RESTORATION POTENTIAL OF THE MAPLE RIVER, AN ABANDONED ANABRANCH OF THE LOWER MUSKEGON RIVER

by

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Abstract

This study examines the potential for restoration of the Maple River in western Michigan (Muskegon and Newaygo Counties). The Maple River is an abandoned anabranch channel of the Muskegon River. Historically the Muskegon split to form Maple Island but in the late 19th century flow was diverted down the northern channel of the Muskegon and the southern branch became what is now the Maple River. In the field I mapped the existing and underlying historic channel bottom size and shape. Then using HEC-RAS I developed a one-dimensional hydraulic model of the Maple River channel for both present and past condition. The model outputs were used to explore channel bankfull conveyance capacity and flooding thresholds. In addition I performed Weighted Useable Area (WUA) analysis to estimate potential increases in hydraulic habitat that restored connectivity with the Muskegon River might bring. Fishes in the Maple River were found to be less plentiful in diversity and evenness when compared to the Muskegon River. With the removal of nearly a meter of soft sediment the restored channel model provided more conveyance capacity than the existing channel model and contributed to an increase in hydraulic capacity for some of the life stages of the species of interest in this study. Hydraulic weighted useable area was predicted to increase for the eggs of chinook salmon, adult walleye, and both juvenile and adult steelhead under the restored channel model conditions. There is much more research necessary to weigh all the options for a restoration of the Maple River but there is evidence that hydraulic habitat may be improved for some fishes with the removal of the accumulated sediment throughout the Maple River channel.

Acknowledgements

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I thank all those that helped collected field data for volunteering their time and effort: the UofM Fluvial Ecosystems Lab class of 2012, Andrea Dominguez, Kellie Donajkowski, Michael Fainter, Andrew Layman, Courtney Yan, and Carla Rosier. I also thank Terry Hackenberg of Grant, MI and John Thiel of Twin Lakes, MI; without permission to access their land, I would have been unable to reach much of my study area.

Lastly a special thanks to Carla Rosier for her incredible support and patience.

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Introduction

The Maple River today is a relatively small stream channel that flows for approximately 4.5 miles before joining the Muskegon River at the bottom of Maple Island, in western Michigan. It delimits the eastern and southern edges of Maple Island, straddling the borders of Muskegon and Newaygo Counties. Historical accounts indicate that what is today the Maple River was originally not a separate river channel, but a southern anabranch of the mainstream Muskegon River; plat maps from 1837 clearly show the Muskegon River branching and flowing around either side of Maple Island (Figure 1a). Furthermore both anabranches (North and South) were mapped by the original surveyors as being similar in size (channel widths typically 60-80 m). Late nineteen century flooding due to log jams which formed at the downstream confluence of the two branches became an issue and led to monetary settlements between logging companies and Maple Island residents (Rozeboom 1978). Historical documents refer to improvements made to the channel in order to move logs around the island as well as a “dam” near Maple Island (Spooner & Wantz 1987). Eventually these logging interests closed the southern anabranch in order to deepen the northern anabranch channel and better float logs through what is today the mainstream Muskegon River on the north side of the island (Woodard 2009). At the head of Maple Island, an earthen berm and road now divides the Muskegon River from the Maple paleo-channel and the low wet areas along the southern edge of the Muskegon valley have become the headwaters of a much smaller Maple River channel.

Repeated flood events on Maple Island, and growing local interest of Maple Island residents in the ecological health of the Maple River, led to the formation of a small committee of citizens interested in the possibility of restoring historic flows in the Maple channel. In 2012 the committee met with representatives of the Muskegon River Watershed Assembly (MRWA), MDNR, MDEQ, and Dr. M. Wiley from the University of Michigan (representing the Muskegon Watershed Research Partnership, MWRP) to discuss the possibility of a preliminary feasibility study. The Muskegon River watershed had been the focus of a large amount of earlier research by MWRP, a coalition of universities, agencies, and NGO's (Stevenson et al. 2008, Wiley et al. 2008), which included channel models that seemed relevant to the restoration question. Several meetings later and after a public discussion with residents at nearby Cedar Township Hall, preliminary investigations, including this study, were initiated to evaluate the restoration potential of the Maple River.

The objectives of my study were to:

1. Document the current hydraulic conditions of the channel as well the fish species now present in the Maple River and around Maple Island.
2. Create hydraulic models of the Maple River channel to assess historic, current and potentially restored hydraulics.
3. Evaluate potential gains in fish habitat that might result from hydrologic restoration.

Methods

Study Site

Maple Island forms at a key transitional point in the Muskegon River valley. The valley doubles in width from 0.8 miles at the head of Maple Island to 1.6 miles where the Maple River rejoins the Muskegon River. A few miles upstream the valley is rarely wider than 0.5 miles and downstream of the island it is rarely less than 1.5 miles wide. The valley walls near Maple Island are steep and rise roughly 100 feet above the Muskegon River. Soils on and around Maple Island are generally loam or sandy loam and in many areas provide for excellent farm land if well drained and protected from flooding during the growing season (USDA 2015).

Sampling locations for both surveying and fish collection were chosen to represent the diversity of the Maple River channel from top to bottom, however they were also constrained by permission to access private land and physical difficulties moving within the channel. The Maple River was broken into three reaches (Figure 1b). The furthest downstream, referred to as the DNR reach, stretches upstream from the confluence with the Muskegon River to a culvert under Bayne Road. This reach tended to be relatively flat and wide (55 to 85 feet wide) and the banks were heavily forested, state-owned land as part of the Muskegon State Game Area. The middle section of the river, referred to as the Thiel reach, had the highest average gradient and the narrowest channel (10 to 20 feet wide, with the exception of broader impounded areas), and generally flowed along the base of high bluffs to the east of Maple Island. The most upstream, hereafter referred to as the Hackenberg reach, transitions from low to moderate gradient and relatively wide to narrow except where flow is locally impounded (3 to 55 feet wide).

Cross-section survey locations were selected to adequately represent the channel forms that characterized each reach progressing from the headwaters to the confluence with the Muskegon River. In total, six cross-sections were surveyed. In addition, a GPS survey of land-elevations was conducted along the entire profile of the channel to collect control and slope data. These locations were chosen based on the following criteria: equal distribution of survey points along channel, private land access permissions, and satellite signal quality and tree coverage.

Four fish collection sites were chosen with an emphasis on sampling in each of the three reaches of the channel. One site was selected in each distinct segment of the Maple River channel as a proxy for that entire section. In addition, one site outside of the Maple River channel was chosen and sampled to be a proxy for the Maple River channel if it is restored. This site is a side channel of the Muskegon River flowing around Troque Island immediately upstream of the historic Muskegon River and Maple River connection at the head of Maple Island.

Water Temperature

Water temperature data were collected at two sites in the DNR reach, and one each in the Thiel and Hackenberg reaches. HOBO™ Pro V2 Water Temp Loggers were installed at each site in a shaded location near the bottom of the channel. Temperatures were logged hourly between June 12, 2013 and November 3, 2013 with the exception of the Hackenberg site at which the logger was not recovered and its last data collected on July 17, 2013.

Fish Collection

All fish collections were made with electroshocking equipment. A backpack, barge, or boat unit was used based on water depth at each site. Sampling consisted of single pass electrofishing covering all habitat types available in the channel at each site. All fish were counted and identified to species. Collections were made with a single sampling event in the Maple River and two samples of the Troque Island channel at relatively low and high water conditions.

Cross-Section Channel Surveys

At each cross-section the transect distance, relative elevation, water depth (when in channel), and soft sediment depth to refusal were recorded every 1.5 to 3 meters, depending on the width of the channel; evenly distributed across the river channel between right and left bank floodplains. Sediment refusal was determined by probing with half-inch diameter, four meter long steel rebar; the depth at which the rerod could no longer be pushed into the sediment because of solid resistance was noted. Although sediment cores can afford a higher degree of accuracy when possible, probing methods have been used successfully elsewhere to approximate soft sediment type and depth (e.g. Limno-Tech 2004). Lastly, a benchmark location was surveyed in (using a Trimble GeoXH 6000 series GPS unit) at the same time as cross-section elevations to provide an elevation control and tie-in point to the larger model for all cross-sections.

Long profile elevations used to establish channel slope were measured from top to bottom in the Maple River channel as well as on the Muskegon River at the head and outflow of the Maple River. Elevations and cross-section benchmarks were determined using a Trimble GeoXH 6000 series GPS unit with all measurements post-processed and filtered based on horizontal and vertical accuracy. Post processing utilized the nearest base stations from the MDOT CORS network (Table 1).

Channel Model

The U.S. Army Corps' Hydrologic Engineering Centers River Analysis System (HEC-RAS v 4.1) software was used to create models of the Maple River channel. The HEC-RAS software allows the creation of one-dimensional steady flow, unsteady flow, mixed flow, sediment transportation, and water temperature models. Channel cross section dimensions and elevations are used in the software for geometric and hydraulic computations at user designated flow scenarios/profiles. I used steady flow simulations to estimate channel depths, velocities and shears at a variety of flow rates, for the existing, and potentially restored Maple channel system.

A combination of field-surveyed and digitally extracted data were used to parameterize the model. Field-surveyed channel dimensions were augmented with GIS and GPS data to provide extended flood plain elevation data past the surveyed cross sections. The flood plain elevation data were taken from a TIN surface created around Maple Island (Figure 2), using SRTM DEM elevations.

Two channel geometry models were constructed. The first, the existing channel model (EC), represented the current channel configuration, including bridge and culvert crossings as they existed during this survey (with the exception of one culvert crossing not surveyed due to a lack of land-owner permission). The second model, the restored channel model (RC), represented both the historical and restored channel by removing the soft sediment found through the probe data collected from all transects. Removing the soft sediment served as a proxy for both the assumed conditions of the past channel, before sedimentation, as well as the conditions a hypothetical restoration in the Maple River channel might emulate. The RC did not contain any bridge crossings or culverts on the assumption that a deepening of the channel and added flowmight necessitate removing or retrofitting all of these structures.

WUA Calculations

A weighted useable area (WUA) calculation provided a simulation of useable fish hydraulic habitat and predicted habitat changes across a range of discharge rates between the existing channel model and the restored channel model. Depth, velocity, and substrate were multiplied by suitability ratings to determine useable habitat in each channel by fish species and life stage. Note that temperature preference were not included in these WUA estimates. Hydraulic habitat preferences were taken from habitat suitability index models for each species of interest (after Wiley et al 2010). Fish species were chosen based on their significance to both public and research interests in the Muskegon River Watershed, and as a result are important game fish: brown trout, chinook salmon, steelhead, and walleye.

Results

Water Temperature

Water temperatures were warmest at the furthest downstream site (DNR footbridge) and coolest at the furthest upstream site (Hackenberg) and were. Average July temperatures were 20.8°C at the DNR footbridge, 20.4°C at the DNR office, 18.9°C at the Thiel site, and 15.6°C at the Hackenberg site for July 1-17, the only July data before the temperature logger was lost (Figure 3).

Fish Sampling

In the Maple River channel the number of fish taxa collected increased with proximity to the downstream confluence with the Muskegon River. There were three species found in the Hackenberg reach, eight species through the Thiel reach, and sixteen species in the DNR reach (Table 2). The Maple River fishes tended to be warm water, small bodied species, dominated by cyprinids and percids. The only species collected at all three sites was the central mudminnows (*Umbra limi*). Many of the other species collected were rare, represented by only a single or few individuals.

A few species dominated the relative abundance at each site. Fathead minnows and central mudminnows made up most of the individuals collected at the Hackenberg site, representing 50% and 47% respectively, of all individuals collected (Table 2). The Thiel site was dominated by mudminnows, making up 87% of all individuals collected. The DNR site which showed the highest diversity also had the most evenness of relative abundance but was still dominated by three species comprising 70% of all individuals collected; common shiners, rosyface shiners, and bluntnose minnows comprised 33%, 20%, and 17% of individuals collected respectively.

In the Muskegon River/Troque Island channel the two sampling events at different water levels found different taxa (Table 2). The high water sampling produced eleven species while the low water sampling netted twenty species. Bluntnose minnows had the highest relative abundance in the low water collection yet represented only 19.8% of the individuals collected, while golden redhorse were the most abundant in the high water sampling with 28.3% of individuals.

Species diversity and evenness were higher in the Muskegon samples and the one Maple River sample closest to the confluence with the Muskegon River when compared to Maple River samples further upstream. The low and high water collections in the Muskegon River had a Shannon-Weiner diversity index (H) of 2.45 and 2.06 respectively, and evenness (E) values of 0.83 and 0.86 (Table 2). In the Maple River the DNR reach sample was H=2.01, E=0.73, while further upstream, away from the confluence with the Muskegon, the Thiel reach was H=0.63, E=0.30, and the Hackenberg reach was H=0.90, E=0.82 (Table 2).

Channel Measurements and model

At all six cross-sections (Table 3) I found both current bottom elevations as well as the elevations of the underlying, original channel bottom (Table 4, Figure 4). At each cross section there was a firm substrate buried beneath the soft sediment in the channel which I interpreted as the original channel bottom of sand or coarser materials. The channel cross sections were generally U-shaped except through the Thiel Reach where the modern channel was narrower and water flowed more quickly, there it was more V-shaped. I observed a thicker layer of soft sediment on the, lower-gradient, downstream portion of the channel. The amount of soft sediment was noticeably thinner in the narrow, relatively quick flowing Thiel reach.

I combined all elevation data in order to fit a hydraulic slope for each segment of the current Maple River channel, vertically accurate to 0.2 m or less (Table 5, Figure 5). Average slope varied along the Maple River channel and was intermediate upstream at the Hackenberg reach (-0.267 m/km) highest in the Thiel reach (-0.8546) m/km. and lowest downstream at the DNR reach (-0.1679 m/km). The mainstem Muskegon River channel had an average slope of -0.1865 m/km between the top and bottom of Maple Island. The overall slope for the Maple River was much steeper: -0.3799 m/km. Measured streamflow in the current Maple River channel ranged from 0.1 to 1.5 cms.

HEC-RAS Model Simulations

The existing channel (EC) model had the capacity to carry a maximum of slightly more than 1.5 cms flow without overbank conditions. At 3 cms there was minor flooding in the upper portion of the DNR reach and moderate flooding upstream of the culverts in the Thiel reach. Major overbank flooding occurred in the model at all discharges above 5 cms. The restored channel (RC) model channel capacity appeared to be about 8 cms, with minor flooding in the lower portion of the Hackenberg reach and in narrow sections of the Thiel reach at 10 cms. Significant overbank flooding occurred in the Hackenberg and DNR reaches above 14 cms and was widespread in all reaches at 20 cms.

The EC and the RC had (as expected because of differences in channel shape) large differences in volume, surface area, and water depth (Tables 6 & 7). The RC was on average 0.69m deeper at 0.1 cms, and increased to an average of 0.83m deeper at 1.5 cms, the last common discharge scenario before overbank flows in the EC model. When comparing the EC and RC at their approximate bankfull discharge scenarios, the RC cross sections were 1.43m deeper on average than the EC.

The estimated restored channel scenario also had much greater average shear stress and average stream power across all flow profiles. At the lowest flow scenario, 0.1 cms, the existing channel produced 0.5 N/m^2 average shear stress and 0.04 N/m s average stream power while the restored channel at the same flow produced 0.7 N/m^2 and 0.1 N/m s (Tables 6 & 7). At the 1.5 cms flow scenarios which was the highest common in-bank flow scenario between the two models, the EC model resulted in 1.4 N/m^2 average shear stress and 0.2 N/m s average stream power compared to 1.9 N/m^2 and 0.6 N/m s respectively in the RC model. These differences were even greater when comparing the EC model bankfull scenario (1.5 cms) to the RC model at its bankfull (8 cms) flow scenario with the EC model producing 1.4 N/m^2 average shear stress and 0.2 N/m s average stream power compared to 3.6 N/m^2 and 1.8 N/m s in the RC model.

The EC channel contained higher cross-section average hydraulic velocities than the RC channel when comparing directly across flow scenarios (Tables 6 & 7). But when comparing between bankfull-flow scenarios in each model, the EC had a lower average velocity of 0.111 m/s at 1.5cms compared to 0.167 m/s at 8 cms in the RC.

Backwater effects resulting from the Muskegon River flows affecting Maple River flows at the downstream confluence were observed with both channel models. The backwater effect tended to fill the DNR reach and the lower Thiel reach in both models for flow scenarios less than 5 cms. Average volume, surface area, and depth were all higher with the backwater effect than in the models that did not account for Muskegon backwater (Tables 7 & 8). In the EC model, all flow scenarios less than 5 cms resulted in bankfull conditions or minor flooding throughout the lower half of the Maple River due to the backwater effect. Above 5 cms the channel also had minor flooding above the culverts in the Thiel reach, and there was substantial overbank flooding throughout the channel at 8 cms. In the RC model there was bankfull or minor flooding throughout the DNR and lower Thiel reaches for all discharge scenarios less than 10 cms and more flooding at 14 cms. The upper Thiel and Hackenberg reaches only had overbank conditions upstream of the narrowing in the Thiel reach at 10 and 14 cms.

I tested the EC's sensitivity to the inclusion of bridges and culverts by removing those structures in alternate model geometries. Those model runs showed that removal of bridges and culverts did have an effect on model results. However, hydraulic differences between the EC geometry with and without bridges and culverts were much smaller than the differences observed between the original EC and the RC runs. The model geometry with bridges and culverts resulted in higher channel volumes, total wetted surface areas, and hydraulic depth; as well as lower average cross-section velocities, shear stress, and stream power.

Fish WUA Simulations

The EC WUA analysis suggests hydraulic brown trout habitat should be plentiful under the current conditions in the Maple River, with juveniles having the highest WUA, followed by adults, and then eggs (Figure 6, Table 10). The RC calculations predict a similar pattern in WUA for each life stage, but with slightly more habitat predicted at the lowest flows for the RC model but less at bankfull flow scenarios than the EC. (Figure 7, Table 10).

The WUA results for chinook salmon predicted the hydraulics in each model favor the egg life stage much more than either juveniles or adults in both the EC and RC (Figures 8 & 9; Table 10). The RC outputs projected more useable habitat for the egg stage than in the EC, especially at high discharges, nearly triple the predicted useable habitat for the egg stage at bankfull flow.

For walleye, only the adult life stage was predicted to have significant useable habitat in either model (Figures 10 & 11; Table 11). The RC WUA estimate predicted an increase in habitat from the EC WUA of roughly 25 times at each channel bankfull flow scenario (Table 11).

Steelhead were predicted to have large amounts of useable habitat for both adults and juveniles in both the EC and the RC (Figures 12 & 13; Table 11). The RC WUA estimates produced much more useable habitat for steelhead than the EC WUA across all discharges.

Overall the hydraulic weighted usable area was predicted to increase in the restored channel when compared to the existing channel. Brown trout were the only species in which the existing channel was predicted to have more useable habitat than the restored channel, and at higher flow scenarios only. In all other species of interest the WUA of hydraulic habitat was predicted to be larger in the restored channel.

Discussion

The fish species collected in the Maple River represented only a small proportion of the species documented in the Muskegon River and surrounding tributaries (Table 12), this is likely a result of the lack of substantial flow in the Maple River and inadequate habitat; and possibly some sampling bias. During this study the difficulty in moving in and around the Maple River limited my ability to sample as often and extensively as I would have liked, this undermines the usefulness of my fish data as an absolute population census, however my sampling does illustrate there are relatively few species and individuals in the Maple River compared to the Muskegon River nearby. Sparks-Jackson compiled fish collection data from MRWRP sampling (Stevenson et al 2008, Wiley et al 2010) as well as made additional collections in the mainstem Muskegon River and tributaries in the area of the Maple River channel. These data give a more exhaustive picture of the species that would be available to colonize and inhabit the Maple Channel after any restoration efforts (Sparks-Jackson 2014). The decrease in species collected in the Maple River while moving upstream, away from the connection with the Muskegon River, suggests that many of the taxa, such as bass, panfish, and shiners, are moving into the channel by migrating upstream from the current confluence; those fishes were not found further upstream in the Maple River. Collections made earlier in the year versus later in the summer also suggest that only a few species are able to survive in the upper half of the Maple River during summer low-water conditions where flow can become intermittent, in those areas the tolerant central mudminnow was one of the most prevalent species collected, presumably relying on its ability to breath air when dissolved oxygen drops during low flows.

In the EC model, flows higher than 8 cms produced flood waters that covered all of Maple Island and joined the Muskegon River channel on the far side of the island. Since my models did not include simultaneous flows in the Muskegon mainstem, high flow simulations with extensive flooding are undoubtedly inaccurate with respect to flood water distributions. At very high flows, flooding from both the mainstem and the Maple would interact and inundate the floodplain from both directions. This being the case, my EC and RC models should be integrated with a mainstem Muskegon model to get a more complete picture of how flooding behaves around the island during high flows; for example, the Muskegon River Watershed Ecological Assessment Project (MRWEAP) produced a HEC-RAS model of the Muskegon River that covers the Maple Island area and many miles upstream and downstream. Due to its increased channel size the RC model could handle discharges up to 10 cms before it too predicts widespread flooding which could interact directly with mainstem flood water. While both models are unlikely to provide realistic estimates of floodwater depths beyond the channel proper, they should provide reasonable estimates of bankfull and lower flows, and of flows likely to result in extensive flooding.

During recent flood events (notably in 1986 and again in 2011 and 2014) high water made clear just how much the two channels interact as water levels rise above both the Muskegon and Maple channels and flow through the drainage ditches, roadways, farm fields and relict channels of Maple Island (Peters 2014). A combined model of the entire area would have the ability to simulate events like these.

A comparison of EC geometries with and without culverts suggested that significant flow improvements in the Maple could be expected from simply enlarging or removing some (or all) of these constriction points. During high flows the culverts in the model cause significant backup of water, and at times, flooding upstream. This impoundment and flooding has been confirmed by field observations. The model without bridges and culverts flooded less at higher discharges, and had a greater bankfull capacity. The effects of removing those constriction points also contribute to the change in flows seen in the RC channels since no attempts were made to predict what culverts or bridges would be put in place if this deeper channel was to be re-created. However, from the model runs it is clear than the current infrastructure, and culverts specifically, are problematic. A restored, deeper Maple River channel would have to move more sediment through the system if it is to remain deeper. Hydraulic stress estimates suggest the RC system on average should be able to erode and transport fine gravel at flows above 10cms; despite the fact that the topography of Maple Island is relatively flat.

The models give some indication that habitat for many fish might improve as many of the modeled discharges produce an increase in average hydraulic depth as well as slightly increased channel velocities at higher discharges, both may provide better flow and oxygen levels for fish. Similarly the RC's prediction of a channel that is capable of carrying more volume in a smaller average surface area gives some hope that there may be marginal relief from flooding along the channel. However, since there is no escaping the fact that the surrounding terrain is quite flat these improvements will always be limited, especially at the very high flows when the Muskegon River still drives the flooding regime of the entire area.

While the WUA computations suggested that a deeper, restored channel would provide more usable habitat for some life stages of game fish of interest, there is discrepancy between those fish actually collected in the channel and those predicted to have existing usable habitat in the EC, representing that the current day channel. In the model simulations higher flows in the Maple Channel produced much of the usable habitat area, during the summer those flows did not usually occur in the real Maple River channel. Therefore while the WUA in the restored channel provides much more habitat at bankfull flow, during much of the year those high flows are rarely seen in the present channel configuration and increases in usable habitat in the restored channel would be more modest at low flows. A more in-depth study on which species and life stages can use the Maple River channel throughout the year may explain some of the discrepancy between predicted habitat and the scarcity of those fishes.

The flow and water temperature in the Maple River channel is quite complex. While much of the WUA in the models is associated with higher discharges, during summer low flow periods the Maple is dominated by the small groundwater springs along the south edge of the channel system and a few very small tributaries. For many months of the year the Maple behaves like a very small, shallow groundwater stream interrupted by warm impoundments instead of a continuously flowing river.

Undoubtedly the temperature regime in the Maple River channel would shift with a reconnection to the Muskegon River. Thermal considerations would affect the habitat available in the channel, independently from hydraulic characteristics. The predicted July average temperature in the Muskegon River near Maple Island is 24.6°C (Wiley et al 2010). In its current configuration the average July temperature in the Maple River ranges from 20.8°C at the most downstream cross section, to 15.6°C far upstream, however the water temperature is much warmer in the impounded areas of the channel. An influx of Muskegon River water would likely raise the July average temperature slightly but provide more flow and mixing, especially though the areas that were formerly impounded. The more thermally stable channel could allow a more stable guild of fishes to form (Wehrly et al 2003). However, for the colder water species like brown trout, warmer Muskegon River water may push Maple River water temperatures above what would be optimal or tolerable. Using a weighted mean July temperature based on 30% Maple River water and 70% Muskegon River water, a new July mean temperature would be 23.2°C. On the other hand, there is also the potential that the deeper channel would increase the flow of groundwater into the Maple River perhaps negating the warming effect of the Muskegon's water.

A deeper restored channel with a reconnection to the Muskegon River could have a positive effect on water quality in the Maple River channel during the summer months. During the low-flows, water quality may be more limiting for many fish species than the amount of physical habitat present. During the summer, dissolved oxygen concentrations were extremely low in the slower moving sections of the channel. A reconnection with the Muskegon would lead to an influx of flowing water and higher dissolved oxygen throughout the channel, a likely benefit to all of the fish species present.

Prospects for Restoration

There is consensus that regardless of the chosen approach to a restoration project, documentation of pre and post restoration conditions is vital for establishing the efficacy of restoration efforts (Suding 2011). In this thesis I have begun to assemble that documentation. In addition to thorough documentation of the restoration process, effective research and planning should also be carried out to ensure the best chances of success for the project. Based on my analysis, I believe that a Maple River channel that is reconnected to the Muskegon River would likely improve fish habitat for many of the species found there or nearby, including some game species.

The flood abatement potential of a restored Maple River is likely of interest to many of the stakeholders in the area. The potential for the Maple River to absorb some flood pulses and for a deeper, cleaner channel to convey water more quickly around the island offer some hope for those living in frequently flooded areas. Further research is needed to determine the impact that a reconnection to the Muskegon River would have on flooding around Maple Island. A coupling of the larger Muskegon River and the Maple River HEC-RAS models could provide valuable insight on this issue.

There are also potential problems that could arise with a reconnection to the mainstem Muskegon River that deserve attention. Reconnecting the Muskegon and Maple Rivers without grade control bears some small risk of the Maple channel capturing much or all of the Muskegon's flow. This would likely be an unacceptable outcome for those people living on the Muskegon River as their view and river-access could be significantly changed. Therefore any reconnection would likely have to be done via a structure to divert water from the Muskegon into the Maple channel in a controlled way. During much of the year redirecting water from the Muskegon channel would pose little problem. However, during summers of exceptional low water levels, navigation of the existing Muskegon channel can already be difficult for boaters, a situation which would only be exacerbated if some portion of those flows were earmarked for the Maple River channel. A balance between the needs of each channel would need to be found and agreed upon before such challenges arise.

The combination of historical documentation and the underlying shape of consolidated sediments found by probing the existing channel provides compelling evidence that the Maple River of today was the southern anabranch channel of the Muskegon River in the early to mid-19th century. With the lumber era of the Muskegon long gone the original purpose of isolating this channel from the main stem Muskegon is past, yet a reconnection may still be difficult; and may or may not be desirable from a natural resource management perspective. While a Maple River with more flow would be beneficial to its fish communities, an argument for restoration based on flood abatement may prove to be more influential. There will need to be additional data collection, hydraulic and fisheries habitat modeling before a compelling argument can be made to return the system to its former structure.

Tables and Figures

Figure 1a. Two pages of 1837 plat maps, Township 11 North, Range 14 West and Township 11 North, Range 15 West. Cropped and joined to show Maple Island.

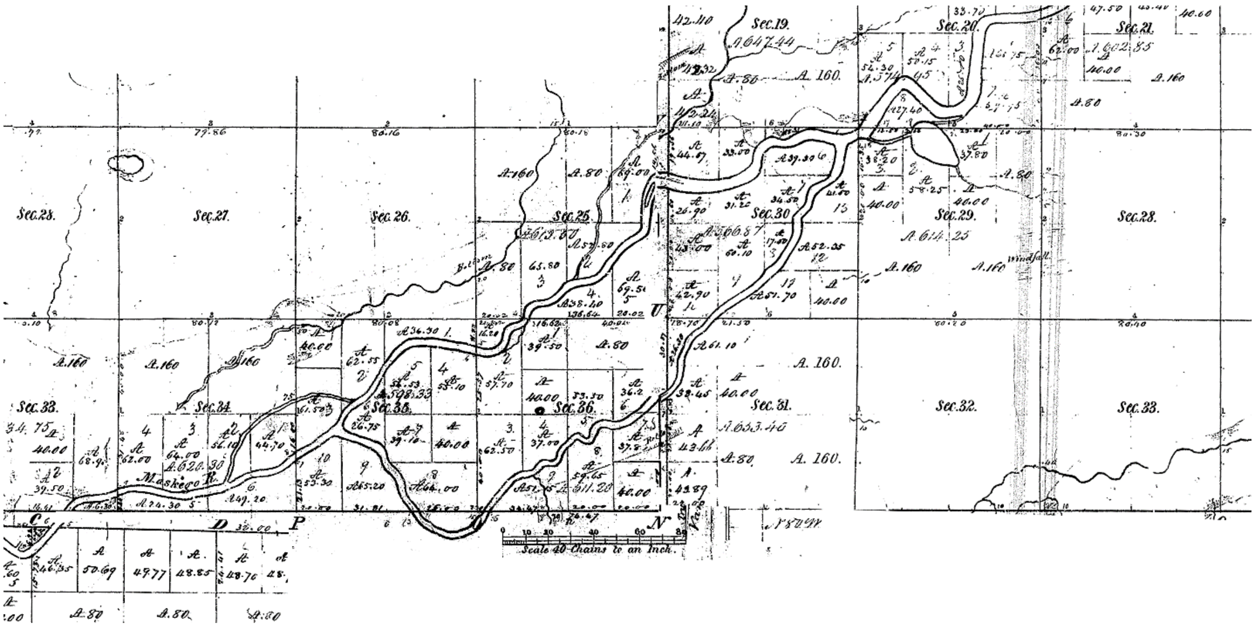

Figure 1b. GIS map of Maple Island with my surveyed cross sections on the Maple River.

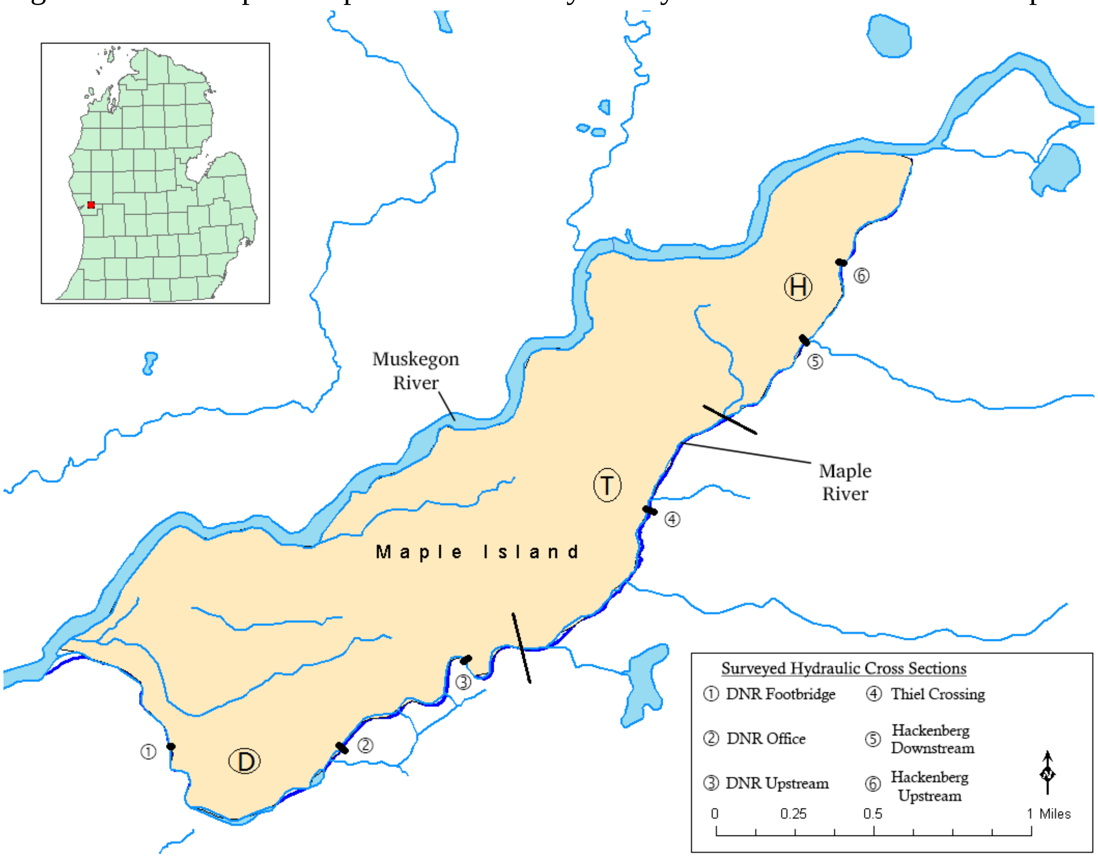

Table 1. Base stations from the MDOT CORS network

Site Name	Site Code	Latitude	Longitude
Muskegon	MSKY	43° 14’ 15.14037” N	86° 03’ 16.47883” W
Muskegon Heights	MIMK	43° 12’ 11.26761” N	86° 14' 57.61081" W
White Cloud	MIWC	43° 34' 09.34966" N	85° 46' 40.03992" W

Figure 2.Composite TIN DEM based on survey data and SRTM elevations. The Muskegon River is show in dark blue, the Maple River is center, shown in light blue with Maple Island as the gray landmass between the two.

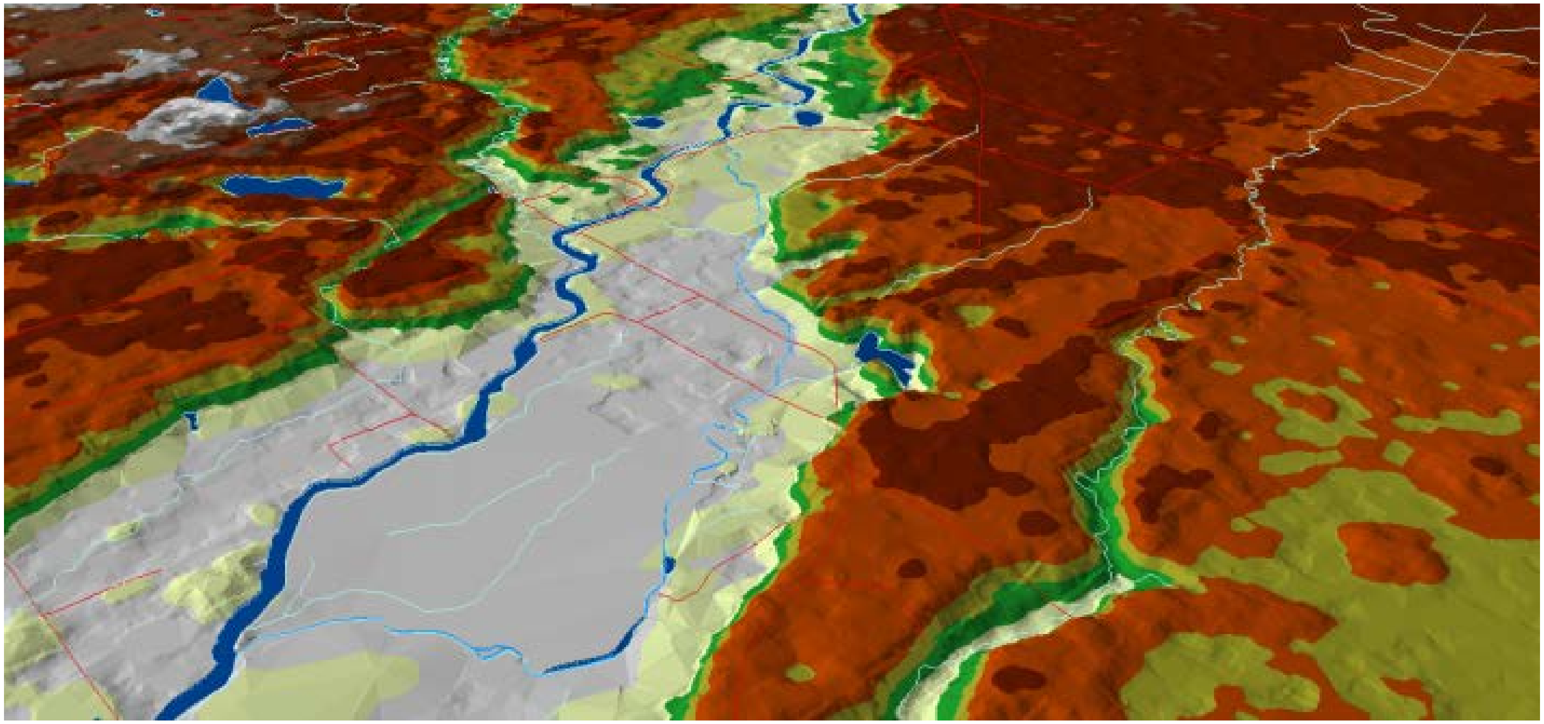

Figure 3. Maple River water temperature, 48-hour running average temperature in °F/°C for June 12, 2013 – November 2, 2013.

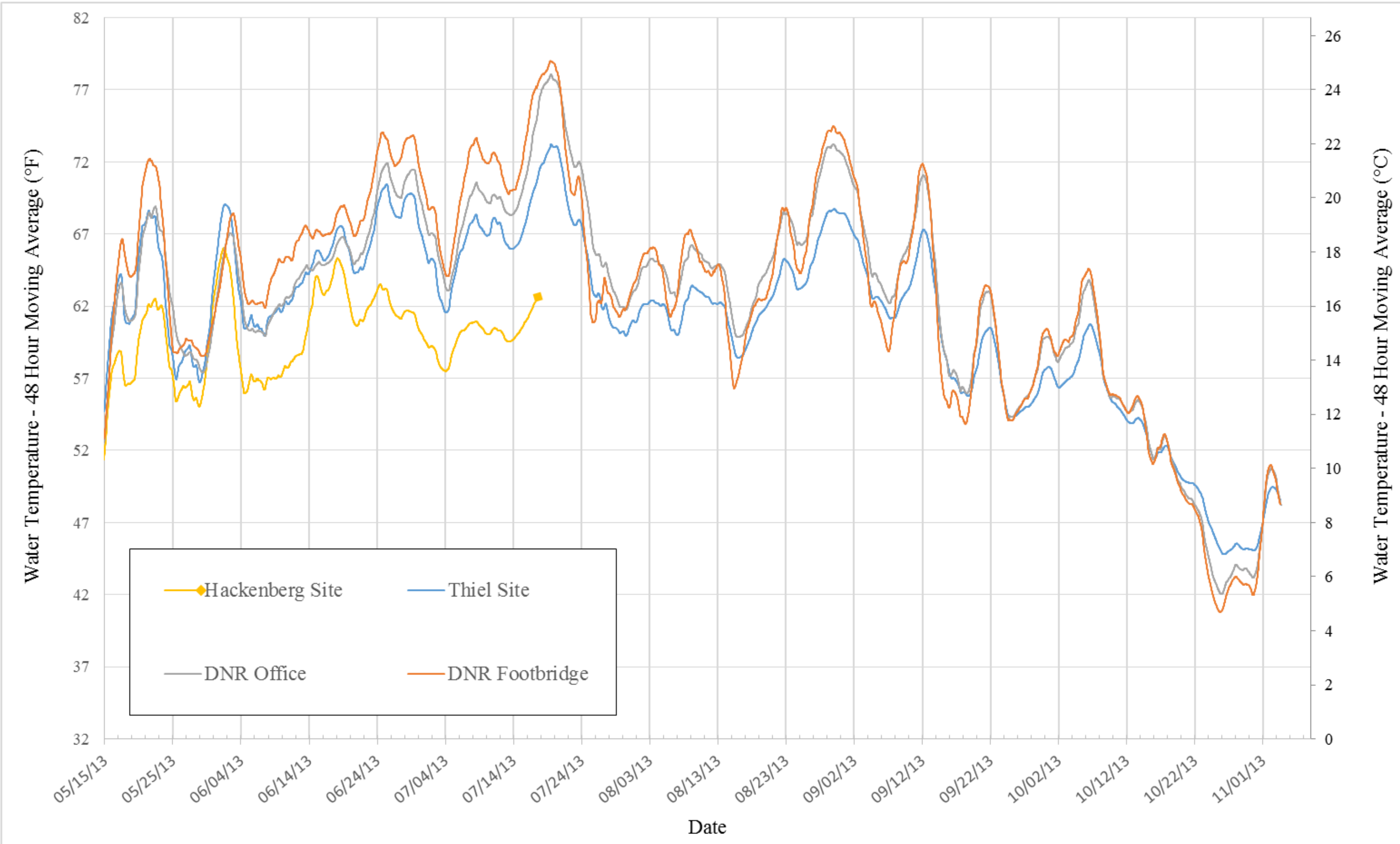

Table 2. Fishes collected around Maple Island; individual counts, relative abundance (RA), Shannon-Weiner index (H), and evenness (E), by collection site.

Species	Maple River *n=20*			Muskegon River *n=23*	
	DNR Reach 05/07/2013 *n=16* H=2.01 E=0.73	**Thiel Reach** 05/07/2013 *n=8* H=0.63 E=0.30	**Hackenberg Reach** 05/12/2013 *n=3* H=0.90 E=0.82	**Troque Island Channel** Low Water 09/16/2012 *n=19* H=2.45 E=0.83	**Troque Island Channel** High Water 05/08/2013 *n=11* H=2.06 E=0.86
	Individuals (RA)	Individuals (RA)	Individuals (RA)	Individuals (RA)	Individuals (RA)
black bullhead	1 (0.01)				
blackside darter				1 (0.003)	
bluegill	1 (0.01)			4 (0.014)	
bluntnose minnow	20 (0.17)	2 (0.02)		57 (0.198)	
central mudminnow	1 (0.01)	85 (0.87)	6 (0.43)		
common shiner	38 (0.33)	2 (0.02)		44 (0.153)	6 (0.113)
creek chub		4 (0.04)			
emerald shiner				18 (0.063)	6 (0.113)
fathead minnow	2 (0.02)		7 (0.50)		
golden shiner	1 (0.01)	1 (0.01)			
grass pickerel			1 (0.07)		
hornyhead chub				34 (0.118)	
johnny darter				5 (0.017)	
lake chubsucker		1 (0.01)			
largemouth bass	3 (0.03)			18 (0.063)	9 (0.170)
northern hogsucker	1 (0.01)			6 (0.021)	
northern quillback					1 (0.019)
pumpkinseed	3 (0.03)			4 (0.014)	
rainbow darter				6 (0.021)	
rainbow trout					1 (0.019)
redhorse, black					4 (0.075)
redhorse, golden					15 (0.283)
redhorse, shorthead				1 (0.003)	5 (0.094)
river chub				5 (0.017)	1 (0.019)
rock bass	4 (0.03)	1 (0.01)		36 (0.125)	4 (0.075)
rosyface shiner	23 (0.20)				
round goby				16 (0.056)	
sand shiner	8 (0.07)				
smallmouth bass	1 (0.01)			14 (0.049)	1 (0.019)
spotfin shiner	7 (0.06)			16 (0.056)	
spottail shiner				1 (0.003)	
white sucker		2 (0.02)		2 (0.007)	
yellow perch	1 (0.01)				

Table 3. Cross section locations, latitude and longitude in decimal degrees.

Cross Section Name	Latitude (°N)	Longitude (°W)
DNR Footbridge	43.295096	-86.066847
DNR Office	43.295135	-86.055991
DNR Upstream	43.299167	-86.048239
Thiel Crossing	43.307379	-86.036002
Hackenberg Downstream	43.313671	-86.026987
Hackenberg Upstream	43.317253	-86.024715

Table 4. Cross-section channel elevations in meters, EC for existing channel bottom, and RC for restored or original channel bottom.

Hackenberg Upstream	Cross-section Width	0.0	6.5	8.2	10.0	11.7	13.4	15.1	16.8	18.5	20.2	21.9	23.6		
	EC Probing Elevation	183.5	183.2	183.0	182.8	182.6	182.5	182.5	182.5	182.6	182.7	182.9	183.3		
	RC Probing Elevation	182.7	182.7	182.2	180.8	180.8	180.8	181.0	181.0	181.0	181.2	181.5	181.6		
Hackenberg Downstream	Cross-section Width	0.0	3.0	6.0	9.0	12.0	14.4	15.7	18.0	21.0	24.0				
	EC Probing Elevation	183.3	183.2	183.2	183.2	183.2	183.1	183.1	183.2	183.2	183.3				
	RC Probing Elevation	182.0	180.9	182.1	182.1	181.8	182.3	182.1	182.3	182.7	184.1				
Thiel Crossing	Cross-section Width	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	6.5	7.0
	EC Probing Elevation	183.4	183.1	182.9	182.7	182.3	182.2	182.2	182.2	182.0	181.8	181.9	182.2	182.3	183.1
	RC Probing Elevation	183.4	183.1	182.9	182.7	181.9	181.5	181.3	181.2	181.1	180.8	181.1	181.3	181.6	183.1
DNR Upstream	Cross-section Width	0.0	4.6	6.8	9.1	11.3	13.6	15.8	18.1	20.4	22.6	24.9	27.1	30.2	
	EC Probing Elevation	182.7	181.7	181.3	181.0	181.0	180.8	180.8	180.8	180.6	181.0	181.2	181.7	184.3	
	RC Probing Elevation	182.7	175.2	175.0	175.0	175.3	175.4	175.4	175.6	175.9	176.1	176.3	176.3	180.1	
DNR Office	Cross-section Width	0.0	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.0				
	EC Probing Elevation	181.4	181.3	181.3	181.2	181.2	181.2	181.2	181.3	181.3	181.4				
	RC Probing Elevation	177.6	177.1	178.0	178.1	178.1	178.2	178.2	178.4	178.4	178.4				
DNR Downstream	Cross-section Width	0.0	1.5	3.0	4.6	6.9	9.1	10.7	13.7	15.2	18.3	19.8	21.3	22.9	
	EC Probing Elevation	181.3	181.3	181.2	181.0	180.9	180.8	180.7	180.6	180.6	180.7	180.7	180.8	180.8	
	RC Probing Elevation	181.3	180.3	180.1	179.8	179.5	179.3	179.3	179.2	179.3	179.4	179.4	179.7	179.7	

Figure 4. Cross section diagrams. Top dark line is current substrate, bottom dotted line is soft sediment removal depth in model. A – DNR footbridge; B – DNR office; C- DNR upstream; D- Thiel crossing; E- Hackenberg downstream; F- Hackenberg upstream.

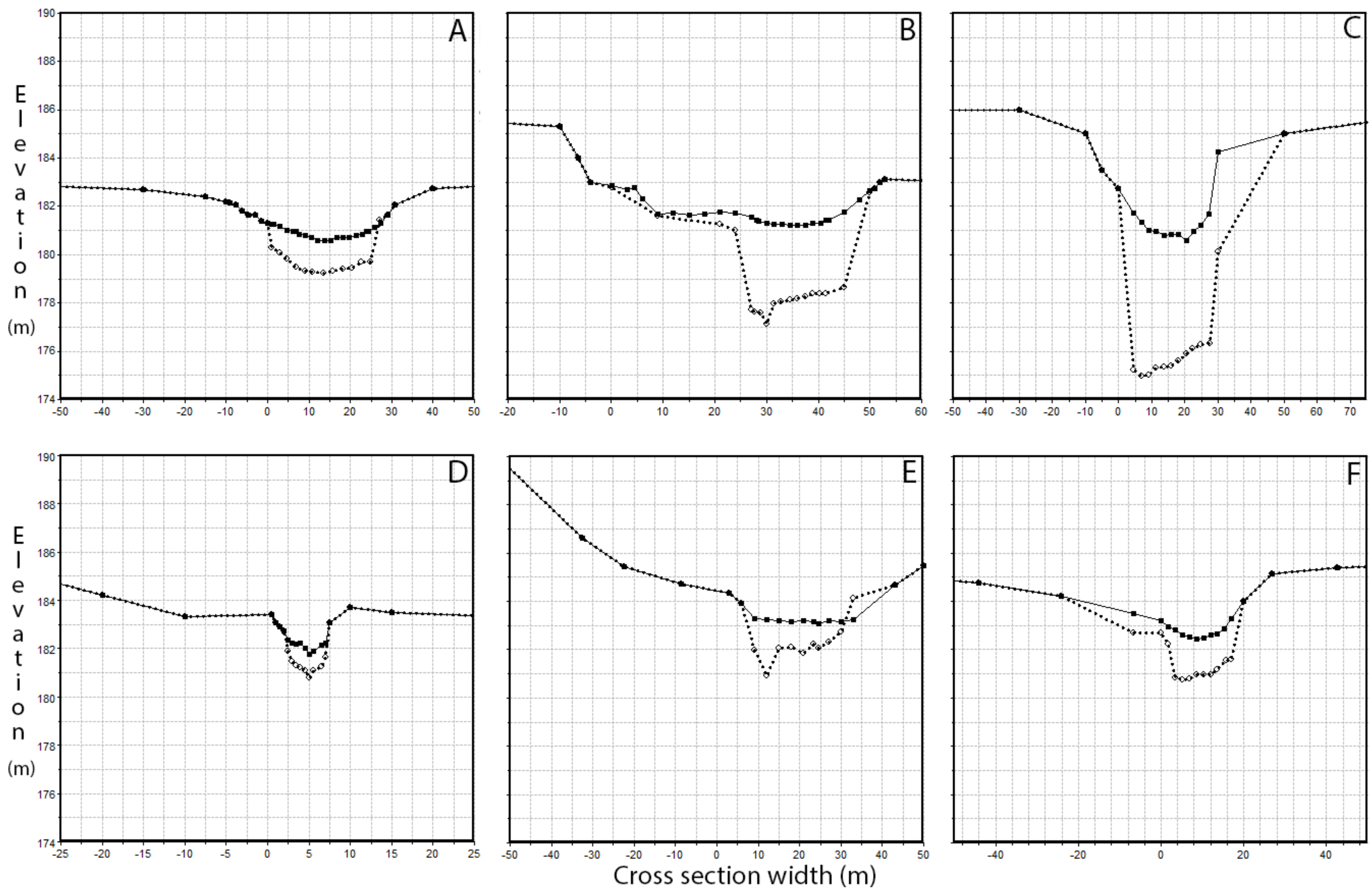

Table 5. Maple River channel point elevations.

River course (km)	0	1.15	2.3	2.45	2.45	2.97	3.48	5.17	5.82	6.11
Point elevation (m)	183.29	183.15	182.33	182.35	182.40	181.83	181.48	181.34	181.14	180.99

Figure 5. Maple River channel elevations and slope

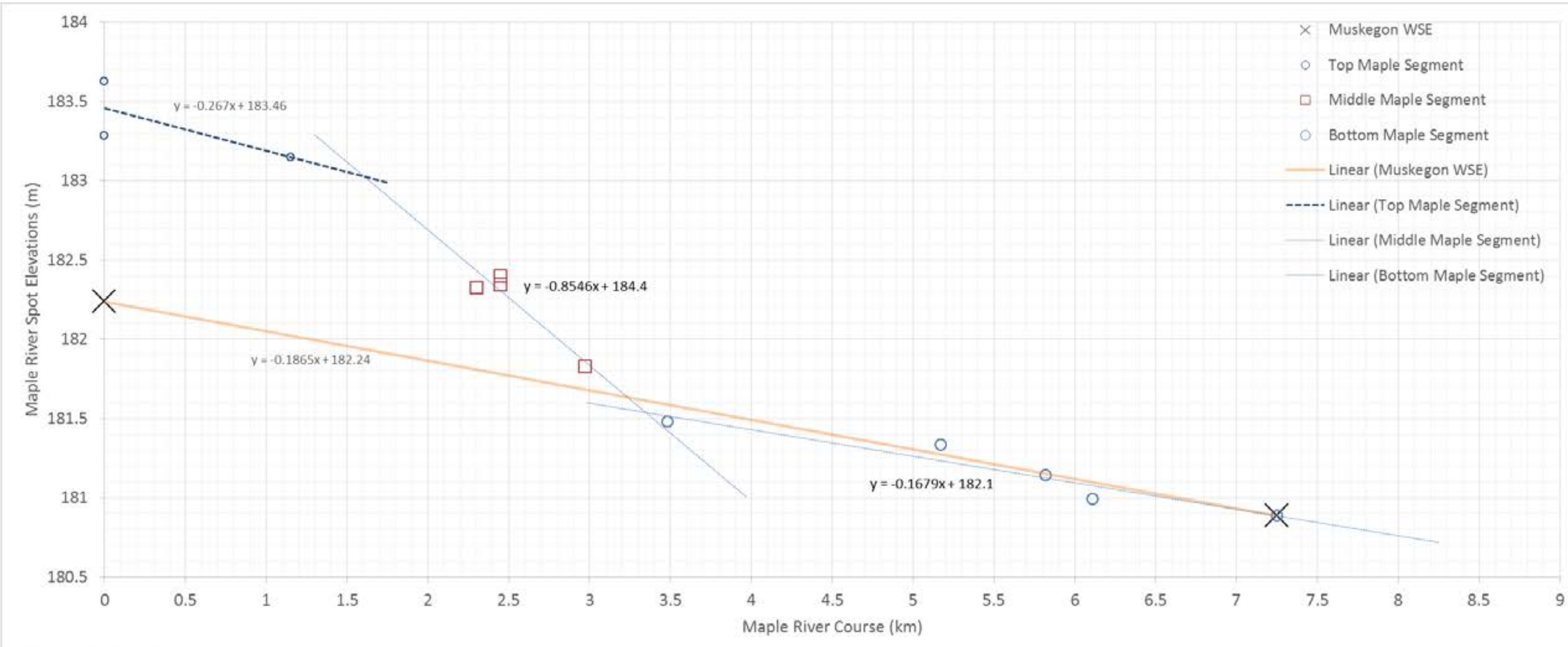

Table 6. Existing channel model summary data, no backwater effects at downstream boundary. Total and average cross sectional data for each flow scenario. The horizontal line and shading indicates the transition to overbank flows in at least some parts of the river.

Model Discharge	**Total Volume** (1000 m^3)	**Total Surface Area** (1000 m^2)	**Avg. Hydraulic Depth** (m)	**Avg. Velocity** (m/s)	**Avg. Shear Stress** (N/ m^2)	**Avg. Stream Power** (N/m s)
0.1 cms	24.4	109.2	0.21	0.046	0.512	0.038
0.2 cms	33.3	120.3	0.27	0.058	0.691	0.062
0.5 cms	54.3	136.0	0.41	0.079	0.951	0.106
1 cms	83.8	159.1	0.56	0.096	1.153	0.154
1.5 cms	107.8	173.4	0.66	0.111	1.410	0.212
3 cms	174.7	220.7	0.81	0.132	1.550	0.241

Table 7. Restored channel model summary data, no backwater effects at downstream boundary. Total and average cross sectional data for each flow scenario. The horizontal line and shading indicates the transition to overbank flows in at least some parts of the river.

Model Discharge	**Total Volume** (1000 m^3)	**Total Surface Area** (1000 m^2)	**Avg. Hydraulic Depth** (m)	**Avg. Velocity** (m/s)	**Avg. Shear Stress** (N/ m^2)	**Avg. Stream Power** (N/m s)
0.1 cms	131.8	101.3	0.90	0.038	0.659	0.098
0.2 cms	147.5	112.7	0.98	0.048	0.875	0.151
0.5 cms	180.5	129.7	1.15	0.065	1.297	0.288
1 cms	222.0	144.9	1.33	0.083	1.754	0.477
1.5 cms	269.0	160.4	1.49	0.091	1.949	0.576
3 cms	349.8	185.2	1.75	0.116	2.554	0.894
5 cms	421.9	206.3	1.95	0.140	3.240	1.341
8 cms	504.1	239.7	2.04	0.167	3.574	1.772
10 cms	571.0	311.4	2.01	0.173	3.445	1.739

Table 8. Existing channel model summary data, with backwater effects at downstream boundary. Total and average cross sectional data for each flow scenario. The horizontal line and shading indicates the transition to overbank flows in at least some parts of the river.

Model Discharge	**Total Volume** (1000 m^3)	**Total Surface Area** (1000 m^2)	**Avg. Hydraulic Depth** (m)	**Avg. Velocity** (m/s)	**Avg. Shear Stress** (N/ m^2)	**Avg. Stream Power** (N/m s)
0.1 cms	131.0	193.4	0.55	0.022	0.221	0.014
0.2 cms	134.6	196.6	0.58	0.033	0.337	0.027
0.5 cms	143.9	200.3	0.65	0.050	0.511	0.053
1 cms	158.7	206.7	0.74	0.067	0.718	0.094
1.5 cms	171.8	212.7	0.80	0.084	0.961	0.147
3 cms	214.5	246.9	0.88	0.110	1.149	0.173

Table 9. Restored channel model summary data, with backwater effects at downstream boundary. Total and average cross sectional data for each flow scenario. The horizontal line and shading indicates the transition to overbank flows in at least some parts of the river.

Model Discharge	**Total Volume** (1000 m^3)	**Total Surface Area** (1000 m^2)	**Avg. Hydraulic Depth** (m)	**Avg. Velocity** (m/s)	**Avg. Shear Stress** (N/m^2)	**Avg. Stream Power** (N/m s)
0.1 cms	422.2	207.4	1.70	0.008	0.097	0.008
0.2 cms	423.0	207.8	1.70	0.014	0.159	0.015
0.5 cms	426.5	209.7	1.73	0.031	0.339	0.041
1 cms	433.9	212.6	1.77	0.050	0.649	0.097
1.5 cms	441.8	215.5	1.81	0.063	0.938	0.170
3 cms	465.1	223.6	1.93	0.094	1.700	0.460
5 cms	495.4	232.1	2.05	0.122	2.571	0.951
8 cms	536.4	255.3	2.05	0.158	3.195	1.531
10 cms	570.1	311.2	2.01	0.171	3.426	1.744

Figure 6. EC brown trout WUA output. Dashed lines mark transition to overbank discharge.

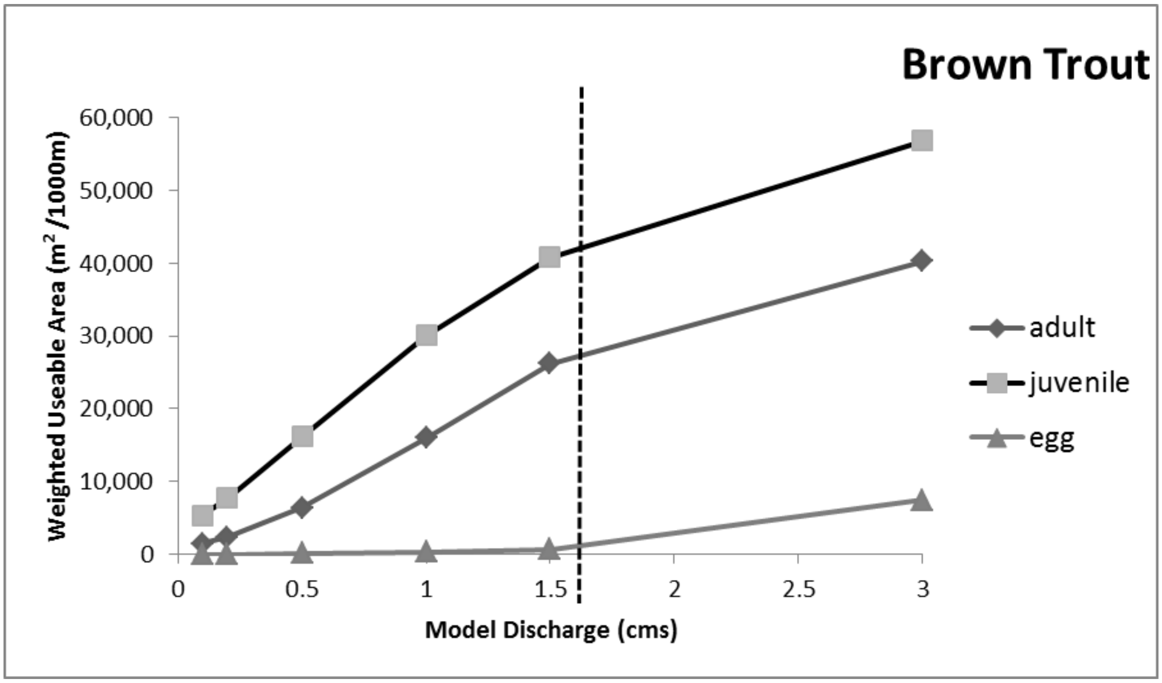

Figure 7. RC brown trout WUA output. Dashed lines mark transition to overbank discharge.

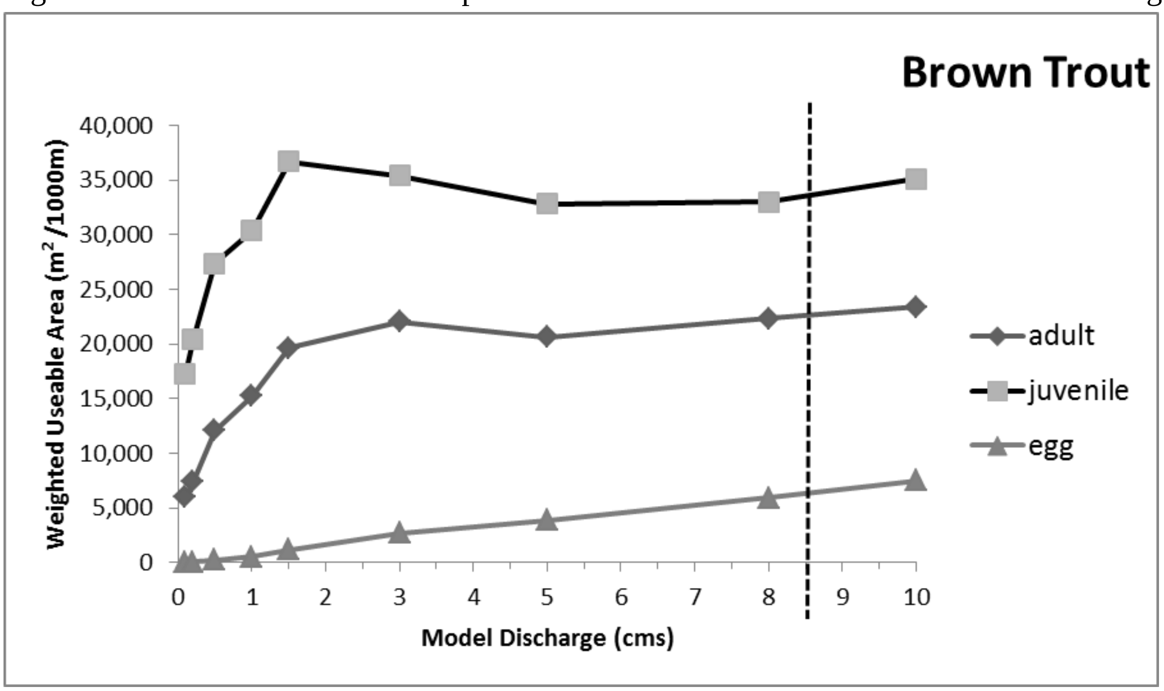

Figure 9. EC chinook salmon WUA output. Dashed lines mark transition to overbank discharge.

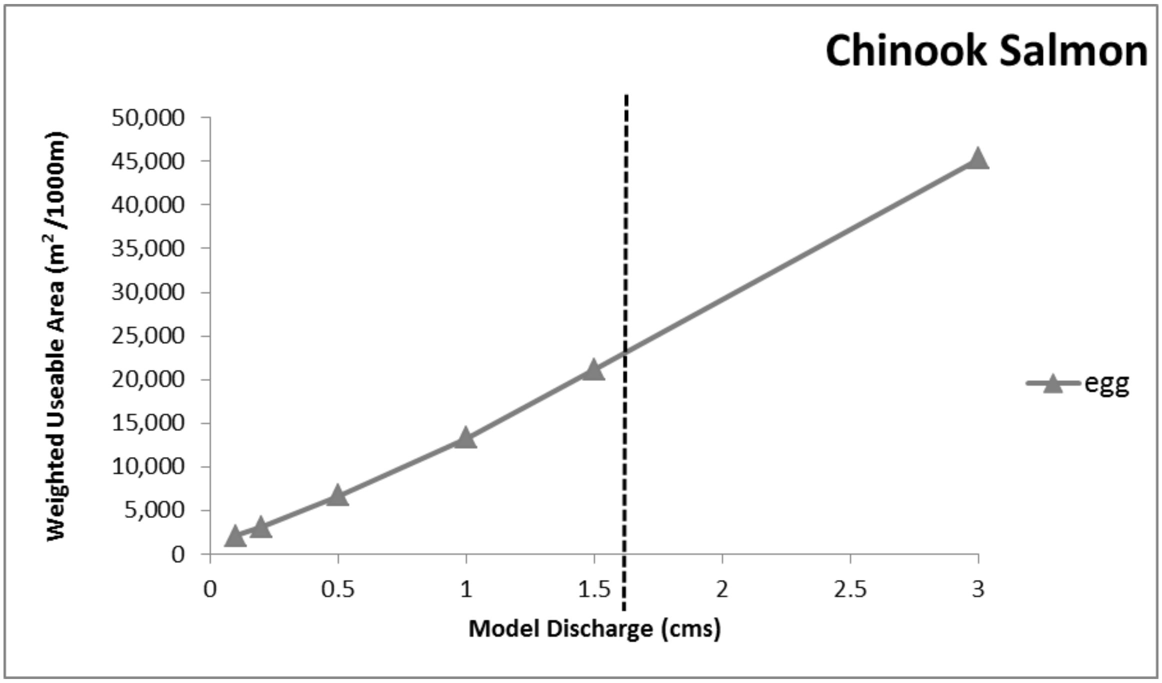

Figure 9. RC chinook salmon WUA output. Dashed lines mark transition to overbank discharge.

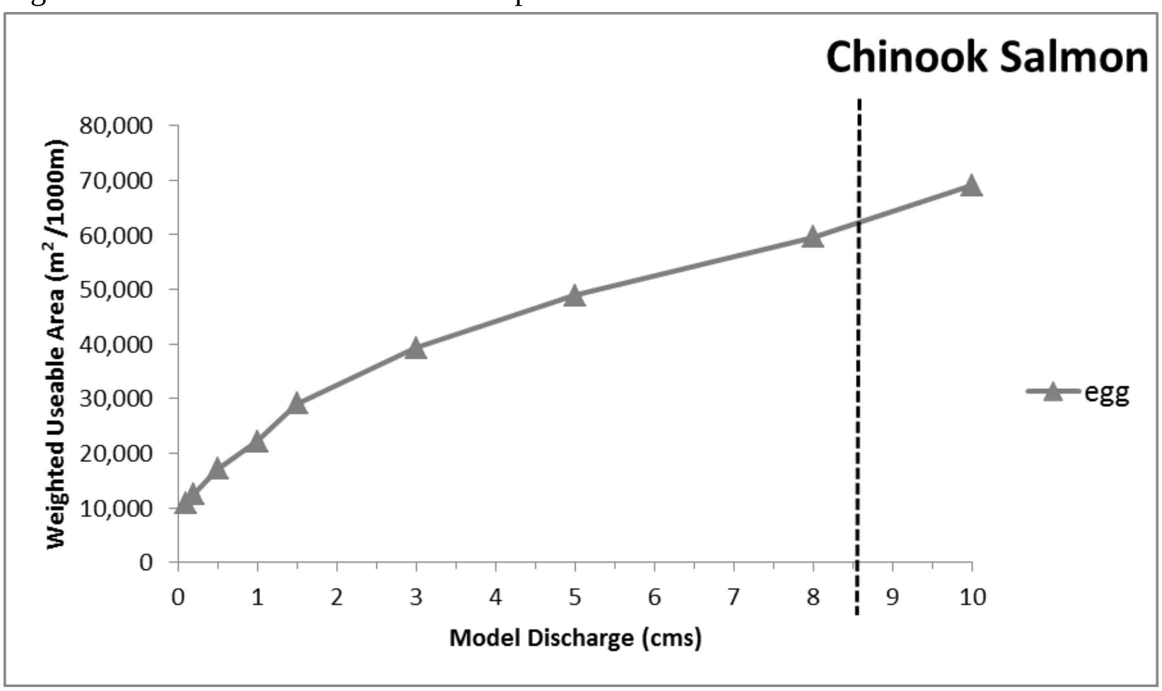

Figure 10. EC walleye WUA output. Dashed lines mark transition to overbank discharge.

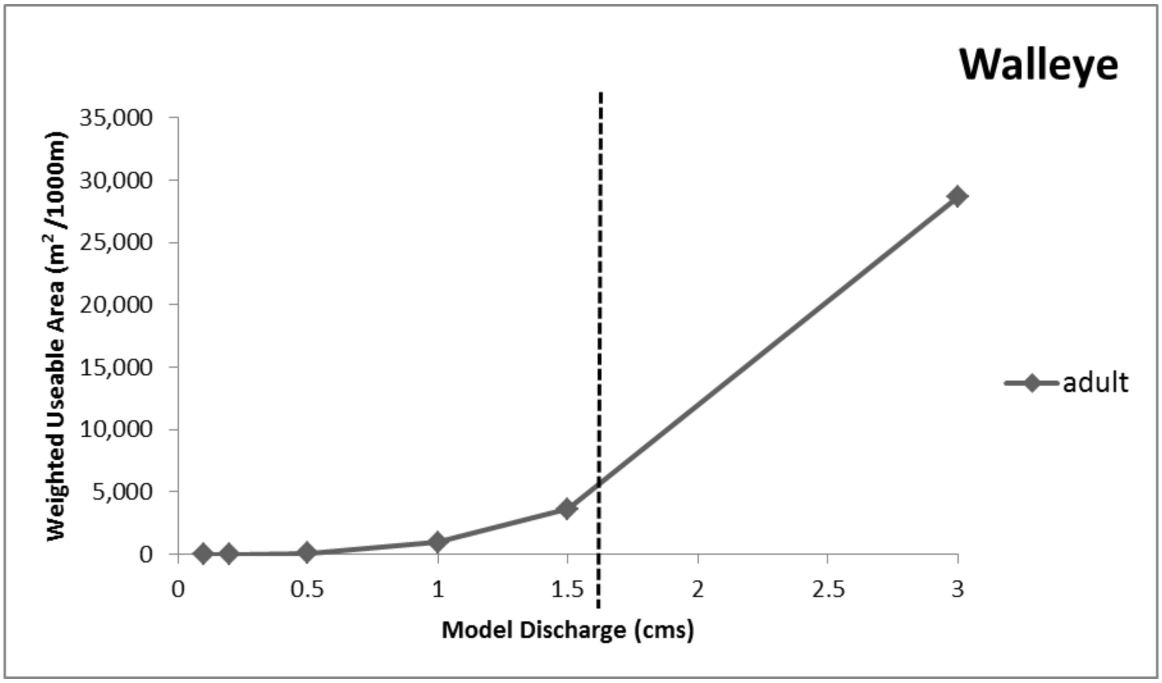

Figure 11. RC walleye WUA output. Dashed lines mark transition to overbank discharge.

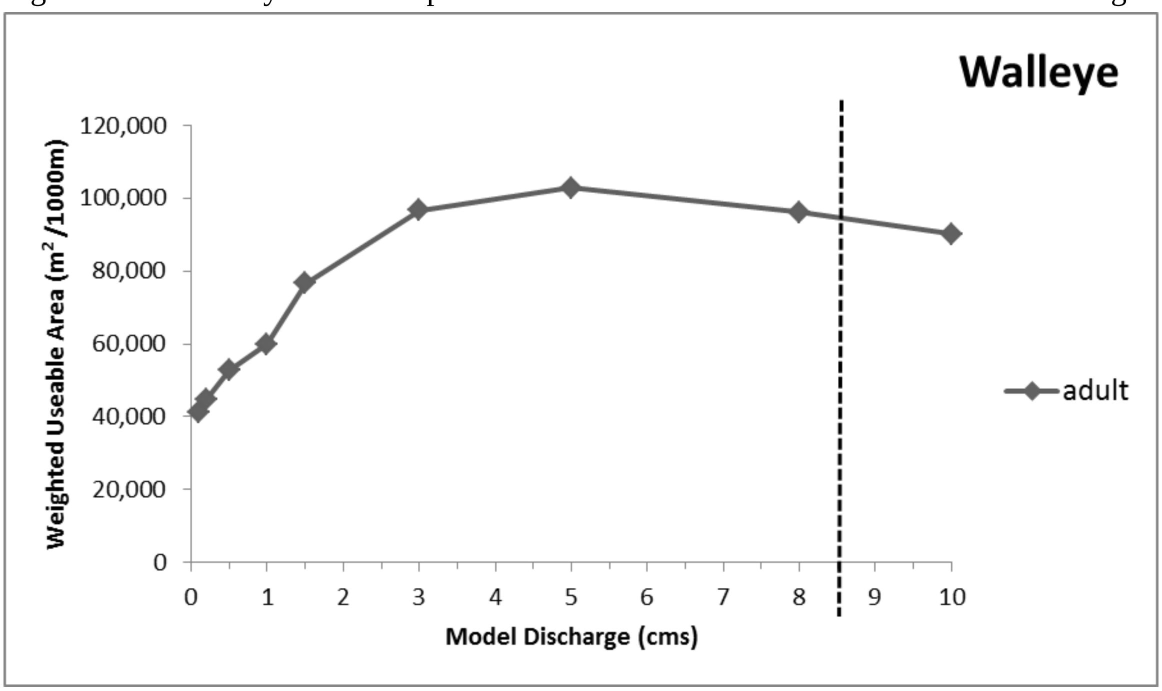

Figure 12. EC steelhead WUA output. Dashed lines mark transition to overbank discharge.

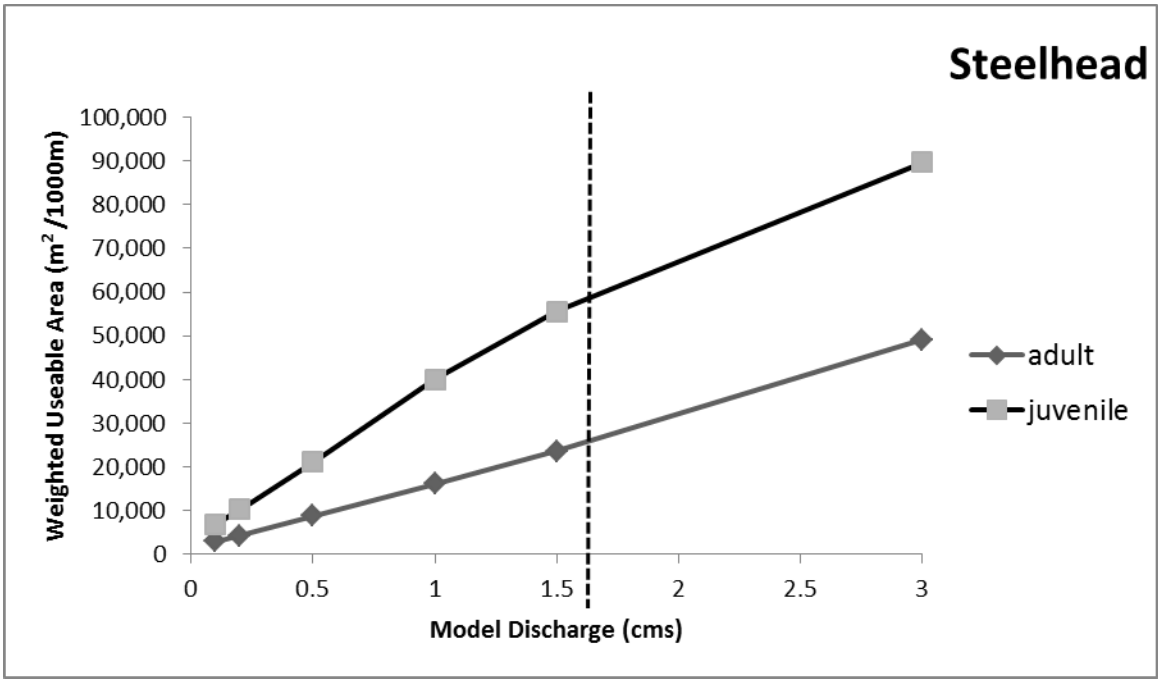

Figure 13. RC steelhead WUA output. Dashed lines mark transition to overbank discharge.

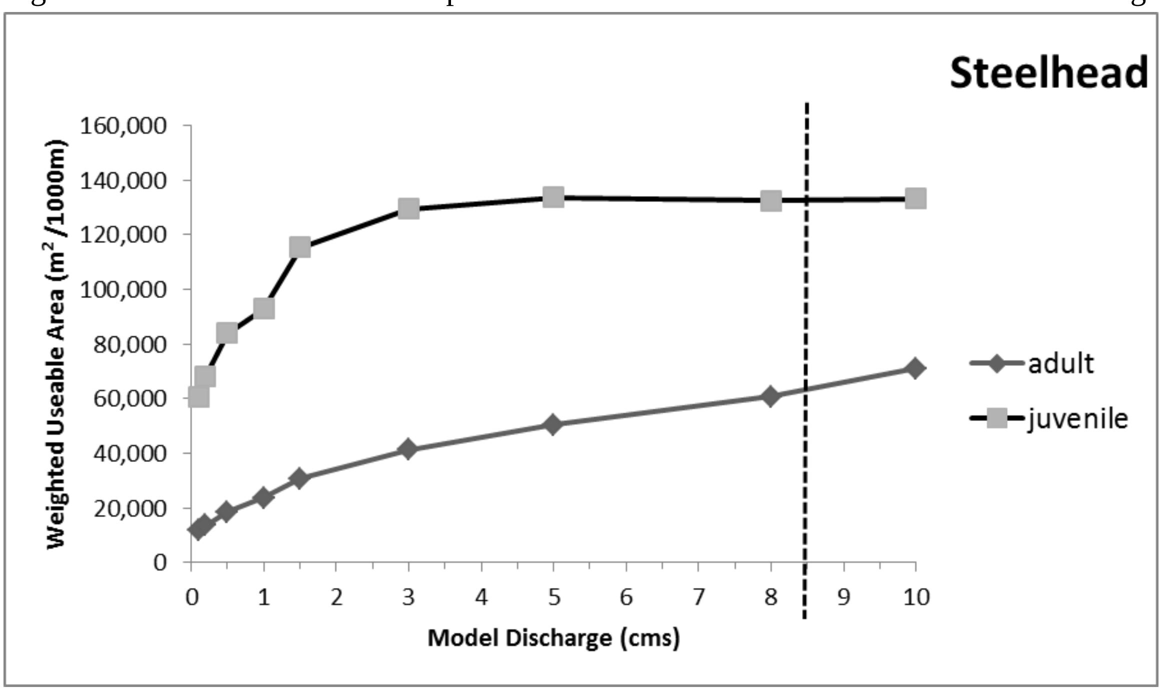

Table 10. Comparison of EC and RC brown trout and chinook salmon WUA simulation outputs. The horizontal line and shading in each table indicates the transition to overbank flows in at least some parts of the river.

EC Brown Trout

Discharge	WUA (m^2/km)		
	adult	juvenile	egg
0.1 cms	1,464	5,370	0
0.2 cms	2,366	7,728	15
0.5 cms	6,393	16,166	160
1 cms	16,017	30,053	356
1.5 cms	26,219	40,801	724
3 cms	40,288	56,798	7,465

RC Brown Trout

Discharge	WUA (m^2/km)		
	adult	juvenile	egg
0.1 cms	6,024	17,232	23
0.2 cms	7,385	20,406	66
0.5 cms	12,042	27,358	240
1 cms	15,226	30,352	530
1.5 cms	19,608	36,693	1,140
3 cms	22,015	35,441	2,704
5 cms	20,656	32,827	3,851
8 cms	22,357	32,996	5,898
10 cms	23,418	35,099	7,512

EC Chinook Salmon

Discharge	WUA (m^2/km)		
	adult	juvenile	egg
0.1 cms	0	0	2,095
0.2 cms	0	0	3,109
0.5 cms	3	0	6,713
1 cms	8	0	13,351
1.5 cms	23	7	21,192
3 cms	484	435	45,320

RC Chinook Salmon

Discharge	WUA (m^2/km)		
	adult	juvenile	egg
0.1 cms	0	0	10,816
0.2 cms	1	0	12,434
0.5 cms	8	6	17,100
1 cms	24	18	22,122
1.5 cms	48	32	29,064
3 cms	103	57	39,245
5 cms	174	98	48,906
8 cms	278	138	59,594
10 cms	322	125	69,038

Table 11. Comparison of EC and RC steelhead and walleye WUA simulation outputs. The horizontal line and shading in each table indicates the transition to overbank flows in at least some parts of the river.

EC Steelhead

Discharge	WUA (m^2/km)		
	adult	juvenile	egg
0.1 cms	2,906	6,896	0
1 cms	16,045	40,019	0
1.5 cms	23,549	55,515	108
3 cms	49,060	89,747	1,913

RC Steelhead

Discharge	WUA (m^2/km)		
	adult	juvenile	egg
0.1 cms	11,657	60,819	0
1 cms	23,680	92,787	316
1.5 cms	30,761	115,296	548
3 cms	41,185	129,399	1,022
5 cms	50,284	133,694	1,821
8 cms	60,789	132,568	2,780
10 cms	71,085	133,163	2,630

EC Walleye

Discharge	WUA (m^2/km)		
	adult	juvenile	egg
0.1 cms	0	0	0
0.2 cms	0	0	0
0.5 cms	78	0	0
1 cms	939	0	0
1.5 cms	3,652	0	0
3 cms	28,635	12	0

RC Walleye

Discharge	WUA (m^2/km)		
	adult	juvenile	egg
0.1 cms	41,368	0	0
0.2 cms	44,674	0	0
0.5 cms	52,760	0	0
1 cms	59,989	4	0
1.5 cms	76,605	18	0
3 cms	96,730	126	0
5 cms	102,824	249	0
8 cms	96,220	170	0
10 cms	90,177	82	0

Table 12. Comparison of Maple River fish species and those from surrounding tributaries and the mainstem of the Muskegon River (Sparks-Jackson 2014). * marks those Muskegon River species I collected in the Troque Island channel of the Muskegon River.

Maple River		Muskegon River	Mosquito Creek	Brooks Creek
Central mudminnow		Black buffalo	American brook lamprey	Black crappie
Common shiner	*	Black redhorse	Blackchin shiner	Blacknose dace
Rock bass		Blackchin shiner	Blacknose dace	Blackside darter
Rosyface shiner		Blacknose dace	Blackside darter	Bluegill
Bluntnose minnow	*	Blackside darter	Bluegill	Bluntnose minnow
Creek chub	*	Bluegill	Bluntnose minnow	Bowfin
Fathead minnow	*	Bluntnose minnow	Bowfin	Brook stickleback
Golden shiner		Bowfin	Brook stickleback	Brook trout
Black bullhead		Brown trout	Brook trout	Brown trout
Bluegill		Burbot	Central mudminnow	Burbot
Grass pickerel		Central mudminnow	Chinook salmon	Central mudminnow
Lake chubsucker		Channel catfish	Common carp	Common carp
Largemouth bass		Common carp	Common shiner	Common shiner
Northern hogsucker	*	Common shiner	Creek chub	Creek chub
Pumpkinseed		Creek chub	Creek chubsucker	Emerald shiner
Sand shiner		Creek chubsucker	Golden redhorse	Golden shiner
Smallmouth bass	*	Emerald shiner	Golden shiner	Grass pickerel
Spotfin shiner		Fathead minnow	Grass pickerel	Hornyhead chub
White sucker		Flathead catfish	Hornyhead chub	Johnny darter
Yellow perch		Freshwater drum	Johnny darter	Largemouth bass
	*	Golden redhorse	Largemouth bass	Longnose dace
		Grass pickerel	Mimic shiner	Mottled sculpin
	*	Hornyhead chub	Mottled sculpin	Northern redbelly dace
	*	Johnny darter	Northern pike	Pumpkinseed
	*	Largemouth bass	Pirate perch	Rainbow darter
		Logperch	Pumpkinseed	Rainbow trout
		Longnose gar	Rainbow darter	River chub
		Mimic shiner	Rock Bass	Rock bass
	*	Northern hogsucker	Round goby	Sand shiner
		Northern pike	Sea lamprey	Shorthead redhorse
		Northern redbelly dace	Shorthead redhorse	Smallmouth bass
	*	Pumpkinseed	Silver redhorse	Steelhead
	*	Quillback	Tadpole madtom	White crappie
	*	Rainbow darter	White sucker	White sucker
		Redhorse	Yellow bullhead	Yellow bullhead
	*	River chub	Yellow perch	Yellow perch
		River redhorse	YOY Brown Trout	YOY Chinook salmon
	*	Rock Bass		
		Rosyface shiner		
	*	Round goby		
		Sand shiner		
	*	Shorthead redhorse		
		Silver redhorse		
	*	Smallmouth bass		
	*	Spotfin shiner		
		Spotted sucker		
	*	Steelhead		
		Tadpole madtom		
		Walleye		
	*	White sucker		
		Yellow perch		
		YOY Chinook salmon		

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