PROJECT PERFORMANCE MONITORING REPORT

WATERVLIET DAMS REMOVAL
PAW PAW RIVER, MICHIGAN

Great Lakes Restoration Initiative
National Oceanic and Atmospheric Administration
Fisheries Habitat Conservation Program

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Prepared for
Berrien County
Brownfield Redevelopment Authority

This report was prepared and submitted in fulfillment of project performance monitoring requirements for a Great Lakes Restoration Initiative (GLRI) grant awarded to Berrien County by the National Oceanic and Atmospheric Administration (NOAA), Fisheries Habitat Conservation Program Office, for removal of two dams on the Paw Paw River in Watervliet, Michigan, Berrien County.

<u>Project Name</u>

GLRI NOAA - Watervliet Dams Removal, Paw Paw River, Michigan

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1.0 INTRODUCTION

1.1 Project Background

The National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) awarded a Great Lakes Restoration Initiative (GLRI) grant to Berrien County's Brownfield Redevelopment Authority for removal of two related dams on the Paw Paw River, located in the City of Watervliet (Award #NA10NMF4630411). NOAA's stated goals for the Great Lakes Habitat Restoration Program as they specifically apply to the Watervliet Dams Removal project are 1) benefit native diadromous fish and their habitat, particularly projects that remove in-stream migration barriers; 2) restore habitats limiting productivity; and 3) restore natural systems. The Watervliet Dams Removal project was conceived and designed to accomplish all three of those goals.

The Watervliet Dams were originally constructed in the early 1900s in various forms and locations in support of the lumber industry. The dams are located in Section 23 of Watervliet Township (T3S, R17W, Figure 1). The dams were refurbished and rebuilt throughout their histories, but were most recently owned and operated by the former Watervliet Paper Company. The dams provided process water and electricity for the former paper mill that was located on the south shoreline of the Paw Paw River west of M-140. Both dams are located east of M-140. The exact date when the dams were no longer actively used to dam the Paw Paw River and generate electricity for the mill is unknown. The dams were largely inoperable and in a state of disrepair when Berrien County acquired the dams and surrounding property in 2000.

The Watervliet Dams Removal project was originally conceived and spearheaded by the Michigan Department of Natural Resources, Fisheries Division, Southern Lake Michigan Management Unit. In partnership with the Southwest Michigan Planning Commission, The Nature Conservancy, and Berrien County Brownfield Redevelopment Authority, the MDNR awarded an Inland Fisheries Grant to Berrien County in May 2009. The United States Fish & Wildlife Service awarded a Fish Passage Program grant to Berrien County in 2008. Total project funding available in 2009 was not sufficient to allow Berrien County to remove both structures, which was the best outcome for the Paw Paw River and citizens of Berrien County. Therefore, Berrien County pursued additional funding in 2010 through the GLRI and NOAA's Great Lakes Habitat Restoration Program. NOAA awarded Berrien County a grant in October of 2010, allowing the project to be implemented based on removal of both dam structures.

Project design began in October 2010. Construction began in August 2011 and was completed on November 23, 2011. Ecological monitoring was 100% funded by the NOAA GLRI grant. Baseline monitoring began in March of 2011 and was completed in July 2011, prior to the start of construction in August 2011. Post-construction monitoring started in March of 2012 and was completed in June 2012. This report is the final project performance monitoring report presenting the results of one baseline sampling year prior to dam removal and two years of sampling after dam removal. Initial funding provided for one year of post-removal monitoring. Due to lower than anticipated construction costs, a portion of the NOAA GLRI grant was not 100% utilized by the original grant end date of June 30, 2012. Therefore, NOAA granted an extension until June 30, 2013 and approved utilization of the remaining grant funds to extend post-construction monitoring into 2013.

1.2 Project Site and Description

The Watervliet dams were formerly located on the Paw Paw River, a major tributary of the St. Joseph River. The Paw Paw River watershed is 446 square miles and encompasses 435 miles of streams, including 99 miles of the mainstem Paw Paw River and 435 miles of tributaries. The Paw Paw River joins the St. Joseph River in downtown Benton Harbor, just downstream of the West Main Street Bridge over the St. Joseph River. The mouth of the Paw Paw River is located approximately 2,000 feet upstream of Lake Michigan and there are no fish migration barriers on the St. Joseph River downstream of the Paw Paw River. The Watervliet dams were located in Section 23 of Watervliet Township (T3S, R17W), approximately 25 river miles upstream of the St. Joseph River (Figure 1).

The two dams are identified by their original function (Figure 2). The furthest downstream dam is called the spillway dam. The spillway dam was located within the City of Watervliet, but was wholly owned by Berrien County. It was used primarily to impound the Paw Paw River and direct flow into the mill race and through the former power house. The furthest upstream dam was called the diversion dam. The diversion dam was located within Watervliet Township, but was wholly owned by Berrien County. The spillway and diversion dams were co-operated to impound the Paw Paw River upstream of the spillway dam and, while operational, direct river flow through a small power house located immediately west of the spillway dam. The two dams were linked by a continuous earthen berm running parallel to the natural flow of the river. The earthen berm is located on the island created by the north and south channels.

The Paw Paw River appears to have been split into two natural channels upstream of M-140; both channels are present in a 1887 plat map (Figure 3). The diversion dam was used to direct or divert river flow away from the northern channel. Therefore, the former impoundment was located in the southern channel and extended southward into the City of Watervliet and eastward into Watervliet Township. The northern channel is referred to in this report as the “historic channel” because continuous flow had been diverted from that channel for approximately 100 years (since the dams were constructed and operated in their most recent configurations). As a result of the flow diversion, the northern historic channel had filled with sediment, supported an abundance of wetland vegetation, contained warmer water temperatures, and shallower water depths, and supported a warm water fishery. The southern channel is called the “mill race” even though it technically is a natural channel and part of the former impoundment. The actual mill race was located west of the spillway dam and ran east-to-west under M-140 and south of the former paper mill.

At the time of project conception and funding in 2010, the dams and related infrastructure had been substantially altered to address public safety concerns and conduct brownfield remediation activities. The spillway dam supported a road deck and utilities above the concrete spillway in addition to supporting stop logs (Figure 4-1). The steel super structure and utilities were removed in 2002. The remaining structural components in 2010 included the concrete spillway, concrete abutments, and cobble-stone/concrete wing walls (Figure 4-2). Portions of the steel super structure embedded in the concrete abutments and spillway were still present and protruded from the concrete. The former power house and mill race located west of the spillway dam had been demolished and the mill race filled with soil. The spillway dam could not be used for impounding water above the spillway elevation at the start of the project in 2010.

The diversion dam also supported a steel super structure and utilities, although the structure appears to have only supported a catwalk for foot traffic (Figure 5-1). By 2010 the utilities and catwalk had been removed. The remaining structural components present in 2010 included the concrete spillway, concrete abutments, concrete wing walls, catwalk support framing, and guardrail (Figure 5-2). The diversion dam was not used for impounding water; therefore, it did not contain a steel superstructure for support gates or stoplogs.

The earthen berm connecting the two dams was still present in 2010 and had not been altered along its entire length. The earthen berm extended from M-140 eastward across the island (between the north and south channels) and eastward beyond the diversion dam several hundred feet (Figure 2). The earthen berm prevented the former impoundment from extending north of the southern channel except during large flood events that caused over topping of the diversion dam and backwater conditions on the southern historic channel.

The Watervliet dams removal and restoration project included complete removal of both dam structures below the streambed, concrete abutments, and concrete/cobble stone wing walls (Figures 6-1 and 6-2). Due to removal of the diversion dam, continuous flow under all flow regimes was restored to the historic channel. Three constructed riffles and armored bankfull benches were used to fix the bed elevations at the two former dam locations and at the downstream end of the historic channel. The riffles and armored bankfull benches fixed the dimensions (i.e., width and depth) of the channels and the amount of flow that would naturally split between the two channels. The design channel dimensions and bed elevations were based on a flow split of 20% to the historic channel and 80% to the southern channel under the bankfull discharge. However, the flow split will vary with total stream discharge and stage. Based on design, target fish species should be able to freely swim through all three riffles, the historic channel, and the mill race.

2.0 METHODS

2.1 Monitoring Goals and Objectives

NOAA's stated goals for the Great Lakes Habitat Restoration Program as they specifically apply to the Watervliet Dams Removal project are 1) benefit native diadromous fish and their habitat, particularly projects that remove in-stream migration barriers; 2) restore habitats limiting productivity; and 3) restore natural systems. The Watervliet Dams Removal project was conceived and designed to accomplish all three of those goals. Successful attainment of the restoration goals was measured through ecological monitoring. Ecological monitoring included assessment of physical barrier attributes and habitat changes, changes in channel morphology, fish community changes, and fish passage by target potadromous fish species.

A project monitoring protocol was developed in consultation with the Michigan Department of Natural Resources (MDNR), Fisheries Division; United States Fish and Wildlife Service, Green Bay Fish and Wildlife Conservation Office; and NOAA, Office of Response & Restoration. The MDNR Fisheries Division Manual of Fisheries Survey Methods II (Schneider, 2000) was consulted and used as a guide for various aspects of the fish community monitoring. The overall goal of ecological monitoring was to determine if removing the two Watervliet dams effectively restored unrestricted potadromous and native riverine fish movement within the Paw Paw River while restoring habitat, thereby benefiting and conserving the native and potadromous fish communities of the Paw Paw River, St. Joseph River, and Lake Michigan. Several pre- and post-removal monitoring objectives were identified in the project monitoring protocol to guide ecological monitoring.

Pre-Removal Objectives

- Characterize the existing fish communities upstream and downstream of the dams using multiple community indices, test for statistical significance.
- Map habitat types and distribution within the upstream and downstream sampling stations.
- Characterize the existing fish communities within the historical channel and mill race using multiple community indices, test for statistical significance.
- Map habitat types and distribution within the historical channel and mill race.

- Document the existing bed profile and slope through both dams and upstream/downstream of the dams.
- Document the existing elevation head, bed slope, channel average width, and mean flow velocity through both dams.
- Fin clip representative fish species captured downstream of the dams.

Post-Removal Objectives

- Characterize the existing fish communities upstream and downstream of the dams using multiple community indices, test for statistical significance.
- Map habitat types and distribution within the upstream and downstream sampling stations.
- Characterize the existing fish communities within the historical channel and mill race using multiple community indices, test for statistical significance.
- Map habitat types and distribution within the historical channel and mill race.
- Document the existing bed profile and slope through both dams and upstream/downstream of the dams.
- Document the existing elevation head, bed slope, channel average width, and mean flow velocity through both dams.
- Capture fin clipped fish upstream of the former dam locations.

Following pre-construction sampling the monitoring objectives were modified in consultation with NOAA. Given water depth and abundance of large woody debris, electrofishing using a boat-mounted boom shocker was not effective enough to obtain a robust fish community sample at some sampling locations. In particular, the length of boat-accessible river between impassable large woody debris jams at some stations was less than the required length of 2,500 feet. Furthermore, the habitats within the reaches were very complex and very similar. Both reaches were dominated by large woody debris and associated pools. Sand was the predominant bed material in both reaches and distinct riffle bed forms were absent in both reaches. Water depth and flow velocity were highly variable due to the abundance of large woody debris rather than distinct morphological bed forms. Due to the difficulty in mapping such complex habitats and the inefficiency of fish community sampling encountered, fish community monitoring was discontinued at the upstream, downstream, and mill race stations.

Fish community monitoring was continued for the historic channel. Monitoring resources were reallocated to the efforts to mark and recapture target fish species (i.e., evaluate fish passage), asses the artificial riffles as productive aquatic habitats, and document morphological changes in response to dam removal. Consequently, the following two post-construction monitoring objectives were added following NOAA's approval.

- Document macroinvertebrate community colonization in the three artificial riffles.
- Re-survey twelve channel cross-sections surveyed prior to dam removal.

2.2 Null Hypothesis

The monitoring protocol was developed to answer two principal questions:

- Did dam removal restore the lotic habitat and fish community within the historic channel of the Paw Paw River previously impacted by the dams?
- Did dam removal restore unrestricted fish movement?

From these two questions, the following null hypothesis was derived.

> *Removing the two Watervliet dams on the Paw Paw River will not allow passage of target fish species nor significantly change fish community diversity in the historic channel by restoring a continuous flow regime.*

If statistical testing shows that there is a statistically significant difference in the fish community diversity after dam removal and unrestricted fish movement is documented, then the null hypothesis would be rejected, indicating that the removal of the Watervliet dams has significantly changed the fish community of the historic channel and restored unrestricted fish movement. A Student's t-test for the Shannon-Wiener Index will be used to test for a significant change in the diversity of the historic channel fish community after dam removal (Section 2.5). A statistical fish passage test is not included in the data analysis and hypothesis testing because a simple presence/absence test will be used. If target fish captured and marked downstream of the dams are recaptured upstream of the dams, then the null hypothesis will be rejected.

2.3 Monitoring Stations

Fish collection and monitoring stations were selected for fish community monitoring and target fish marking based on accessibility and proximity to the project. Table 1 summarizes the river stations where fish were collected. The location of fish collections reaches are shown on Figures 7-1, 7-2, and 7-3. A total of eight reaches were sampled from 2011 through 2013. Details of fish community monitoring efforts at each station for the purpose of fish community monitoring and fish marking are further described below.

Fish Community Monitoring

Four fish community sampling stations were originally selected to monitor the fish communities upstream and downstream of the dams and within the historic channel (north channel) and mill race (south channel): M-140 campground (upstream); North Paw Paw Street (downstream); entire historic channel; and entire mill race. Lyons (1992) recommended a minimum sampling length of 35 times average stream width for fish assemblage surveys. The Paw Paw River averages approximately 70 feet in width between Coloma and the Berrien-Van Buren county line. Therefore, the selected sampling reach length is 2,500 feet (35 x 70 = 2,450 feet, minimum recommended length).

Fish were collected at the two downstream stations in Coloma (Paw Paw Street and DPW) and the M-140 Campground station in June of 2012 prior to dam removal, but fish community monitoring was abandoned at both stations due to sampling difficulties as discussed in Section 2.1. Due to large woody debris jams in the upstream and downstream stations, ECT was not able to access 2,500 feet of stream at either station and the number of species captured was low compared to the number of species previously documented in the Paw Paw River. A fifth station was later identified as an alternative for the downstream station at the Coloma Department of Public Works (Coloma DPW) building because the accessible length of river at North Paw Paw Street was only 1,500 feet. However, a low number of species was captured in that reach as well. A low number of species was also captured in the mill race. Due to these sampling difficulties, fish community monitoring was abandoned for the mill race, downstream, and upstream locations. The stations at

M-140 Campground and in Coloma were not surveyed again. Fish collections were later conducted in the mill race while looking for recaptures.

The total length of the Historic Channel is 1,700 feet, which is less than the recommended length of 2,500 feet. However, the data analysis and statistical test described in Section 2.5 only require equal sampling effort before and after treatment. Therefore, for before and after treatment comparisons (i.e., dam removal), it is acceptable to repeat sampling over a shorter length of river providing the sampling effort is equal. Due to a large woody debris jam in the historic channel, only 1,200 feet of the historic channel was actually sampled before and after dam removal. The sampling reach began at the mouth of the historic channel (upstream end of the riffle after construction) and extended upstream 1,200 feet.

Fish Marking and Recapture Attempts

Target fish were captured for marking (Section 2.4) at five locations downstream of the dams: Benton Harbor; North Paw Paw Street (Coloma); Coloma DPW; M-140 (Watervliet); and historic channel (Table 1, Figures 7-1, 7-2, 7-3). Some of these stations are the same as the fish community monitoring stations described above and were only sampled once in 2011. All target fish species captured in the fish community monitoring stations located downstream of the dams were marked as described in Section 2.4, including fish captured in the historic channel (downstream of the diversion dam). Sampling conducted at the Benton Harbor and M-140 reaches was performed for marking fish only. Marked fish recapture attempts were conducted in the mill race, upstream diversion, and Hartford reaches. Sampling was only conducted at Hartford once, however, due to difficult boat access and debris jams.

2.4 Fish Collection and Marking

Fish were collected using a boom-shocker mounted on a 17-foot aluminum flat bottom boat powered by a 20-hp, 4-cycle outboard motor. The boom shocker was powered by a Smith-Root GPP5.0 electrofisher supplying DC voltage to two boom-mounted electrode arrays manufactured by Smith-Root. The GPP5.0 was set for low-range voltage at 30% of power and 60 pulses per second. This configuration resulted in 5 to 6 amps of output while allowing effective capture of fish and short recovery times.

The health and condition of released fish appeared to be good. The electrofisher's built-in timer was used to record actual fishing time (i.e., power-on) in seconds.

Fish were stunned and netted from the river by handlers and temporarily held in on-board tanks containing fresh river water obtained from the Paw Paw River until processing. Fish were held for a maximum of ten minutes prior to processing and release. Captured fish were identified to species and counted. All adult suckers (Catostomidae species) and walleye (*Sander vitreus*) captured downstream of the dams were marked by clipping 50% of the anal fin for later recapture.

Because fish collections were conducted during the spring steelhead run and large numbers of steelhead were stunned, stunned steelhead were not collected and handled to reduce stress on migrating steelhead. Most stunned steelhead observed recovered quickly.

2.5 Data Analysis and Hypothesis Testing

The following data analyses and statistics will be used to test the monitoring null hypothesis. Fish community diversity (Shannon-Weiner index), species richness (number of species), and species composition will be determined to compare the fish community of the historic channel before and after dam removal. Similarity between the pre- and post-construction historic channel fish communities will be evaluated using Sørensen's similarity index. The equations that will be used to calculate each of these community indices are provided below.

<u>Shannon-Wiener Index of Diversity</u> $H' = -\Sigma p_i \log p_i$

Where:

H' Shannon-Wiener Index

p_i proportion of species i

<u>Catch per Effort</u> $CPE = \frac{n}{T}$

Where:

CPE catch per effort (#/minute)

n total number of individuals or sample size (catch)

T sampling time in minutes (effort)

<u>Species Composition</u> $$SC_i = \frac{n_i}{n}$$

Where:

SC_i species composition of species *i*

n_i number of species *i*

n total number of individuals or sample size

<u>Sørensen's Similarity Index</u> $$\beta = \frac{2c}{n_1 + n_2}$$

Where:

β Sørensen's Similarity Index (0-1, dimensionless)

c number of species common between sample stations

n_1 number of species in station 1 sample

n_2 number of species in station 2 sample

The Shannon-Wiener diversity index has been used extensively in the scientific literature to evaluate the difference in biological diversity over time or between sampling stations/treatments. Hutcheson (1970) is credited with developing a t-test for the Shannon-Wiener Index as noted and cited by Poole (1974) and Magurran (2004). The variance of the Shannon-Wiener index (varH'), degrees of freedom (*df*), and t-statistic are calculated using the equations below from Hutcheson (1970).

<u>Variance</u> $$\operatorname{var} H' = \frac{\Sigma p_i \ln^2 p_i - (\Sigma p_i \ln p_i)^2}{n} + \frac{s-1}{2n^2}$$

Where:

varH' variance of the Shannon-Wiener Index (H')

p_i proportion of species *i*

ln natural log

s number of species

n number of individuals of all species

Degrees of Freedom
$$df = \frac{\left[\mathrm{var}(H'_1) + \mathrm{var}(H'_2)\right]^2}{\left[\mathrm{var}(H'_1)^2 / n_1\right] + \left[\mathrm{var}(H'_2)^2 / n_2\right]}$$

Where:

varH'_1 variance of the Shannon-Wiener Index (H') for community 1

varH'_2 variance of the Shannon-Wiener Index (H') for community 2

n_1 number of individuals for community 1

n_2 number of individuals for community 2

t-Statistic
$$t = \frac{H'_1 - H'_2}{\left[\mathrm{var}\,H'_1 + \mathrm{var}\,H'_2\right]^{1/2}}$$

Where:

H'_1 Shannon-Wiener Index for community 1

H'_2 Shannon-Wiener Index for community 2

varH'_1 variance of the Shannon-Wiener Index (H') for community 1

varH'_2 variance of the Shannon-Wiener Index (H') for community 2

The Hutcheson Student's t-test for the Shannon-Wiener Index were used with α=0.10 to test for statistically significant differences between the pre- and post-construction fish community diversity in the historic channel.

The Shannon-Wiener Index and statistical testing described above can show a significant difference between communities at station or over time (i.e., pre- to post site restoration) based on taxonomic diversity. However, the index cannot adequately describe the difference or the magnitude of the difference. Diversity is a combination of both species richness and evenness. To further evaluate differences and change (including magnitude of change) within fish communities of the historic channel before and after dam removal, the other community indices above and a conversion of the Shannon-Wiener Index were used as described below.

When the number of species in a community doubles, the community diversity intuitively doubles. This is not the case with the Shannon-Wiener Index, which is non-linear. A very large change in true diversity within a community can be represented by a very small change in the Shannon-Wiener Index, thereby masking the true magnitude of the change. Banos (2006) suggests a means of converting the Shannon-Wiener Index from a measure of entropy to a true measure of diversity expressed as the "effective number of species." The effective number of species is the number of species with equal frequency (i.e., species evenness = 1.0) that would result in a Shannon-Wiener index of a certain value. Banos (2006) equates it to true diversity. Mathematically, Banos (2006) defines the effective number of species as the exponential of the Shannon Index [exp(H') or $e^{H'}$; the base of the natural logarithm raised to the power of H']. The effective number of species is proportional to the number of equally common species in a community. If the number of equally common species in a community doubles, the measure of diversity used should also intuitively double.

As the Shannon-Wiener index measures it, diversity is high when there is a high number of species in the community with high equitability (i.e., evenness). Therefore, a high effective number of species equates to high diversity and vice-versa. It is useful to convert the Shannon-Wiener index to the effective number of species because it allows an assessment of the magnitude of difference/change in addition to the statistical significance of that difference/change when used to compare two communities or compare diversity over time in response to a change/disturbance/experimental treatment within a system.

Species composition was used as a side-by-side comparison of fish assemblages. That is, the percent composition or abundance for all species between two communities will be compared side-by-side to illustrate compositional differences in the communities. Consideration of habitat preferences and species rarity/absence were considered in the analysis to highlight differences in the communities that could be attributed to the effects of dam removal on aquatic habitat within the historic channel. To graphically illustrate compositional differences between communities, k-dominance curves were created by plotting cumulative percent dominance (i.e., % composition) on the y-axis and the natural log of the each species' rank based on abundance on the x-axis. The shape of the k-dominance curves are compared visually to highlight the differences in the communities.

Sørenson's Similarity Index was used to assess similarity between communities. Sorenson's provides an estimate of the percent similarity between species assemblages based on presence-absence data. More overlap in species between two communities will result in a higher index value, meaning the two communities are similar. Two communities with the exact same species assemblage will be 100% similar (index value of 1.0).

A fish passage test is not included in the analysis and hypothesis testing because a simple presence/absence test was used. Capture of a fin-clipped fish upstream of the dams that was captured and marked downstream of the dams will result in rejection of the null hypothesis, and confirms fish passage was restored. Conversely, the absence of fin-clipped fish upstream of the dams would result in a failure to reject the null hypothesis or the conclusion that the study was not able to detect a change in fish passage. During the spring and summer 2012 surveys, the number of fin clipped fish captured at the upstream monitoring station and the five upstream barriers will be recorded. The number of fin clipped fish upstream of the barrier will further validate and confirm successful migration throughout the Paw Paw River as a direct result of dam removal. However, the number of recaptures will be heavily dependent on the number of fish that can be fin clipped in 2011 and 2012 prior to dam removal.

2.6 Accessible River Miles

The efficacy of removing the Watervliet dams is predicated on making suitable fish spawning habitat located upstream of the dams accessible. The amount of spawning habitat located upstream of the Watervliet dams is directly proportional to the length of accessible stream upstream of the dams. Therefore, GIS and spatial data were used to calculate the length of river upstream of the dams that was made accessible through dam removal and successful restoration of fish passage. The stream network was obtained from the Michigan Spatial Data Library in ESRI shape file format. In order to calculate the number of accessible river miles, the location of other upstream fish barriers in the Paw Paw River watershed must be known. A barrier inventory was conducted for the St. Joseph River watershed concurrent with removal of the Watervliet dams and the results were available in 2012. The location of known barriers identified in the St. Joseph River barrier inventory were used in GIS to calculate stream miles between the Watervliet spillway dam and all known upstream barriers on the mainstem Paw Paw River and its tributaries.

2.7 Physical Barrier Attributes

Monitoring physical barrier attributes before and after dam removal provides an indirect assessment of successful fish passage restoration. Physical barrier attributes monitored for the Watervliet Dams project include channel and water surface slope, jump height, and flow velocity.

Channel and Water Surface Slope

Channel and water surface slope were evaluated using cross-sectional survey data collected before and after dam removal. Dams create excessive channel and water surface slope by elevating the upstream water surface elevation. Dams also decrease the upstream water surface slope, causing sedimentation over otherwise productive stream habitats. Dam removal is expected to decrease the reach average slope through the dams by lowering the upstream water surface, while increasing the upstream water surface slope and mobilizing accumulated sediment.

Jump Height

Jump height is the vertical distance a fish must navigate from the water surface profile downstream of a barrier to the water surface profile upstream of the barrier. For all practical purposes, the maximum jump height required to navigate a barrier is equivalent to the hydraulic head of a dam or other migration barrier (e.g. a perched culvert). The hydraulic head is the difference or distance between the upstream and downstream water surface elevations. The hydraulic head and jump height vary over time with discharge at some barriers (this effect is negligible for high dams). In the case of the Watervliet dams, the hydraulic head was greatest at low to moderate (i.e., 2-year return interval discharge) discharges and decreased with increasing discharge. Hydraulic head was used to assess jump height. Hydraulic head was assessed using survey data collected prior to dam removal and hydraulic modeling to evaluate the discharge under which maximum jump height occurred.

Flow Velocity and Target Fish Swimming Capabilities

Removal of the Waterlviet Dams resulted in complete above-grade removal of both dams. Therefore, the existing elevation head was virtually eliminated. However, some grade change was maintained through both dam sites by constructing riffles. The three constructed riffles maintained approximately one foot of grade change over 100 feet or 1% slopes. While the riffles do not present a jump height, they do create higher flow velocity than the reach average slope of the Paw Paw River (0.03%, 1.5 ft/mile). Therefore the velocity of water flowing over the dams prior to removal was compared to water flowing through the constructed riffles to assess fish passage based on fish swimming capability.

The swimming capabilities of walleye, white sucker, longnose sucker, and northern pike as representative and important indicator fish species are compared to measured flow velocity before and after dam removal. Critical velocity was selected as the best representation of swimming capability in natural environments where a burst of energy is required to maintain a high swimming speed for a prolonged period of time. Such swimming performance is required for a fish to navigate a typical high flow field found in nature, such as a riffle or boulder cascade. Experimentally, critical swimming speed is defined as the maximum swimming speed that can be maintained for ten minutes ($Ucrit_{10}$). Experimental critical velocity data from Peake (2008) and Peake et al. (2000) are summarized in Table 2 for the four target fish species. Figure 7 shows the estimated critical flow velocities based on fish body length for those four species (Jones et al. 1974). Using the velocity equation developed by Jones et al. (1974), McMahon et al. (1984) noted a critical velocity of 2.4 ft/s for an 11.8 inch adult walleye in the U.S.

A Marsh-McBirney Flow-Mate 2000 optical flow velocity meter and wading rod were used to measure flow velocity over the spillway dam prior to construction. Water does not flow over the diversion dam during low flows when water velocity can be safely measured, so flow velocity was not measured at the diversion dam. Flow velocity was measured at the center of the spillway bays and over the downstream spillway face at arms-length immediately downstream of the bay measurements. Only ten of the twelve concrete bays contained sufficient water depth to measure velocity (the two outside bays did not have sufficient water depth). Only five measurements could be made on the downstream apron because the remainder of the apron was damaged and contained turbulent flow. Velocity was measured at 60% of water depth. After dam removal flow velocity was measured through the three constructed riffles using the Marsh-McBirney Flow-Mate 2000 optical flow velocity meter and wading rod. Velocity was measured at 60% of water depth at five-foot increments across the riffle starting at one foot from the wetted edge. Water depth was recorded at each velocity measurement point. The river discharge at the time of velocity measurements was estimated using the velocity-area method.

2.8 Reference Riffle Pebble Counts

A Wolman pebble count approach was used to quantify the particle size distribution in the natural reference riffle located approximately 300 feet downstream of M-140 before and after dam removal. The primary reason for monitoring particle size was to evaluate changes in habitats resulting from dam removal. Given the M-140 riffle is located within 900 feet of the spillway dam and historic channel, there was the potential for fine sediments (sand in particular) transported from the historic channel and upstream of the spillway dam to alter the riffle habitat.

A minimum of 100 particles were randomly selected from the bed and measured along the intermediate access in millimeters at three cross-sections within the riffle (upstream, middle, and downstream). The axis length was recorded for each particle. The counts were conducted along three different cross-sections to account for variability along the riffle profile. The riffle habitat is approximately 400 feet long. Riffle counts were conducted before dam removal in 2011 and after dam removal in 2012.

2.9 Macroinvertebrate Collections

Macroinvertebrates were collected at the three constructed riffles and the M-140 reference riffle using methods described in Michigan's Procedure 51, a macroinvertebrate index of biotic integrity (IBI). The Procedure 51 IBI was not used because sampling was biased by collecting from riffle habitats only. However, Procedure 51 sample collection methods were used to standardize sampling effort between sampling events. Each riffle was sampled for 60 minutes. A D-frame dip net with a 500 micron net was used to capture macroinvertebrates dislodged from rocks and wood debris found in the riffles. Organisms were dislodged by kicking finer substrates and hand-wiping rock surfaces while the dip was held downstream. Rocks were also removed from the riffle and hand-picked for organisms. Macroinvertebrate samples were preserved in 80% denatured ethyl alcohol for later identification. Merrit and Cummins (1996) and Voshell (2002) were used as necessary to identify organisms to the family level.

3.0 RESULTS AND DISCUSSION

3.1 Accessible River Miles

Table 3 provides a summary of accessible stream miles in the Paw Paw River watershed pre- and post-dam removal. The project performance target was set at 200 river miles based on expected potential. As Table 3 shows removal of the Watervliet dams has provided access to 56 miles of the Paw Paw River mainstem (including the north and south branches) and 216 miles of tributaries, a total of 272 miles of stream. Prior to dam removal, only 101 river miles (19%) of the total 534 river miles were accessible. After dam removal, 373 river miles (70%) of the total 534 river miles are accessible. The remaining inaccessible river miles (161 miles, 30%) are located upstream of remaining fish migration barriers on the South Branch Paw Paw River (i.e., Maple Lake) and other minor tributaries of the Paw Paw River (primarily lake level control structures). Providing that unrestricted fish passage has been restored, removal of the Watervliet dams has significantly increased the length of stream accessible to native potadromous fish and an abundance of important spawning habitat. Target fish species including white sucker, longnose sucker, walleye, northern pike, and lake sturgeon are expected to benefit through increased reproduction and natural stock recruitment.

3.2 Physical Barrier Attributes

Jump Height

The maximum jump heights based on summer 2010 surveying conducted during low flows are reported in Table 4A as denoted by "Elevation Head." Elevation head is the absolute difference between the upstream and downstream water surface elevations. The maximum jump heights exceed the jumping capabilities of walleye, northern pike, and native suckers. None of those representative species are reported to employ jumping to pass obstacles. The maximum jump height occurs at low flows when the difference between the upstream and downstream water surface elevations is the greatest. Hydraulic modeling shows that the difference in elevation decreases with increasing discharge until they are approximately the same during the 100-year flood (Table 4C). After dam removal the jump height was completely removed by removing the entire dam structure above the bed (Table 4A).

An important characteristic of the spillway dam worth noting is that the downstream concrete apron and spillway effectively created a ramp over which water flowed as opposed to falling. This characteristic created a situation where fish species with high swimming speeds could actually swim over the dam; they were not required to jump. Pacific salmon and steelhead were observed swimming over the spillway dam during construction. Consequently, flow rate over the spillway was probably a more important characteristic of the spillway dam than jump height. The opposite is true for the diversion dam.

<u>Channel and Water Surface Slope</u>

Based on as-built survey data, the bed slope through the two is 0.84%, similar to the design riffle slope of 1% (Table 4A). The water surface slope over the constructed riffles was not surveyed while documenting as-built conditions, but the slope is expected to be <1% and similar to the riffle bed slope at both dams under normal flow conditions. However, the water surface slope over the riffles will vary with discharge, becoming flatter as discharge increases and more similar to the riffle bed slope as discharge decreases. The as-built data show that the bed slope has been increased at the dams due to installation of the riffles at 1% slopes to control bed grade. However. The water surface slopes have been substantially decreased by dam removal.

Reach-based water surface slopes were calculated using cross-section survey data collected before and after dam removal to further evaluate desirable morphological changes. Table 4B presents then resulting slopes calculated between surveyed cross-sections. The data demonstrate that removing the dams decreased water surface slope through the reaches where the dams were located. In addition, the water surface slope in the historic channel and mill race upstream of the dams increased as a result of removing the dams. Both of these changes were planned and are desirable for fish passage and maintaining high quality riverine habitat.

Flow Velocity

Table 5 summarizes water and volumetric flow data for selected sites pre- and post-dam removal. Prior to dam removal flow rates were measured between 5 and 6 ft/s over the spillway dam at normal flow. Following the removal of the dams, flow rates in the riffles were significantly lower. While it appears the lower discharge estimated during post-removal velocity measurements may result in lower measured velocity, the opposite is actually true. As water stage increases over the riffle the water surface slope decreases and flow velocity decreases. Therefore, it is valid to conclude that removal of the dams and construction of riffles alone has resulted in substantially reduced flow velocities.

Prior to removal of the Watervliet dams, water velocity at the spillway dam exceeded the critical velocities of the target fish species (Table 2), which can severely hinder fish movements. The mean water velocity at the spillway dam before removal was 5.16 ft/s, while maximum critical flow velocities (based on fish length) for the four target species (northern pike, walleye, longnose sucker, and white sucker) are 1.56, 3.74, 3.00, 2.43 ft/s, respectively (Table 2). After removal of the spillway dam, mean velocity at the spillway dam riffle was reduced to 2.6 ft/s, with a range of velocities that was inclusive of critical flow velocities for all target species. Likewise, the mean measured velocity at the diversion dam and decreased to 2.4 fts. The mean measured flow velocity at the historic channel riffle was also 2.4 ft/s with a narrow range than the diversion dam riffle. Figures 9, 10, and 11 show the critical velocities of the target species from Figure 8 in comparison to measured pre- and post-removal velocities at the three constructed riffle locations. Similarly with the spillway dam site, post-monitoring site water velocity ranges were well within the critical swim velocities for all four target fish species.

3.3 Fish Collection Summary

Tables 6A-1 and 6A-2 present a catch summary for all fish collections by station. Fish were collected on eleven different dates and at eight stations. Fish collections occurred on April 14 and June 8, 2011 prior to dam removal, then four different dates in 2012 and five dates in 2013 after dam removal. Eight sampling events were conducted for the purpose of fish marking, while three sampling events weren conducted for fish community monitoring. Across all sampling efforts, a total of 43 species were captured with a combined catch-per-unit-effort (CPUE) of 1.41 fish per minute. The dominant species by number included white sucker (*Catostomas commersonii*), golden redhorse (*Moxostoma erythrurum*) , and shorthead redhorse (*Moxostoma macrolepidotum*). However, species dominance was affected by targeting specific species, habitats, and fish behavior (i.e., spawning migration and congregations) during efforts to capture and mark target fish species. For example, common carp (*Cyprinus carpio*) and rainbow trout (*Oncorhynchus mykiss*) were observed during sampling but were not collected or recorded.

Previous Fish Surveys

The Michigan Department of Natural Resources (MDNR) conducted a survey of the fish community of the Paw Paw River in July of 1989 (MDNR, 1991). The MDNR captured 54 species at seven sites on the Paw Paw River; two of the DNR sampling stations were located within or in close proximity to the project collection sites (Station 6: Watervliet dam apron and Station 1: Benton Harbor, MDNR 1991). Tables 6B-1 and 6B-2 provide a list of species captured during the 1989 MDNR surveys compared to the ECT sampling results. MDNR rotenone sampling below the spillway dam resulted in collection of 40 species, while sampling near Benton Harbor yielded 31 species. However, individual fish count data were not reported. Fish collections conducted by ECT at and downstream of the spillway dam resulted in capture of 27 of the 40 fish species captured by the MDNR using rotenone at the same location in 1989. ECT captured 24 of the 31 species collected by MDNR during rotenone sampling near Benton Harbor. Michigan DNR sampling near Benton Harbor showed walleye and rock bass were the most abundant species collected with sport fish comprising 71.6% of the total catch (MDNR, 1991). Sampling conducted by ECT near Benton Harbor resulted in only 10% of the total catch being sport fish and 83% being sucker and redhorse species. Again, sampling at Benton Harbor intentionally targeted the sucker spawning season and is a potential reason why sucker species were more abundant than during MDNR sampling. Overall, differences in ECT and MDNR sampling results were most likely due to timing and gear. As noted, ECT targeted the sucker spawning migration and specific fish species. The Paw Paw

River is a large, deep river. It is difficult to sample with a boom shocker and capture efficiency can be low. The survey methods used by MDNR in 1989 are more efficient in medium to large non-wadable rivers.

Interestingly, no white suckers were caught below the spillway dam by the MDNR, whereas sampling conducted by ECT resulted in white suckers comprising 42% of the total catch below the dam. This is most likely due to the timing of ECT's sampling efforts in the spring, which intentionally targeted sucker species and walleye during spring spawning migrations, whereas MDNR sampled in July. Overall, redhorse and sucker species comprised 6.5% of the catch by number during MDNR sampling (MDNR, 1991), but comprised 82% of the total catch during ECT sampling. In addition, the 1989 MDNR survey did not result in capture of longnose sucker at any of the seven stations. These results strongly suggest that the white sucker and longnose sucker populations in the Paw Paw River (at least downstream of the spillway dam) are lake-run populations that migrate upstream from Lake Michigan to spawn and then return to Lake Michigan. While length and weight data were not collected, the typically large size of white suckers captured by ECT also seem to suggest that those fish lived primarily in Lake Michigan where productivity is higher and adult white suckers can grow to larger a size. Many of the longnose suckers were of similar large body size.

3.4 Historic Channel Fish Community

The fish community in the historic channel before and after the removal of the dams was assessed for 1) similarity between the communities, 2) compositional differences in the communities, and 3) the diversity of the communities (with a statistical test for significance). Before the removal of the dam, the historic channel was more representative of a lentic environment, with little to no flow, warmer water temperatures, shallower water depths, and an abundance of submerged, floating, and emergent aquatic vegetation. The mean depth of measured sediment depths at five cross-sections ranged from 1.2 to 1,9 feet. After the removal of the diversion dam, continuous flow was restored to the historic channel and the aquatic habitat shifted from lentic to lotic. The historic channel was sampled before the removal of the dam on June 8, 2011 and sampled again after the dam was removed on June 21, 2012 and on June 4, 2013. The downstream most 1,200 feet of the historic channel was sampled rather than the entire length due to a woody debris jam that blocked access to the remainder of the channel.

Table 7 presents a summary of fish collected in the historic channel before and after dam removal. Before removal of the dam, 59 individuals were collected, representing 14 different species. The dominant species collected by number were bluegill (22%), pumpkinseed (19%), and spotted sucker (15%). After removal of the dam in 2012, 45 individuals were collected from the historic channel, representing 15 different species. Unlike before removal, the historic channel had higher species evenness, and the species dominance was much less pronounced. However, the most abundant species collected were golden redhorse (20%), bluegill (11%), and white sucker (11%). In 2013, 50 individuals were collected representing 14 different species. The most abundant species by number were golden redhorse (20%), shorthead redhorse (18%), and white sucker (18%).

Evaluation of catch data in Table 7 reveals that the historic channel supported fewer lotic (i.e., riverine) species prior to dam removal. Catch data from 2011 revealed a habitat that supported mostly lentic species, or ones that are commonly found in warmer, non-flowing water bodies. Examples of such species include a higher abundance of Lepomid species such as bluegill and pumpkinseed, and the absence of riverine or lotic species such as darters, minnows, and smallmouth bass. Following removal of the dam in 2012, species that were found in the historic channel that were not present pre-removal include the common shiner (*Luxilus cornutus*), greater redhorse (*Moxostoma valenciennesi*), logperch (*Percina caprodes*), mudminnow (*Umbra limi*), shorthead redhorse (*Moxostoma macrolepidotum*), smallmouth bass (*Micropterus dolomieu*), spottail shiner (*Notropis hudsonius*), and white sucker (*Catostomus commersonii*). During the 2013 sampling period, three species were collected that were not present during the previous sampling trips: northern hog sucker (*Hypentelium nigricans*), mottled sculpin (*Cottus bairdii*), and burbot (*Lota lota*). With the addition of the northern hog sucker in 2013, the number of sucker species increased from 2 to 6 following dam removal (from 2011 to 2013), indicating the historic channel is being colonized by more lotic species. Overall, eleven new species were captured in the historic channel after dam removal, including desirable lotic species such as smallmouth bass, northern hog sucker, shorthead redhorse, greater redhorse, mottled sculpin, and white sucker. At the same time, lentic species such as pumpkinseed, bluegill, black crappie, and bullhead were not captured after dam removal or their abundance was substantially reduced. These results are likely a direct result of restoring natural flow to this section of the Paw Paw River.

The Sørensen's Similarity Index states that the more similar two fish communities are, the closer the index approaches 1. Mathematically, Sørensen's Similarity Index quantifies the probability of selecting the same value from two separate data sets. In the case of ecological data it determines the probability of a species in one data set also occurring in a second data set with similar abundance. If the same species are present in two different communities with identical abundance then the communities are 100% similar and the Sørensen's Similarity Index would be equal to 1.

Analysis of the fish community data in the historic channel in 2011 and 2012 (one year after removal of the dam) resulted in a Sørensen's Similarity Index of 0.48, indicating the two fish communities in the historic channel pre- and post- removal were not similar. When comparing 2011 and 2013, the resulting index value was 0.36, indicating an even larger difference in the community structure following removal of the dam. Additionally, results from 2011 and 2012 had seven species in common, while comparing results form 2011 and 2013 showed only five species in common. However, comparing the two post-construction years (2012 and 2013), the Sørensen's Similarity Index was 0.69. In terms of similarity, historic channel fish community has changed significantly since removal of the dam, but is beginning to stabilize with time.

The Shannon-Wiener Index increased from 2.20 in 2011 to 2.51 in 2012, indicating that the diversity of the historic channel fish community increased after dam removal. However, comparing 2011 and 2013, the diversity index increased only slightly, from 2.20 to 2.27, indicating the diversity was similar in 2011 and 2013. Comparing 2012 and 2013, the diversity index actually decreased, from 2.51 to 2.27 respectively. Results from the Hutcheson's t-test for the Shannon-Wiener Index showed a significant difference in the diversity of the two fish communities from 2011 to 2012, before and after removal of the dam in the historic channel (t_{100} = -1.991, $p < 0.05$, $\alpha = 0.1$).

However, there was no statistically significant difference between the Shannon-Wiener Indexes between 2011 and 2013 ($t_{100} = -0.433$, $p > 0.05$, $\alpha = 0.1$), as well as 2012 and 2013 ($t_{100} = 1.477$, $p > 0.05$, $\alpha = 0.1$). Because the Shannon-Wiener Index is highly non-linear, these small changes in the diversity index can be represented by a fairly large increase in actual diversity.

To highlight the actual magnitude of change, the Shannon-Wiener Index was converted to the effective number of species. The effective number of species is on a linear scale, so a 2x increase in the effective number of species represents a 2x increase in diversity. The effective number of species is the number of equally common species required to derive a particular Shannon-Wiener Index score. Removal of the dam increased the effective number of species in the historic channel in 2011 and 2012 from 8.98 to 12.34, resulting in approximately a 37% increase. In other words, the number of equally common species in the historic channel increased by 37% after the dam was removed. From 2012 to 2013, the effective number of species decreased by 22%, likely due to the loss or decreased abundance of lentic species, which were still present and fairly abundant in 2012. Comparing 2011 and 2013, the effective number of species increased only slightly, by approximately 7%.

Evenness within a community is the measure of how abundance compares across the species present. A community is said to have high species evenness when all of the species are similarly abundant, and less even when a few species dominate the composition. Evenness can be used to evaluate change in fish community structure. Before removal of the dam, the historic channel had a species evenness of 0.83. Following dam removal species evenness increased to 0.93. This would indicate that after removal of the dam, there was less variation in the number of individuals within each species collected and the environment was not dominated by a small number of species. This is evidenced in Table 7, where there was an increase in the number and types of lotic species and a decrease in the more dominant, lentic species, such as bluegill and pumpkinseed which was observed before removal of the dam. However, comparing 2011 to 2013, evenness was almost identical (0.83 and 0.86, respectively). From 2012 to 2013, evenness decreased from 0.93 in 2012 to 0.86 in 2013. This is the same trend observed in the Shannon-Wiener Index. The catch data in Table 7 shows how this trend occurred with a shift in the type of fish species inhabiting the historic channel. Before removal, the most abundant species were typical of lentic environments and only contained two sucker species. In 2012, the historic channel contained a wide mix of species, both of which contained numerous lentic and lotic species. Then in 2013, the shift towards mostly lotic species composition was more complete, where six sucker species were found and the three most abundant species were all from the Catostomidae family.

Community diversity and species evenness can be graphically displayed using k-dominance curves. Curves that plot higher along the y-axis indicate lower diversity, while curves plotting lower on the y-axis indicate higher diversity. Curves with flatter slopes indicate greater species evenness, while steeper curves indicate less species evenness. Comparison of the two assemblages in the historic channel in 2011 and in 2012 indicates higher species diversity with less species dominance (i.e., higher species evenness) in the historic channel following removal of the dam (Figure 12). From 2012 to 2013, the k-dominance curves show a slightly more diverse community structure in 2012 with similar evenness (Figure 13). This is likely because of the large shift in habitat and stream morphology that occurred following the removal of the dam. The more lotic species were beginning to inhabit the historic channel in 2012 while the more lacustrine species were leaving the area due to establishment of continuous flow. In 2013, the system likely continued to stabilize as the riverine species became more established and the lacustrine species were mostly absent, thereby reducing the diversity slightly. By examining k-dominance curves between 2011 and 2013 (Figure 14), there is an almost identical curve between the two. While the diversity and evenness with the fish community in 2013 was similar to that of 2011, the actual species composition has changed drastically.

3.5 Fish Passage Test

During fish collections in 2011 and 2012, all native sucker species and walleye captured downstream of the dams (including the historic channel) were marked with an anal fin clip. Marking conducted in March and April of 2012 and 2013 occurred after dam removal, but only fish captured downstream of the former dam locations were fin-clipped. Fin clipping was continued in 2012 and 2013 to increase the number of marked fish in the river system, thereby increasing the probability of recaptures. This approach worked well in light of the fact that recaptures included four of the species marked (longnose sucker, white sucker, walleye, and golden redhorse). Captured northern pike were not fin-clipped because of low catch rates. Table 8 summarizes the species and number of fish that were marked, and the number recaptured upstream of the dams. A total of 568 fish were marked over all collection efforts conducted between April 2011 and April 2013.

Following the removal of the dam, fish collections were made at North Center Street in Hartford on February 24, 2012, and in the mill race and upstream of the spillway dam for approximately 4,000 feet on March 27, 2012 and June 21, 2012. On March 27, 2012, a golden redhorse marked below the dam was recaptured upstream of the spillway dam in the mill race, indicating marked fish species (i.e., target species) were able to move upstream of the former dam site. On April 8, 2013, three previously clipped golden redhorse and 11 previously clipped white sucker were recaptured in the mill race and upstream of the diversion dam. A fin-clipped large adult white sucker was recaptured over 4,500 feet upstream of the spillway dam. Successful mark-and-recapture of representative and important native sucker species is a direct measure of fish passage and results in rejection of the null hypothesis. Removing the Watervliet dams has restored unrestricted fish passage for native potadromous (e.g. walleye, white sucker, and longnose sucker) and resident fish species (e.g. redhorses, smallmouth bass, and walleye).

3.6 Macroinvertebrate Colonization on Constructed Riffles

Three rock riffles were constructed after dam removal to assist with restoration and stabilization of the river channel. Riffles were constructed at the two former dam locations and at the downstream end of the historic channel. The riffles not only help stabilize the channel, but can also provide important aquatic habitat for fish and macroinvetebrates. Macroinvertebrate colonization at the three constructed riffles was compared to the macroinvertebrate population of a natural reference riffle located downstream of M-140 in 2012 and 2013. The natural reference riffle was located approximately 250 feet downstream of M-140. All four riffles were sampled in 2012 and 2013 to assess whether the riffles provide macroinvertebrate habitat and if colonization changed over time (one to two years following construction). Table 9 summarizes sampling results.

In 2012, macroinvertebrate taxanomic richness ranged from 10 to 13 different families present within the 4 riffles, with the lowest richness within the reference riffle (10) and the highest within the historic channel (13) and spillway (13) riffles; a total of 22 taxa were represented for all sites combined. Talitridae, Chironomidae, Simuliidae, Baetidae, Perlidae, and Hydropsychidae were collected at all four riffle sites. For all sites combined, the most abundant families present were Chironomidae (27%), Simuliidae (24%), and Hydropsychidae (12%). Each of the three constructed riffles all contained a higher number of different families present than the reference riffle, and approximately 30-60% more individuals were collected at each constructed riffle compared to the reference riffle. The constructed riffle located at the downstream end of the historic channel contained the highest number of individuals collected (241).

All riffles were sampled again in 2013 to evaluate change in the macroinvertebrate community structure. A total of 31 different families were identified including 1,419 individuals, and increase from 22 in 2012. Similar to 2012, the constructed riffles contained a higher number of taxa and individuals than the reference riffle. The increases in the number of individuals between the two years ranged from 19% to 217%. Similarly with 2012, the most abundant families for all sites combined were Simuliidae (30%), Chironomidae (21%), and Hydropsychidae (13%). As with 2012, the constructed riffle located at the downstream end of the historic channel contained the highest number of individuals collected (556) as well as the highest number of taxa (21).

There were very notable changes to the macroinvertebrate community structure of the constructed riffles between 2012 and 2013. All three sites saw an increase in both the number of individuals and the number of taxa collected. The constructed riffles at the diversion dam and historic channel saw the highest increase in family diversity, adding 11 and 8 new families, respectively. Interestingly, in 2012 there were no giant stonefly larvae (Petronarcyidae) collected at any of the riffles sampled. However, in 2013 all of the constructed riffles contained giant stonefly nymphs, a species that is considered to be sensitive. Additionally, the water penny (Psephenidae; another sensitive species) was only found in the historic channel constructed riffle (one) in 2012 while in 2013 it was found in all three constructed riffles. This was also true for the Snailcase caddisfly (Heliopsychidae), and the flat-headed mayfly (Heptageniidae). None of these species were present in the reference riffle during sampling in 2012 or 2013. In 2012, the northern caddisfly (Limnephillidae) was only found in the reference riffle. However, in 2013 Limnephillidae was found at all sites except the constructed riffle at the diversion dam.

3.7 M-140 Riffle Pebble Counts

Pebble counts were conducted in the natural reference riffle downstream of M-140 on July 8, 2011 before the dam was removed and again on June 14, 2012 after the dam was removed to assess whether sediment transport resulting from dam removal affected the natural riffle substrates. Table 10 summarizes six different metrics that characterize the particle size distributions before and after dam removal. The particle size distributions are graphically compared in Figure 15.

After removal, there was a slight coarsening of the particle size distribution with a slight increase in the percent composition of silt/clay and sand. Silt/clay and sand-size particles increased by 3% and 1% respectively, gravel decreased by 9%, and cobble increased from 1% to 5%. The median particle size increased from 7.6 mm to 9.6 mm after dam removal. There was also more variability in the type and size of substrate found in the M-140 riffle site following removal.

Some of the differences observed could be due to sampling variability because particles are not selected from the exact same point on the stream bed during pebble counts before and after dam removal. For example, the increase in percent-cobble from 1% to 5% is most likely due to sampling location on the streambed or redistribution of cobbles along the streambed rather than an increase in cobble within the riffle because the cobble is not readily transported and is in short supply upstream of the reference riffle. The increase in silt/clay and sand-size particles could be due to increased sediment transport from the historic channel or upstream of the spillway dam, but such a small increase could easily be attributed to sample variability. Likewise, the increase in median particle size could easily be attributed to sample variability as it is affected by the increase in percentage of cobble-size particles. Regardless, the nominal increases in fine particle sizes (silt/clay and sand) and median particle size suggest that the natural reference riffle has not been impacted or substantially altered by removal of the dams.

3.8 Channel Morphology

Nine cross-sections that were surveyed prior to dam removal were resurveyed in 2012 and 2013 to evaluate changes in channel morphology, particularly due to head cutting upstream of the dams or deposition downstream of the dams. Eight of the cross-sections are located on the Paw Paw River, including two that span the mill race and historic channel (M-M and K-K). The eight Paw Paw River cross-sections also include the furthest upstream (A-A) and downstream (BB-BB) cross-sections surveyed prior to dam removal. One of the cross-sections surveyed is located on Mill Creek (CC-CC) at the furthest upstream location surveyed in 2011. Figure 16 shows the location of the monitoring cross-sections. Cross-sections are labeled using letters according their original 2011 cross-section designations (e.g. A-A), but were also renamed using numbers for ease of reference. The cross-sections were consecutively numbered from upstream to downstream and separately for the mill races and historic channel, resulting in eleven cross-sections for evaluation.

Figures 17 to 27 show the plotted cross-section data collected in 2011 prior to dam removal compared to 2012 and 2013 data collected after dam removal. The cross-sections are oriented such that they are viewed looking in the upstream direction. However, the discussion below uses the conventional definitions of left and right bank when looking downstream. Bed elevations were mostly unchanged at all of the cross-sections, with the exception of cross-sections 2, 5, 6, and 7 within the Paw Paw River (historic channel and mill race), and cross-section 11 within Mill Creek.

Cross-section #5, located just upstream of the spillway dam in the historic channel, the bed decreased approximately 1.6 feet in elevation in some areas after removal of the dam, indicating mobilization of accumulated sediment following restoration of continuous flow (due to removal of the diversion dam). Sediment depths of up to 1.7 feet were measured at this location during site data collection and design.

Cross-section #6 experienced an increase in bed elevation along the left bank (when looking downstream) and scour of a depositional feature along the right bank. The scour along the right bank was observed during removal of the spillway dam. The increases in bed elevation along the left bank was also observed and is primarily due to a lowering of the water elevation at the mouth of Mill Creek that has changed sediment transport characteristics. The sediment deposited in that area of cross-section #6 consists primarily of sand, gravel, and small cobble.

Cross-section #7, located just downstream of the former spillway dam site, experienced a large increase in sedimentation following removal of the dam, a maximum of almost 5 ft. of bed elevation in some areas. Cross-section #7 is located in the former scour pool downstream of the spillway dam. The scour pool was projected to fill in after removal of the dams. In addition to raising of the bed, the deposition is also occurring along both banks, resulting in decreased width of the scour pool. Again, this was an expected result.

Cross-section #2 is located in an area of the Paw Paw River upstream of the diversion dam that appeared to have aggraded while the spillway dam was used to impound the Paw Paw River. The river at this location was much wider and shallower than upstream and downstream conditions (e.g. cross-sections 1 and 10). The bed consisted of primarily sand across the entire river width and was wadable in October 2011. Therefore, sediment mobilization was expected in this reach. At cross-section #2, changes in sediment transport characteristics have led to a decrease in bed elevation in the right-bank half of the channel of approximately one foot on average and migration of the right bank.

Based on cross-section surveys at the boundaries of the project area (Sites 1, 10, 12), head cuts have not formed and migrated upstream of the dams and deposition has not affected channel morphology downstream of the dam. Observed morphological changes were expected, and due to changes in sediment transport characteristics in the historic channel and mill race.

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5.0 TABLES

Table 1. Sampling locations for fish community structure analyses and fish collections for mark/recapture (assess upstream migration of marked fish).

Station Location/Name	Dates Sampled	Purpose of Sampling
M-140 Bridge	4/14/2011	Fin clip target fish, downstream, pre-dam removal
	2/24/2012	Fin clip target fish, downstream, post-dam removal
	3/21/2012	Fin clip target fish, downstream, post-dam removal
	3/27/2012	Fin clip target fish, downstream, post-dam removal
	3/28/2013	Fin clip target fish, downstream, post-dam removal
	4/8/2013	Fin clip target fish, downstream, post-dam removal
M-140 Campground (Upstream)	6/8/2011	Capture/enumerate all species for fish community structure analyses Fin clip target fish, downstream, post-dam removal
Coloma DPW (Downstream)	6/8/2011	Capture/enumerate all species for fish community structure analyses Fin clip target fish, downstream, post-dam removal
Historic Channel	6/8/2011	Capture/enumerate all species for fish community structure analyses Fin clip target fish, downstream, pre-dam removal
	6/21/2012	Capture/enumerate all species for fish community structure analyses Fin clip target fish, downstream, pre-dam removal
	6/4/2013	Capture/enumerate all species for fish community structure analyses
Mill Race	6/8/2011	Capture/enumerate all species for community structure analyses
	3/27/2012	Assess upstream migration of fin-clipped target fish
	6/21/2012	Assess upstream migration of fin-clipped target fish
	4/8/2013	Assess upstream migration of fin-clipped target fish
	4/12/2013	Assess upstream migration of fin-clipped target fish
Hartford	2/24/2012	Assess upstream migration of clipped species
Benton Harbor	3/21/2012	Fin clip target fish, downstream, post-dam removal
	3/27/2013	Fin clip target fish, downstream, post-dam removal
	3/28/2013	Fin clip target fish, downstream, post-dam removal
Upstream Diversion Dam	3/27/2012	Assess upstream migration of fin-clipped target fish
	4/8/2013	Assess upstream migration of fin-clipped target fish
	4/12/2013	Assess upstream migration of fin-clipped target fish
	6/4/2013	Assess upstream migration of fin-clipped target fish

Table 2. Summary of critical swimming velocity ($Ucrit_{10}$) estimates for four representative and important fish species of the Paw Paw River, Berrien County, Michigan.

Species Common Name	Species Scientific Name	Mean Length (in)	Mean Critical Velocity (ft/s)	Min Critical Velocity (ft/s)	Max Critical Velocity (ft/s)
Northern pike[1]	*Esox lucius*	11.2	0.99	0.43	1.56
Walleye[2]	*Stizostedion vitreum*	7.1-26.4	2.58	1.41	3.74
Longnose sucker[1]	*Catostomus catostomus*	11.4	2.06	0.75	3.00
White sucker[1]	*Catostomus commersoni*	10.8	2.02	1.56	2.43

1 Peake 2008

2 Peake et al. 2000 ($Ucrit_{10}$)

Table 3. Number of stream miles in the Paw Paw River watershed accessible to Lake Michigan potadromous fish before and after removal of the Watervliet dams, City of Watervliet, Berrien County, Michigan.

	Total After	After		Before	
		Downstream	Upstream	Downstream	Upstream
Accessible	**373**	101	**272**	101	0
Mainstem	81	25	56	25	0
Tributaries	292	76	216	76	0
Inaccessible	**161**	0	**161**	0	433
Mainstem	18	0	18	0	74
Tributaries	143	0	143	0	359
Total	**534**	101	433		
Mainstem	99	25	74		
Tributaries	435	76	359		

Table 4A. Summary of physical barrier attributes before and after removal of the Watervliet Dams, Paw Paw River, Berrien County, Michigan.

	Spillway Dam		Diversion Dam	
Parameter	Pre	Post[1]	Pre	Post[1]
Channel Width (feet)	85	72	95	62
Maximum Elevation Head, Jump Height (feet)	3.5	0	5.8	0
Bed Slope (Upstream-Downstream of Dams)	0.16%	0.84%	0.13%	0.84%
Water Surface Slope @ Dams	5.8%	<1%[2]	7.8%	<1%[2]

1 Values derived from as-built survey data collected after construction was complete.

2 The water surface over the riffles was not surveyed after dam removal. Assumed to be similar to bed slope of riffles (~0.84%).

Table 4B. Summary of reach-based changes in water surface slope following removal of the Watervliet Dams, Paw Paw River, Berrien County, Michigan.

Upstream-Downstream Stations[1]	Before Removal	After Removal	Change
Spillway Dam: Cross-sections M-M to N-N	0.74%	0.46%	Decrease
Diversion Dam: Cross-sections E-E to K-K	0.18%	0.13%	Decrease
Historic Channel: Cross-sections K-K to M-M	0.00%	0.02%	Increase
Mill Race: Cross-sections A-A to K-K	0.01%	0.04%	Increase

1 See Figure 15 for cross-section locations.

Table 4C. Pre-removal elevation head at various low-flow and flood discharges.

	Spillway Dam		Diversion Dam	
Flow Event	Pre	Post[1]	Pre	Post[1]
Low (measured)	3.5	0	5.8[2]	0
Bankfull	3.1	0	5.8 (4.1)[2]	0
2-Year	1.6	0	3.0	0
10-Year	0.3	0	1.7	0
100-Year	0.01	0	0.3	0

1 As predicted by hydraulic modeling. Actual value will be measured by repeat surveying at low flow in 2012.

2 Based on elevation of the diversion dam, which is higher than the upstream water surface elevation at low flow. Bankfull water elevation difference noted in parenthesis.

Table 5. Range and mean flow velocities, and volumetric flow of selected sites before and after removal of the Watervliet dams, City of Watervliet, Berrien County, Michigan.

Measurement Location	**Minimum Velocity** (ft/s)	**Mean Velocity** (ft/s)	**Maximum Velocity** (ft/s)	**Calculated Discharge** (cfs)
Pre-Construction				
Mill Race	0.7	1.44	2.04	273
M-140 Riffle	0.18	1.1	1.95	273
Spillway Dam	4.24	5.16	5.75	271
Spillway Dam Downstream Apron	5.3	5.83	6.63	271
Post-Construction				
Historic Channel Riffle	1.4	2.4	3.2	160
Spillway Dam Riffle	0.4	2.6	4.8	195
Diversion Dam Riffle	0.24	2.4	3.4	166

Table 6A-1. Species collection summary for all sites sampled April 14, 2011 through June 4, 2013.

Species Common Name	Species Scientific Name	M-140 Bridge	M-140 Campground	Coloma DPW	Historic Channel	Mill Race	Hartford	Benton Harbor	Upstream of Diversion Dam	Total	Percent Composition
White Sucker	Catostomus commersoni	228			14	126		154	191	713	42.8
Golden Redhorse	Moxostoma erythrurum	91	13	8	27	73	6	109	124	451	27.1
Shorthead Redhorse	Moxostoma macrolepidotum	45		3	11	6	2	6	19	92	5.5
Longnose Sucker	Catostomus catostomus	17				24		9	1	51	3.1
Walleye	Sander vitreus	33				2		5	11	51	3.1
Emerald Shiner	Notropis atherinoides	5				1		11	6	23	1.4
Northern Pike	Esox lucius	7			6	2		7	1	23	1.4
Quillback	Carpoides cyprinus	15		1				6	1	23	1.4
Bluegill	Lepomis macrochirus				19			3		22	1.3
Smallmouth Bass	Micropterus dolomieu	1			2	1		9	8	21	1.3
Common Shiner	Luxilis cornutus	3		2	8	1			5	19	1.1
Spotted Sucker	Minytrema melanops	3			12	1		1	1	18	1.1
Rock Bass	Ambloplites rupestris	4			6	1		3	2	16	1.0
Spottail Shiner	Notropis hudsonius	2			4			9		15	0.9
Green Sunfish	Lepomis cyanellus	1			6		6	1		14	0.8
Northern Hogsucker	Hypentelium nigricans	3			2	1			8	14	0.8
Greater Redhorse	Moxostoma valenciennesi	3			4	1			5	13	0.8
Pumpkinseed	Lepomis gibbosus				12			1		13	0.8
Brown Trout	Salmo trutta	2				2			3	7	0.4
Silver Redhorse	Moxostoma anisurum	5				1		1		7	0.4
Spotfin Shiner	Cyprinella spiloptera				3	1		3		7	0.4
Mottled Sculpin	Cottus bairdii	2			1			2	1	6	0.4

Table 6A-2. Species collection summary for all sites sampled April 14, 2011 through June 4, 2013.

Species Common Name	Species Scientific Name	M-140 Bridge	M-140 Campground	Coloma DPW	Historic Channel	Mill Race	Hartford	Benton Harbor	Upstream of Diversion Dam	Total	Percent Composition
Black Crappie	Pomoxis nigromaculatus				2	1			1	4	0.2
Largemouth Bass	Micropterus salmoides	1			3					4	0.2
Steelhead	Oncorhynchus mykiss	3							1	4	0.2
Blackside Darter	Percina maculata	1			1	1				3	0.2
Bowfin	Amia calva				2			1		3	0.2
Central Mudminnow	Umbra limi				3					3	0.2
Golden Shiner	Notemigonus crysoleucas	1			2					3	0.2
Redfin Shiner	Lythrurus umbratilis	2							1	3	0.2
Round Goby	Neogobius melanostomus	1			1			1		3	0.2
Burbot	Lota lota	1			1					2	0.1
Chestnut Lamprey	Ichthyomyzon castaneus								2	2	0.1
Rosyface Shiner	Notropis rubellus			1					1	2	0.1
Blacknose Dace	Rhinichthys atratulus								1	1	0.1
Bluntnose Minnow	Pimephales notatus							1		1	0.1
Channel Catfish	Ictalurus punctatus	1								1	0.1
Freshwater Drum	Aplodinotus grunniens							1		1	0.1
Gizzard Shad	Dorosoma cepedianum							1		1	0.1
Greenside Darter	Etheostoma blennioides							1		1	0.1
Logperch	Percina caprodes				1					1	0.1
River Redhorse	Moxostoma carinatum					1				1	0.1
Yellow Bullhead	Ameiurus natalis				1					1	0.1
Total Individuals		481	13	15	154	247	14	346	394	1664	
Total Species		27	1	5	26	19	3	24	22	43	

Table 6B-1. Fish capture results from Michigan Department of Natural Resources rotenone sampling (MDNR, 1991) and Watervliet Dams Removal project monitoring sampling on the Paw Paw River, Berrien County, Michigan.

Common Name	Scientific Name	Below Dam MDNR	M140 Bridge ECT	Benton Harbor MDNR	Benton Harbor ECT
Alewife	*Alosa pseudoharengus*	●			
Black Bullhead	*Ameirurus melas*	●			
Black Crappie	*Pomoxis negromaculatus*	●		●	
Black Redhorse	*Moxostoma duquesnei*	●		●	
Blackside Darter	*Percina maculata*	●	●		
Bluegill	*Lepomis macrochirus*	●		●	●
Bluntnose Minnow	*Pimephales promelas*	●		●	●
Bowfin	*Amia calva*				●
Brassy Minnow	*Hybognathus hankinsoni*	●			
Brown Trout	*Salmo trutta*		●		
Burbot	*Lota lota*	●	●	●	
Central Mudminnow	*Umbra limi*		●	●	
Channel Catfish	*Ictalurus punctatus*		●	●	
Common Carp	*Cyprinus carpio*	●		●	
Common Shiner	*Luxilus cornutus*	●	●		
Creek Chub	*Semotilus atromaculatus*	●			
Emerald Shiner	*Notropis atherinoides*		●		●
Flathead Catfish	*Pylodictus olivaris*			●	
Freshwater Drum	*Aplodinotus grunniens*				●
Gizzard Shad	*Dorosoma cepedianum*			●	●
Golden Redhorse	*Moxostoma erythrurum*	●	●	●	●
Golden Shiner	*Notemigonus crysoleucas*		●		
Grass Pickerel	*Esox americanus vermiculatus*	●		●	
Greater Redhorse	*Moxostoma valenciennesi*		●		
Green Sunfish	*Lepomis cyanellus*	●	●	●	●
Greenside Darter	*Etheostoma blennioides*				●
Hornyhead Chub	*Nocomis biguttatus*	●			
Johnny Darter	*Etheostoma nigrum*	●		●	

Table 6B-2. Fish capture results from Michigan Deptartment of Natural Resources rotenone sampling (MDNR, 1991) and Watervliet Dams Removal project monitoring sampling on the Paw Paw River, Berrien County, Michigan.

Common Name	Scientific Name	Below Dam MDNR	M140 Bridge ECT	Benton Harbor MDNR	Benton Harbor ECT
Largemouth Bass	*Micropterus salmoides*	●	●	●	
Logperch	*Percina caprodes*	●			
Longear Sunfish	*Lepomis megalotis*	●			
Longnose Sucker	*Catostomus catostomus*		●		●
Mottled Sculpin	*Cottus bairdi*	●	●	●	●
Northern Hogsucker	*Hypentilium nigricans*	●	●		
Northern Pike	*Esox lucius*	●	●	●	●
Pirate Perch	*Aphredoderus sayanus*	●		●	
Pumpkinseed	*Lepomis gibbosus*	●		●	●
Quillback	*Carpiodes cyprinus*	●	●	●	●
Rainbow Darter	*Etheostoma caeruleum*	●			
Redfin Shiner	*Notropis umbratilis*		●		
Rock Bass	*Ambloplites rupestris*	●	●	●	●
Rosyface Shiner	*Notropis rubellus*	●			
Round Goby	*Neogobius melanostomus*		●		●
Sand Shiner	*Notropis stramineus*	●			
Shorthead Redhorse	*Moxostoma macrolepidotum*	●	●		●
Silver Redhorse	*Moxostoma anisurum*	●	●	●	●
Smallmouth Bass	*Micropterus dolomieu*	●	●	●	●
Spotfin Shiner	*Notropis spilopterus*	●		●	●
Spottail Shiner	*Notropis hudsonius*		●	●	●
Spotted Sucker	*Minytrema melanops*	●	●		●
Steelhead	*Oncorhynchus mykiss*		●		
Stonecat Madtom	*Noturus flavus*	●		●	
Tadpole Madtom	*Noturus gyrinus*	●		●	
Walleye	*Sander vitreus*	●	●	●	●
Warmouth	*Lepomis gulosus*	●		●	
White Crappie	*Pomoxis annularis*			●	
White Sucker	*Catostomus commersonii*		●		●
Yellow Bullhead	*Ameiurus natalis*	●		●	

Table 7. Number captured by species and sampling date during historic channel sampling before (6/8/2011) and after (6/12/2012, 6/4/2013) removal of the Watervliet dams, Paw Paw River, Berrien County, Michigan.

Species Common Name[1]	Sampling Date		
	6/8/2011	6/21/2012	6/4/2013
Black Crappie	2		
Blackside Darter	1		
Bluegill	13	5	1
Bowfin	2		
Burbot			1
Central Mudminnow		3	
Common Shiner		2	6
Golden Redhorse	8	9	10
Golden Shiner	2		
Greater Redhorse		2	2
Green Sunfish	6		
Largemouth Bass	1	2	
Log Perch		1	
Mottled Sculpin			1
Northern Hog Sucker			2
Northern Pike	1	4	1
Pumpkinseed	11	1	
Rock Bass	1	3	2
Round Goby	1		
Shorthead Redhorse		2	9
Smallmouth Bass		2	
Spotfin Shiner			3
Spottail Shiner		3	1
Spotted Sucker	9	1	2
White Sucker		5	9
Yellow Bullhead	1		

1 See Table 6A-1 and 6A-2 for scientific names.

Table 8. Target fish species mark-recapture summary. Fish were marked with a anal fin clip and released for later recapture to assess fish passage after removal of the Watervleit Dams, Paw Paw River, Berrien County, Michigan. Pre-removal fin clipping occurred on April 14 and June 8, 2011, and post-removal fin clipping and recapture sampling occurred on various dates between February 12, 2012 and April 8, 2013.

Species Common Name	Pre-Removal	Post-Removal	
	Clipped	Clipped	Upstream Recapture
Golden Redhorse	48	168	3
Greater Redhorse		3	
Longnose Sucker	9	17	
Northern Hogsucker	2		
Quillback Carpsucker	13	9	
Shorthead Redhorse	25	32	
Silver Redhorse		1	
Spotted Sucker	9	2	
Walleye	17	21	
White Sucker	67	315	11
Total	190	568	14

Table 9-1. Constructed riffle macroinvertebrate sampling results for 2012 and 2013, Watervliet Dams Removal project , Paw Paw River, Berrien County, Michigan.

Order	Family	Diversion 2012	Diversion 2013	Historic 2012	Historic 2013	Spillway 2012	Spillway 2013	M140 2012	M140 2013	Total
Amphipoda	Talitridae	1	31	6	5	16	4	39	1	103
Annelida	Hirudenia	1							1	2
Annelida	Oligochaeta				1					1
Bivalvia	Various			1						1
Coleoptera	Elmidae					2	9	1	2	14
Coleoptera	Gyrinidae							2		2
Coleoptera	Haliplidae		3		2					5
Coleoptera	Hydrophilidae		1							1
Coleoptera	Psephenidae		3	1	1		1			6
Diptera	Athericidae					1				1
Diptera	Blephariceridae					3				3
Diptera	Chaoboridae		10							10
Diptera	Chironomidae	49	91	86	55	41	72	12	73	479
Diptera	Culicidae						1			1
Diptera	Simuliidae	76	16	69	219	23	132		55	590
Diptera	Tipulidae		2							2
Diptera	Unknown		1							1
Ephemeroptera	Baetidae	5	2	43	50	23	48	12	1	184
Ephemeroptera	Ephemerellidae				7		1			8
Ephemeroptera	Heptageniidae	16	29	11	35	10	20			121
Ephemeroptera	Isonychiidae	1				1				2
Gastropoda	Various			4			6		2	12

Table 9-2. Constructed riffle macroinvertebrate sampling results for 2012 and 2013, Watervliet Dams Removal project , Paw Paw River, Berrien County, Michigan.

Order	Family	Diversion 2012	Diversion 2013	Historic 2012	Historic 2013	Spillway 2012	Spillway 2013	M140 2012	M140 2013	Total
Hydracarina	Hydrachnidae		1		1		9			11
Isopoda	Asellidae		3		4					7
Isopoda	Unknown			1						1
Nematoda	Various			3		4		2		9
Odonata	Gomphidae		1							1
Platyhelmintes	Turbellaria				1		1			2
Plecoptera	Peltoperlidae		1							1
Plecoptera	Perlidae	4	22	2	39	1	31	6	1	106
Plecoptera	Pteronarcyidae		2		1		3			6
Plecoptera	Taeniopterygidae	2								2
Pulmonata	Ancylidae		1		1				1	3
Trichoptera	Brachycentridae	2	3		3	1	4	1	6	20
Trichoptera	Glossostomatidae		1	6	3				3	13
Trichoptera	Heliopsychidae		1		1		1			3
Trichoptera	Hydropsychidae	56	28	9	105	13	48	6	10	275
Trichoptera	Limnephilidae				19		49	16	14	98
Trichoptera	Odontoceridae				3					3
Total Individuals		213	253	242	556	139	440	97	170	2110
Total Taxa		11	22	13	21	13	18	10	13	39

Table 10. Particle size distribution metrics based on pebble counts conducted in a natural reference riffle located downstream of M-140 before and after dam removal.

Metric	Before Removal July 8, 2011	After Removal June 14, 2012
D50 (median, mm)	7.6	9.6
D84 (mm)	25	29
Silt/Clay (%)	12	15
Sand (%)	22	23
Gravel (%)	65	56
Cobble (%)	1	5

6.0 FIGURES

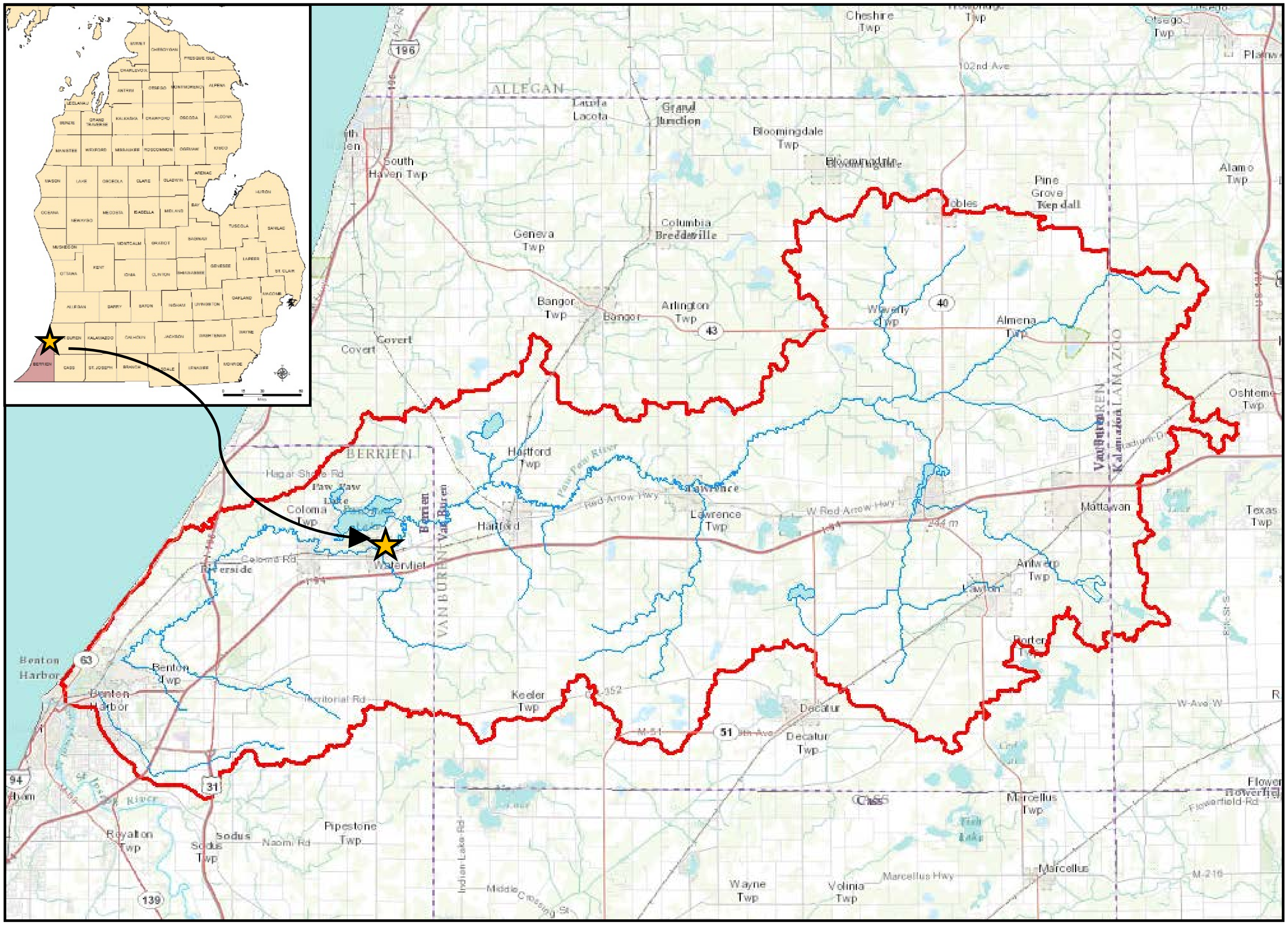

Figure 1. Watervliet Dams Removal project location, Paw Paw River, Berrien County, Michigan.

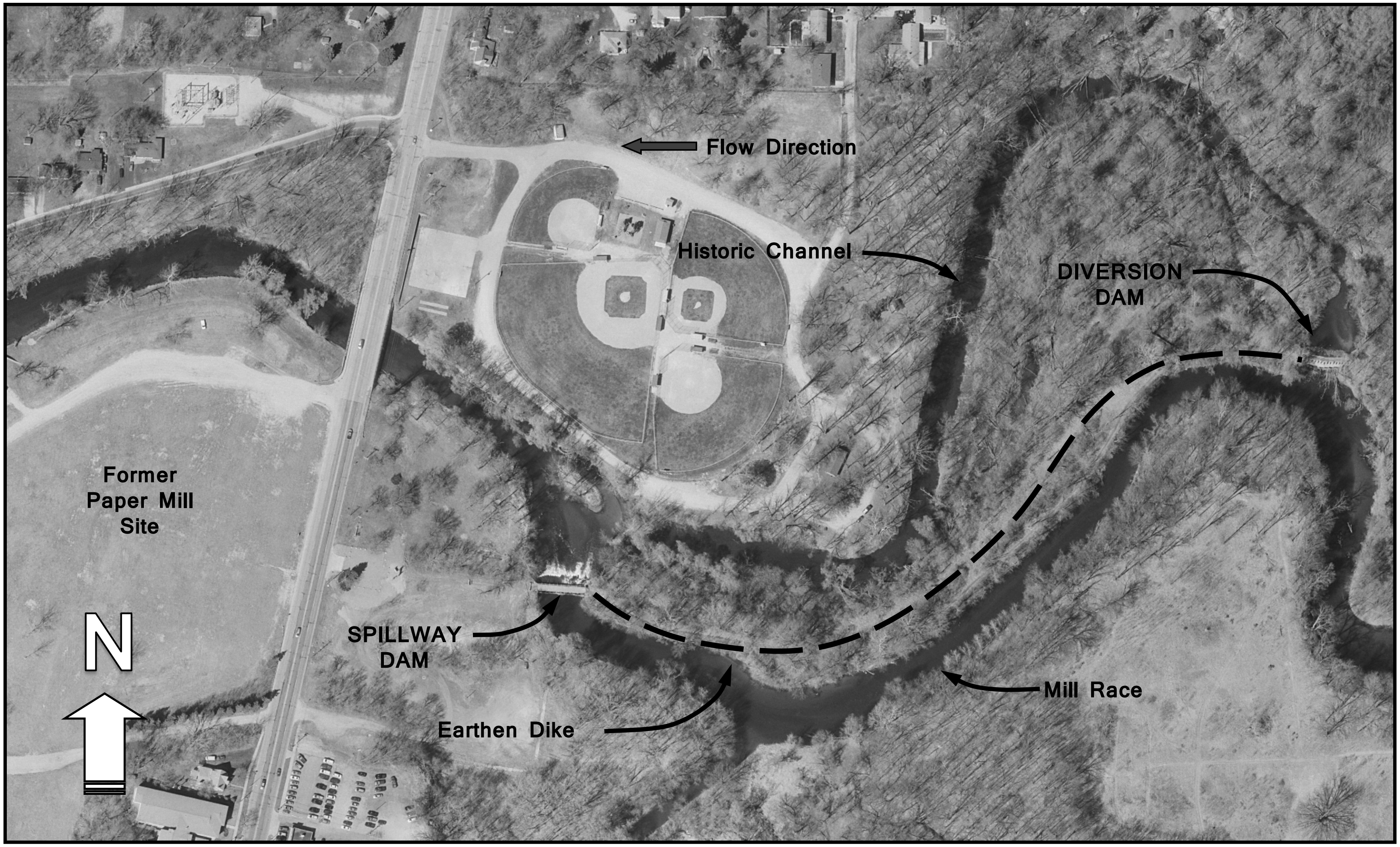

Figure 2. Watervliet Dams Removal, project vicinity map, City of Watervliet, Berrien County, Michigan.

Atlas of Berrien County, Michigan / compiled from actual surveys and the county records by W. W. Graves.
Author: Graves, W. W. (Washburn W.)

1887

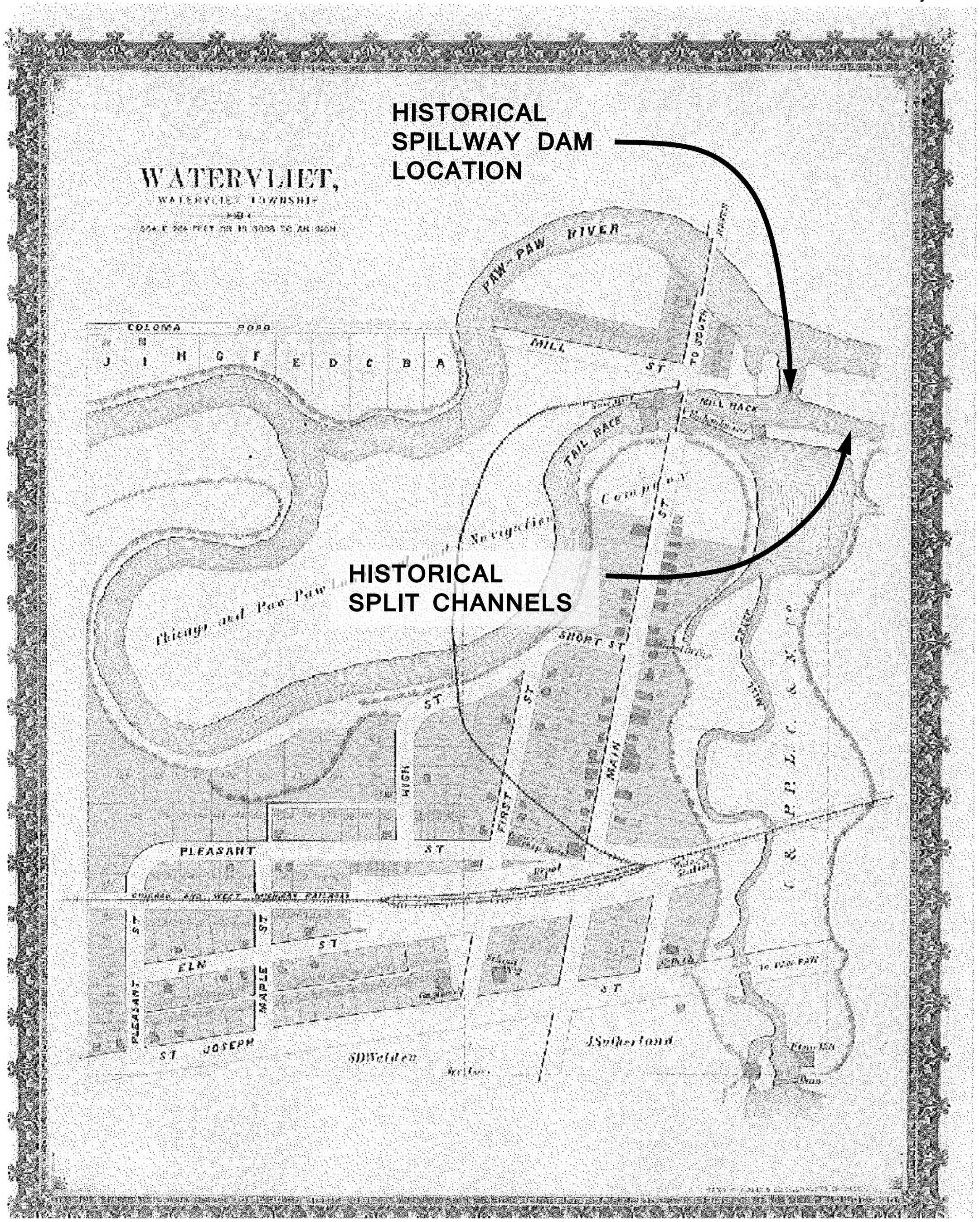

Figure 3. City of Watervliet 1887 plat map, Berrien County, Michigan.

Figure 4-1. Spillway dam prior to acquisition by Berrien County in 2000 showing infrastructure that was removed prior to dam removal.

Figure 4-2. Spillway dam at initiation of dam removal design/funding.

Figure 5-1. Diversion dam prior to acquisition by Berrien County in 2000 showing utilities that had been removed prior to dam removal.

Figure 5-2. Diversion dam at initiation of dam removal design/funding.

Figure 6-1. Historic channel (left) and spillway dam (center) constructed riffles and backfull benches after dam removal.

Figure 6-2. Diversion dam (center) constructed riffle and backfull benches after dam removal.

Figure 7-1. Fish collection reaches: 1) historic channel, 2) mill race (upstream spillway dam), 3) upstream diversion dam, 4) M-140 Campground, 5) M-140 Watervliet.

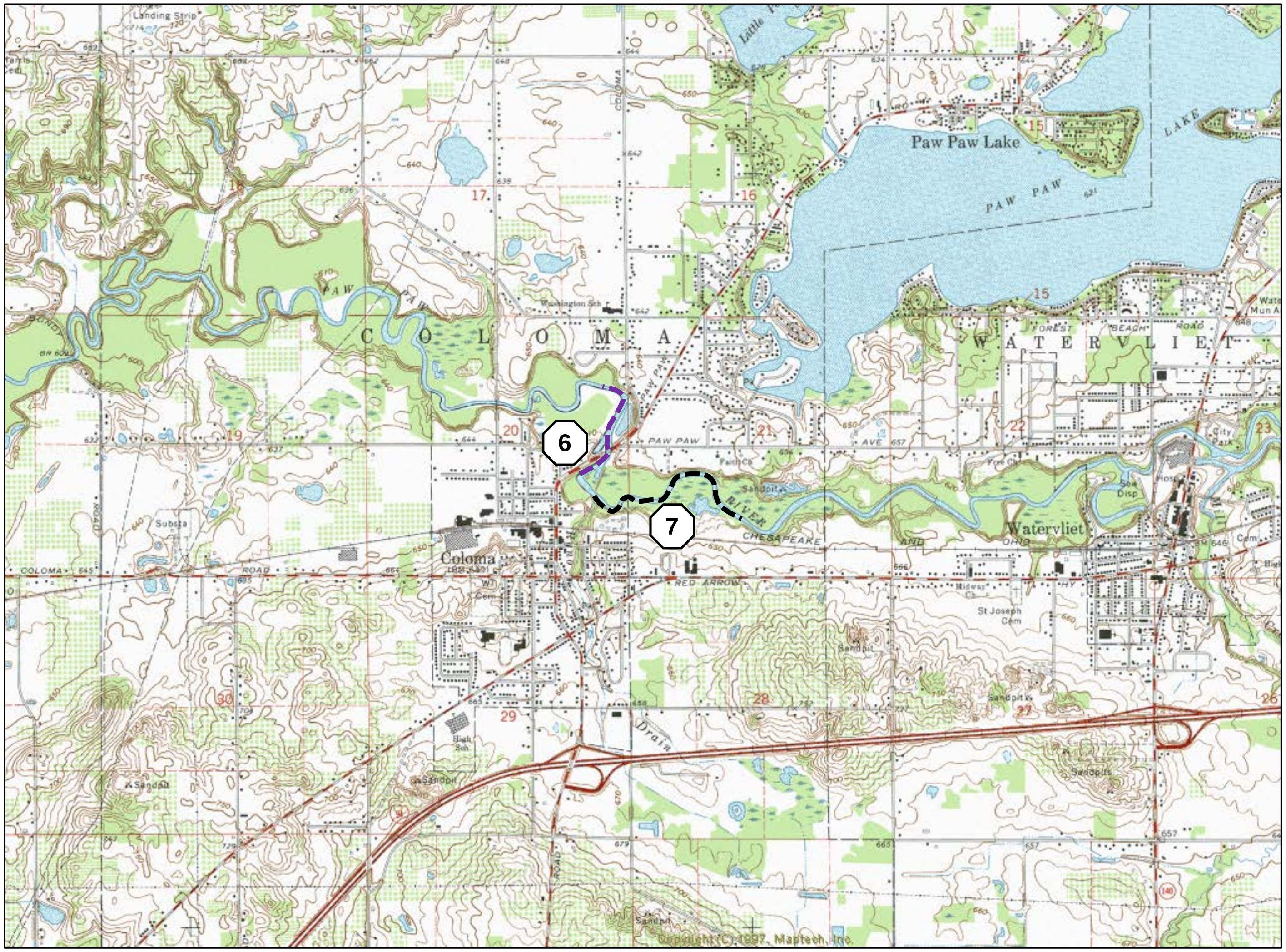

Figure 7-2. Fish collection reaches: 6) Coloma DPW-downstream and 7) Coloma DPW-upstream (combined as "Coloma DPW" in data summaries).

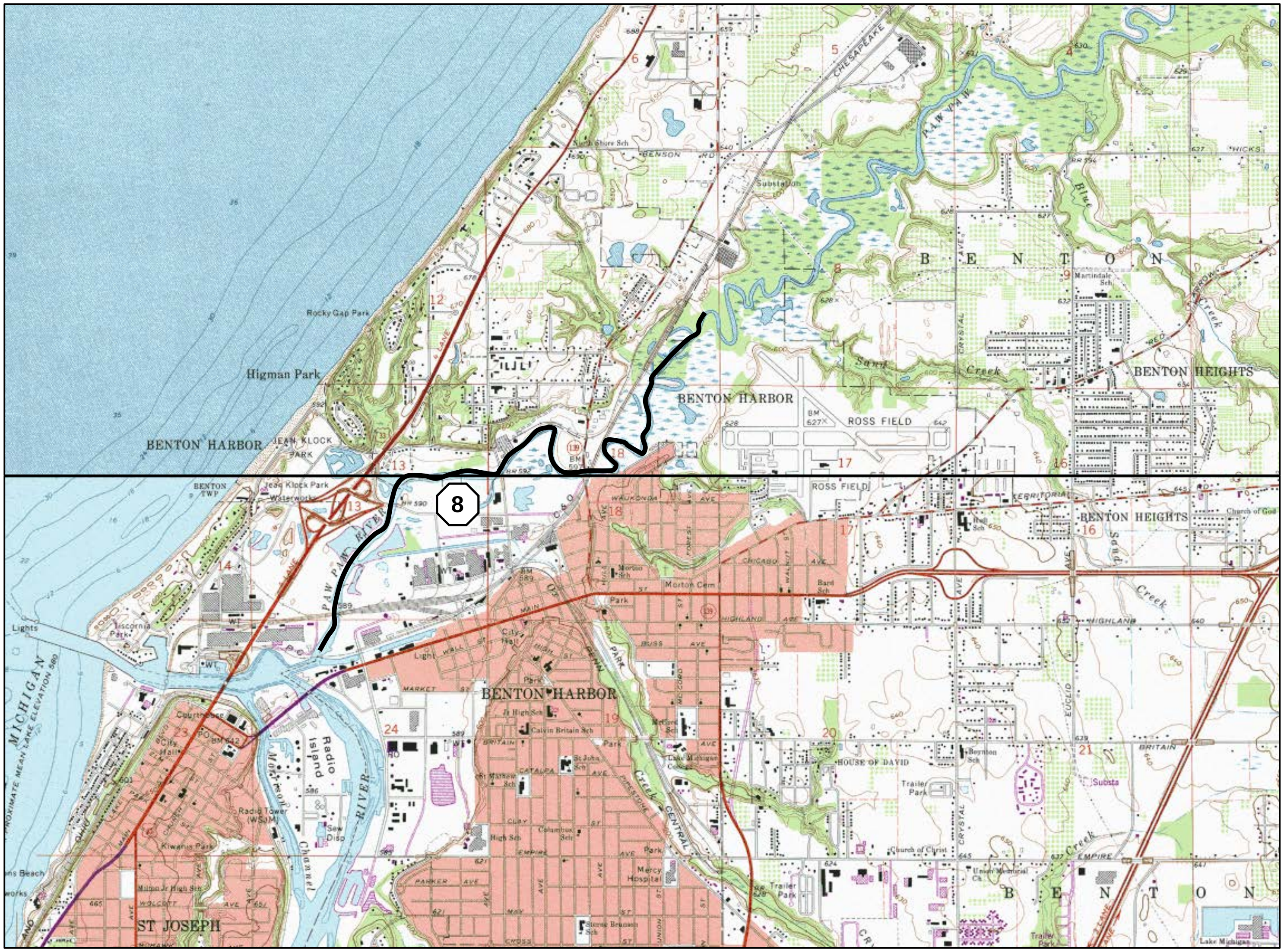

Figure 7-3. Fish collection reaches: 8) Benton Harbor.

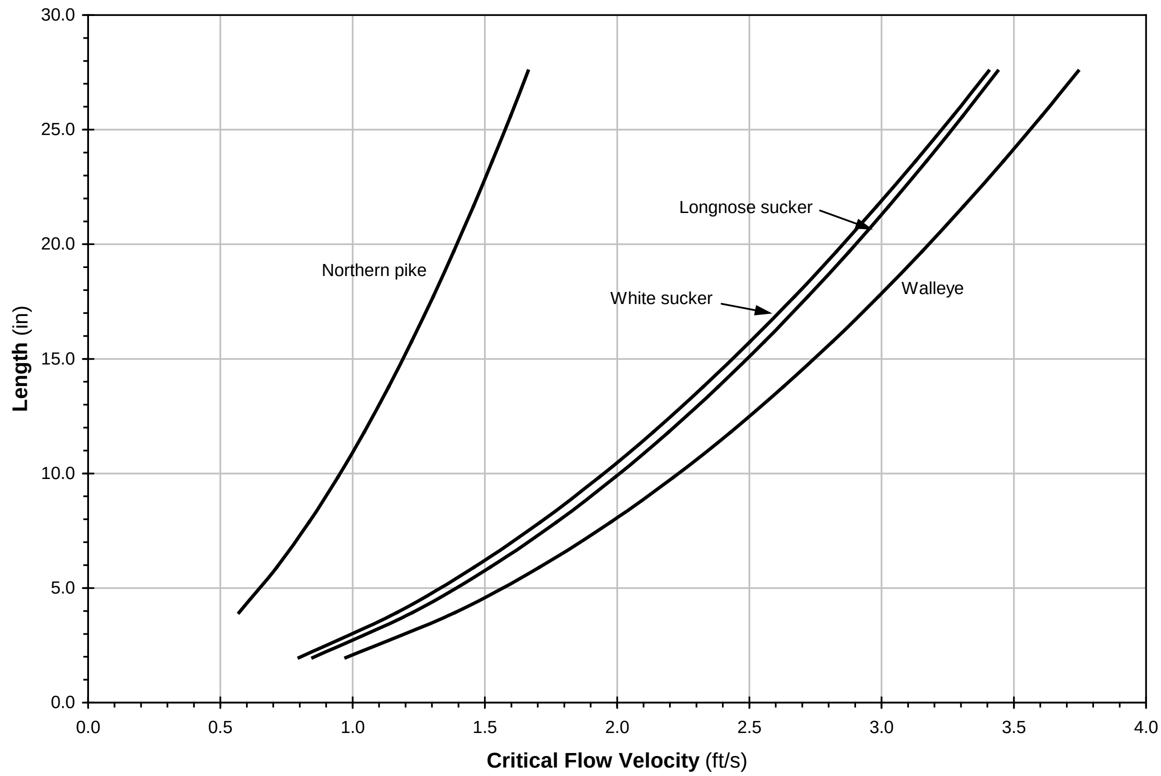

Figure 8. Critical velocity by length for northern pike (*Esox lucius*), walleye (*Sander vitreus*), longnose sucker (*Catostomus catostomus*), and white sucker (*Catostomus commersonii*) from Jones et al. 1974.

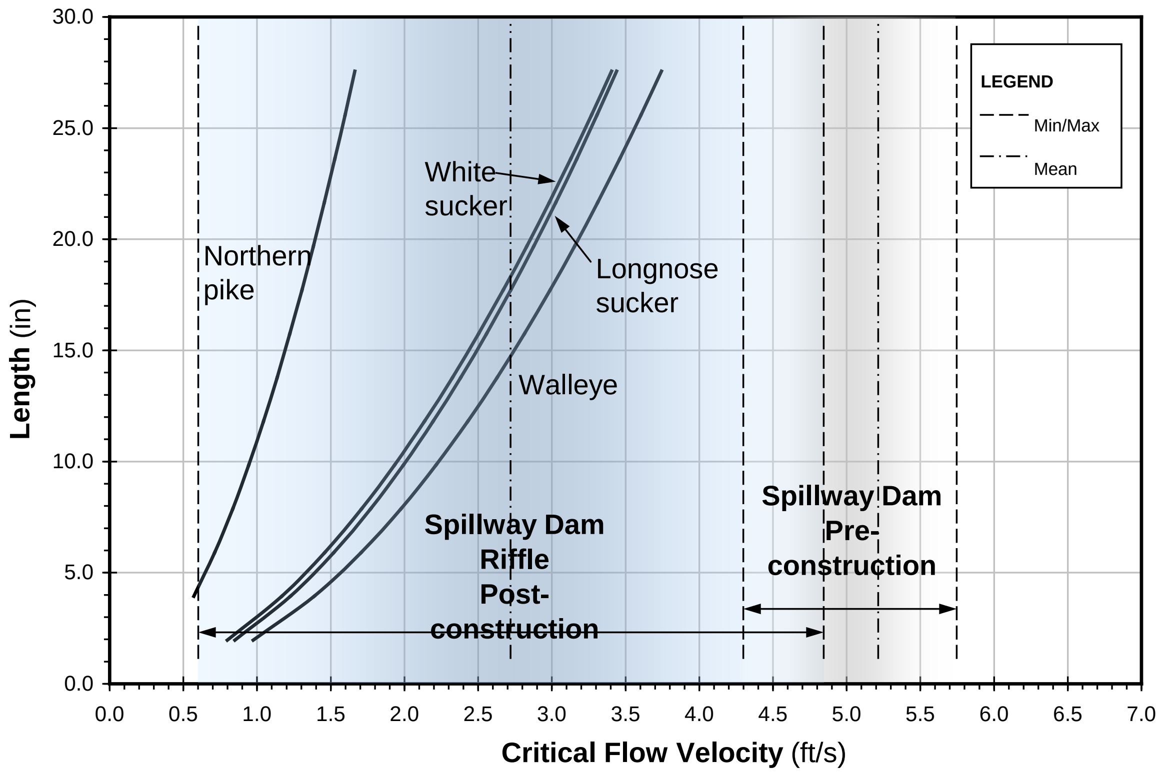

Figure 9. Critical velocities (ft/s) for the four target species and measured water velocity (range and means) at the spillway dam before and after removal of the Watervliet Dams, City of Watervliet, Berrien County, Michigan. Black shading indicates values measured within the pre-removal period, and blue shading indicates values measured post-dam removal.

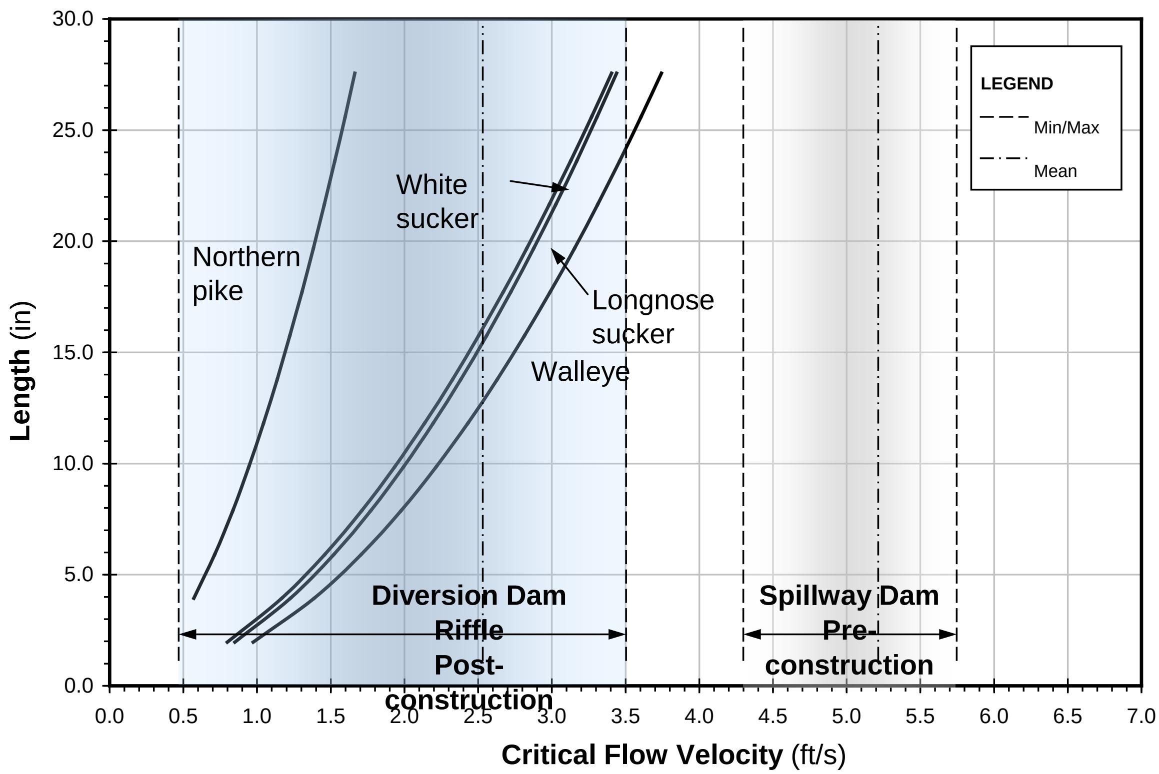

Figure 10. Critical velocities (ft/s) for the four target species and measured water velocity (range and means) at the diversion dam before and after removal of the Watervliet Dams, City of Watervliet, Berrien County, Michigan. Black shading indicates values reported within the pre-removal period, and blue shading indicates values reported post-dam removal. The spillway dam pre-removal velocities are shown for comparison because it was not possible to measure velocity over the diversion dam prior to removal.

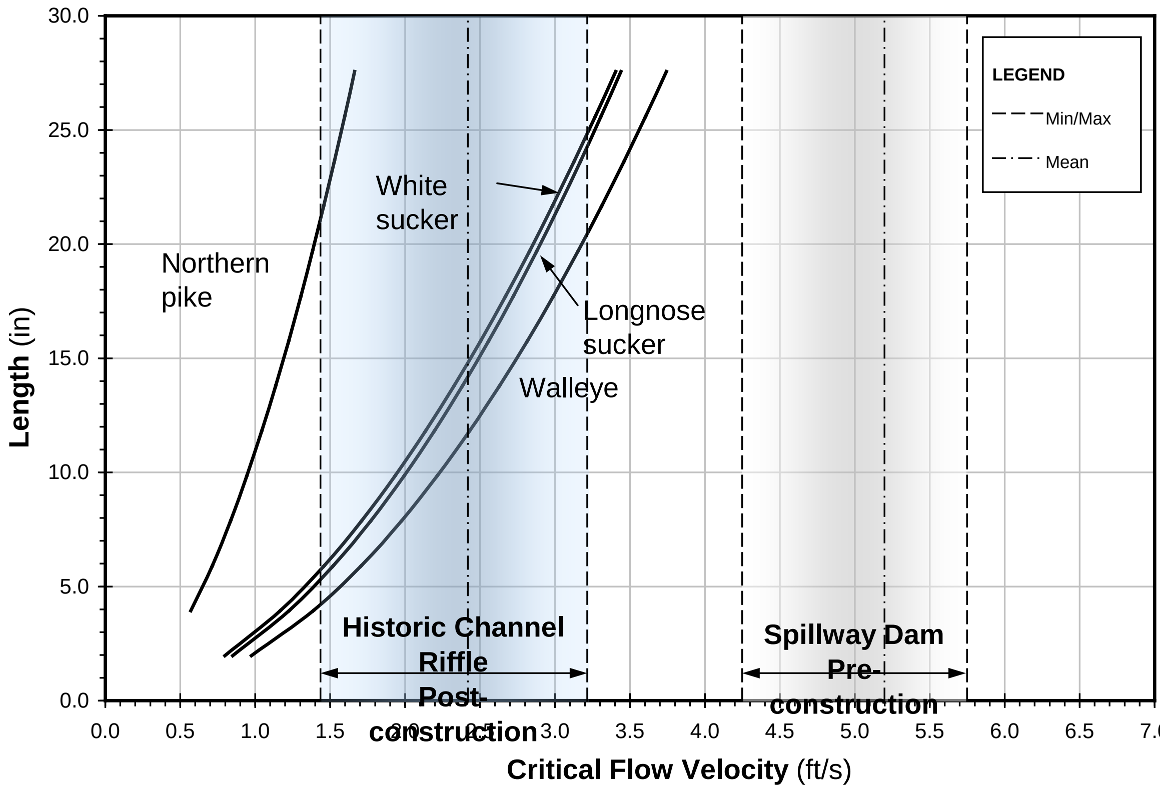

Figure 11. Critical velocities (ft/s) for the four target species and the water velocity (range and means) at the historic channel riffle (compared to the spillway dam pre-removal) before and after removal of the Watervliet Dams, City of Watervliet, Berrien County, Michigan. Black shading indicates values reported within the pre-removal period, and blue shading indicates values reported post-dam removal.

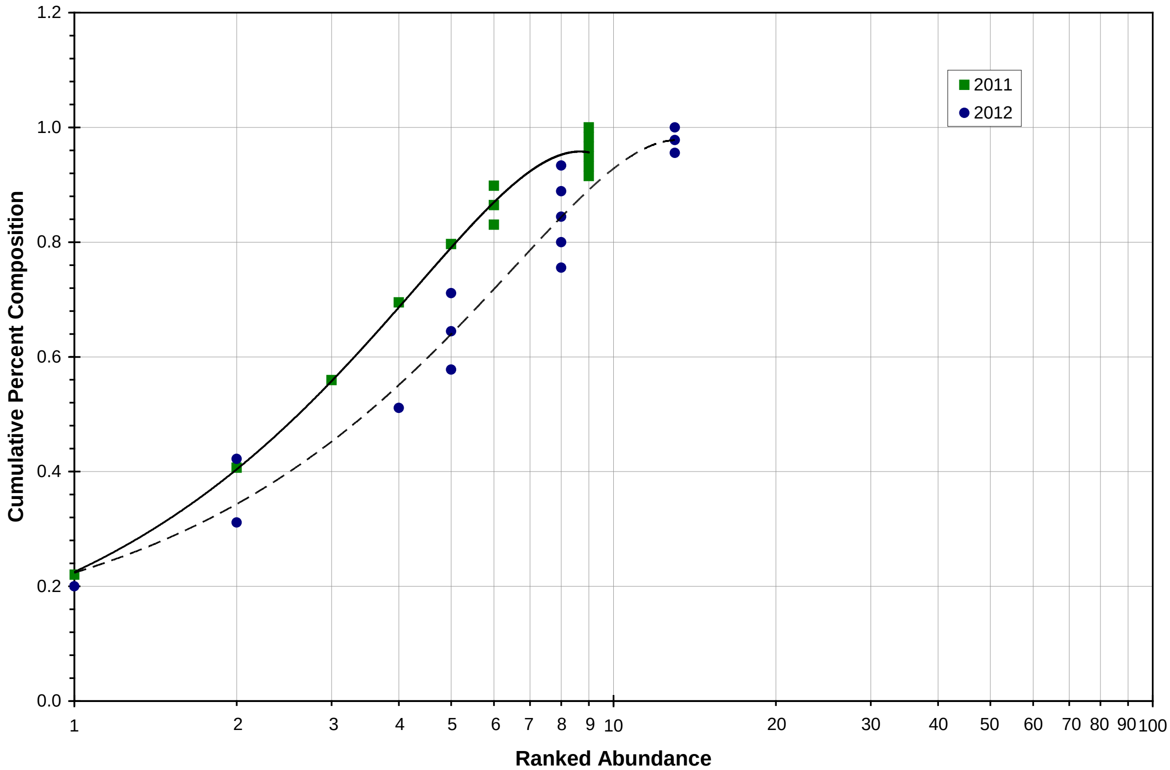

Figure 12. k-dominance curves for the fish community of the historic channel before (2011, ■) and after (2012, ●) removal of the Watervliet dams, City of Watervliet, Berrien County, MI.

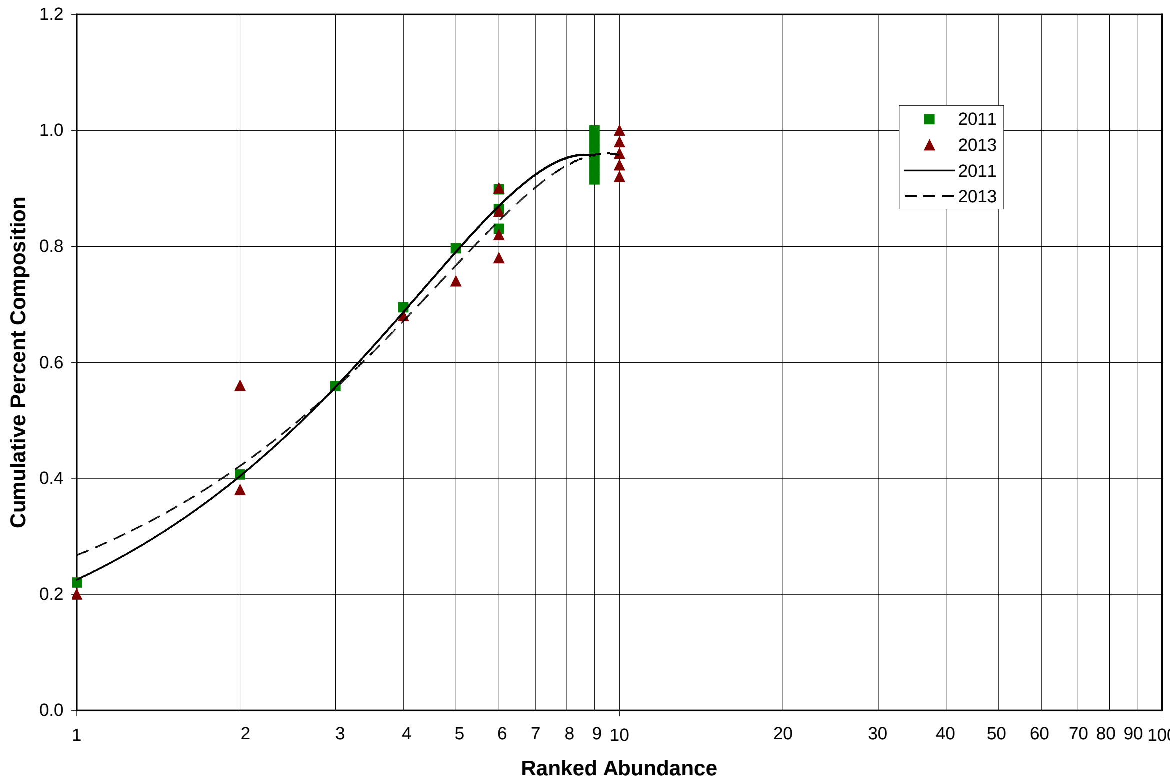

Figure 13. k-dominance curves for the fish community of the historic channel before (2011, ■) and after (2013, ▲) removal of the Watervliet dams, City of Watervliet, Berrien County, MI.

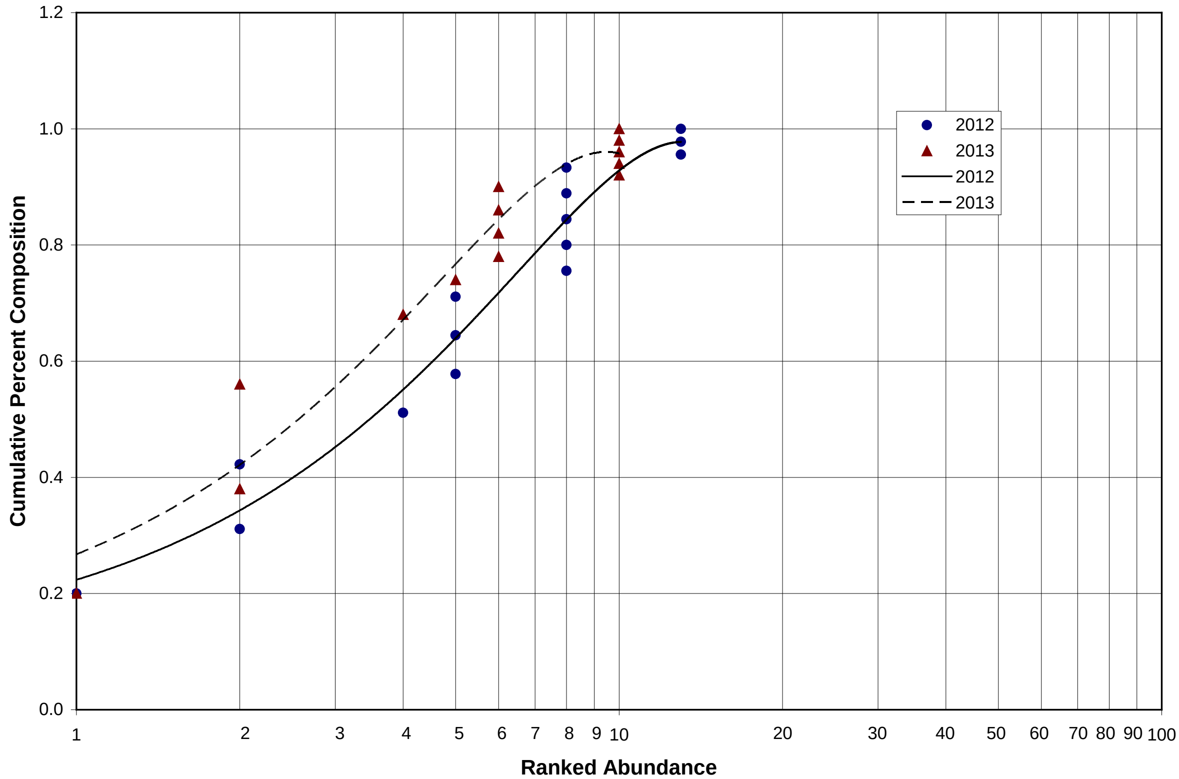

Figure 14. k-dominance curves for the fish community of the historic channel for two years (2012, ●, 2013, ▲) following removal of the Watervliet dams, City of Watervliet, Berrien County, MI.

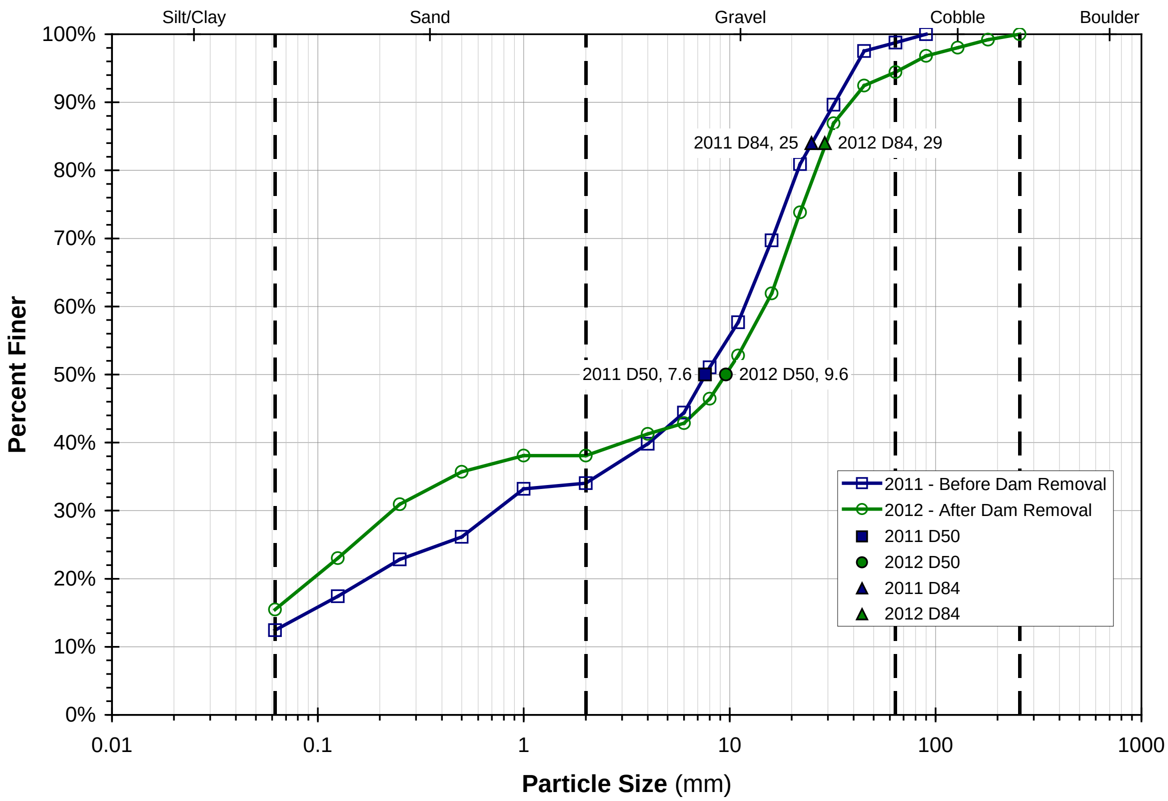

Figure 15. Cumulative particle size distributions for the M-140 riffle substrates based on Wolman pebble counts conducted before (2011) and after (2012) removal of the Watervliet Dams, Berrien County, Michigan.

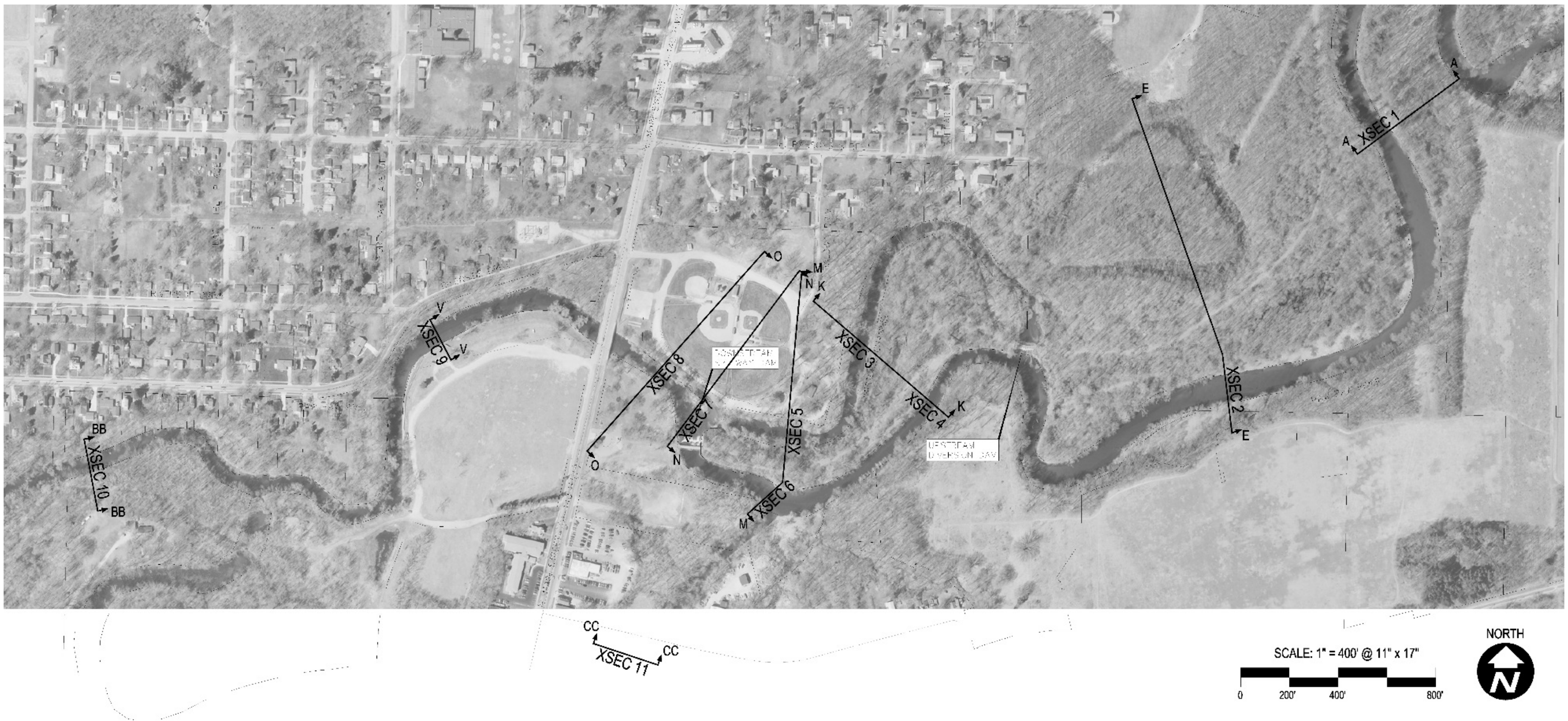

Figure 16. Location of cross-sections surveyed before and after removal of the Watervliet Dams for morphological monitoring, Paw Paw River, Berrien County, Michigan.

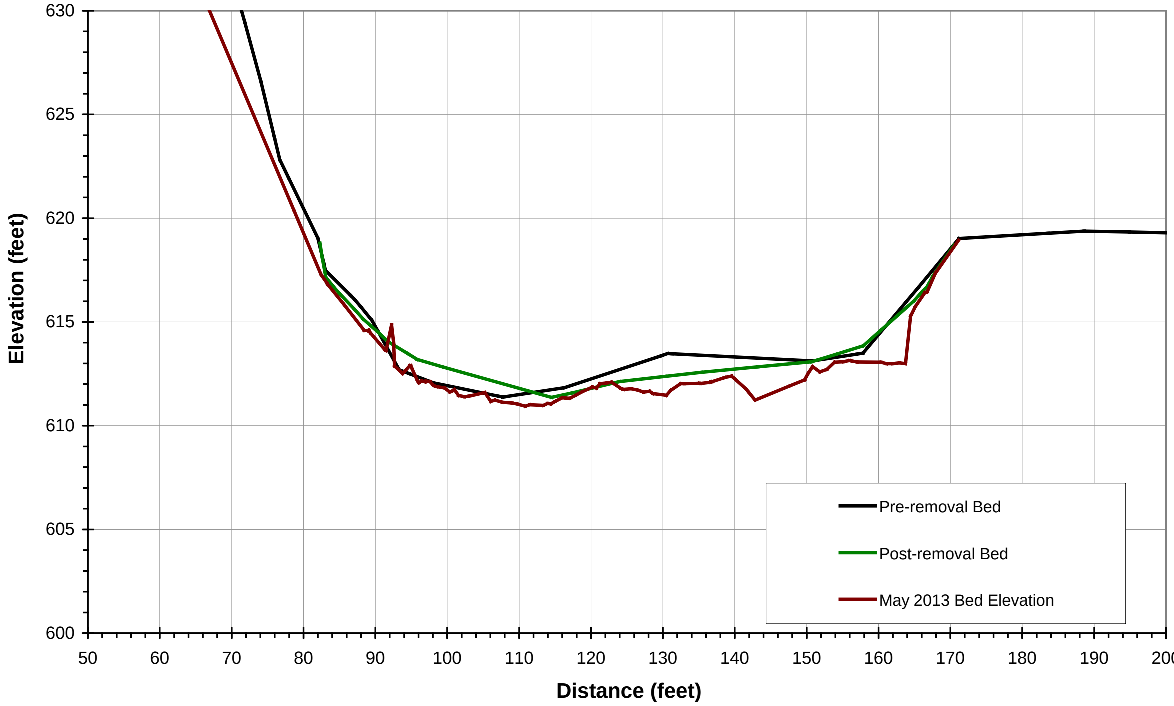

Figure 17. Cross Section #1 (A-A)

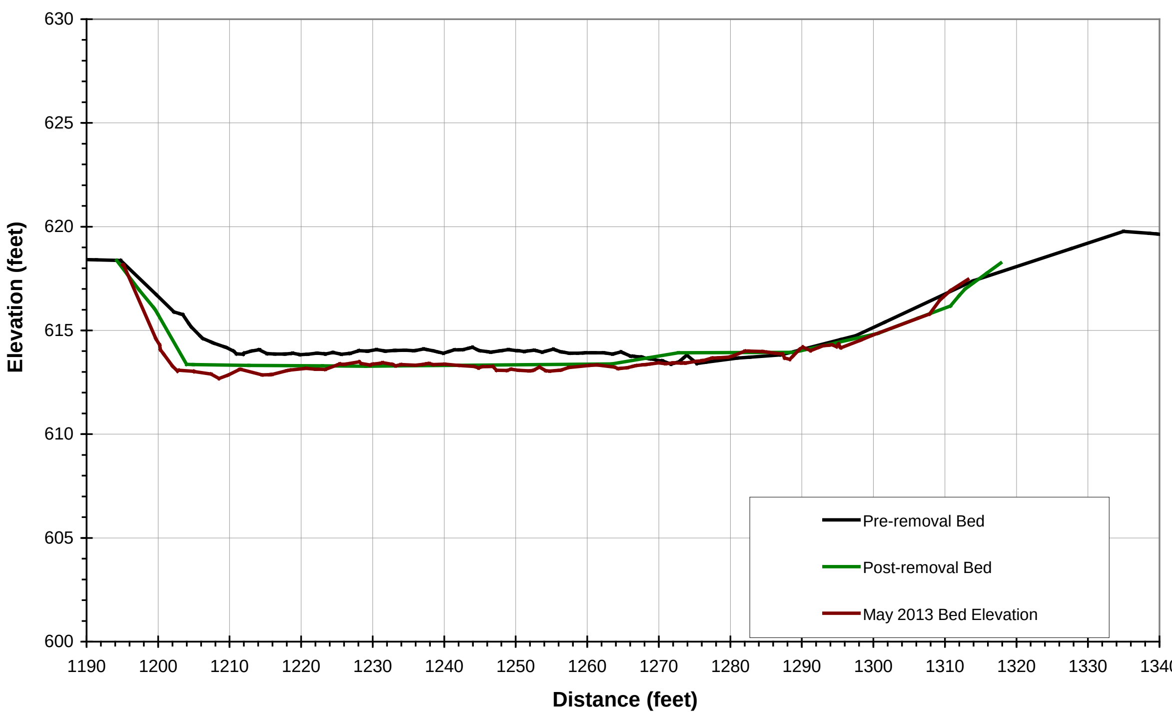

Figure 18. Cross Section #2 (E-E)

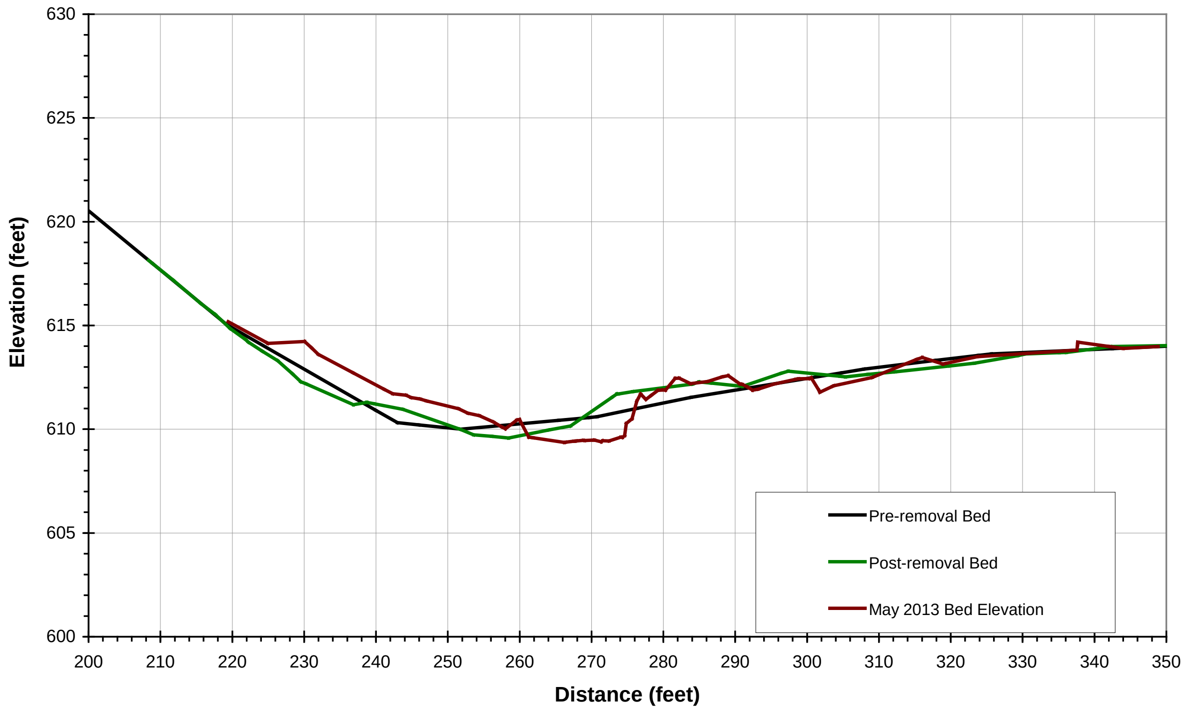

Figure 19. Cross Section #3 (K-K, historic channel)

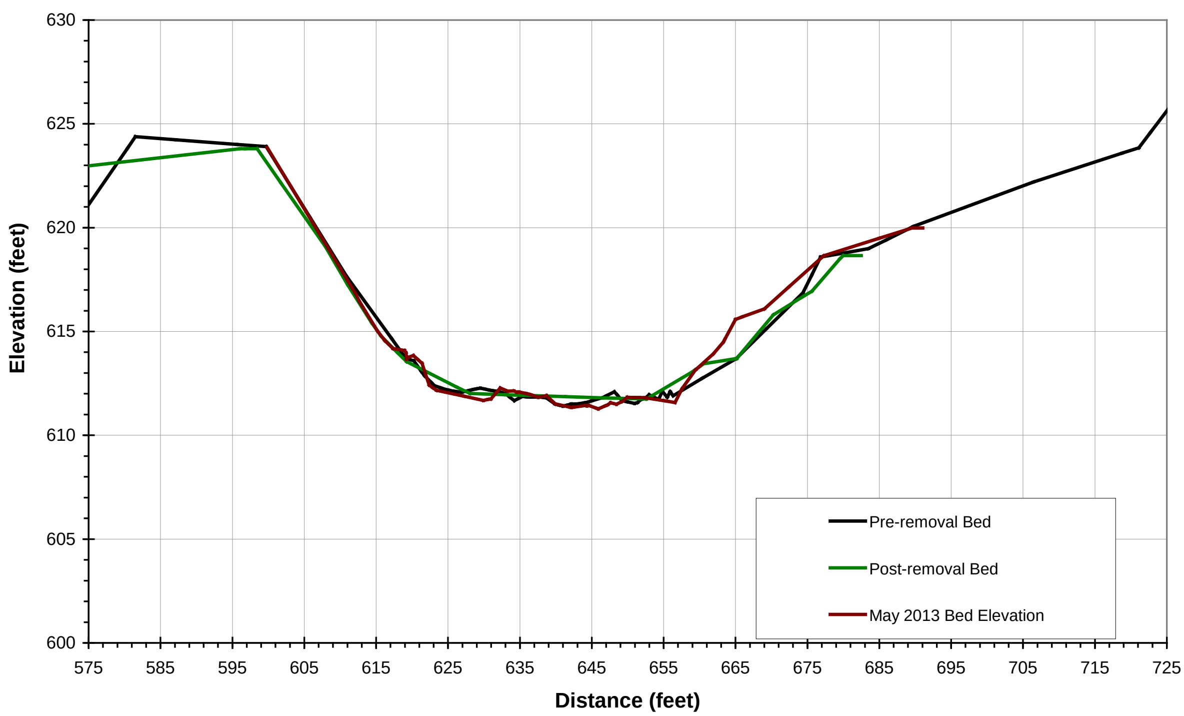

Figure 20. Cross Section #4 (K-K, mill race)

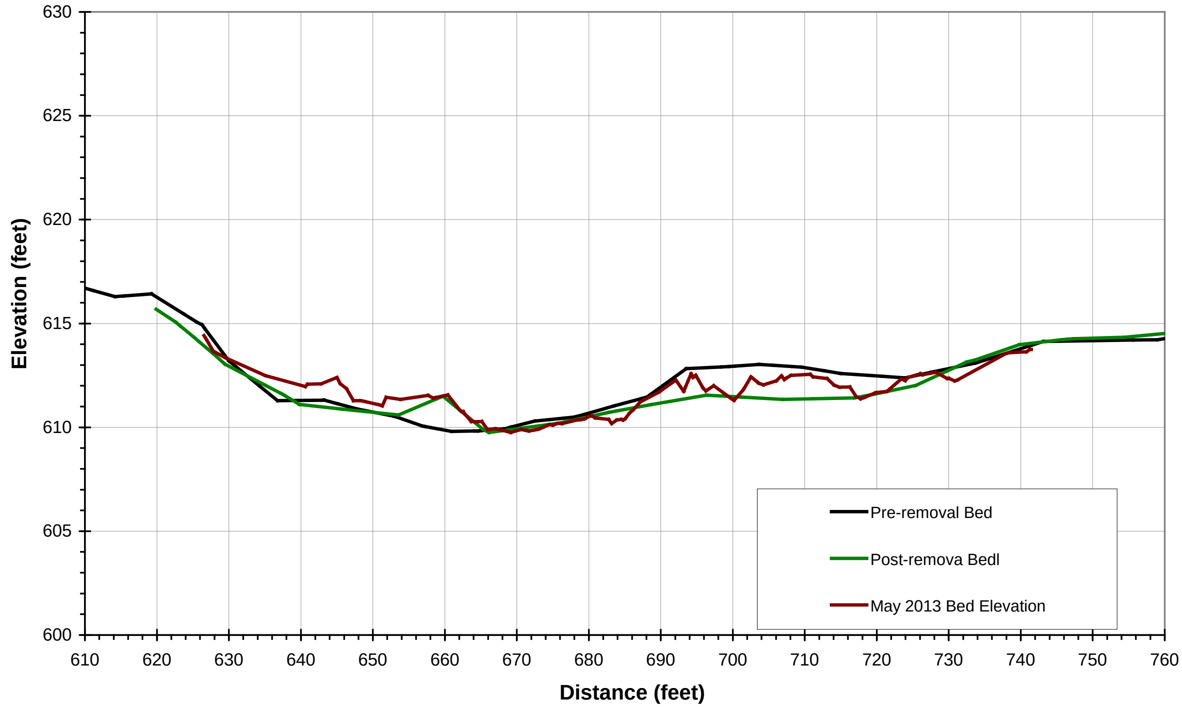

Figure 21. Cross Section #5 (M-M, historic channel)

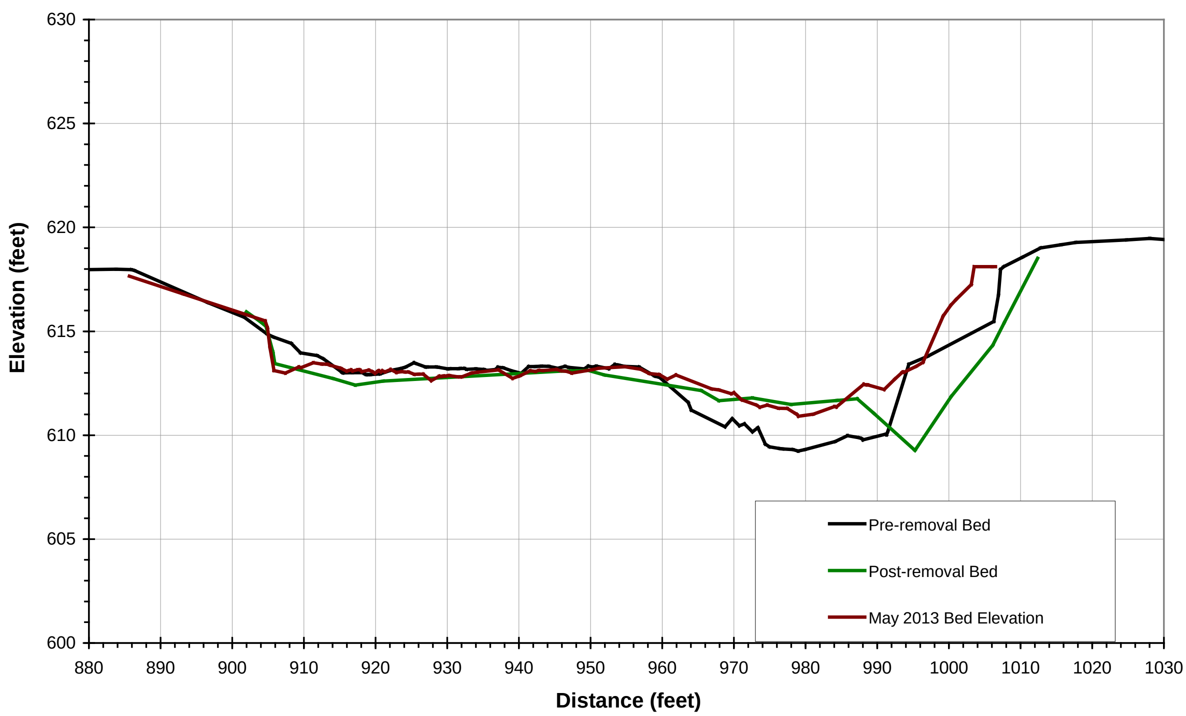

Figure 22. Cross Section #6 (M-M, mill race)

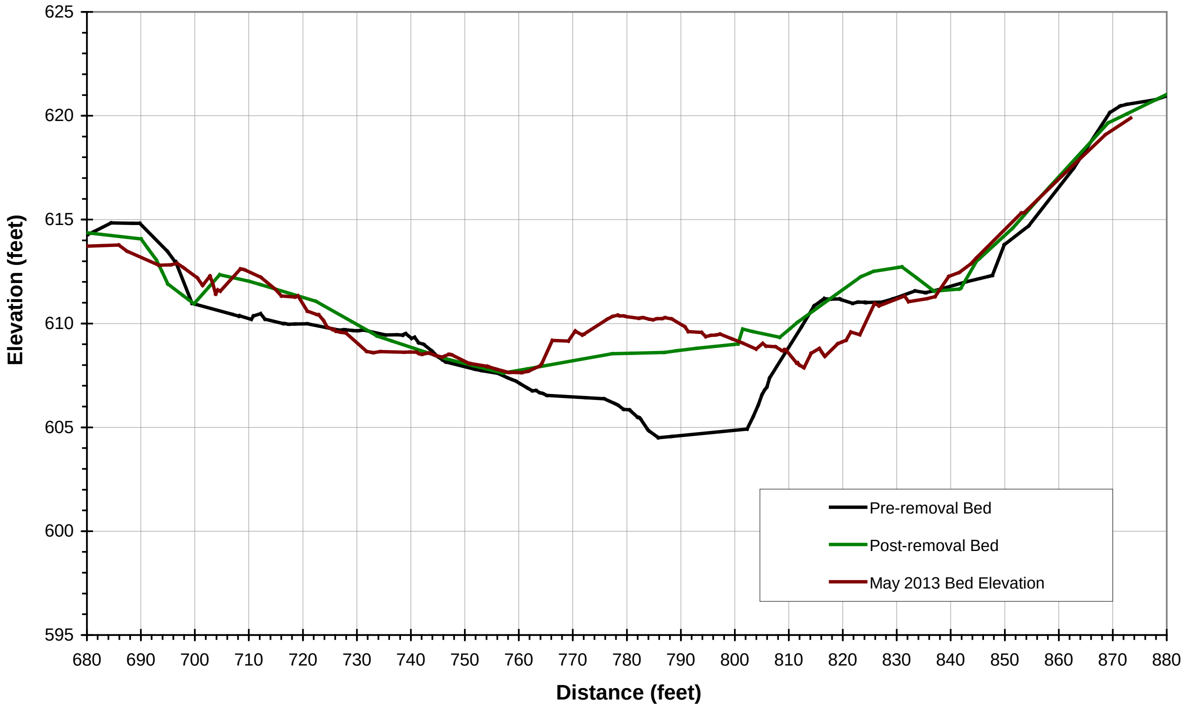

Figure 23. Cross Section #7 (N-N)

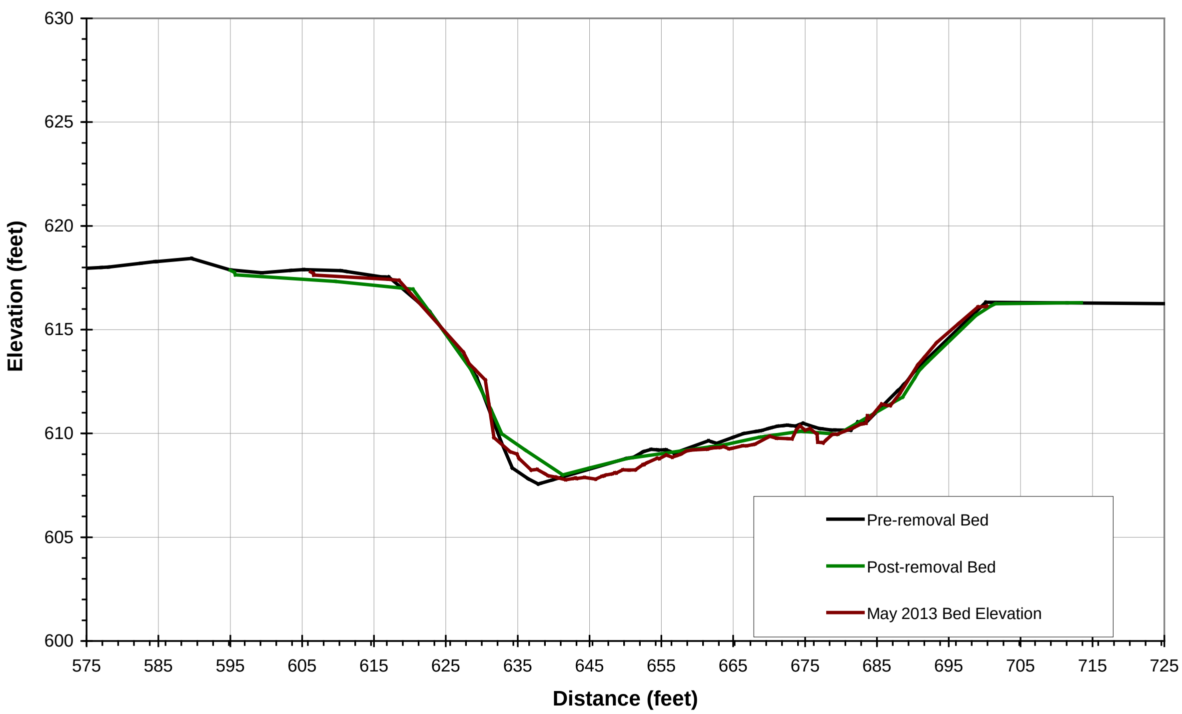

Figure 24. Cross Section #8 (O-O)

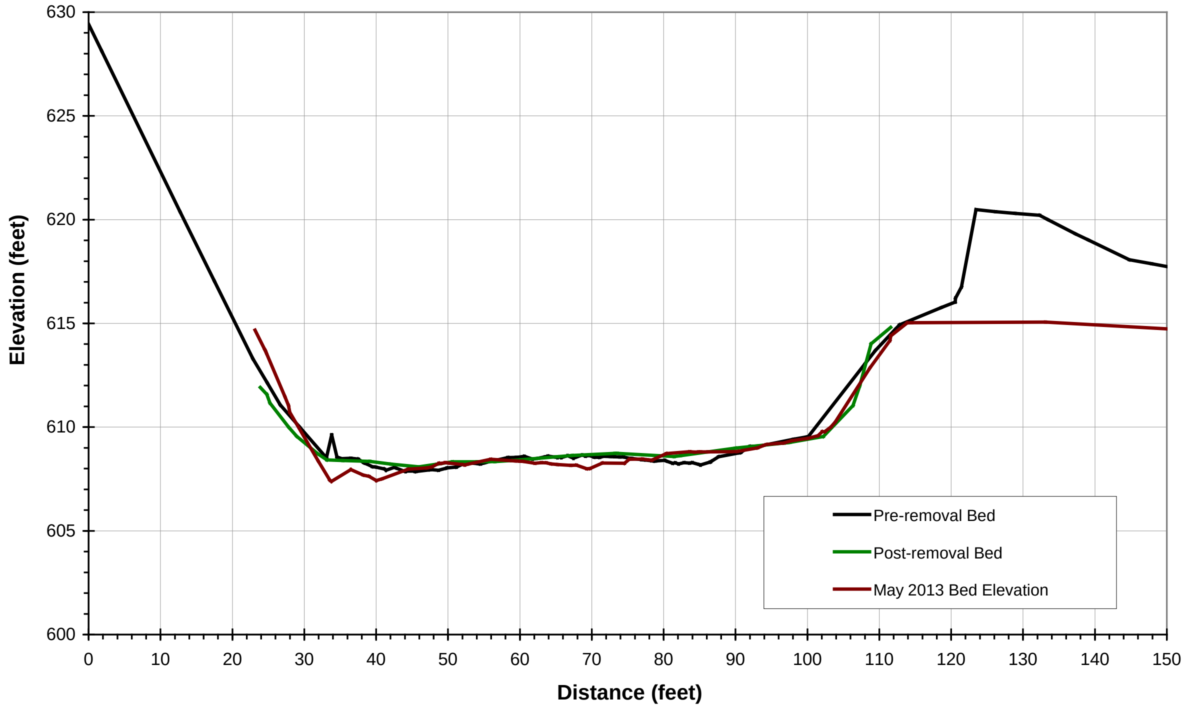

Figure 25. Cross Section #9 (V-V)

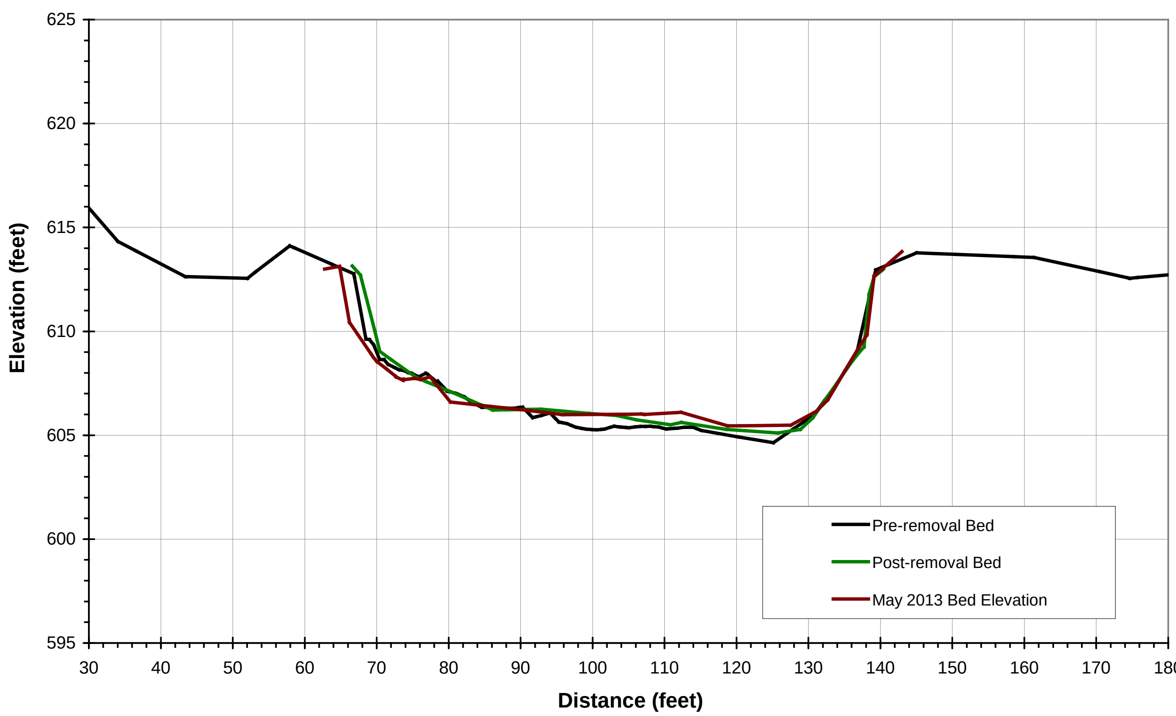

Figure 26. Cross Section #10 (BB-BB)

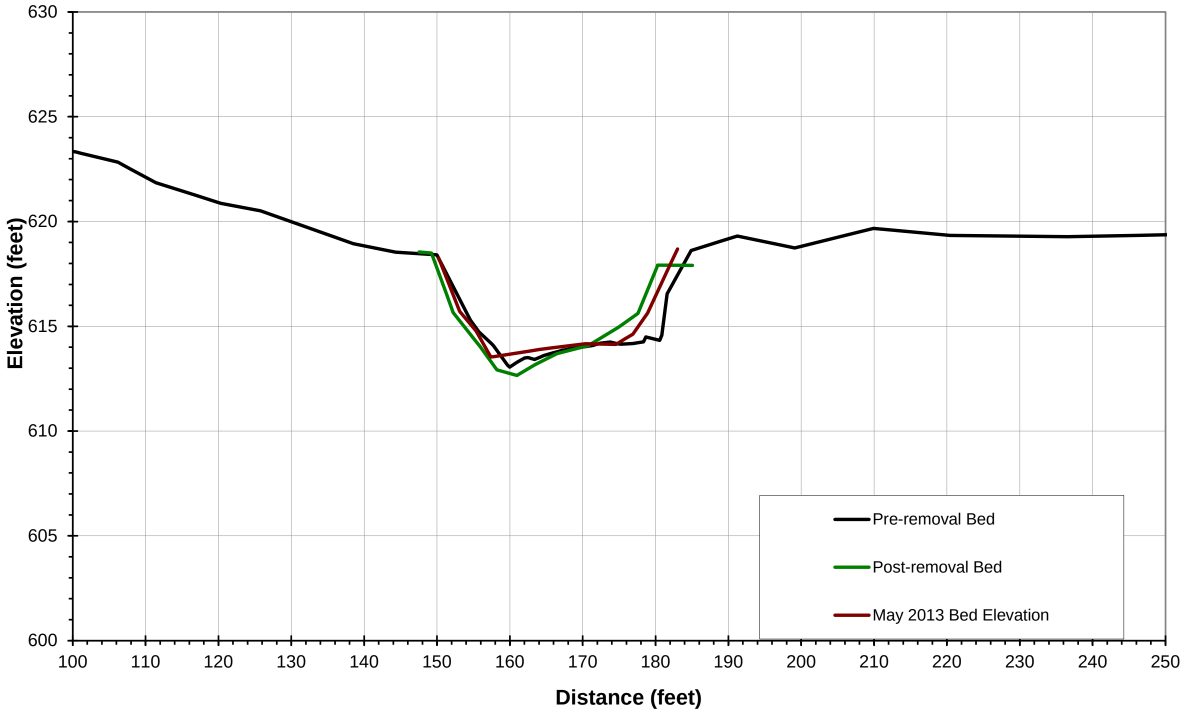

Figure 27. Cross Section #11 (CC-CC, Mill Creek)