

1 **Citizen science as a long-term environmental baseline: assessing**
2 **impacts of a small dam removal in Montana, USA**
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8 **Abstract.** As dam removals increase in frequency across [Europe and North America](#), ~~the U.S.~~, most research has focused on
9 the impact of larger dam removals, despite the removal of small dams being much more common. There are hundreds of small
10 dams in Montana, [USA](#), and this research investigates impact on stream ecology and morphology using citizen science data
11 collected over eight years spanning before and after a 2020 small dam removal in Rattlesnake Creek. We analyzed pebble
12 count grain size distributions and aquatic macroinvertebrate biotic indices from 2017 to 2024 to assess changes in sediment
13 transport and macroinvertebrate population as well as evaluate the efficacy of citizen science for long-term stream monitoring.
14 Our analysis includes comparisons of pre- and post-dam removal data collected from above and below the dam site. Our
15 findings revealed no significant changes in grain size or macroinvertebrate index values between upstream and downstream
16 reaches post-dam removal, suggesting that the removal of this small dam had minimal detectable impact on sediment transport
17 and macroinvertebrate communities within the study period. Our study also demonstrates the capacity for citizen science
18 programs to effectively collect robust and valuable datasets. This study underscores the importance of meticulous data
19 management along with the potential for, and challenges of, citizen science for environmental research. We provide
20 recommendations for “best practices” to improve future citizen science monitoring and informing decision-making for future
21 dam removals, particularly for the nine dams further upstream within the Rattlesnake Creek watershed.

22 **1 Introduction**

23 The U.S. has an estimated 2.5 million dams, the majority of which are under 1.83 m tall and are classified as small dams
24 (Brewitt [and](#) Colwyn, 2019; Kibler et al., 2011). A dam serves as a barrier to more than just water, blocking the transport of
25 sediment, [large wood](#) ~~logs~~, [and](#) nutrients, [as well as](#) ~~and~~ passage of fish. As a result, dams can negatively impact the health of
26 the stream, decreasing the presence of certain biota [and the complexity of physical habitat](#) ~~and hindering the growth of juvenile~~

27 fish (Foley et al., 2017; Hart et al., 2002; Kibler et al., 2011; Tonitto and Riha, 2016; Tullos et al., 2014; Lu et al., 2022).
 28 However, particularly for the removal of historic dams, the rapid release of sediment, large wood, and nutrients and woody
 29 debris large fragments of wood can negatively impact species of fish and macroinvertebrates immediately following removal
 30 as well (Chiu et al., 2013; Hart et al., 2002; Lu et al., 2022; Orr et al., 2008; Tullos et al., 2014). Understanding how small dam
 31 removals affect the geomorphology and ecology of a stream is essential to understanding the extent of impacts on a stream
 32 from dam removal. Given the diverse geographical distribution of dams in the United States and the role of sediment size,
 33 channel slope, flow, and other watershed-specific variables on creek restoration, it is important to understand the effects of
 34 small dam removal in specific environments (Hart et al., 2002; Kibler et al., 2011). In addition, most studies lack the duration
 35 necessary to determine long-term impacts of dam removal (Bellmore et al., 2016; Foley et al., 2017; Hart et al., 2002; Tonitto
 36 and Riha, 2016). By understanding how small dam removals in Montana have impacted waterways, the effects of dam removal
 37 can be more accurately anticipated when proposing similar projects in the Pacific Northwest. Advancing the science on small
 38 dam removals will help quantify the impact of these removals and promote healthier streams for ecological, societal,
 39 environmental, and recreational benefits. Especially relevant to this study site in Rattlesnake Creek, Montana, are the nine
 40 additional dams upstream in the Rattlesnake Wilderness (Rice &and Armatas, 2024; Rattlesnake Wilderness Dams,
 41 2024 Engage Missoula). The present study will help determine how their removal may impact the creek.

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42
 43 The Watershed Education Network (WEN) is a non-profit organization in Missoula, Montana, that has been leading citizen
 44 science efforts locally for 21 years. Stream Team is a WEN citizen science program that engages community members of all
 45 ages and backgrounds to monitor two creeks in Missoula, collecting valuable scientific data to document long-term trends in
 46 discharge, water chemistry, vegetation, aquatic macroinvertebrates, pebble counts, and cross-section profiles. Participating in
 47 citizen science endeavors has shown to improve individuals' knowledge of the scientific process, and community-based
 48 scientific monitoring gives voices to people who otherwise would not be in environmental conversations (Bonney et al., 2015).
 49 Citizen science is an especially effective method of environmental education when combined with focusing on local
 50 environmental issues, taking action, and reporting data (Ardoin et al., 2019). Furthermore, citizen science allows data collection
 51 on a spatial and temporal scale that would otherwise be difficult to obtain without significant funding, and by establishing
 52 "best practices" citizen science can meet the standards of data collection and further scientific research (Rubio-Iglesias et al.,
 53 2020)

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 55 This research seeks to answer the following questions: (1) How has Rattlesnake Creek changed since the dam removal in
 56 2020? (2) Can citizen science projects effectively monitor Wadeable streams local to their communities?

2 Background

2.1 Small dam removal in the western United States

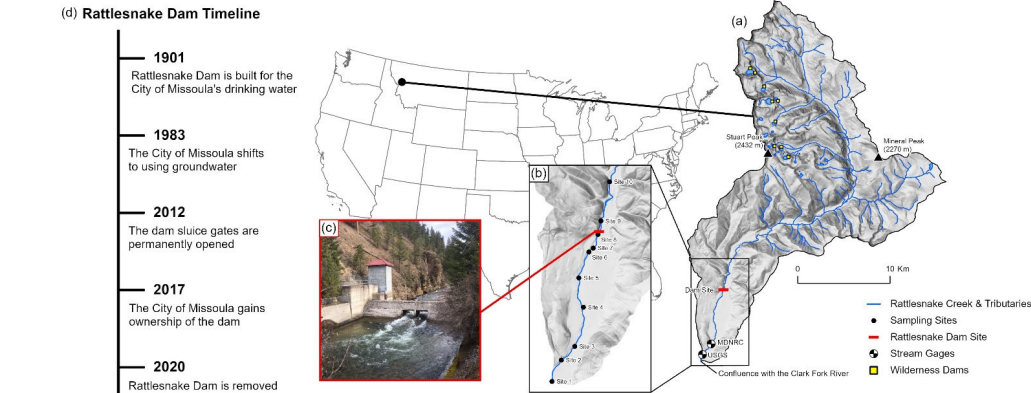
Research on the removal of small historic dams has shown the ecological benefits of small dam removal (Abbot et al., 2022; Orr et al., 2008; Tullos et al., 2014). For most dam removals, no data is collected, and most studies focus on short-term post-dam removal impacts and include little to no pre-dam removal data (Bellmore et al., 2016; Foley et al., 2017). Some positive impacts of dam removal have been identified as the return of macroinvertebrate communities, dissolved oxygen, and sediment composition levels to healthier or upstream of the dam values (Abbot et al., 2022; Mahan et al., 2021; [Maloney et al., 2008](#); Orr et al., 2008; Tullos et al., 2014). While the impacts of small dam removal are mostly positive, studies show that the release of trapped sediment [and restored connectivity](#) post-dam removal can initially lower water quality (Orr et al., 2008), [shift decrease](#) macroinvertebrate [diversity assemblages](#) (Mahan et al., 2021; [Maloney et al., 2008](#)), [negatively impact juvenile fish growth](#) (Lu et al., 2022), and allow the downstream spread of invasive species (Mahan et al., 2021).

[The erosion of non-cohesive reservoir sediment following dam removal has been characterized as a two-phase response, starting with a 'process-driven' rapid flush of sediment phase, which is followed by a supply-limited phase where further erosion requires high flows](#) (Collins et al., 2017; East et al., 2018; Pearson et al., 2011). The resilience of a river to dam removal depends on several factors, including response to this pulse in sediment, the magnitude of the changing conditions, the complexity and connectivity of the creek, and whether there is enough energy in the creek to process the disturbance and return to its natural state (Tullos et al., 2014). [-Additionally, the response of a river to dam removal relies on the timeline of dam removal](#) (Duda and Bellmore, 2022; Foley et al., 2017; Sawaske et al., 2012). [Staged dam removals, which occur over months to years, tend to have lower erosion rates following removal compared to nonstaged removal, where the dam is removed in one period](#) (Sawaske et al., 2012). [-It has also been found that Additionally, phased dam removals can minimize the impacts of the removal on fish and sensitive aquatic species](#) (Duda and Bellmore, 2022).

In response to river management and restoration, dam removals globally have been increasing, particularly those of small old dams in Europe and North America (Ding et al., 2019; Foley et al., 2017). Within North America, most research conducted on small historic dam removals has been focused on the eastern United States (Tonitto [and Riha, et al.,](#) 2016). Similar results may be expected in the western US in terms of hydrologic flows, sediment transport, and channel evolution; however, each of these variables are impacted by the specific watershed environment and require local studies. Given the complexity of how streams respond to the changes resulting from dam removal, it is important to build upon the existing research with additional studies, especially those contributing to the emerging dataset of the western US.

87 **2.2 Geographic setting of Rattlesnake Creek, Montana**

88 Rattlesnake Creek is a perennial, third-order tributary to the Clark Fork River northeast of the city of Missoula, Montana, in
89 the Pacific Northwest (Fig. 1). The upstream portion of the creek flows through the Rattlesnake Wilderness area managed by
90 the U.S. Forest Service. The watershed outlet is at the confluence with the Clark Fork River (Fig. 1a; 46.86737°, -113.98562°).
91 Its total drainage area is 210 km² and flows for approximately 37 km. Rattlesnake Creek runs through the valley between Stuart
92 Peak (2432 m elevation) and Mineral Peak (2270 m elevation). The total relief of the watershed is 1655 m with a mean basin
93 elevation of 1738 m. Mean annual precipitation of the watershed is 102.2 cm, mean annual temperature is 3.95° C, and about
94 81% of the watershed is forested (USGS, 2019). Rattlesnake Creek runs through the Rattlesnake National Recreation Area
95 and Wilderness, which is situated immediately to the northwest and adjacent to the city of Missoula, Montana. This area is
96 popular for recreation year-round including hiking, biking, horseback riding, skiing, trail running, kayaking, and family
97 picnicking.
98



99 Figure 1: Location of the Rattlesnake Creek watershed (a) in Montana, United States, with the locations of the nine upstream wilderness
100 dams (yellow squares). Stream Team monitoring site locations are indicated along with the Rattlesnake Dam site (red bar) and the Montana
101 Department of Natural Resources and Conservation (MDNRC) stream gage and decommissioned USGS stream gage. Downstream sites 1–
102 8 are the impact sites (b), upstream sites 9 and 10 are the reference sites (b). A photo of the dam (c) before removal and after permanent
103 opening of the sluice gates is shown (from TU). A timeline of the Rattlesnake dam (d) highlights main events from the construction to
104 removal of the dam.
105

106
107 An active stream gage managed by the Montana Department of Natural Resources and Conservation (MDNRC) is located at
108 the upper end of Greenough Park, 2.3 km from the outlet of Rattlesnake Creek into the Clark Fork River. The upper 98.8% of
109 the watershed is discharged through this gaging station. This station began recording in 2017, documenting discharge that

ranges from 0.23 m³/s to 31.8 m³/s, with an average annual discharge of approximately 3.0 m³/s. There is also an abandoned USGS gage (12341000) on the creek that operated briefly in 1899 and continuously from 1958 to 1967 and is located 270 meters upstream from the outlet to the Clark Fork River. In its headwaters, Rattlesnake Creek is fed by approximately 45 high-elevation lakes, seven of which are dammed (Rice & Armatas, 2024). The dams were built between 1911 and 1923 to increase water storage for the City of Missoula. In 2024, the McKinley Lake dam was removed, leaving nine dams in the wilderness (Engage Missoula).

The downstream-most dam on Rattlesnake Creek was located 8 km from the confluence with the Clark Fork River (Fig. 1). The dam was constructed in 1901 and was 18 m wide, 3 m tall, and 4.5 m thick, and at that location, blocked 95% of the watershed. The reservoir provided drinking water for the City of Missoula until 1983, when, due to giardia concerns, the City shifted to using groundwater (TU et al., 2021). The reservoir was maintained as a backup water supply, but because Rattlesnake Creek supports native species of fish, including bull trout (*Salvelinus confluentus*), westslope cutthroat trout (*Oncorhynchus clarkii lewisi*), longnose dace (*Rhinichthys cataractae*), and mountain whitefish (*Prosopium williamsoni*), a fish ladder was installed in 2003. The fish ladder had an estimated 50–90% efficiency (Fassnacht, March 30, 2025; Knotek et al., 2020; Novak, October 21, 2024). By 2011, the reservoir was no longer being used as a backup water supply, and in 2012 the dam sluice gates were permanently opened, allowing passage of water, fish, and sediment during low to moderate flow through the holes that were previously the sluice gates (Fig. 1c). During high flow, however, the water velocity through the sluice gate opening was too high for spring fish migration (TU et al., 2021). Studies have shown fish recovery through spawning success after weir removal in similar riverine settings (e.g. Birnie-Gauvin et al., 2018), however no fish specific study was conducted on Rattlesnake Creek after the full dam removal had been completed (TU et al., 2021).

In 2017, the City of Missoula obtained ownership of the dam and agreed to work with Trout Unlimited (TU) to develop a plan for its removal due to safety and conservation concerns related to the dam's deterioration. In 2020, the dam removal project began: Rattlesnake Creek was dewatered in July, and the stream channel and banks were reconstructed using gravel, logs, brush, cobbles, and boulders from the site. In total, over 300 meters of stream were reconstructed by the completion of the project in October 2020 (TU et al., 2021). The total cost of the dam removal was 1.1 million USD, and Rattlesnake Creek remains heavily dammed upstream in the wilderness area (Rice & Armatas, 2024).

~~Finally, Rattlesnake Creek runs through the Rattlesnake National Recreation Area and Wilderness, which is situated immediately to the northwest and adjacent to the city of Missoula, Montana. This area is popular for recreation year-round including hiking, biking, horseback riding, skiing, trail running, kayaking, and family picnicking.~~

141 **2.3 Citizen science and public engagement in the environment**

142 Getting the public involved in environmental education promotes actions, behaviors, and improvements for the environment
143 (Ardoin et al., 2019; Church et al., 2019; Frigerio et al., 2021). The most effective environmental education programs focus
144 on localized environmental issues, collaboration with scientists and resource managers, and taking actions that lead to physical
145 environmental improvements (Ardoin et al., 2019). Citizen science is an especially effective method of environmental
146 education, as it involves local focus, taking action, and reporting and has shown improvement in the scientific knowledge of
147 participants (Ardoin et al., 2019; Bonney et al., 2015; Frigerio et al., 2021). Community-based scientific monitoring also helps
148 shape scientific questions to address community needs and gives community members opportunities to engage with local
149 environmental issues and take environmental action (Ardoin et al., 2019; Bonney et al., 2015; Novacek, 2008).

150
151 Citizen science is also an effective means for collecting data at temporal and spatial scales that are often not possible otherwise
152 (Blake [and](#) Rhanor, 2020; Church et al., 2019; Deacon et al., 2023; Rubio-Iglesias et al., 2020). Despite some scientists being
153 skeptical of the quality of datasets generated by volunteers from the general public (e.g. Aceves-Bueno et al., 2017; Downs et
154 al., 2021; Kosmala et al., 2016), the potential for citizen science to advance environmental research exceeds those concerns
155 (Kosmala et al., 2016; Rubio-Iglesias et al., 2020). Some researchers have found citizen science data to be more variable than
156 data collected by professionals, other studies have found volunteers' data collection to be comparable to that of scientists, and
157 others assert that direct comparisons between data from professional scientists and citizen scientists are not appropriate for
158 assessing quality due to different methods and the ability to find and correct for patterns in citizen science data (Aceves-Bueno
159 et al., 2017; Downs et al., 2021; Kosmala et al., 2016; Specht [and](#) Lewandowski, 2018). Importantly, citizen science
160 frequently produces data that is scientifically sound and of high enough quality to use in scientific research, especially when
161 data quality is documented (Ardoin et al., 2019; Deacon et al., 2023; Downs et al., 2021; Kosmala et al., 2016).

162 **2.4 The Watershed Education Network and the Rattlesnake Creek project**

163 WEN's mission is to 'foster knowledge, awareness, and appreciation of watershed health through citizen science, youth and
164 school engagement, and outreach to our [sic] communities' (WEN, 2025). WEN organizes school programs for rural and
165 under-served schools in Western Montana, a Backyard Citizen Science program to give families kits to monitor water near
166 their homes, Backcountry Stream Corps to [conduct wood surveys](#) ~~monitor distribution of large fragments of woody debris~~,
167 groundwater monitoring excursions, and Stream Team to monitor Rattlesnake Creek and Grant Creek (Novak, October 21,
168 2024). Stream Team's monitoring of Rattlesnake Creek began in 2017, 3 years before the dam removal in 2020, and has been
169 ongoing post-dam removal with annual monitoring of locations above and below the dam site (Fig. 1b). Throughout this
170 project, WEN has involved hundreds of citizen scientists who have collectively volunteered over 4,000 hours from 2017 to
171 2024 ([Table 1](#); Fassnacht, March 30, 2025).

172

During the planning stages of the dam removal, TU gave funds to WEN to support monitoring the health of the creek before and after the dam removal. This study analyzes the data collected by citizen scientists from WEN's Stream Team program, which received supplemental support from the Open Rivers Fund and other partners to monitor Rattlesnake Creek's response to the removal of this small dam. The Stream Team data will be used to quantify impact from the removal of the dam, assess the efficacy of the citizen science stream health monitoring protocol, and contribute to the broader understanding of how similar small dam removals impact streams in the Pacific Northwest.

3 Methods

3.1 Stream Team: citizen science data collection

WEN's Stream Team is a citizen science program where community members volunteer to monitor various stream attributes. Volunteers, including families, students, retirees, and community members, meet every Sunday from August to November. WEN actively recruits for Stream Team by tabling at community events, word of mouth, posters at schools and businesses, and sandwich boards set up during Stream Team outings (Novak, 2026). Anyone is welcome to volunteer and they do so by acknowledging their interest via e-mail or signing up at a tabling event. Stream Team outing dates are communicated to those who indicated their interest and volunteers show up at the given time and location. WEN strives to include individuals of all backgrounds and abilities in their programs, adjusting programs as needed to minimize risk to participants while maintaining scientific rigor. Citizen scientists act in the capacity of a true researcher and any identifying information they provide is kept strictly confidential. The only exception to this is when participants agree to share their identity with WEN, such as for photos or testimonials, and signed permissions are obtained. All volunteers sign waivers prior to attending Stream Team outings (Novak, 2026).

Stream Team monitored Rattlesnake Creek from 2017 to 2024. On average a Stream Team outing has up to 20% new volunteers accompanying a consistent core group of citizen scientists (Novak, 2026). Stream Team collects a variety of stream health monitoring data that includes cross-sectional profiles, pebble counts, velocity, temperature, chemistry, turbidity, and aquatic macroinvertebrate counts (Fig. S1). ~~For detailed The monitoring protocol for each which that~~ Stream Team volunteers are trained in every outing morning ~~are described see Blakey (2025a). below as provided by Stephie Novak, WEN Stream Team coordinator (October 21, 2024).~~

~~Because the dam sluice gates were permanently opened in 2012, allowing most streamflow to travel unimpeded downstream, we didn't expect to see changes in water properties like chemistry, temperature, or turbidity, and chose not to analyze these data in the present study. To address research question 1, 'how has Rattlesnake Creek changed since the dam removal in 2020', we planned to analyze cross-sections, pebble counts, and aquatic macroinvertebrates as these characteristics have been shown~~

204 to change post-dam removal (Hart et al., 2002; Maloney et al., 2008; Orr et al., 2008). Previous studies have also found
205 sediment transport and geomorphology to vary greatly depending on stream characteristics (East et al., 2018; Hart et al., 2002).
206 Unfortunately, ~~Due to incomplete data recording,~~ cross-sections could not be analyzed, which is discussed further in
207 Limitations. The details for site selection, pebble counts, and macroinvertebrate counts are described below as provided by
208 [Stephie Novak, WEN Stream Team coordinator \(October 21, 2024\).](#)

210 Ten sites, two upstream and eight downstream of the dam site along Rattlesnake Creek, were identified at the beginning of the
211 project in 2017. Ten sites were selected to ensure that all sites could be visited with a once-a-week outing schedule during the
212 nine to twelve weeks of baseline flow during the field season. The site locations ([Table S1](#)) were chosen to be within a 15-
213 minute walk from a trailhead and with all but one site outside the Rattlesnake National Recreation Area ~~&~~and Wilderness,
214 which has stricter access regulations. These selection criteria resulted in there being only two upstream sites, with the remaining
215 eight downstream of the dam. The three lowermost sites were selected because of their location downstream of a bridge where
216 future construction (beyond the timeline of the present study) is planned. Each year, photos and GPS points were used to ensure
217 monitoring at sites remained consistent. Site information and summary of the vegetation, general morphology, and weather
218 conditions were also reported as part of the monitoring protocol. The Stream Team monitoring hours each season varied,
219 ranging from ~~about~~low as 200 to nearly 900 hours, depending on weather (influencing season duration) and the number of
220 volunteers (Table 1). ~~The initiation of the project in 2017, followed by the first full monitoring season in 2018, meant fewer~~
221 ~~volunteers and fewer site visits in those years, including only one of the upstream sites.~~ Upstream and downstream cross-
222 sections were delineated at the same locations every year using the site guide (including photos and GPS points). All additional
223 data was collected between the two established cross-section locations. The cross-sections were set up at least 50 feet ~~apart~~
224 ~~with~~apart, each delineated by a levelled and tightened string and tape measure attached at bankfull level across the stream.

226 ~~The measurement protocol for cross-sections is as follows: the width of the stream is divided into 20 to 50 intervals to balance~~
227 ~~resolution and time in the field, as well as allow for simple field calculations. The distance from the stream bed to the string~~
228 ~~(bankfull depth) and water depth are recorded for each interval with a stadia rod to the nearest 0.5 inches. Additional~~
229 ~~measurements are recorded for the wetted edges on each bank. If the measurement is taken on top of a rock and causes the~~
230 ~~stadia rod to be above the water, the measurement is marked with an "R".~~

231

Table 1. Stream Team Monitoring Hours for Rattlesnake Creek							
	2018	2019	2020	2021	2022	2023	2024
# volunteers	21	38	38	47	74	77	56
Total hours	200	355	760	499	887	816	896

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Table 1. Stream Team Monitoring Hours for Rattlesnake Creek									
	2017	2018	2019	2020	2021	2022	2023	2024	

# volunteers	18	21	38	38	47	74	77	56
Total hours	160	200	355	760	499	887	816	896

A pebble count was conducted between the two cross-section locations from left to right bankfull following Wolman's (1954) procedure, measuring at least 100 samples. ~~Samplers walked diagonally across the stream and every two steps looked away (to avoid bias in substrate selection) and picked up the rock closest to the tip of their right wader. The rock's intermediate (b) axis was measured using a gravelometer or less commonly, a ruler. The samplers called out the measurements to be recorded by someone at the bank and the process continued until at least 100 samples were collected. For mud and sand, a value of <4 mm was recorded and for rocks larger than the gravelometer, >300 mm was recorded.~~

~~Velocity was measured using a tennis ball thrown upstream, each starting at different distances from the bank. The time the tennis ball takes to travel from the upstream cross-section to the downstream cross-section was recorded for at least 10 trials. The distance between the cross-sections and the average time was recorded to calculate the surface water velocity as the average tennis ball travel time divided by the distance. To estimate stream velocity, the surface water value was multiplied by a coefficient of 0.8 to account for surface water having a higher velocity than the rest of the stream. Finally, discharge was estimated from the product of the average velocity, average water depth, and average wetted edge distance for the two cross-sections.~~

~~For temperature, three thermometers were set out to collect ambient air temperature (°C). Once this value was recorded, the thermometers were held under water at approximately one quarter of the distance into the stream from the bank. After submerging for at least 30 seconds, the thermometer was quickly pulled out, immediately read, and the temperature (°C) recorded.~~

~~For pH, six glass vials were rinsed out with water from the stream. Then, each vial was filled up to the 5 milliliter line with stream water. While wearing protective eyewear and gloves, volunteers added three drops of pH reagent for the normal range test to three of the water samples and mixed by inverting. Five drops of the high-range pH reagent were put into the remaining three samples and also mixed by inverting. After being capped and resting for several minutes, the resulting colored liquid was compared to the pH key and the corresponding pH value was recorded for each trial.~~

~~To measure dissolved oxygen (DO), a specific DO bottle was brought into the stream to a section with no unusually still water or heavy ripples and rapids. Facing upstream, the DO bottle was submerged until it overflowed, and all air escaped the bottle. The stopper was inserted underwater to ensure no air bubbles were in the bottle. If air bubbles were present in the sample, it had to be retaken. While wearing gloves and protective eyewear, volunteers opened the DO Reagent 1 and 2 powder pillows~~

and poured them into the water sample one at a time, ensuring all the powder entered the sample. The stopper was then put back in place and the bottle was inverted multiple times to mix the reagents. The solution sat until the precipitate settled to approximately half of the bottle. The bottle was inverted again, allowed to precipitate a second time, and then mixed a third time before being unstoppered for a third powder pillow to be mixed in. After re-stoppering, the bottle was vigorously shaken until no precipitate was left and the powder was fully mixed. The sample was then poured into a measuring vial and then into a square vial. The square vial was placed on a sheet of white paper to improve color differentiation, and the titration solution (sodium thiosulfate) was added one drop at a time, counting each number of drops and mixing between drops by swirling. When the solution was clear, one more drop of titrant was added. If the last drop did not improve transparency, the volunteer recorded the original number of drops; if it did improve clarity, they recorded the total number of drops. Each drop represents one mg/L of DO, so the number of drops was recorded as mg/L of DO present in the stream water sample. Two more DO measurements were made with new water samples using the same process. Then, the percentage of saturated oxygen was calculated based on the water temperature and mg/L of DO.

For aquatic macroinvertebrate counts, volunteers placed a D-ring net on the river bottom downstream of their position. With the net facing upstream, volunteers kicked the stream bed to collect macroinvertebrates and brought the nets back to the bank to sort by taxa. Volunteers continued collection at locations approximately six meters apart until at least 300 macroinvertebrates were collected.

For aquatic macroinvertebrate counts, a net was placed on the river bottom downstream of the volunteer's position with the D-ring net opening facing upstream. The stream bed was vigorously kicked for 45 seconds. Then, the nets were brought to the bank where the macroinvertebrates were removed from the net into a tub. Multiple collections were made, each approximately twenty feet apart in the stream. At the bank, macroinvertebrates were sorted by taxa (generally family or order) using a dichotomous key and placed in ice cube trays with the same taxa for separation and counting. The macroinvertebrates were also separated by size to avoid larger macroinvertebrates consuming smaller ones. This procedure continued until at least 300 macroinvertebrates were sampled and sorted into taxa. After the required sample size had been completely documented, the macroinvertebrates were released back into the creek.

3.2 Data selection, compilation, and cleaning

WEN created fill-in-the-blank paper datasheets for each data type collected by Stream Team volunteers. The forms include date, names of volunteers, instructions, number of trials, and information relevant to each data type. Datasheets were filled out and collected at the end of each Stream Team outing. During the winter season, after the completion of site visits, WEN volunteers entered the data into Excel workbooks for each site, with a sheet for every paper datasheet and corresponding cells for the information collected (i.e., a block of cells designated for entering each pebble's b-axis on the pebble count sheet). An example of a page from the workbook is included in the supplemental materials (Fig. S2). Each cell is color-coded and labeled to ensure information is placed correctly in the correct place. Cells not intended to have data entered are filled with black to

ensure data goes in the correct place. Calculations are automated, including a stream quality metric from the macroinvertebrate count, a histogram of pebble count data, velocity measurements, and data averages. Any additional information was recorded as notes. WEN staff verified that the Excel workbook and physical datasheets had the same information.

~~To address research question 1, ‘how has Rattlesnake Creek changed since the dam removal in 2020’, we analyzed cross-sections, pebble counts, and aquatic macroinvertebrates as these characteristics have been shown to change post-dam removal (Hart et al., 2002; Maloney et al., 2008; Orr et al., 2008). Previous studies have also found sediment transport and geomorphology to vary greatly depending on stream characteristics (East et al., 2018; Hart et al., 2002). Because the dam sluice gates were permanently opened in 2012, allowing most streamflow to travel unimpeded downstream, we didn’t expect to see changes in water properties like chemistry, temperature, or turbidity, and chose not to analyze these data in the present study.~~

3.2.3 Data analysis

To analyze the data in RStudio (Version [4.6.12025.09.2](#)), we extracted values from the sheets in the Excel workbooks and put them in CSV files organized by site, year, and datatype that could be read into the program. Further cleaning was done in R to remove spaces before and after data and establish all data entries into a single column in the workbook. Missing data and obvious data entry errors were cross-checked with WEN to ensure all data were included and there weren’t entry errors from the physical datasheets. Unfortunately, the cross-section profiles had substantial missing data until 2021. Thus, we chose to only analyze pebble counts and macroinvertebrates, as both datasets were mostly complete.

To analyze the pebble counts, we plotted grain size distributions for each site for every year and calculated the median grain size, D_{50} ; the 84th percentile grain size, D_{84} ; and the 16th percentile grain size, D_{16} , as described by Wolman (1954) and others (e.g., Kibler et al., 2011).

To quantify stream health from macroinvertebrate data, we used the Water Action Volunteers (WAV) Biotic Index, a water quality index developed for Wisconsin streams that classifies taxa of macroinvertebrates based on how pollutant tolerant they are (WAV, 2023). This biotic index was adapted from the Hilsenhoff Biotic Index (HBI), which identifies organisms down to genus or species (Crall et al., 2011). Because species identification is not always possible in the field and difficult for citizen scientists, Wisconsin scientists from the Department of Natural Resources and the University of Wisconsin-Madison designed the WAV Biotic Index to align with the HBI, but with less taxonomic resolution (WAV, 2023). While this index was designed for use in Wisconsin streams, the taxa included in this biotic index are the same as the taxa monitored by WEN. Because the taxa are the same and the application is for citizen science-based stream monitoring, we determined that the WAV Biotic Index is appropriate to use for the present study’s macroinvertebrate data.

329

330 This study uses the concepts developed for assessing the impacts of dam removal, including before-after/-control-impact
331 (BACI). BACI is a method that takes control sites and impacted sites to quantify change related to a time-specific event. For
332 the present study, BACI is used to compare upstream and downstream reaches of this section of Rattlesnake Creek before and
333 after the dam removal. Upstream sites are used for comparison (reference sites) as the characteristics from the upstream
334 locations should not change post-dam removal (Conner et al., 2016; East et al., 2018; Orr et al., 2008; Smith 2002; [Stewart-
335 Oaten et al., 1986](#)). We used the BACI approach to quantitatively evaluate if the difference between upstream and downstream
336 variables changed after the dam removal [using the equation:](#)

337
$$(\bar{x}_{\text{impact-control after}} - \bar{x}_{\text{impact-control before}}) (1)$$

338 [which calculates the mean difference between upstream and downstream sites following the dam removal minus the mean
339 difference between upstream and downstream sites prior to dam removal \(Abbott et al., 2022; Stewart-Oaten et al., 1986\). We
340 also calculated the standard error for each. ~~We calculated the mean value for each variable for every site above the dam and
341 below the dam to calculate the difference.~~](#) We did not include data collected in 2020, as data for some sites was collected
342 during the dam removal and some was collected after. Due to the small numbers of observations, especially for the reference
343 sites (n=4 before dam removal and n=8 after dam removal), descriptive statistics were used for this analysis, rather than an
344 ANOVA or t-test.

345 4 Results

346 To address research question 1, ‘how has Rattlesnake Creek changed since the dam removal in 2020’, we conducted a
347 comparison of pebble counts and biotic index values upstream and downstream of the dam site from pre- to post-dam removal
348 datasets. A fining in the median grain size downstream post-dam removal and a transition to upstream and downstream reaches
349 having similar grain sizes would indicate restored movement of sediment past the dam (East et al., 2018; Lu et al., 2022;
350 Magilligan et al., 2021; Potyondy & Hardy, 1994). For macroinvertebrates, a decreasing WAV Biotic Index downstream
351 would indicate a decrease in stream health and increase in pollution, while an increase in the index would indicate an increase
352 in stream health and decrease in pollution (WAV, 2023). ~~In 2017, fewer sites were visited as the program was getting
353 organized, resulting in only one upstream and four downstream sites visited. Similarly, in 2018 only one upstream site was
354 visited.~~

356 [Before the dam removal \(2017–2019\), the \$D_{16}\$, \$D_{50}\$, and \$D_{84}\$ were roughly similar between sites upstream \(sites 9–10; e.g. \$D_{50}\$
357 had a mean of \$105.9 \pm 7.6\$ mm and ranged from 88.0 mm to 124.3 mm ~~with a mean of \$105.9 \pm 7.6\$ mm~~\) and downstream \(sites
358 1–8; e.g. \$D_{50}\$ had a mean of \$100.1 \pm 6.9\$ mm and ranged from 59.0 mm to 146.7 mm ~~with a mean of \$100.1 \pm 6.9\$ mm~~\) of the
359 dam; Table 2, Figs 2a, S3, S4, and S5\). ~~and showed little change following dam removal.~~ Following dam removal, the grain
360 size distributions remained similar between sites upstream \(e.g. \$D_{50}\$ had a mean of \$92.9 \pm 8.4\$ mm and ranged from 71.6 mm](#)

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361 to 128 mm with a mean of 92.9 ± 8.4 mm) and downstream (e.g. D_{60} had a mean of 93.3 ± 3.0 mm and ranged from 63.6 mm
 362 to 127 mm with a mean of 93.3 ± 3.0 mm of the dam; Table 2, Figs. 2b, S3, S4, and S5). To quantify the effect of the dam
 363 removal while accounting for background effects, the magnitude of difference was calculated using Eq. (1). We found that all
 364 BACI values were less than their standard error, indicating that there was no notable magnitude of difference following dam
 365 removal across any of the measured grain size percentiles (Table S2; e.g. D_{60} value of 6.2 ± 13.6 mm). (Table 2, Figs. 2, S3,
 366 S4, & S5). Following dam removal (2021–2024), grain size remained similar across percentiles, with only minor fining in
 367 the downstream mean D_{16} from pre-dam removal (48.8 ± 4.9 mm) and post-dam removal (40.3 ± 2.3 mm).
 368
 369 At the site immediately downstream of the dam, mean D_{16} grain sizes fined from before the the mean before dam removal
 370 (2017–2019; 55.1 ± 16.4 mm) to immediately after dam removal in October 2020 (26.9 mm; Fig. S6?), though the D_{60} and D_{84}
 371 were not significantly substantially different. However, compared to the year immediately prior to dam removal (2019; $D_{16} =$
 372 22.5 mm), the post-removal measurement shows minor coarsening. The D_{60} and D_{84} showed no substantial trends at this site,
 373 and overall, we found no significant notable change in grain size downstream of the dam following dam removal across any
 374 site (Figure S6).
 375
 376 Similarly, there was no notable difference in the WAV Biotic Index values before the dam removal between sites upstream
 377 (mean of 2.993 ± 0.13 and range of 2.71 to 3.20 with a mean of 3.0 ± 0.1) and downstream (mean of 3.081 ± 0.064 and range
 378 of 2.33 to 3.50 with a mean of 3.1 ± 0.1 of the dam; Table 2, Figs. 3a, and S7). Following dam removal, the index values
 379 remained similar between sites upstream (mean of 2.92 ± 0.04 and range of 2.83 to 3.14 with a mean of 2.9 ± 0.0) and
 380 downstream (mean of 2.889 ± 0.03 and range of 2.57 to 3.25 with a mean of 2.9 ± 0.0) of the dam; Table 2; Figs. 3b and S7).
 381 The mean WAV Biotic Index scores upstream, downstream, before, and after dam removal were all within the “Good”
 382 threshold (2.5–3.5). The average WAV Biotic Index score downstream of the dam site remained in the “Good” threshold (2.5–
 383 3.5) across the pre-dam removal (3.08 ± 0.06) and post-dam removal (2.88 ± 0.03) periods. Overall, there was no substantial
 384 difference in index values following the dam removal after accounting for differences between upstream and downstream
 385 reaches (Eq. (1); Table S2; -0.13 ± 0.15). Individual sites saw variation largely within the “Good” health threshold throughout
 386 the study period (2.5–3.5; WAV, 2023), and no prominent trends exist, including for the site immediately downstream of the
 387 dam (Fig S8). (Table 3, Figs. 3 & S6). As such, we found no significant change in the biotic index following the dam
 388 removal.
 389
 390 From 2017 to 2024, pebble-count grain-size data show no discernible trend (Fig. 2) nor do D_{16} , D_{50} , D_{84} (Figs. S3, S4 & S5).
 391 Similarly, our calculated WAV Biotic Index shows no discernible trend in the distribution of taxa present across sites and
 392 years (Figs. 3 and S6). For both grain size and macroinvertebrate data, sites 7–10 were used to compare the data immediately
 393 upstream and downstream of the dam site from pre- and post-dam removal. We found no significant change in the difference

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Table 2: Mean and standard error values of grain size percentiles and WAV Biotic Index values for sites upstream and downstream of the dam before and after dam removal

	Pre-dam Removal									
	2017		2018		2019		2020		Mean	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
D ₁₆ (mm)	15.6	60.1 ± 9.4	58.5	59.2 ± 7.1	39.1 ± 12.2	36.7 ± 5.83	2020 data was collected during and following dam removal and thus was excluded		38.1 ± 10.1	48.8 ± 4.9
D ₅₀ (mm)	88	114.7 ± 20.1	124.3	110.2 ± 11.5	105.7 ± 4.3	87.3 ± 8.5			105.9 ± 7.6	100.1 ± 6.9
D ₈₄ (mm)	165.5	213.7 ± 68.8	189.6	204.2 ± 20.8	284.9 ± 61.3	226.8 ± 27.3			231.2 ± 40.1	216.0 ± 16.2
WAV Biotic Index	2.71	3.05 ± 0.10	3.20	3.23 ± 0.06	3.02 ± 0.18	2.94 ± 0.11			2.99 ± 0.13	3.08 ± 0.06
Maximum flow ^a (m ³ /s)	9.9 ^b		36.5		31.5		35.5		n/a	
	Post-dam Removal									
	2021		2022		2023		2024		Mean	
	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream
D ₁₆ (mm)	39.1 ± 23.4	48.6 ± 4.5	42.0 ± 15.4	42.0 ± 3.9	29.0 ± 9.5	35.4 ± 3.1	27.7 ± 3.7	31.1 ± 4.2	34.4 ± 6.1	40.3 ± 2.3
D ₅₀ (mm)	99.3 ± 27.7	109.0 ± 6.1	100.3 ± 27.7	95.7 ± 4.8	92.7 ± 13.1	84.1 ± 4.6	79.2 ± 0.4	84.4 ± 4.22	92.9 ± 8.4	93.3 ± 3.0
D ₈₄ (mm)	257.6 ± 63.68	270.0 ± 17.8	230.7 ± 76.4	247.9 ± 17.5	279.2 ± 14.6	190.5 ± 24.5	243.9 ± 23.8	216.5 ± 17.1	252.9 ± 20.7	249.6 ± 7.9
WAV Biotic Index	2.85 ± 0.02	3.01 ± 0.06	2.99 ± 0.16	2.88 ± 0.06	2.85 ± 0.01	2.78 ± 0.04	3.00 ± 0.00	2.86 ± 0.03	2.92 ± 0.04	2.88 ± 0.03
Maximum flow ^a (m ³ /s)	23.5		26.5		32.4		17.2		n/a	

^a Discharge data was collected from the Montana Division of Natural Resources gage on Rattlesnake Creek

^b Discharge measurements began on November 7, 2017

between the reference and impact sites with respect to the grain size percentiles, nor with respect to the WAV Biotic Index.

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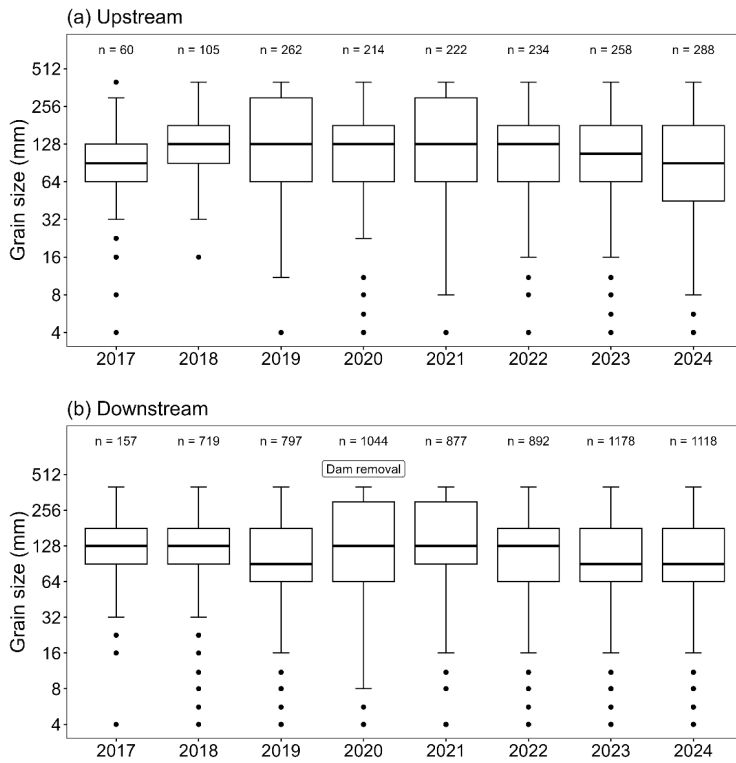


Figure 2. Grain size variations from 2017 to 2024. Top chart (a) shows grain size variations in sites 9 and 10, which are upstream of the dam. Bottom chart (b) shows grain size variations in sites 1-8, downstream of the dam. The thick horizontal line through the box shows the median, the height of the box shows the interquartile range, the vertical lines represent 1.5 times the interquartile range, and the circles represent data points outside of 1.5 times the interquartile range. The number of observations (pebbles counted) for each year are indicated at the top of the plot. [Dam removal occurred in 2020, and sites were sampled before, during, and after dam removal that year.](#)

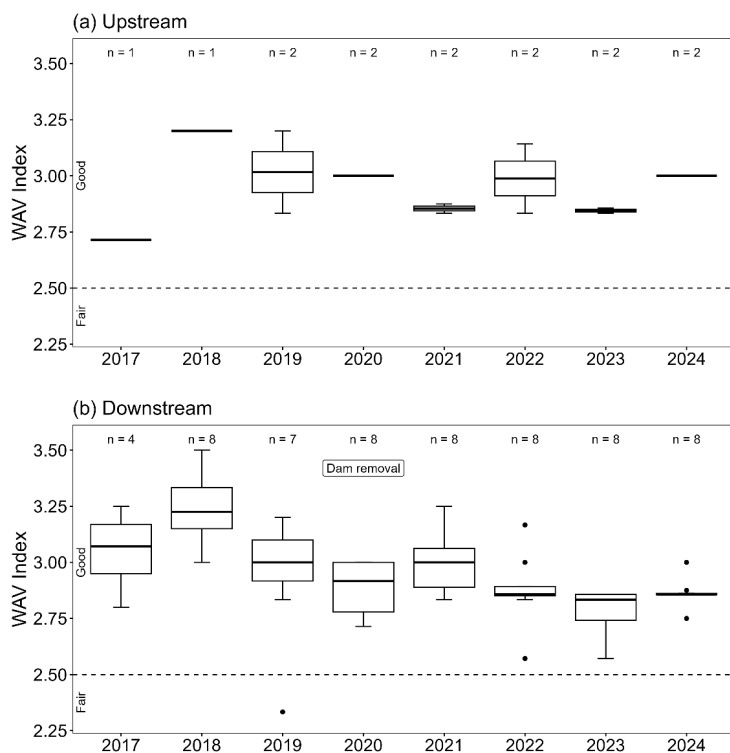


Figure 3. WAV biotic index data from macroinvertebrate counts from 2017 to 2024. Top chart (a) shows WAV variations in reference sites 9 and 10, which are upstream of the dam. Bottom chart (b) shows WAV variations in comparison sites 1-8, downstream of the dam. The thick horizontal line through the box shows the median, the height of the box shows the interquartile range, the vertical lines represent 1.5 times the interquartile range, and the circles represent data points outside of 1.5 times the interquartile range. The number of observations for each year are indicated at the top of the plot. Years with only one observation point are represented with dashed lines. Dam removal occurred in 2020, and sites were sampled before, during, and after dam removal that year. Stream health thresholds defined by WAV are included with a horizontal dashed line.

To address research question 2, ‘can citizen science projects effectively monitor local streams?’, we must consider the completeness and usability of the data collected by WEN volunteers. Of the three datasets identified as the most relevant for assessing the impact of the dam removal project on Rattlesnake Creek, one dataset (cross-sections) was unfortunately incomplete and will be discussed further in Limitations. However, the citizen science data collection protocol yielded eight

consecutive years of data for pebble counts and aquatic macroinvertebrate taxa that were complete and viable for our analyses. For these datasets, this demonstrates the efficacy of citizen science endeavors for long-term stream monitoring. The incomplete, cross-section dataset serves to provide insight on where to make improvements in the data verification protocol.

5 Discussion

5.1 Overall Assessment of Dam Removal Impacts

Our complete pebble count and macroinvertebrate data analysis results span three years before the dam removal to four years after and demonstrate no notable shifts in grain size, indicating that the removal of this dam on Rattlesnake Creek caused minimal impact on sediment distribution downstream. Similarly, macroinvertebrate diversity, frequently used as the biotic indicator of stream health, showed no discernible trend from before to after the dam removal. We attribute the lack of change and the similarity between upstream and downstream reaches prior to dam removal to two factors: first, the open sluice gates, and second, the lack of major discharge events following dam removal.

At the time of complete dam removal, the sluice gates had been open for eight years, analogous to a staged dam removal rate rather than a single-phase removal (Sawaske et al., 2012). Staged dam removal has been found to significantly reduce the volume of eroded sediment (Sawaske et al., 2012) and is often favored for this reason to mitigate sediment release (Foley et al., 2017). Strongly considering the role of the opening left behind from the removal of the sluice gates, the findings from our data suggest that the removal of a small dam with a large opening in the center does not impact sediment transport or aquatic macroinvertebrate populations on the scale of years. As evidenced by the lack of difference between upstream and downstream reaches prior to dam removal, we interpret that the dam removal itself served as an ecological and geomorphic “non-event”, as the river was fully adjusted prior to the removal of the dam. As such, we argue that this multi-year “staged removal” was an effective management strategy to eliminate downstream ecological trauma.

Our results may support the two-phase dam removal response where initially large quantities of reservoir sediment are eroded, followed by slower erosion rates that are dependent on larger floods (Collins et al., 2017; East et al., 2018; Pearson et al., 2011). The first phase of this response may have occurred during the permanent opening of the sluice gates, and as such data collection before and after the sluice gate opening may have revealed some change in sediment transport and macroinvertebrate populations downstream. At the time of Stream Team surveying, it is possible that the river had already transitioned to the second ‘event-driven’ phase (Pearson et al., 2011). During the study period, no significant flood events occurred. The discharge record from the MDNRC gaging station (Table 2) shows that the two years prior to dam removal had higher maximum flows than the two years that followed removal (~32 m³/s in May 2018 and ~29 m³/s in May 2019 versus ~21 m³/s in June 2021 and ~25 m³/s in June 2022), however the maximum flow in 2023 was much closer to that of 2018 (~30 m³/s in May 2023) and no

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significant flooding events occurred. In line with the two-phase model, interpreting the lack of change in sediment distribution requires considering the possibility that flows were insufficient after the dam removal to entrain and transport much sediment. This is consistent with the findings of Foley et al., (2017) with respect to both the occasional necessity of high flows to erode accumulated sediment and that most erosion occurs when a dam is breached instantaneously rather than in stages.

5.2 Effectiveness and Community Impact of Citizen Science Stream Monitoring

To address research question 2, ‘can citizen science projects effectively monitor local streams?’, we must consider the completeness and usability of the data collected by WEN volunteers. Stream Team citizen scientists include students, professionals, families, and retirees. Anecdotally, people love identifying the bugs, walking in the creek, and connecting with their environment (Fassnacht, March 30, 2025). For example, a volunteer said:

“I love the camaraderie of the group, being in the stream together and trying to figure things out.....a great way for people to kinda fulfill childhood dreams of looking at bugs and counting rocks and it’s going to matter for something. You get to learn about some sort of stream ecology and share it with friends.” (WEN, 2026)

Indeed, the citizen science data collection protocol yielded eight consecutive years of data for pebble counts and aquatic macroinvertebrate taxa that were complete and viable for our analyses. For these datasets, this demonstrates the efficacy of citizen science endeavors for long-term stream monitoring.

While irregular variation from year to year may be due to user-dependent bias from mistakes in measuring and biased selection—which has been shown to increase as different observers collect data (Downs et al., 2021; Marcus et al., 1995)—this problem is also observed in data from professional scientists (Crall et al., 2011; Kosmala et al., 2016). Of the three datasets identified as the most relevant for assessing the impact of the dam removal project on Rattlesnake Creek, only one dataset (cross-sections) was incomplete and will be discussed further in Limitations. However, due to being incomplete, the cross-section dataset serves to provide insight on where to make improvements in the data verification protocol.

Additional variation in the data may be attributed to the fact that Rattlesnake Creek, particularly the reaches within this study area, is heavily used for recreation. From children building rock piles to kayakers moving large pieces of wood, there is an unquantifiable human impact that must be considered with respect to both sediment transport and macroinvertebrates in this area.

We attribute the successful monitoring of pebble counts and aquatic macroinvertebrate populations to verification of the data in the field, well-designed field data entry sheets, and the relative simplicity of data collection. Both pebble counts and macroinvertebrate counts include working with a large team and routine verification, as well as collecting only tallies. Conversely, the cross-section dataset was incomplete due to missing field data, which is discussed further in Limitations. This

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missing data provides important insights into where to make improvements in the data collection and verification protocol, including ensuring field verification. Previous work confirms that successful data collection from citizen science projects includes effective planning, working in groups, and including quality assessment throughout the project (Crall et al., 2011; Downs et al., 2021).

Programs like Stream Team also give members of the community the chance to learn things, collect valuable data, and work without stress or a “traditional education” background knowledge requirement. For example, a volunteer said:

“...it showed me that, ‘oh hey you can do science’ it’s not all organic chemistry, and it can be collecting data or doing these fun things in the stream. I think that’s what it does for me...” (WEN, 2026)

WEN’s Stream Team program teaches people that science is approachable and helps them build camaraderie with like-minded people in their community, solving problems on the fly, and pointing out the wildlife, rocks, and bugs. Since Rattlesnake Creek is a popular recreational area, hikers are often walking by, and they love stopping and seeing what bugs Stream Team has found and ask what the volunteers are doing in the creek (Fassnacht, March 30, 2025). Volunteers, in turn, get the opportunity to share what they’re doing and invite the hikers to join next time. Previous studies have similarly found that participating in citizen science is an effective way of introducing environmental science as something that is approachable and understandable (Ardoin et al., 2019; Bonney et al., 2016; Novacek, 2008).

Our complete pebble count and macroinvertebrate data analysis results span three years before the dam removal to four years after and demonstrate no shifts in grain size, indicating that the removal of this dam on Rattlesnake Creek caused minimal impact on sediment distribution downstream. Similarly, macroinvertebrate diversity, frequently used as the biotic indicator of stream health, showed no discernible trend from before to after the dam removal.

The discharge record from the MDNRC gaging station shows that the two years prior to dam removal had higher maximum flows than the two years that followed removal (~32 m³/s in May 2018 and ~29 m³/s in May 2019 versus ~21 m³/s in June 2021 and ~25 m³/s in June 2022), however the maximum flow in 2023 was much closer to that of 2018 (~30 m³/s in May 2023). Interpreting the lack of change in the sediment distribution requires considering the possibility that flows were insufficient after the dam removal to entrain and transport much bedload. This is consistent with the findings of Foley et al., (2017) with respect to both the occasional necessity of high flows to erode accumulated sediment and that most erosion occurs when a dam is breached instantaneously rather than in stages. At the time of complete dam removal, the sluice gates had been open for eight years which is more akin to a staged dam removal (taking months to years) than a single phase removal (Sawaske et al., 2012). Staged dam removal has been found to significantly reduce the volume of eroded sediment (Sawaske et al., 2012) and is often favored for this reason to mitigate sediment release (Foley et al., 2017). Furthermore, irregular variation in pebble counts from year to year can also be due to heterogeneity of observers (Downs et al., 2021) that can result in user-dependent bias as was found by Marcus et al., (1995) with individuals consistently collecting different sized pebbles from

the same site. However, year-to-year data from professional scientists also has been found to have substantial variations (Crall et al., 2011; Kosmala et al., 2016).

Rattlesnake Creek, in particular the reaches within this study area, is heavily used for recreation. From children building rock piles to kayakers moving woody debris, there is an unquantifiable human impact that must be considered with respect to both sediment transport and macroinvertebrates in this area. For the pebble count and macroinvertebrate datasets, it is important to recognize that the Stream Team volunteers collected substantial usable data for monitoring baseline stream health. WEN's Stream Team program also teaches people that science is approachable and helps them build camaraderie with like-minded people in their community, solving problems on the fly, and pointing out the wildlife, rocks, and bugs. Since Rattlesnake Creek is a popular recreational area, hikers are often walking by, and they love stopping and seeing what bugs Stream Team has found and ask what the volunteers are doing in the creek (Fassnacht, March 30, 2025). Volunteers, in turn, get the opportunity to share what they're doing and invite the hikers to join next time. Previous studies have similarly found that participating in citizen science is an effective way of introducing environmental science as something that is approachable and understandable (Ardoin et al., 2019; Bonney et al., 2016; Novacek, 2008).

Our results span three years before the dam removal to four years after and demonstrate no significant shifts in grain size, indicating that the removal of this dam on Rattlesnake Creek caused minimal impact on sediment distribution downstream. The discharge record from the MDNRC gaging station shows that the two years prior to dam removal had higher maximum flows than the two years that followed removal ($\sim 32 \text{ m}^3/\text{s}$ in May 2018 and $\sim 29 \text{ m}^3/\text{s}$ in May 2019 versus $\sim 21 \text{ m}^3/\text{s}$ in June 2021 and $\sim 25 \text{ m}^3/\text{s}$ in June 2022), however the maximum flow in 2023 was much closer to that of 2018 ($\sim 30 \text{ m}^3/\text{s}$ in May 2023). Interpreting the lack of change in the sediment distribution requires considering the possibility that flows were insufficient after the dam removal to entrain and transport much bedload. Furthermore, irregular variation in pebble counts from year to year can also be due to heterogeneity of observers (Downs et al., 2021) that can result in user-dependent bias as was found by Marcus et al., (1995) with individuals consistently collecting different sized pebbles from the same site. However, year-to-year data from professional scientists also has been found to have substantial variations (Crall et al., 2011; Kosmala et al., 2016).

Similarly, macroinvertebrate diversity, frequently used as the biotic indicator of stream health, showed no discernible trend from before to after the dam removal. Rattlesnake Creek, in particular the reaches within this study area, is heavily used for recreation. From children building rock piles to kayakers moving woody debris, there is an unquantifiable human impact that must be considered with respect to both sediment transport and macroinvertebrates in this area. Finally, at the time of the dam removal, the sluice gates had been open for eight years, so perhaps data collection before and after this opening would have revealed some change in sediment transport and macroinvertebrate populations downstream. Strongly considering the role of the opening left behind from the removal of the sluice gates, the findings from our data suggest that the removal of a small

dam with a large opening in the center does not impact sediment transport or aquatic macroinvertebrate populations on the scale of years. However, for these two datasets, it is important to recognize that the Stream Team volunteers collected substantial usable data for monitoring baseline stream health.

Stream Team citizen scientists include students, professionals, families, and retirees. Anecdotally, people love identifying the bugs, walking in the creek, and connecting with their environment (Fassnacht, March 30, 2025). For example, volunteers said:

“I love the camaraderie of the group, being in the stream together and trying to figure things out.....a great way for people to kinda fulfill childhood dreams of looking at bugs and counting rocks and it’s going to matter for something. You get to learn about some sort of stream ecology and share it with friends.” (WEN, 2026)

“...as soon as you are forced to engage with it first hand you are engaged to start to form that relationship with the beauty of the natural world, and then you start to care about it because you’ve experienced it first hand.” (WEN, 2026)

It also gives members of the community the chance to learn things, collect valuable data, and work without stress or a “traditional education” background knowledge requirement. For example, volunteers said:

“I was really deterred in college from doing real science because I had really bad experiences in high school with chemistry and physics...so I did enjoy redeeming my relationship with chemistry and tell myself, ‘oh yeah, I can still do this’...” (WEN, 2026)

“...it showed me that, ‘oh hey you can do science’ it’s not all organic chemistry, and it can be collecting data or doing these fun things in the stream. I think that’s what it does for me...” (WEN, 2026)

Since Rattlesnake Creek is a popular recreational area, hikers are often walking by and they love stopping and seeing what bugs Stream Team has found and ask what the volunteers are doing in the creek (Fassnacht, March 30, 2025). Volunteers, in turn, get the opportunity to share what they’re doing and invite the hikers to join next time.

WEN’s Stream Team program also teaches people that science is approachable and helps them build camaraderie with like-minded people in their community, solving problems on the fly, and pointing out the wildlife, rocks, and bugs. Previous studies have similarly found that participating in citizen science is an effective way of introducing environmental science as something that is approachable and understandable (Ardoin et al., 2019; Bonney et al., 2016; Novacek, 2008).

6 Limitations

To analyze the impacts of the dam removal, we had intended to compare upstream and downstream cross-sections over time, as these data would have given us insights on how the dam removal impacted the geomorphology of the stream (Magilligan et al., 2021). Unfortunately, cross-sectional data was not usable, as the dataset was incomplete in multiple ways. The two major missing data issues for the cross-sections were related to measurement locations and location labeling. Most water depth and

bankfull data were recorded, but almost every dataset before 2021 was missing the measurement increments across the stream, making it impossible to discern where the elevation and water depths were taken. [Prior to 2021, volunteers recorded numeric intervals rather than measurements across the stream \(for example, channel widths from year to year could be divided into 20–50 increments without noting the length of those increments\).](#) Proper datasheet set-up could have rendered more complete datasets (e.g. including specific quantitative increments across the stream channel).- Additionally, for each site, the protocol requires the measurement of two cross-sections: one upstream and one downstream, marking the boundaries for all other data collection. Unfortunately, though datasheets provide evidence that two cross sections were measured, identification of which cross-section was upstream and which was downstream was frequently not recorded, making year-to-year comparisons between them impossible.

Data consistency was also limited because both physical and digital datasheets varied with revisions as both Stream Team coordinators and the volunteers changed over time. Fundamentally, and specifically for the cross-section data, a lack of in-situ verification of complete data collection and accurate data recording before leaving the site at the end of Stream Team field days led to these missing data.

7. Conclusions and future work

We found no evidence of a change in stream sediment size or macroinvertebrate diversity following the removal of the Rattlesnake Creek dam. We believe there are many contributing factors to this lack of change, emphasizing the unimpeded flow through the open sluice gates for eight years prior to dam removal and [the lack of major flood events potentially including lower discharge after following](#) dam removal, as well as the ongoing recreation activities in the stream. We do not attribute the lack of change in these variables to a lack of quality of the citizen scientist—collected data of sediment size or macroinvertebrates.

Citizen science data that was collected consistently over time was helpful for monitoring the stream when it was recorded completely and correctly, which was the case for most (e.g., sediment size and macroinvertebrates), but not all (e.g., cross-sections), datasets. Based on the extensive data compilation and cleaning prior to analysis, we have identified four ‘best practices’ for improving citizen science data collection for use in scientific analysis: 1) ensure everything that needs to be recorded has a place in the datasheet for recording it and verify that the data has been collected before leaving the field; 2) design digital datasheets [that make it so that it is](#) clear where data needs to be entered and makes it easy to do so for volunteers; 3) keep data in one column or row for the same data (i.e. keep all pebble count measurements in one column); 4) create an easy-to-access location for the data, such as a summary page, where the data can be read by a coding language to do the analysis. At the time of publication, WEN is developing an app with Aelid Development Inc. that will be used to record site

visit data on tablets including required entry fields. The app will be designed to address data entry and quality concerns by mitigating data loss that can occur in the field and during transfer from field notes to spreadsheet.

Finally, future work should include an examination of the completeness of the data not analyzed in this study, which includes all the stream chemistry measurements, temperature, velocity, and turbidity.

Data availability

The citizen science data that supports this research are online at <https://doi.org/10.6084/m9.figshare.30752828> (Blakey et al., 2025, last access: 1520 April–July 2026).

Interactive computing environment

Quarto R files for the analysis and plotting of this data are available at <https://doi.org/10.6084/m9.figshare.30758267> (Blakey, 2026, last access: 15 July 20–April 2026).

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753 **Author contribution**

754 BB, in collaboration with WEN, conceived the experiment and designed the research protocol for this study. The manuscript
755 was written by NB and BB. BB created the figures. BB and NB discussed the results and manuscript narrative as well as
756 contributed to the editing process.

757 **Competing interests**

758 The authors declare they have no conflict of interest.

760 **Ethical statement**

761 This study did not involve human-subject research as it involved the examination of empirical data collected by citizen
762 scientists; therefore, formal ethical approval was not required. All anecdotal statements from citizen scientists were previously
763 published and contributed voluntarily to the Watershed Education Network.