sounding below the water level at interval of 5m, plotting the profile of the cross-sectional area and drawing the high flood level or water surface level measured in meters per second (m/s). The data used for plotting the cross-section of the river were the Distance (m), Depth in meters (m) of the river at the given distance, and the elevation of the water at the given distance and depth in meters. This was obtained at the installed gauge station in the river. Discharge was calculated for a given channel cross-section by measuring its cross-sectional area and the mean flow velocity: $Q = A \times v$, Where Q = discharge, A = cross-sectional area and v = mean flow velocity (Ro 2008). According to Upper Benue River Basin Development (2024), the below Discharge Measurement Computation Notes-Q was used.

The river discharge values were computed using the following discharge measurement note: Mean revolution was obtained by adding the revolution per second and divide by two. Mean revolution per second was obtained by dividing the mean revolution by sixty seconds (60s). Velocity at point was obtained by taking the reading from the BMF 001 or 002 charts. Mean in section was obtained by adding figures at point vertical number 1 and 2 and divide by 2. Area of section (m^2) was obtained by adding the figures of depth for (vert. no. 1.and 2 then divide by 2 and multiply by the width). Discharge (Q) m^3s^{-1}. is obtained by multiplying the mean in section (m^2) by the Area of section (m^2). Total discharge was obtained by adding all the Discharge (Q) m^3s^{-1}. Total Area was obtained by adding all areas (m^2). Mean velocity was obtained by adding the velocity at point and divided by the numbers. Cross-sectional area (A) was obtained by taking sounding below the water level at interval of 16m, plotting the profile of the cross-sectional area and drawing water surface level measured in meters per second (ms^{-1}).

The data used for plotting the cross-section of the river were the Distance (m), Depth of the river at the given distance and the elevation of the water at the given distance. River discharges values for both dry and rainy seasons were obtained from computation of obtained data as follows: - $Q = \bar{v} A$, Where Q is Discharge (m^3s^{-1}); $\bar{v}$ is mean velocity and A is cross sectional area of the river at the sample station.

The turbulence behavior of the river for both dry and rainy seasons were determined using the Froude Number (F_r) expressed as:

$F_r = \frac{v}{\sqrt{dg}}$ Where v = flow velocity, d = flow depth, g = gravitational acceleration ($9.81ms^{-1}$). If $F_r < 1$ the flow is sub- critical or tranquil, If $F_r > 1$ the flow is supercritical and If $F_r = 1$ the flow is critical.

The stream power of the river in terms of energy expended per unit area as presented by Thomas and Goudie (2000) was computed as follows: $\omega = \rho g d v s$, Where ρ = density of water ($1000gcm^{-3}$, g = gravitational acceleration ($9.81ms^{-1}$), d = flow depth, v = flow velocity and s = Channel slope. If the value of ω ranges from < $1J\ m^{-2}s^{-1}$ in inter-rill flow to > $12{,}000J\ m^{-2}s^{-2}$ in riverine flood flows the latter is sufficient to move boulders meters in diameters (Leopold, Wolman, & Miller, 1995).

RESULTS AND DISCUSSION

In Table 1, the cross-sectional measurements of the River Benue at Jimeta Bridge offer important insights into the river's depth and elevation profile. The depth ranges from 0.0 meters to 3.3 meters, with the deepest points occurring approximately 64 meters from the bridge. Elevation varies from 149.918 meters to 153.218 meters above the zero level, indicating a non-uniform riverbed. These depth and elevation variations significantly affect water flow, sediment deposition, and aquatic habitats.

These findings align with similar hydrological studies on the Niger River which has shown that sediment deposits affect depth and water quality, affecting local ecosystems (Jibrin et al., 2017). Another study on the Volga River highlighted how irregularities in riverbed elevation affect water flow patterns and sediment distribution (Sokolov et al., 2019). The results from Jimeta Bridge are consistent with these observations, emphasizing how local topographic variations influence river systems. Variations in river depth affect aquatic biodiversity. Deeper areas support different species compared to shallower ones, influencing overall ecosystem health (Miller et al., 2018). Changes in riverbed topography alter habitats and affect species distribution, which is crucial for maintaining biodiversity. Accurate depth and elevation data are essential for effective water management (Kumar et al., 2019). The river's depth and elevation profile are important for infrastructure planning, including bridges and dams. Accurate measurements are necessary to ensure the stability and safety of such structures, as variations in depth affect construction and maintenance (Harris et al., 2021). The data contributes to flood risk assessments by providing insights into how water accumulates and flows. Variations in depth and elevation affect floodplain management and emergency response planning, helping to mitigate flood risks and enhance community preparedness (Smith et al., 2022).

Table 1: Cross-sectional Measurement of River Benue at Jimeta Bridge. State: Adamawa, Station: Jimeta Bridge, Zero Level: 151.166m, Water level: 2.52m Date: 12 May, 2024

S/N	DISTANCE-m	DEPTH-m	ELEVATION-m
1	10	0.0	153.218
2	16	0.8	152.418
3	32	2.5	150.718
4	48	2.5	150.718
5	64	3.3	149.918
6	80	2.4	150.818
7	96	2.0	151.218
8	112	1.8	151.418
9	128	2.1	151.118
10	144	1.8	151.418
11	160	1.7	151.518
12	172	1.3	151.918
13	192	1.5	151.718
14	208	0.7	152.518
15	224	0.7	152.518
16	240	0.0	153.218

Source: Fieldwork, 2024.

Based on Figure 2, which depicts the cross-sectional measurement of the River Benue at Jimeta Bridge, the graph indicates significant bed erosion. The deepest part of the river is now 149.918 meters, compared to the previous zero level of 151.166 meters. The area highlighted in yellow represents the section that experienced erosion, likely due to the stream flow characteristics. The total discharge was 121.1084 m^3/sec, with a total area of 373.20 m^2 and a mean velocity of 0.2809 m/sec. The discharge recorded on July 27, 2024 (Table 3), shows higher erosion, attributed to the stream flow velocity, which was greater than that recorded on May 12, 2024 (Table 1).

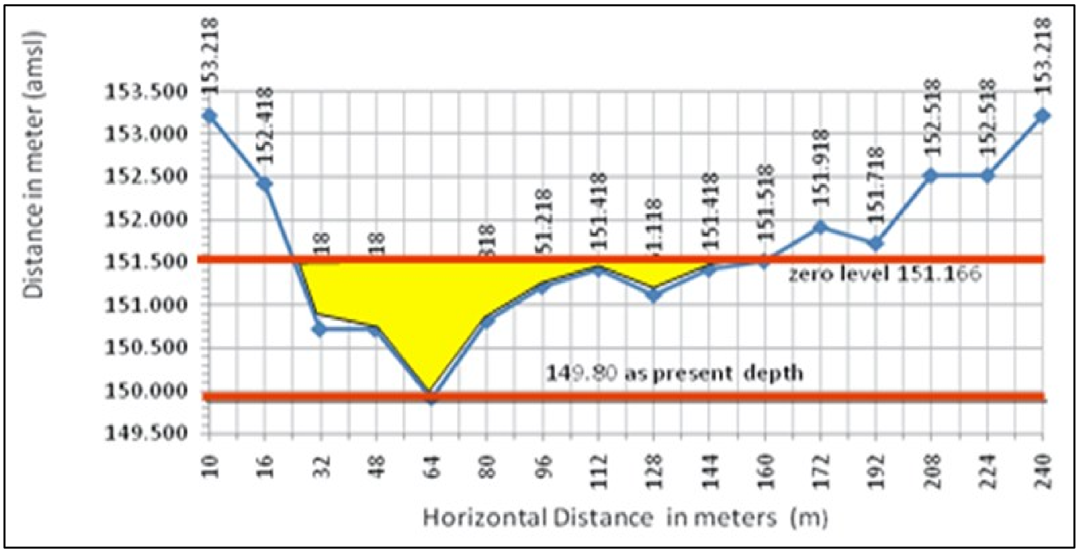

Figure 2: Graph of cross-sectional measurement on River Benue at Jimeta Bridge on 12 May, 2024. Source: Fieldwork, 2024.

Table 2 has shown that the cross-sectional measurement of the River Benue at Jimeta Bridge on July 27, 2024, provides significant insights into the current conditions river. The water level was recorded at 2.52 meters, with the zero level set at 151.166 meters above sea level (masl) (Upper Benue River Basin Development Authority, 2024). The depth measurements varied along the distance from the initial point, ranging from 0 meters to 4.5 meters. The depth measurements at Jimeta Bridge show significant variation, with the deepest point reaching 4.5 meters and the shallowest being 0 meters. This variation can be attributed to several factors including sediment deposition, riverbed erosion, and seasonal changes. The study by Oliver et al. (2022) on riverbed changes in River Yedzeram in Mubi also highlighted similar depth variations due to sediment movement and changes in water flow. The riverbed levels ranged from 148.403 masl to 152.903 masl. This suggests considerable fluctuations in the riverbed's elevation, with some sections being significantly lower than others. A research work by Ezekiel, Sayd, and Kadmiel (2020) in Yedzeram rivers found that variations in riverbed elevation are common and often linked to the interaction between river flow and sediment transport.

The variation in water depth and riverbed levels at Jimeta Bridge indicates that the river is experiencing dynamic changes. Such variations can affect water flow patterns, sediment transport, and the overall hydrology of the river system.

According to Wang et al. (2023), fluctuating riverbed elevations can impact flood risk, water quality, and aquatic habitats. The depth variations and riverbed elevation changes influence aquatic ecosystems. Shallow areas experience higher water temperatures and lower oxygen levels, affecting aquatic life. Conversely, deeper areas serve as important habitats for fish and other aquatic organisms. Smith et al. (2022) highlights that changes in river depth significantly affect the distribution and health of aquatic species. For local communities relying on the river for water, transportation, and other activities, such depth variations and riverbed changes have practical implications. Variations in water depth affect navigation, especially for small boats and ferries. Infrastructure such as bridges and water intake structures also be affected by changing water levels and sediment accumulation. According to Eze et al. (2021), fluctuating river levels can challenge infrastructure stability and increase maintenance costs.

Table 2. Cross-sectional measurement of river Benue at Jimeta Bridge, 27 July, 2024. Water level: 2.52m, Date: 27 July, 2024, State: Adamawa, Station: Jimeta Bridge, Zero Level: 151.166m

S/N	Distance From Initial Point (M)	Depth Of Water (M)	River Bed Level (Masl)
1	078	0.0	152.903
2	102	1.5	151.403
3	114	1.0	151.903
4	126	1.0	151.903
5	135	1.9	151.003
6	144	3.4	149.503
7	153	3.9	149.003
8	162	4.1	148.803
9	168	2.5	150.403
10	177	3.3	149.603
11	186	4.0	148.903
12	195	3.3	149.603
13	204	3.1	149.803
14	213	3.4	149.503
15	219	3.7	149.203
16	228	3.4	149.503
17	237	4.5	148.403
18	246	3.3	149.603
19	255	2.6	150.303
20	264	1.7	151.203
21	276	1.5	151.403

22	285	1.2	151.703
23	294	1.2	151.703
24	303	1.0	151.903
25	312	0.0	152.903
26	318	0.0	152.903
27	510	1.5	151.403
28	537	0.0	152.903

Source: Fieldwork 2024.

The cross-sectional area of the Benue River at Jimeta Bridge in Yola, measured on July 27, 2014, in Figure 3 shows significant variations in riverbed elevation. The central part of the river, marked in yellow, indicates an eroded zone where the riverbed has been worn down to a new low level of 148.5 meters above sea level (masl), below the expected bed level of 151.166 masl. This erosion likely results from strong water currents scouring the riverbed. On either side of this eroded zone, there are raised areas where sediment has accumulated, shown by brown regions, which represent deposited particles. These deposits suggest slower water flow in these sections, allowing materials like silt and sand to settle. The cross-sectional profile extends horizontally across 318 meters, illustrating the significant changes in bed elevation caused by natural river processes. This data is crucial for understanding the river's behavior, including erosion, sedimentation, and potential implications for water management, flood control, and infrastructure stability in the area. Figure 3 showed that river Benue at Jimeta Bridge experienced reasonable amount of erosion due to the increase in the stream velocity compared to Figure 2.

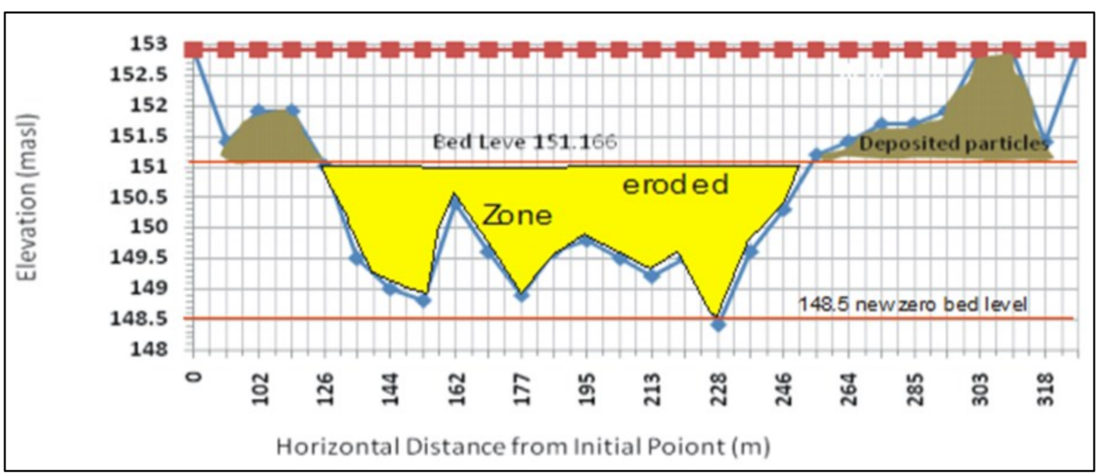

Figure 3: Graph of cross-sectional measurement on River Benue at Jimeta Bridge on 27 July, 2024.
Source: Fieldwork, 2024.

The cross-sectional measurement of the River Benue at Jimeta Bridge on August 25, 2024 in Table 3, provides a detailed profile of the river's depth and elevation across various distances from the bridge. This data reveals notable variations in river depth and elevation, which are crucial for understanding both hydrological patterns and potential environmental effects. The measurements show that river depth varies significantly along the cross-section, ranging from 0.0 meters to 7.6 meters. The elevation fluctuates from 148.516 meters to 156.116 meters. This variability suggests that the riverbed at Jimeta Bridge is uneven, with deeper channels and shallower areas interspersed throughout the stretch measured. At a distance of 54 meters from the initial point, the river depth is 0.0 meters, indicating a possible shallow or dry area. In contrast, at 151 meters from the initial point, the depth reaches 7.6 meters, which is considerably deeper. This variation is consistent with typical riverbed profiles, where depth change due to natural features such as submerged rocks, sediments, and varying flow rates. These findings are similar to a study on riverbeds which have shown that depth variability is a common feature in many rivers due to geomorphological factors Li et al., 2020; Zhou et al., 2021). Such studies highlight how riverbeds often exhibit significant fluctuations in depth and elevation, which influenced by sediment deposition, erosion, and seasonal changes in water flow. Previous studies have documented changes in river profiles over time, often linking these changes to anthropogenic activities, such as dam construction and land use changes, as well as natural factors like climate variations.

The observed depth variations are important for hydrological management and flood risk assessment. Areas with deeper depths mostly are prone to higher water volumes and potential flooding, especially during heavy rainfall or upstream Lagdo dam releases. This information can be used to improve flood prediction models and manage flood risks more effectively. Depth variability impacts aquatic habitats. Deeper sections of the river may support different types of aquatic life compared to shallower areas. Understanding these variations can help in assessing the health of riverine ecosystems and developing conservation strategies. For infrastructure projects, such as bridge construction or maintenance, knowledge of depth and elevation changes is crucial. Variability in river depth affect the stability of foundations and the design of structures, necessitating careful planning and engineering. Changes in depth and elevation also influence sediment transport and deposition patterns, which have downstream effects on water quality and habitats. Monitoring these changes is important for assessing the long-term environmental impact of river management practices.

Table 3. Cross-sectional measurement of river Benue at Jimeta Bridge, 25 August, 2024. State: Adamawa, Station: J/Bridge, Zero Level: I51.166, G. H: 4.95m

S/N	Distance-(M)	Depth.- (M)	Elevation-(M)
0	54	0.0	156.116
1	63	0.4	155.716
2	73	1.1	155.016
3	81	2.4	153.716
4	90	2.6	153.516
5	105	3.6	152.516
6	127	4.0	152.116
7	139	5.4	150.716
8	151	7.6	148.516
9	166	2.7	153.416
10	178	5.4	150.716
11	190	6.2	149.916
12	202	4.7	151.416
13	217	2.3	153.816
14	229	4.9	151.216
15	241	3.9	152.216
16	253	2.6	153.516
17	265	3.5	152.616
18	277	2.7	153.416
19	289	2.8	153.316
20	301	3.0	153.116
21	316	1.4	154.716
22	331	1.5	154.616
23	346	1.7	154.416
24	361	2.3	153.816
25	376	2.7	153.416
26	391	2.2	153.916
27	399	2.0	154.116
28	414	2.1	154.016
29	429	2.8	153.316
30	447	1.5	154.616
31	465	0.4	155.716
32	483	0.5	155.616
33	491	0.6	155.516
34	509	0.7	155.416
35	530	1.6	154.516
36	548	0.9	155.216
37	566	1.7	154.416
38	584	0.4	155.716
39	602	0.5	155.616
40	620	0.6	155.516

41	639	0.3	155.816
42	656	0.4	155.716
43	677	1.0	155.116
44	695	0.8	155.316
45	713	0.6	155.516
46	731	0.5	155.616
47	755	0.2	155.916
48	758	0.0	156.116

Source: Fieldwork, 2024.

Figure 4 illustrates that the River Benue at Jimeta Bridge has undergone a significant increase in erosion, primarily attributed to the heightened stream velocity. This erosion was more pronounced when compared to the results from the previous study conducted in July 2024, as shown in Figure 3. The accelerated stream flow appears to have exacerbated the erosion along the riverbanks, leading to substantial degradation of the surrounding landscape. This increase in velocity due to several contributing factors, such as seasonal changes in rainfall, upstream water management practices, or increased runoff from surrounding areas. In contrast, the data from July 2024 indicated a more stable flow with comparatively less erosion, suggesting a shift in hydrological dynamics over time.

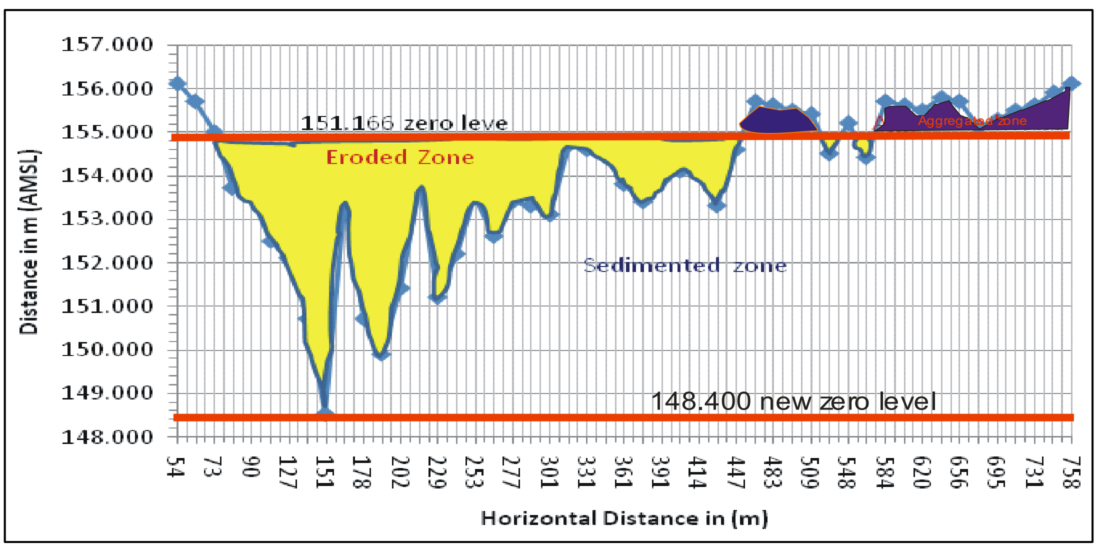

Figure 4: Cross-Sectional Profile of River Benue at Jimeta Bridge (August 25, 2024).
Source: Fieldwork, 2024.

The results for the discharge, area, and mean velocity of River Benue at Jimeta Bridge shown in Table 4 indicate notable variations over the three observed dates. On 12/5/2024, the discharge was recorded at 121.1084 m^3/s, with a total area of 373.20 m^2 and a mean velocity of 0.2809 m/s. By 27/7/2024, the discharge increased significantly to 372.26 m^3/s while the total area remained constant, and the mean velocity rose to 0.8487 m/s. On 25/9/2024, the discharge further increased to 460.80 m^3/s, with a mean velocity of 0.6607 m/s. These results reflect significant temporal changes in the river's discharge and velocity, which attributed to seasonal variations, such as rainfall and runoff patterns. The increase in discharge and velocity from May to September suggests a higher flow rate, due to increased rainfall or upstream water contributions during the rainy season. This aligns with findings from a study on spatiotemporal changes in the channel hydromorphology of river Yedzeram section and its impacts in surroundings, north east Nigeria by Kadmiel and Malgwi, (2024) which indicate that river discharge and velocity often fluctuate with seasonal changes in precipitation.

The implications of these results are significant for both environmental management and local communities. Higher discharge and velocity affect riverbank stability, increase erosion, and potentially lead to flooding. The observed variations suggest a need for enhanced flood management strategies and regular monitoring to mitigate potential risks. The data also highlights the importance of incorporating seasonal variations into hydrological models and flood risk assessments to ensure accurate predictions and effective management strategies.

Table 4: River Benue Discharge, Area, and Velocity at Jimeta Bridge.

S/N	Date	Discharge (m^3s^{-2}	Total Area (m^2	Mean Velocity (ms^{-1})
1	12/5/2024	121.1084	373.20	0.2809
2	27/7/2024	372.26	373.20	0.848705
3	25/9/2024	460.80	373.20	0.660741

Source: Fieldwork 2024

Stream Turbulence of River Benue at Jimeta Bridge: May 12, 2024

The stream turbulence of the channel reach was calculated as: $F_r = \frac{v}{\sqrt{dg}}$ Where v = 0.289ms^2, d = 1.56875m, g = gravitational acceleration (9.81m/sec), If $F_r < 1$ the flow is sub- critical (tranquil), If $F_r > 1$ the flow is supercritical (rapid) and If $F_r = 1$ the flow is critical.

Therefore: $F_r = \frac{v}{\sqrt{dg}}$, $F_r = \frac{0.289ms^{-1}}{\sqrt{1.56875 \times 9.81ms^{-1}}}$, $F_r = \frac{0.289ms^{-1}}{\sqrt{0.1599}}$, $F_r = \frac{0.289ms^{-1}}{0.39989}$ = 0.723**.** The results indicate that the stream turbulence of the River Benue at Jimeta Bridge is categorized as "tranquil" or "sub-critical" based on the Froude number calculation. With a calculated Froude number of 0.723, which is less than 1, the river's flow at this location is considered sub-critical, meaning it is relatively calm and stable rather than turbulent or fast-moving. This suggests that the flow conditions at this section of the river are steady and unlikely to experience sudden or significant turbulence.

Stream Turbulence of River Benue at Jimeta Bridge: July 27, 2024

The stream turbulence of the channel reach is calculated as: $F_r = \frac{v}{\sqrt{dg}}$ Since v = 0.848705m/sec, d = 103.7m (mean depth = 2.160417m) and g = 9.81ms^{-1} $F_r = \frac{0.848705ms^{-1}}{\sqrt{2.160417 \times 9.81ms^{-1}}} = \frac{0.848705ms^{-1}}{\sqrt{21.19369}} = \frac{0.848705ms^{-1}}{4.60366}$ = 0.1844

The Froude number of 0.1844 is significantly less than 1. This indicates that the flow in the channel reach is tranquil or sub-critical. In hydraulic terms, this means that the flow is dominated by gravitational forces, and it is not strong enough to overcome the effects of gravity. In sub-critical (tranquil) flow, the flow is slow and calm. It usually implies that the flow is not likely to experience rapid changes or turbulence. This type of flow is characterized by a gentle slope and less erosive force. The tranquil flow has implications for sediment transport and channel stability. Because the flow is calm, it is less likely to cause erosion or significant sediment transport compared to more turbulent flows. For river management or hydraulic design, understanding that the flow is sub-critical helps in predicting how the river might behave under different conditions. It suggests that the channel is less prone to erosion and flooding issues that might be associated with faster, super-critical flows.

Stream turbulence of river Benue at Jimeta Bridge in the 25 August, 2024

The stream turbulence of the channel reach is calculated as: $F_r = \frac{v}{\sqrt{dg}}$, Where v = flow velocity, d = flow depth and g = gravitational acceleration (9.81m s^{-1}). If $F_r < 1$ the flow is sub- critical (tranquil), If $F_r > 1$ the flow is supercritical (rapid) and If $F_r = 1$ the flow is critical. v = 0.660741ms^{-1}, d = 2.296m and g = 9.81ms^{-1}.

$F_r = \frac{0.66741ms^{-1}}{\sqrt{2.296 \times 9.81ms^{-1}}}$, $= \frac{0.66741ms^{-1}}{\sqrt{22.5266}}$, $= \frac{0.66741ms^{-1}}{4.746}$, = 0.1406. The Froude number (Fr) is a dimensionless parameter used to characterize the flow regime in open channels. It compares the inertial forces to gravitational forces and helps determine the type of flow: subcritical, supercritical, or critical. Since the Froude number (0.1406) is less than 1, the flow is categorized as subcritical. In subcritical flow, the gravitational forces dominate over inertial forces, leading to a tranquil or calm flow. This type of flow is characterized by smooth, gradual changes in water depth and velocity. Erosive Potential: Subcritical flows are generally less erosive compared to supercritical flows. The lower turbulence in subcritical flow means the stream has a reduced capacity to erode its bed and banks. The stream's tranquil nature implies that it is not highly energetic or rapid. This is advantageous for stability in river management, as less erosion and sediment transport can be expected. However, it also affects the stream's capacity to carry sediments or nutrients if such transport is needed for the ecosystem's health. Moreover, the low turbulence in subcritical flows influence the aquatic habitat, potentially favoring species adapted to slower-moving water.

Consistency of Sub-Critical Flow at Jimeta Bridge, River Benue: May to August 2024

Over the course of the three measurements at Jimeta Bridge on the River Benue, the flow characteristics consistently showed a sub-critical, or tranquil, flow regime. On May 12, 2024, the Froude number was calculated as 0.72284. This value, which is less than 1, indicates a sub-critical flow regime, meaning the river's flow was calm and stable with low turbulence. The flow velocity on this date was 0.289 m/s, and the flow depth was 1.56875 m. By July 27, 2024, the flow velocity had increased to 0.848705 m/s, while the flow depth had risen slightly to 2.160417 m. Despite these changes, the Froude number was 0.1844, still less than 1, indicating that the flow remained sub-critical. This suggests a very stable and tranquil flow condition, with even lower potential for turbulence and erosion compared to May.

On August 25, 2024, the flow velocity was 0.660741 m/s, and the flow depth was 2.296 m. The calculated Froude number for this date was 0.1406, which is also below 1, confirming that the flow was still sub-critical. The consistently sub-critical flow, with Froude numbers of 0.72284, 0.1844, and 0.1406 across the three dates, indicates a stable and tranquil flow regime throughout the observation period. This stability implies that the river has a low potential for rapid turbulence and significant erosion. The calm flow conditions are beneficial for maintaining riverbank stability and reducing sediment transport, which can be advantageous for river management and infrastructure planning

(Ezekiel, Y. *et al,* 2020). Furthermore, these conditions create a favorable habitat for aquatic species adapted to slow-moving water, supporting a stable ecosystem. Understanding the sub-critical flow regime aids in predicting the river's behavior under different conditions and helps in designing appropriate measures to manage sediment transport and maintain ecological balance.

Stream Power at Jimeta Bridge on River Benue, May 12, 2024.

Stream power: - ω = pgvds: - Where p = ($1000gcm^{-3}$), g = (9.81m/sec), v = $0.2809ms^{-1}$, d = 1.56875m, s = 0.20625m. ω = $1000\,m^3s^{-2} \times 9.81m^{-2} \times 0.2809 \times 1.56875 \times 0.20625$ ω = 891.59667 $Jm^{-2}s^{-2}$. The stream power of 891.59667 J/m^2s^2 indicates the energy available per unit area per unit time for the river flow to perform work, such as moving sediment and boulders. The calculated stream power is relatively high, suggesting that the river has significant energy available to perform work. However, the statement that the stream power was "< 1 J/m^2s" and "> 12,000 J/m^2s" seems contradictory. Since 891.59667 J/m^2s^2 is between these values, it indicates that the stream power is not in the extreme low or high ranges but rather moderate. The observation that the stream power was not sufficient to move boulders meters in diameter implies that while the river has significant power, it is not enough to overcome the inertia of very large boulders. This suggests that for substantial sediment transport or boulder movement, the stream power would need to be considerably higher.

The moderate stream power suggests that the river is capable of transporting smaller sediment and influencing riverbed morphology, but it is not sufficient for moving very large objects. This has implications for river management, sediment control, and habitat maintenance, as the stream's ability to shape its bed and banks is limited. Understanding stream power is crucial for designing infrastructure like bridges and assessing ecological effects. In this case, the moderate stream power suggests that infrastructure at Jimeta Bridge should be designed with the understanding that while large boulders are unlikely to be moved by the current stream power, smaller sediments may still be transported and affect the riverbed.

Stream Power Analysis of River Benue at Jimeta Bridge, July 27, 2014

Stream power: - ω = pgvds, Where p = ($1000gcm^{-3}$), g = ($9.81Ms^{-1}$), v = $0.66741m^{-2}$, d = 62m and s = 0.375. $\omega = 1000\,m^3s^{-2} \times 9.81m - 2 \times 0.66741 \times 62 \times 0.375$, ω = 152,224.54 $Jm^{-2}s^{-2}$.

The calculated stream power of 152,224.54 J/m^2s^2 indicates the high capacity of the river to perform work. This power level suggests that the river can exert significant force on the sediment and streambed materials. The statement that the stream power is capable of moving boulders meters in diameter aligns with the high value of the calculated stream power. In rivers, stream power is crucial in determining the size of materials that can be transported or moved. If stream power exceeds a certain threshold (in this case, 12,000 J/m^2s^2), it is generally capable of moving large boulders and sediments. The high stream power implies significant erosion potential. The river erodes its bed and banks more effectively, potentially leading to changes in river morphology and increased sediment transport downstream. High stream power affect aquatic habitats by moving large boulders and altering riverbed conditions. This affects the habitats of various aquatic species that rely on stable riverbed structures. For infrastructure near the river, such as embankments, understanding the stream power is crucial for designing structures that withstand the forces exerted by the river. Effective river management and conservation strategies must consider stream power to mitigate erosion and maintain ecological balance. It can also be important for predicting potential flood impacts and planning mitigation measures.

Stream Power Analysis of River Benue at Jimeta Bridge, August 25, 2014

Stream power: - $\omega = pgvds$, Where p = ($1000gcm^{-3}$), g = (9.81m/sec), v = $0.848705m^{-2}$, d =2.160417m and s = 0.7127m. $\omega = 1000\,m^{-3} \times 9.81 ms^{-2} \times 0.848705\,m^{-2} \times 2.160417 \times 0.7127$ ω = 12,819.47 $Jm^{-2}s^{-2}$. The calculated stream power is 12,819.47 $J/m^2/s$. Stream power quantifies the potential of the flow to do work, such as transporting sediment and boulders. Higher stream power indicates a greater ability to move large particles and perform significant geomorphic work. With a stream power of over 12,000 $J/m^2/s$, the river flow is quite powerful. This level of stream power is sufficient to mobilize and transport boulders of considerable size. Boulders that are meters in diameter can be moved or shifted by such a stream, indicating a high potential for significant geomorphic changes. High stream power lead to increased erosion of the riverbed and banks. This affect the stability of the river channel and potentially lead to changes in river morphology over time. The ability to move large boulders and coarse erosion affect aquatic habitats. The physical alteration of the riverbed affects habitats for various aquatic species, potentially leading to changes in biodiversity or ecosystem dynamics. For infrastructure such as riverbank structures, understanding stream power is crucial for designing effective flood defenses and ensuring the stability of such structures. High stream power areas may require more robust engineering solutions. Stream power is often related to the stream's energy and potential for geomorphic processes. It is an important factor in river management and ecological studies, as it helps to predict the river's behavior, sediment transport capacity, and its ability to reshape the landscape. In the context of the River Benue at Jimeta Bridge, knowing the stream power helps assess the river's capacity to impact its environment and guide appropriate management or mitigation strategies.

Stream Power Variability at Jimeta Bridge: May to August 2024

At Jimeta Bridge on the River Benue, stream power measurements over three dates reveal significant variations, each with distinct implications. On May 12, 2024, the stream power was calculated as 891.59667 $J/m^2/s$, with a flow velocity of 0.2809 m/s, flow depth of 1.56875 m, and slope of 0.20625 m. This moderate stream power suggests that while the river has enough energy to perform some work, such as transporting smaller sediments, it is not sufficient to move large boulders with diameters of meters. The implications here are that infrastructure at this time should account for minor sediment transport and limited geomorphic changes but would not need to withstand the forces required to move large objects.

By July 27, 2024, the stream power surged to 152,224.54 $J/m^2/s$, with a flow velocity of 0.66741 m/s, flow depth of 62 m, and slope of 0.375. This high stream power indicates a substantial capacity for the river to move large boulders and sediments, suggesting significant erosion potential. Such high power levels imply that the river could cause considerable changes in its morphology and impact aquatic habitats by moving large riverbed materials. Infrastructure near the river, such as embankments or bridges, must be designed to withstand these forces to prevent damage and ensure stability. On August 25, 2024, the stream power was 12,819.47 $J/m^2/s$, with a flow velocity of 0.848705 m/s, flow depth of 2.160417 m, and slope of 0.7127 m. This level of stream power, while high, is lower than in July but still sufficient to move sizable boulders and sediments. The high stream power at this date indicates the potential for significant geomorphic work and erosion, impacting riverbed stability and aquatic habitats. The infrastructure and river management strategies should continue to consider these powerful conditions to mitigate erosion and habitat disruptions effectively. The varying stream power levels necessitate different considerations for infrastructure. On May 12, moderate power requires minimal considerations for boulder movement, whereas July's extreme power necessitates robust designs to withstand significant forces. August's high but lower power still demands attention to prevent erosion and structural damage. High stream power, particularly on July 27, indicates a significant ability to transport large sediments and boulders, influencing riverbed morphology and requiring strategies to manage sediment transport and erosion. Significant changes in stream power affect aquatic habitats. The high stream power during July and August can alter riverbed conditions, impacting species adapted to stable environments. Effective river management must account for these changes to maintain ecological balance.

CONCLUSION

This study provides a comprehensive analysis of the hydrological dynamics of the River Benue at Jimeta Bridge, focusing on stream turbulence, stream power, and cross-sectional variations over three observation periods. The consistent sub-critical flow regime, indicated by Froude numbers consistently below 1, suggests a generally calm and stable flow environment throughout the study period. This tranquil flow condition has implications for river management, particularly in terms of erosion control and sediment transport. The variations in stream power observed from moderate values in May to significantly high values in July, and a substantial level in August highlight the river's capacity for geomorphic work and its potential impact on the riverbed and surrounding infrastructure. The elevated stream power during July and August indicates periods of increased erosive potential, which necessitates robust infrastructural design and river management strategies to mitigate potential damage and maintain stability. The cross-sectional dynamics, including changes in flow depth and velocity, further illustrate how variations in these parameters influence stream power and the river's overall behavior. Understanding these dynamics is crucial for predicting river conditions, managing sediment transport, and preserving aquatic habitats.

RECOMMENDATIONS

1. Given the variations in stream power, particularly the significant increases observed in July and August, it is crucial to design and implement flood management infrastructure that can withstand high-flow conditions. This includes reinforcing the riverbanks and bridge foundations to handle increased erosive forces and prevent structural damage during peak flow periods. In addition, implementing early warning systems and floodplain management strategies can help mitigate the impact of flooding on surrounding communities.
2. Continuous monitoring of stream flow, velocity, and cross-sectional dynamics is essential for understanding the river's behavior and predicting potential changes. Regular data collection will allow for timely adjustments to management practices and infrastructure maintenance. Establishing a real-time monitoring system for stream power and flow conditions can provide valuable information for flood forecasting and response.
3. To address the potential for significant sediment transport and erosion, especially during periods of high stream power, it is important to implement sediment management and erosion control measures. This includes stabilizing riverbanks with vegetation or engineered solutions, such as riprap or gabions, to reduce erosion and sediment movement.

Regular maintenance and assessment of these measures will ensure their effectiveness in mitigating erosion and maintaining river stability.

4. The variations in flow conditions and stream power affect aquatic habitats and species adapted to stable environments. It is important to incorporate ecological considerations into river management practices to protect and enhance aquatic habitats.

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