Minnehaha Creek:

Active and Bankfull Flow Analysis Downstream from Minnehaha Falls

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Introduction

The System

Minnehaha Creek is a tributary of the Mississippi River. It begins in Lake Minnetonka at the Gray's Bay Dam and flows east for about 35 kilometers until it reaches the Mississippi River in Minneapolis (see Figure 1 for a map of the watershed). Minnehaha Falls is a 16 m tall waterfall in Minneapolis, less than two kilometers from where the creek reaches the Mississippi River.

Understanding river discharge is crucial to effectively managing floods and drought, ensuring that human water needs are met while supporting the ecosystem. The first step in managing water is to understand how it functions. Understanding sediment transport is also crucial for this form of human management of rivers. Sediment not only shapes the river bed through long-term erosion and deposition but also changes water flow in the short term. Sediment is one way engineers change and manage water flow, but by increasing or decreasing the slope of the river at specific locations, they create safer conditions for humans.

Historically, Minnehaha Creek powered flour mills in the 1800s, which were integral to the Twin Cities' early economic development. Today, Minnehaha Creek runs through a variety of neighborhoods and impacts essential ecosystems within the urban landscape. Major flooding would negatively affect many residents and businesses. While most may see Minnehaha Creek as primarily a recreational area, it connects a wealthy population in the state around Lake Minnetonka to a less affluent population in Minneapolis. Additionally, the Mississippi River is a vast system, and every tributary has an impact. Minnehaha Creek carries on average 1.5 million pounds of sediment into the Mississippi River each year (Metropolitan Council: Environmental Services 2014).

The Study

The purpose of this study is to develop a big-picture understanding of how Minnehaha Creek functions, specifically by comparing the channel's active and bankfull flow characteristics.

Data for this study were collected just after the falls, about 300 meters closer to the Mississippi River, near the lower Glen Trail, and at the Wading Area, as defined by Minnehaha Park (see Figure 2 for a map of the study area). Observations and data were collected in early fall, with most on September 30 and October 7, 2025.

Usually in late September and early October, the creek is at normal flow, with consideration given to when the Gray's Bay Dam is opened to lower the water level in Lake Minnetonka for the winter, allowing more water to flow downstream into Minnehaha Creek. In mid-September, water levels in the Minnehaha Creek watershed were decreasing, with the dam discharging 1.4 cubic meters per second (Minnehaha Creek Watershed District 2025). At the end of September, a four-day rain event temporarily elevated water levels (Minnehaha Creek Watershed District 2025).

Field Setting

The drainage basin of Minnehaha Creek is about 469 square kilometers Figure 1. It is regulated by the Minnehaha Creek Watershed District (MCWD) (established in 1967), which manages its flow through the Gray's Bay Dam at Lake Minnetonka. In addition to measuring the creek's water level, the district also manages water quality, erosion control, and recreational permits. The primary water source for Minnehaha Creek is Lake Minnetonka, which serves as a reservoir for the creek. Lake Minnetonka's primary water source is Six Mile Creek in Excelsior, Minnesota, but it also receives water from a variety of other creeks and streams within the watershed. Minnehaha Creek is the only outlet for Lake Minnetonka. As previously mentioned, Minnehaha Creek is a tributary of the Mississippi River.

Minnehaha Creek has been well studied, primarily for maintaining water quality in an urban area. Minnehaha Creek has been highly engineered and essentially recreated by humans to ensure complete control over water levels within the urban-based Minnehaha Watershed. This control also allows for careful management of nutrients and water pollution in the watershed to address the peri-urban area, where agricultural and urban areas blend. As this mid-region between agriculture and urban areas is highly prevalent in Minnesota, these studies are critical to ensuring clean water in urban areas and maintaining soil and water nutrient levels in agricultural areas. Erosion is also well studied in Minnehaha Creek. Many of these studies are completed by government organizations to ensure the success and management of their funded projects. The United States Geological Survey reports daily discharge levels for Minnehaha Creek at station 05289800, "Minnehaha Creek at Hiawatha Ave. in Minneapolis, MN" (U.S. Geological Survey 2025). Along with daily discharge levels, they also report daily temperature, precipitation, water level, and conductivity. In addition to daily measurements taken by their installed sensors, they report any in-field measurements and calculations they conduct, including pH levels and specific chemical analyses. These calculations also include discharge rates during storm events, suspended sediment concentrations, and the calculated dry mass of suspended sediment. While this sediment data isn't nearly as continuous as their water discharge rates, the suspended sediment concentration runs only from June 2013 to June 2024. It presents the data only as mg/L, making comparisons to the percentage of bedload or clast diameter difficult. Additionally, the MCWD reports both the Lake Minnetonka water level, the Minnehaha Creek discharge rates, and the Gray's Bay Dam discharge rate daily.

Methods

The first set of data collected was the distance across the chosen channel cross-section, measured with a 100-meter tape measure held by two people at either end of the channel. This line was maintained for most of the other measurements to ensure consistent locations. One edge is up against an engineered wall (north bank) designed to be high enough even for bankfull flow. The other edge is on a vegetated sloped hill (south bank). From there, the channel depth was recorded using a stadia rod at 1-meter intervals across the channel. These consistently distanced depth measurements created theoretical panels, which were used to organize future measurements and estimate future calculations. The bankfull depth was also measured using the stadia rod at each end of the cross section, with additional tape-measure readings taken to calculate the slope on the vegetated side. See Figure 3 and Figure 4 for the channel cross-section and a visual representation of the panels used.

The cross-sectional area was calculated by first locating each panel and then summing its areas to obtain the total. The area of each panel was determined using a trapezoidal area formula based on four measured points: the panel width (x) and the active depth at each end (y) (Equation 1). The wetted perimeter of the cross section was calculated by determining the partial perimeter for each panel and summing them. The equation used for the partial perimeter of each panel is shown in Equation 2. From there, the hydraulic radius was calculated as the ratio of the cross-sectional area to the wetted perimeter. The active Q was calculated similarly to the area and perimeter: panel-by-panel, then summed across the entire channel. The active Q for the panel was calculated by multiplying the panel area by the velocity measured in the panel.

Equation 1. Panel Area

$$\frac{(x_2 - x_1)(y_1 + y_2)}{2} \tag{1}$$

Equation 2. Wetted Perimeter

$$\sqrt{(y_1 - y_2)^2 + 1} \tag{2}$$

Equation 3. Active Discharge Equation

$$Q = \bar{u} \times A_c \tag{3}$$

The bankfull area, wetted perimeter, and hydraulic radius were calculated using the same equations as for the active channel. However, the bankfull depth for each point across the channel had to be determined before these values could be calculated. From the bankfull measurements, the bankfull water level was 0.57 meters above the active channel. Before the bankfull Q could be calculated, a roughness value, n, needed to be determined. This was completed using three equations to obtain a range of n values and later determining which was most accurate. This included using Manning's Equation (calculated in meters, Equation 4), Limerino's Equation (calculated in feet, Equation 5) and by the USGS descriptive n-values. For Limerino's Equation, d_{84} refers to the 84th percentile of clasts within the river bed. From there, the bankfull q was determined using each n value by multiplying the total bankfull area by each n value.

Equation 4. Manning's Equation

$$n = \frac{R^{\frac{2}{3}} \times S^{\frac{1}{2}}}{\bar{u}} \tag{4}$$

Equation 5. Limerino's Equation

$$n = \frac{0.0926 \times \left(R^{\frac{1}{6}}\right)}{\left(1.16 + 2.0 \times \log\left(\frac{R}{d_{84}}\right)\right)} \tag{5}$$

Slope was calculated from careful measurements using the tape measure and stadia rods. The distance from the observer and the stadia rod was recorded, along with the number that the observer viewed on the stadia rod using an eye level. The amount of water that the observer was standing in, the depth of water at the observer's eye level, and the observer's height were also recorded to ensure the most accurate calculations. Slope was measured perpendicular to the cross-section, and points were selected in shallow areas to reduce the water depth for the observer, making field calculations a little easier.

A price meter was used to record revolutions per minute at the recommended 40% from the river bed, which is believed to represent the average velocity of the channel as a function of depth. This was further tested to determine whether the calculation was accurate for Minnehaha Creek. Measurements were recorded every 0.5 meters along the channel or at the center of each panel. Velocity was recorded as a function of depth in four locations over the course of the two days of data collection. On the first day of data collection, this was completed at 1 meter and 2 meters from the wall (north bank), and on the second day of data collection (a week later), it was completed at 20.5 meters and 22.5 meters, the average velocity and highest velocity locations. The price meter was used to count RPMs at approximately 0.2 feet intervals from the halfway depth point to the riverbed at each location. Velocity was calculated from the price meter's RPMs from the company's given equation (Equation 6). This resulted in a feet-per-second measurement, which was converted to meters per second before determining the average for the entire cross-section.

Equation 6. Price Meter RPM to Feet-Per-Second Conversion

$$2.2048 \times \left(\frac{RPM}{60}\right) + 0.0178 \tag{6}$$

FST hemispheres from KC Denmark were used to measure the density of an object that the active flow could move. This process was completed at 20.50 meters, which was determined as the average velocity of the channel, and at 22.50 meters, which was the highest velocity recorded. For sediment transport and bed roughness calculations, measurements from 100 clasts across the cross-section were gathered. Every 0.25 meters across the cross-section, one clast was collected and measured in three directions. From there, the average clast length was calculated and used in subsequent calculations. The 50th and 84th percentile clast sizes were both determined using the average length of the measured clasts. This value was sorted from smallest to largest, and since only 100 clasts were measured, the 50th-largest clast represents the 50th percentile, and the 84th-largest clast represents the 84th percentile. Basal shear stress and critical shear stress were calculated with the data from the hemispheres at the same depth and velocity as the hemispheres. Active basal shear stress was calculated with Equation 7, with h indicating the depth at the location of measurement and S representing the slope of the river. Bankfull basal shear stress was calculated using the same equation, but with bankfull measurements. Active critical shear stress was calculated using the hemispheres' density (Equation 8), where D is the sediment diameter (the hemisphere's height was used to represent the clast's orientation under the forces), and ρ_s is the sediment density. C is a constant, for which 0.035-0.065 was used based on previous research and descriptions of the site. The diameter of sediment that could be moved at active and bankfull water levels was calculated using the calculated basal shear stress (Equation 9).

Equation 7. Basal Shear Stress Equation

$$\tau_B = \rho_w g h \sin(S) \tag{7}$$

Equation 8. Critical Shear Stress Equation

$$\tau_C = gD(\rho_s - \rho_w)C \tag{8}$$

Equation 9. Sediment Entrainment

$$\frac{\tau}{g(\rho_s - \rho_w)C} \tag{9}$$

Results

Active Channel Flow

Figure 3 shows the active channel cross-section. The active channel width was measured as 24.5 m. See Figure 3 for the active and bankfull cross sections with depth measurements at 1-m intervals. The total area of the cross section was calculated to be 8.09 m2, with a wetted perimeter of 25.02 m. The hydraulic radius is therefore 0.32 m. Figure 4 shows the Q value for each panel, with a total active Q of 3.49 m3/s for the channel. Table 1 shows a summary of the active channel flow results. On the date of active channel data collection, October 7, 2025, the Gray's Bay Dam was discharging at 1.42 m^3/s (Minnehaha Creek Watershed District 2025). On the same collection date. USGS recorded a discharge rate of 2.54 m^3/s at their Monitoring Location (U.S. Geological Survey 2025).

Bankfull Channel Flow

Figure 3 also shows the bankfull channel cross-section. The bankfull width was measured as 25.29 m with an area of 22.65 m^2, the wetted perimeter was calculated as 25.03 m, and the bankfull hydraulic radius as 0.90 m. See Table 2 for a summary of the bankfull channel flow results. The bed roughness value of n was calculated from Manning's equation as 0.049, Limerino's equation as 0.036, and defined by the USGS descriptions as 0.045-0.060 under the description of the main channel, some weeds, and more stones. Manning's n value has been calculated by others, mainly in proposals for engineering projects, as ranging from 0.03 to 0.038 (Houdek 2014, Minnehaha Creek Watershed District 2023). These calculations seem to have been completed farther upstream from this study's data collection spot. From our calculations, the bankfull average velocity was calculated as 0.86 m/s with Manning's n, 1.17 m/s with Limerino's n, and 0.70-0.93 m/s with the USGS n values. Bankfull q is then estimated as 19.52 m3/s, 26.57 m3/s, and 15.79-21.05 m3/s, respectively. Table 3 summarizes the bankfull n value and discharge rate results. The maximum discharge rate from the past year was recorded on June 26th, 2025, at 9.63 m^3/s (U.S. Geological Survey 2025). In 2024, the maximum discharge rate was recorded on August 6^{th} at 9.91 m3/s, and there were 7 other days with discharge rates over 8.5 m^3/s (U.S. Geological Survey 2025). In 2023, maximum discharge was much lower than in the following two years, as there were no days when discharge exceeded 2.5 m^3/s (U.S. Geological Survey 2025). Reviewing the entire history of daily data at this monitoring location, from November 5, 2005, to November 25, 2025, the absolute highest discharge rate occurred on July 20, 2014 (U.S. Geological Survey 2025). This is the only data point reaching above 14.16 m^3/s, at 16.37 m^3/s (U.S. Geological Survey 2025).

Slope

The channel slope was calculated to be -0.002, with a rise of -0.080 m and a run of 41.74 m.

Velocity

Figure 5 shows four velocity profiles. The average velocity of the channel was calculated as 0.43 m/s.

Sediment Entrainment

Figure 6 shows a histogram of clast sizes. The average clast length was 3.26 cm, with the 50th percentile at 2.50 cm and the 84th percentile at 6.00 cm.

The active basal shear stress was calculated as 5.98 Pa at 20.50 m from the north side wall and 6.08 Pa at 22.50 m from the north side wall, whereas the bankfull basal shear stress was found to be 17.85 Pa. The active critical shear stress was calculated to be 8.25-15.32 Pa and 21.64-40.19 Pa at each location, respectively. Therefore, clasts in the 0.55-1.04 cm range could be moved by active flow, accounting for 4-9% of the measured clasts. Using the Hjulström curve diagram, with estimated bed velocities, clasts with a diameter of 0.55 cm should move at 20.50 m from the north wall, and clasts with a diameter of 0.45 cm should move at 22.50 m from the north wall. Table 4 summarizes active channel sediment entrainment results. Based on estimated bankfull levels, clasts within the range of 3.06-1.65 cm could be moved, accounting for 25-62% of the clasts measured at the bed. Table 5 summarizes active channel sediment entrainment results.

Discussion

Water Transport

The discharge rate for Minnehaha Creek, also known as the total Q calculated from the cross section at the time of data collection, is 3.49 m^3/s. It's important to note that this study was completed below the Minnehaha Falls. The USGS monitoring location is directly above the falls from the data collection spot. MCWD also publishes the discharge rate from the Gray's Bay Dam, which is the primary source of water for the creek. As mentioned before, the discharge rate of the dam on the same date as data collection was 1.42 m3/s, while the USGS monitoring location recorded a discharge rate of 2.54 m^3/s (U.S. Geological Survey 2025). Discharge rates naturally increase along a river's length as more water is added from groundwater or runoff sources as it moves downstream. While the measured discharge rate appears to be larger than that measured above the Minnehaha Falls, this is not an inherent correlation. A waterfall is a vertical drop, so if the cross-sectional area of the falls is calculated, the amount of water doesn't change at this spot. The velocity increases to accommodate the amount of water present with a smaller cross-sectional area. Therefore, some water must be entering the creek downstream of the falls. The calculated discharge rate may be high due to simple data uncertainty in the calculations and in data collected at high elevations, though these uncertainties were minimized at every step. 3.49 m^3/s is reasonable and is even on the low end of average for the summer and early fall months (June-October), according to data collected by the USGS at their monitoring location (U.S. Geological Survey 2025).

Manning's n was calculated as 0.049, whereas n was 0.036 using Limerino's equation. Using descriptions from the USGS's classification of n, a range of 0.045 to 0.060 was determined. While others have reported values ranging from 0.030 to 0.038, it is unclear whether those values apply to this research site as well (Houdek 2014, Minnehaha Creek Watershed District 2023). We have concluded that a range of 0.36 – 0.49 makes the most sense, especially when using these n values to estimate a bankfull discharge rate. This range encompasses other groups' calculated n values, and it would inherently make sense that the roughness value would vary across the cross-section from field observations. The south side of the cross-section, near the vegetated side, included much larger clasts, which would increase the roughness value, while the north side, near the wall, had a smoother bed surface from smaller clasts. Some of this variation is assumed to have been associated with previous engineering projects. As the north side is more accessible to visitors and the site is called the "Minnehaha Wading Area," it may have been intentional to create a rougher side near the less accessible south side and a smoother side where people can more easily access the creek. Additionally, from observation, the south side appeared to be moving faster, and as you can see from Figure 4, there are higher Q values within panels farther to the south. Larger clasts could be an attempt to lower the velocity and discharge in that specific area. The discharge rates in this region should be investigated further. More depth, velocity, and clast measurements are needed to comprehensively analyze the significantly higher discharge rates in the southern half of the channel. The roughness value, n, will change as discharge, Q, varies. Q changes as the velocity of flow or the depth of water changes. The depth of water is directly proportional to the hydraulic radius of a stream. Manning's equation is dependent on the average velocity and the hydraulic radius, while Limerino's equation is dependent on the hydraulic radius. Therefore, if Q changes, the roughness value will change as well.

Estimating an average annual bankfull flow from historic rates for the past two years of 9.77 m^3/s, it appears much lower than our measured bankfull Q range of 19.52-26.57 m^3/s. The absolute highest that the creek has experienced in the past 20 years, at 16.37 m^3/s, seems slightly more reasonable (U.S. Geological Survey 2025). The lowest bankfull Q measurement was 15.79, calculated from the USGS descriptive n of 0.060, which was previously disregarded because it was 22.4% greater than the next-largest calculated n value. It resulted in a 23.6% decrease from the bankfull Q calculated with that n to the following smallest bankfull Q. However, it would make sense that the engineered bankfull capacity would be larger than the most recent bankfull flow, to ensure there is little to no chance of flooding. The calculated Q value of 19.52 m^3/s is only about 20% of the buffer from the highest experienced Q value. The differences in measurement locations between the USGS and this study would result in differences in bankfull Q values, as they did for active Q values. The addition of groundwater and runoff could increase bankfull Q at this location, as could differences in channel geometry, slope, and roughness that may be different at the data collection site compared to the USGS monitoring location. It is important to note that the USGS's monitoring location is highly accurate and produces lower errors than hand-measured data, as in this study. However, engineered channels have bankfull capacities larger than natural bankfull flows, thereby protecting against flooding. Since the bankfull measurements were taken relative to the engineered wall (north bank) at the site, the final value may exceed the creek's previous record.

Sediment Entrainment

From field observations, the sediment varied greatly. Some clasts were boulder-sized, while others were pebble-sized. In the exact cross-section of data collection, clasts were on the smaller side. Larger clasts were more prevalent a few meters upstream, specifically on the southern half of the channel. The mean length of clasts along the cross-section was 3.26 cm, with the median (or 50th percentile) being 2.5 cm. The 84th percentile is 6.00 cm. Clasts within the range of 0.55 to 1.04 cm, or smaller, should be within transport during active flow. These calculations were completed with the FST Hemisphere method at a location representing the mean velocity of water flow and the area with the highest velocity. From the data collected with the hemispheres, the critical shear stress for clast entrainment was calculated using a constant range of 0.035-0.065, which is defined as a regular bed that is not closely packed. Therefore, in regions of the channel with lower velocity, clasts smaller than 0.55 cm are transported at active flow, while in the areas on the southern side of the channel, where the velocity is higher, larger clasts, near 1.04 cm, are in transport. The Hjulström diagram reported lower values, as low as 0.45 cm; however, the calculation was based on estimated bed velocities at each location.

During bankfull flow, it is estimated that somewhere between 25 and 62% of the clasts would be entrained. This calculation references an estimated critical shear stress derived from a bankfull basal shear stress calculation. The bankfull basal shear stress was calculated as 17.85 Pa. Active basal shear stress was calculated as 5.98-6.08 Pa, depending on the depth of the measurement location. Bankfull basal shear stress may be slightly high depending on the exact location of interest, as a uniform bankfull depth of 0.91 m was used to calculate it. This does seem somewhat proportional in comparison to the other bankfull versus active calculations. For example, the calculated bankfull discharge rate is about a 450% increase from the active, and the bankfull basal shear stress is about a 200% increase from the active. The ratios won’t be precisely the same because they are based on different calculations with other factors at play; however, it is reassuring that they are on similar magnitudes. This would mean that during bankfull flow, clasts as large as 3.06 cm could move within the fastest-moving panels, whereas 1.65 cm clasts would be an average size to be within transport.

Overall, the engineers did a good job selecting clast sizes for bank stabilization, given the hydraulic conditions of Minnehaha Creek. The previously mentioned engineering design is present at the site, including larger clasts within the southern region of the creek, which experiences faster discharge rates. Larger clasts increase local roughness, reduce cohesivity, and enhance the stability of areas experiencing higher shear stress. There are larger clasts present in the bank that were not measured because they were not precisely within the cross-sectional horizontal line across the river. These larger clasts ensure long-term bank stability. The actual percentage of clasts that could be entrained at bankfull flow is likely much lower than 62%. Since the stream rarely ever reaches the calculated bankfull discharge, if it ever has in its history of being engineered, it's safe to assume that the banks along the creek are stabilized sufficiently.

Conclusion

Minnehaha Creek appears to be functioning safely within the engineered parameters set for the highly managed, urban creek. The hydraulic and sediment transport results of this study, including the calculated bankfull capacity at the site, exceed both recent and historical peak flows, indicating that the current channel design provides an adequate buffer against flooding. The distribution of larger clasts along the higher-velocity southern region of the creek also appears appropriate for stabilizing areas that experience higher shear stress. There should also be more calculations completed in the south region of the channel to investigate the higher discharge rates in this area. Discharge rates increase between the USGS monitoring station and the study site, less than a kilometer downstream. Given the region's active and possible bankfull discharge rates between the falls and the mouth of the creek where it reaches the Mississippi River, we recommend that the USGS and the MCWD continue monitoring groundwater and runoff inputs below Minnehaha Falls. Maintaining existing stabilization structures is essential, along with periodically reassessing roughness, channel morphology, and discharge rates and variability along the channel. Hydraulic conditions will continue to change, and there may be increased pressure on the system below the Minnehaha Falls, a possibility the USGS and MCWD should continue to monitor, especially after significant storm events.

Equations

Tables

Table 1. Active Channel Discharge (Q) Calculations

Total Area	*Wetted Perimeter*	*Hydraulic Radius*	*Average Velocity*	Q_{total}
8.09 m²	25.02 m	0.32 m	0.43 m/s	3.49 m³/2

Table 2. Bankfull Channel Discharge (Q) Calculations

Total Area	*Wetted Perimeter*	*Hydraulic Radius*	*Average Velocity*	Q_{total}
22.65 m²	25.03 m	0.90 m	0.86 – 1.17 m/s	19.52 – 26.57 m³/2

Table 3. Roughness Value (Manning's n) Calculations

	Manning's Equation	*Limerino's Equation*	*USGS Descriptions*
n	0.049	0.036	0.045 – 0.060
Average Velocity	0.86 m/s	1.17 m/s	0.93 – 0.70 m/s
Q	19.52 m³/2	26.57 m³/2	21.05 – 15.79 m³/2

Table 4. Active Channel Shear Stress and Sediment Entrainment Calculations

	Basal Shear Stress	*Critical Shear Stress*	*Entrainment Diameter*	*Percentage of Clasts*	*Hjulström Diagram*
20.50 m from N. side wall	5.98 Pa	8.25 – 15.32 Pa	1.03 – 0.55 cm	9 – 4%	0.55 cm
22.50 m from N. side wall	6.08 Pa	21.64 – 40.19 Pa	1.04 – 0.56 cm	9 – 4%	0.45 cm

Table 5. Bankfull Channel Shear Stress and Sediment Entrainment Calculations

Basal Shear Stress	*Entrainment Diameter*	*Percentage of Clasts*
17.85 Pa	3.06 – 1.65 cm	62 – 25%

Figures

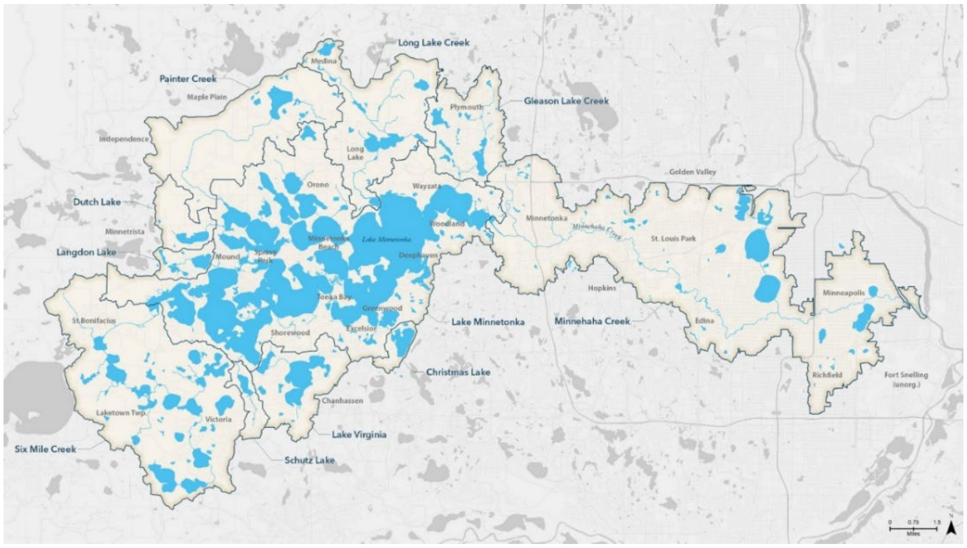

Figure 1. A map of the Minnehaha Creek Watershed.

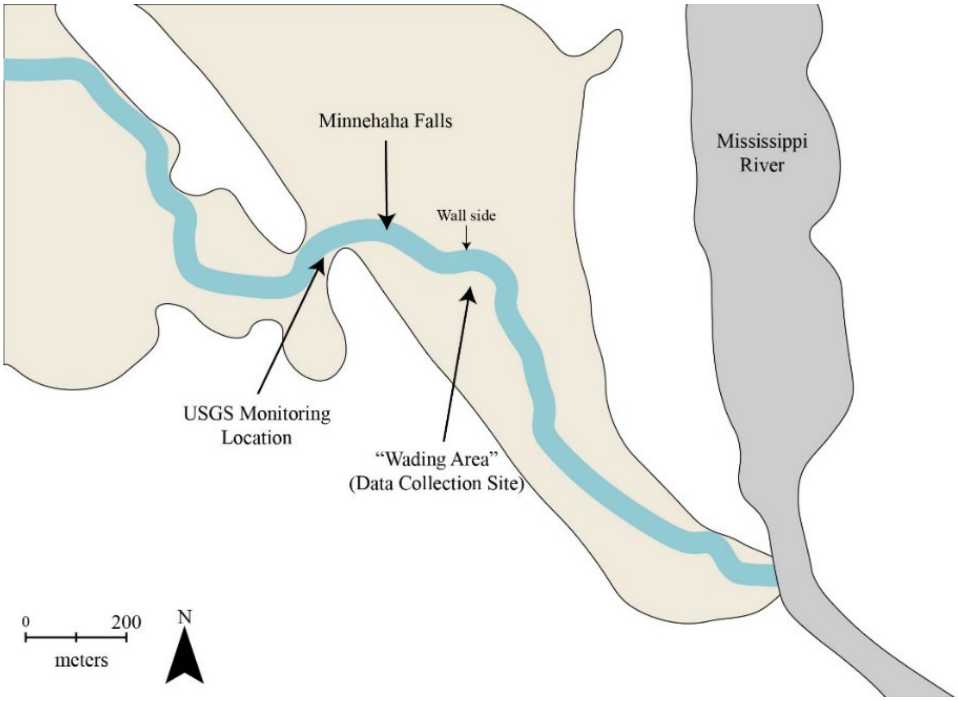

Figure 2. A field map of Minnehaha Creek with references to the USGS monitoring location, the location of the falls, and the specific location of the data collection for this study.

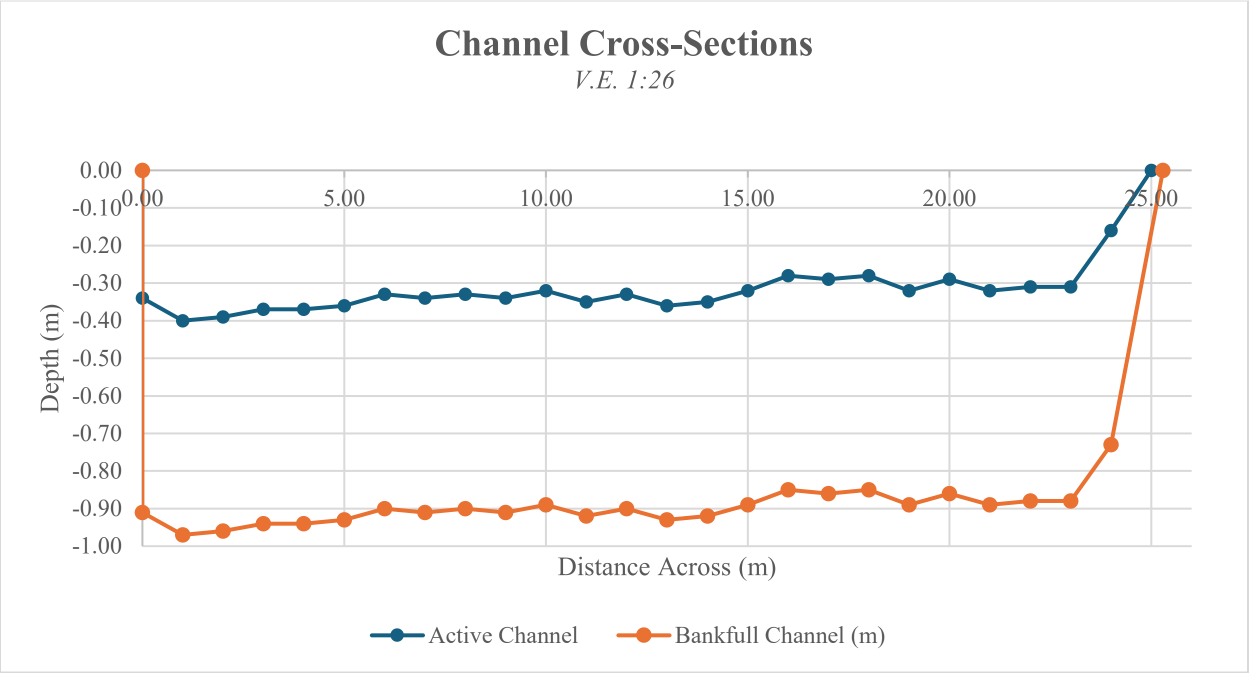

Figure 3. Channel cross-section shows active and bankfull channels.

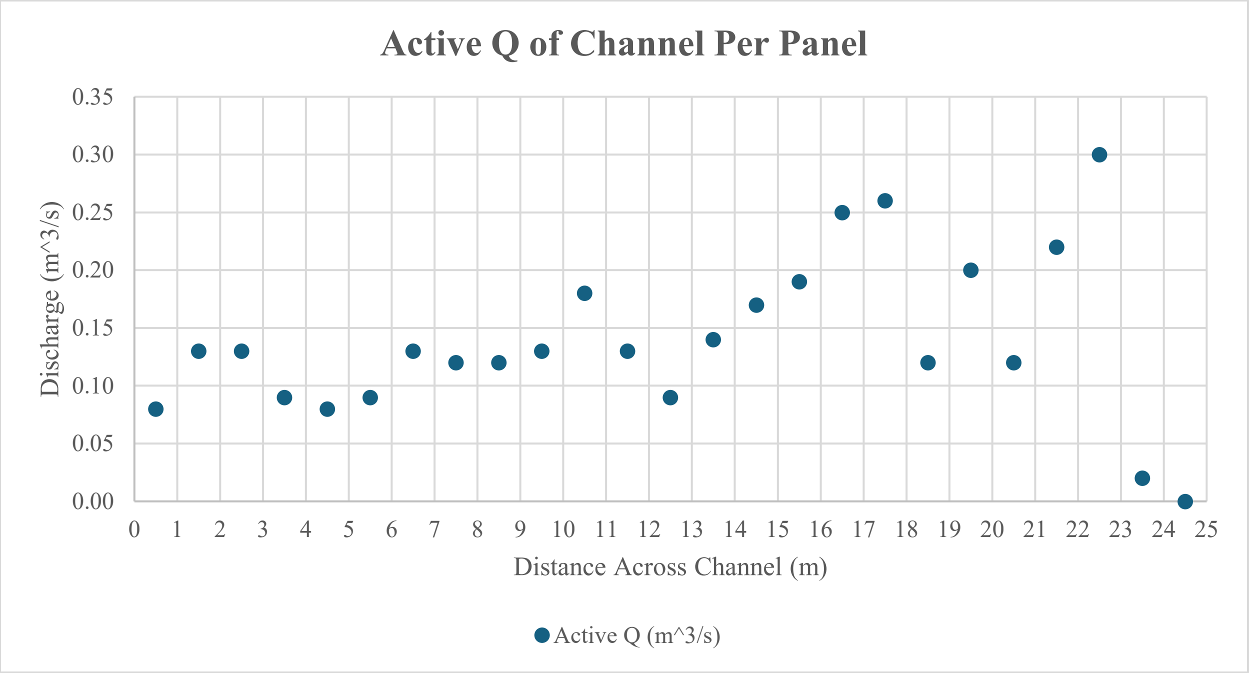

Figure 4. Active discharge (Q) of each panel across the channel cross-section.

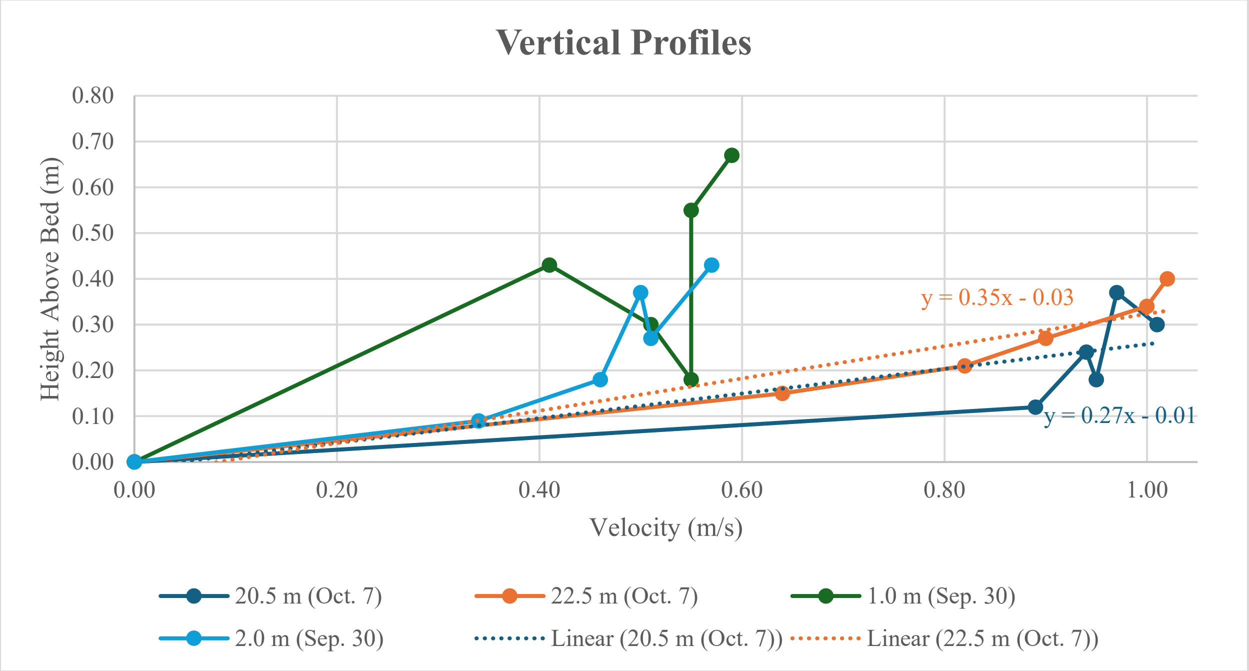

Figure 5. Vertical velocity profiles at various distances across the channel.

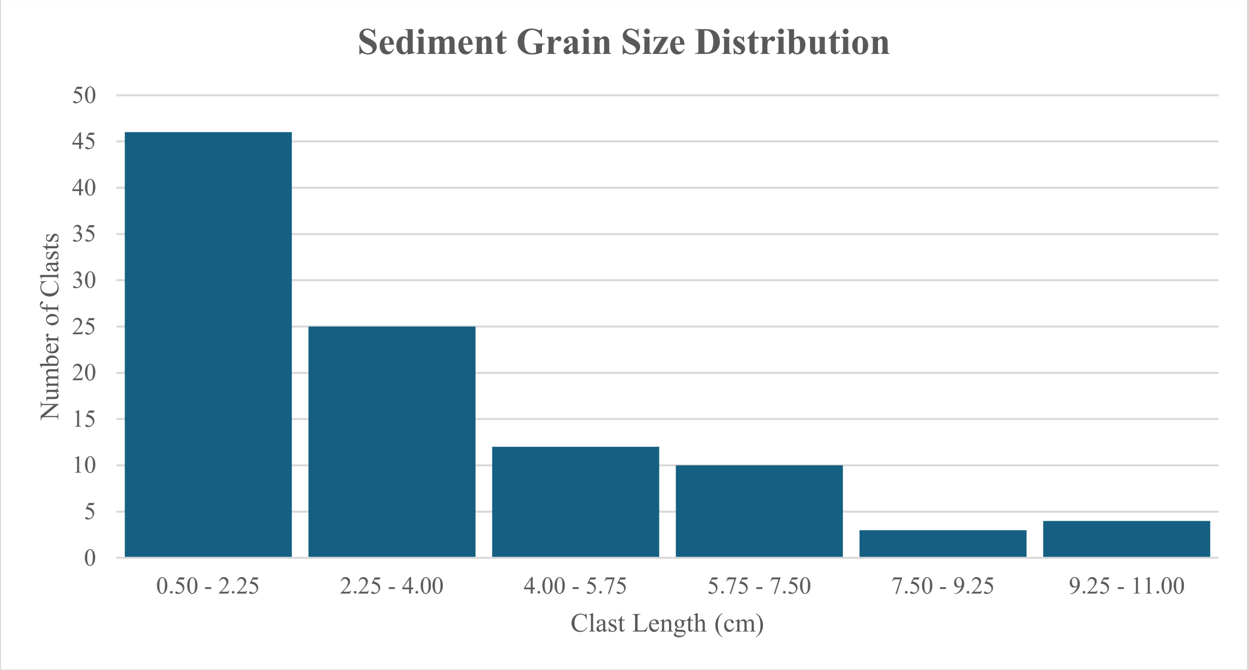

Figure 6. Histogram of measured clast sizes, with a total of 100 clasts measured.

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