EFFECTS OF A HYDRAULIC-LOADING DAM ON GROUNDWATER UPWELLING IN A NORTHERN MICHIGAN RIVER

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Dam removal is becoming a growing concern, as many of the dams built during the 20th century are nearing the end of their structural integrity. Many implications of this beyond the economic effects on society, are on the biotic and abiotic factors of the river ecosystem. Dam removal greatly alters the geological structure of streams as well as offer access to exotic species (Stanley, 2003). Dams effect hydraulic cycles in rivers by impounding sediment, and creating groundwater pressure downstream. This study focused on the effects of the Maple River dam in Pellston, MI. Our findings indicated that dams have a significant effect on the change in substrate downstream. This finding implicates loss to biotic habitats for macroinvertebrates and fish rearing their eggs (Lignon, 1995). We examined temperature differences in beds of algal *Chara*, which have been previously described as indicators of groundwater upwelling (Hendricks, 1988). Our results supported this with the difference in *Chara* temperatures at the surface versus the hyporheic zone. This dam's effect on interstitial water patterns has caused various changes downstream and will have various conservation concerns upon its future removal.

INTRODUCTION

Humans impact groundwater by building various dam structures and altering a river's flow. For example, a hydraulic dam can impede the river's ability to achieve full discharge during storm periods, which does not allow the river to naturally wander. The inability for a stream to meander has many implications for channeling and effects downstream, such as loss in habitat for benthic macroinvertebrates and fish-rearing purposes (Lignon, 1995). In previous studies of hydroelectric dams, hydraulic loading of a river causes a significant increase of groundwater inputs below the dam (Zhang, 2014). The increase in inputs of groundwater can also have serious anthropogenic effects on the geomorphology of the river. Human activities such as mining, agriculture, and industrial waste, all can permeate harmful chemicals into groundwater, and consequently impair fauna in the hyporheic zone of streams.

The substrate and embeddedness of the benthic zone is an important variable, as larger particle size will more easily facilitate groundwater upwelling into hyporheic flow (Godby, 2014). The channeling of a stream from dam impoundment results in alteration and deterioration of substrate conditions used for rearing offspring by sensitive biota such as salmonids (Lignon, 1995). This includes cobble and large gravel, which are resistant to periods of high discharge after storms. As a result of this channeling from dams, groundwater inputs may transport nutrient rich sediment, needed by macrophytes, downstream.

A dam's effects on downstream inputs of groundwater may be characterized by macrophyte presence. This is due to the potential for macrophytes to colonize areas of upwelling with nutrient rich groundwater. Previous studies of interstitial patterns have found *Potamogeton filiformis and P. richardsonii* at the head of riffles. These macrophytes suggest that groundwater is coming through the hyporheic into the pool downstream of a riffle. Beyond *Potamogeton spp., Ranunculus septentrionalis*, *Caltha palustris* and *Nasturtium officinale* are known to grow in lower temperatures of the hyporheic zone, indicating groundwater upwelling (Fortner, 1988).

In addition to macrophytes, upwelling can be correlated with the presence of algal *Chara* beds above the hyporheic zone (Hendricks, 1988). *Chara* are a genera of algae that prefer hard or alkaline waters and will flourish in areas of high nutrient content (Agrilife, 2015). In larger, urban rivers, *Chara* can signal increased nutrients due human loading such as industrial discharge, runoff, and sewage (Ouyang, 2012). In smaller systems like the Maple River, *Chara* is more indicative of natural inputs of nutrients, namely groundwater.

This study was conducted in preparation for the removal of Maple River Dam, in Pellston, Michigan. The dam failed in 1952, but since its reconstruction, it has created an ongoing disturbance to river flow and the lotic ecosystem. Understanding the positioning of groundwater downstream from a hydraulic-loading dam will benefit future conservation efforts, at and below the dam, upon forecasted dam removal (Godsby, 2014). The objective of this study was to examine effects of damming on the groundwater system of the Maple River downstream of Lake Kathleen in Pellston, Michigan. To quantify the effects of the dam downstream we examined how the distribution of upwelling or seeps changed in frequency downstream. We predicted there would be a variance of temperature around *Chara* beds, indicating groundwater input. From previous studies, we also related surface area of *Chara* to strength of upwelling, assuming a larger temperature difference between hyporheic and substrate temperatures with larger hummocks (Hendricks, 1988). This study also addresses dam effects on the river's substrate and embeddedness. We predicted there would be a gradual change in substrate downstream and that areas of low embeddedness may have more upwelling.

MATERIALS AND METHODS

The study sites were located along the main branch of the Maple River in Pellston, Michigan. The river flows outward from Douglas Lake into the East Branch and from Pleasantview swamp to the West Branch. These two branches join at Lake Kathleen, created by the Maple River Dam (Figure 1.).

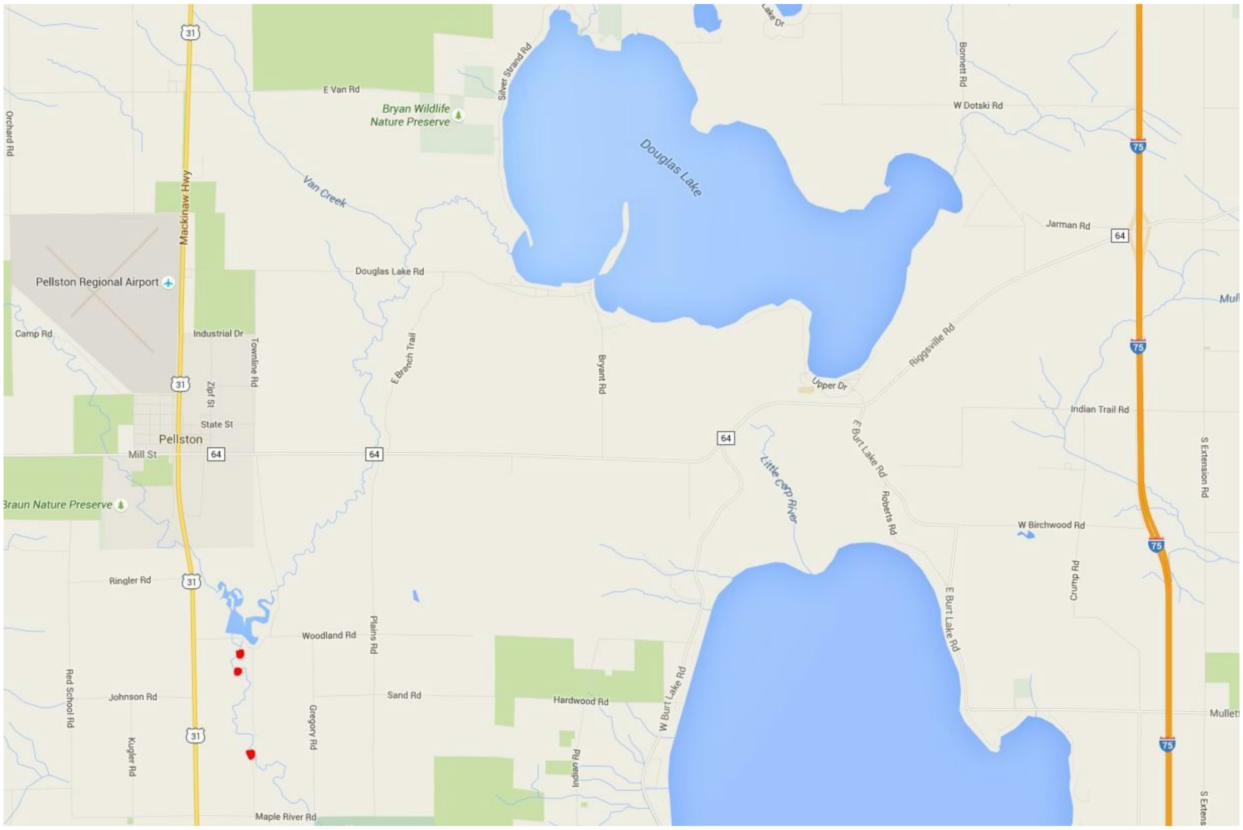


Figure 1. Satellite map of the Maple River and surrounding area, Pellston, Michigan. Study sites up- and downstream denoted by *.

The river maintains relatively low temperatures, it is considered a cold-transitional stream. Most of the terrestrial and aquatic landscapes are artifacts of glaciation in the area. The sediments and glacial till are generally coarse material that are well-suited for groundwater transport between aquatic systems (Godby, 2014).

Each mapping site was 100 meters in length and contained ten transects spaced ten meters apart at the wetted width. The first site (45°31'41.5"N 84°46'26.0"W, Figure 1.) was located shortly below the dam, the second site (45°31'34.2"N 84°46'31.9"W, Figure 1.) was accessed by walking downstream from the dam, and the final site (45°30'53.4"N 84°46'16.3"W, Figure 1.) was located south off of Pine Trail. To record data for future comparison, we used the Collector application for iPad to mark waypoints of *Chara* hummocks, seeps, and riffles as groundwater inputs to the Maple River. General measurements were conducted on clear, sunny days and we took care to avoid areas immediately at the dam as it may have unusually affected the groundwater system.

We measured river discharge at the downstream end of each site with a flow meter and top-set rod (m^3/s, Hach). We estimated the canopy cover (%) at each site using concave densiometer following instructions prescribed by the Washington State Department of Ecology's Environmental Assessment Program (Werner, 2009). At the downstream end of each 100 meter site, we took a 250 milliliter sample of water for chemical analysis of total phosphorus (μg-P/L), phosphate (μg-P/L), total nitrogen (μg-N/L), nitrate (μg-N/L), ammonium (μg-N/L), silicate (mg Si/L), alkalinity (mg $CaCO_3$/L), and filtered chlorophyll-A (Chl-A/L, filter syringe).

We mapped the groundwater upwelling by taking substrate and hyporheic temperatures (℃) with a thermistor probe in and around hummocks of *Chara* to compare groundwater upwelling. Walking downstream from the beginning of site 1 to the end of site 2, and the 100 meter length of site 3, we mapped each hummock's position with a GPS and measured length, width, and depth, as well as the substrate and hyporheic temperatures at the head, tail, and middle of each hummock. To compare the upwelling in these beds we took substrate and hyporheic temperatures in each of the cardinal directions 50 centimeters away from the hummocks edge (Figure 2.).

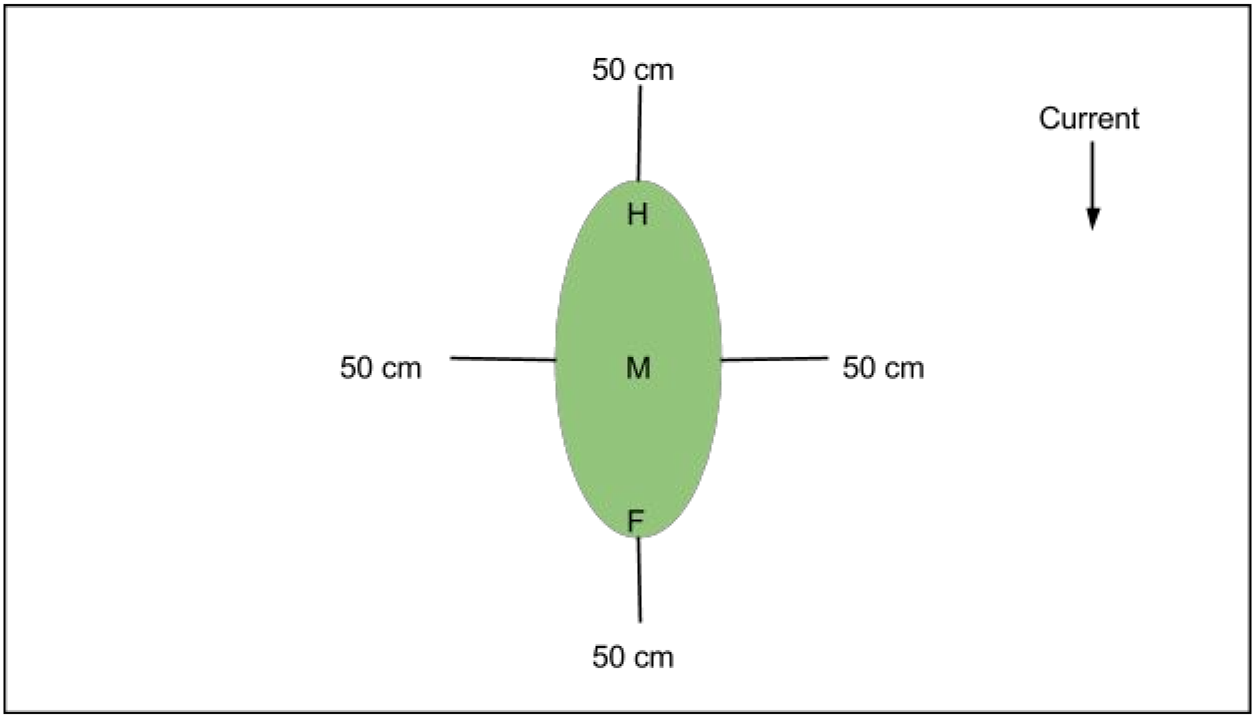
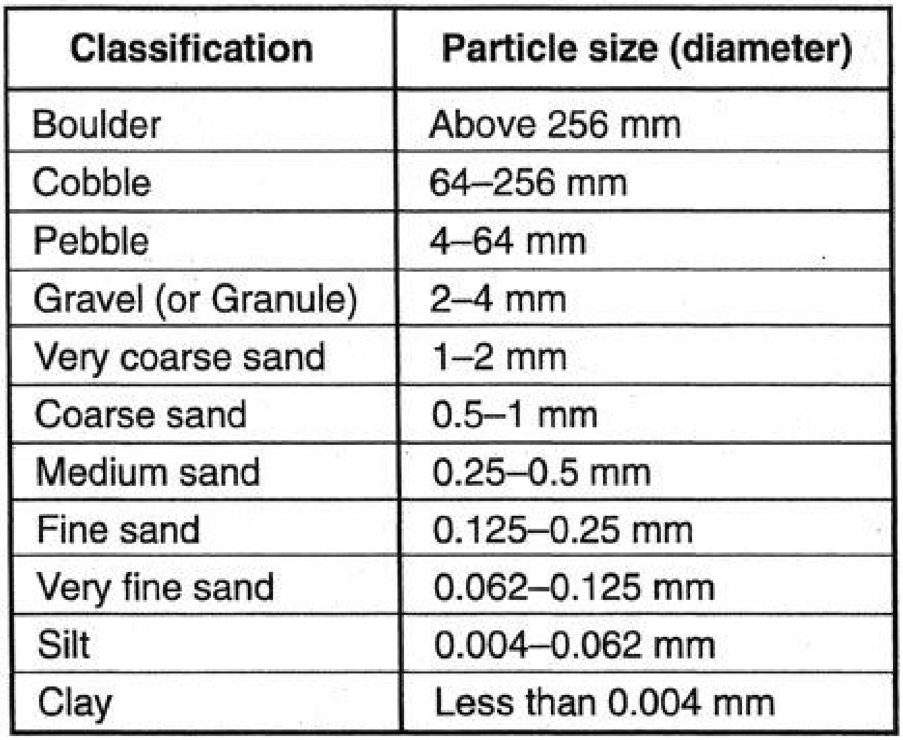


Figure 2. A diagram of *Chara* for surface and hyporheic temperature measurements at the head (H), middle (M), and foot (F), as well as each cardinal direction 50 centimeters away from the *Chara*.

Our prediction that temperature will vary inside and outside of *Chara* hummocks on both the surface and in the hyporheic zone was tested using a two-tailed t-test. Previous studies suggested that strength of groundwater upwelling is correlated to the size of a *Chara* bed (Hendricks, 1988). We tested our own data with variables of temperature difference, between the hyporheic and surface, and the surface area of *Chara* beds.These data best fit a test of linear regression. To calculate means of *Chara* temperatures and means of outside temperature, we first used f-test to establish equal variance, and then used t-tests to find significant difference in distributions.

These distributions were insignificant and allowed us to combine measurements into averages for statistical treatments.

At each habitat measurement site, we divided the 100 m reach into 10 transects, 10 meters apart. At each transect we measured the wetted width of the river (m) and marked five equidistant points along the transect. At each of the five points, we measured: 1. the water depth (cm) 2. sand, gravel, pebble, and cobble, as proportions of the substrate according to the Wentworth scale (% cover, U.S.G.S., 2013, Table 1.)



Classification	Particle size (diameter)
Boulder	Above 256 mm
Cobble	64–256 mm
Pebble	4–64 mm
Gravel (or Granule)	2–4 mm
Very coarse sand	1–2 mm
Coarse sand	0.5–1 mm
Medium sand	0.25–0.5 mm
Fine sand	0.125–0.25 mm
Very fine sand	0.062–0.125 mm
Silt	0.004–0.062 mm
Clay	Less than 0.004 mm

Table 1. The Wentworth scale of substrate particle composition according to particle diameter (U.S.G.S., 2013).

3. macrophyte presence by by species (% cover) 4. embeddedness, which is an index of the deposits of sand and silt over large material (1-5). The embeddedness index describes streambeds with a low number to have less sand deposits between rocks. This index is very important for animal habitats in the benthos. The data to compare embeddedness with distance to upwelling

was analyzed with a linear regression. Our predicted change in substrate composition, according to the Wentworth scale (U.S.G.S., 2013), was treated with a one-way ANOVA.

We mapped riffles in the river and possible seeps by walking upstream with a Garmin GPS and marking waypoints. We input GPS data points into the mapping software, ArcGIS. In this software, we measured distance between the dam and beginning of site 1 upstream. Seeps were predicted by areas of distinguishably lower temperatures, or visible areas of oxygen bubbling up through the sediment into the water column. To calculate a frequency of seeps, we divided each site into 50 meters and counted the number of seeps present in each 50 meters. This ratio indicated the frequency of seeps and was performed in the same manner from the upstream to downstream limits of site 3 as well. Each of these frequencies were associated with a specific distance downstream from the dam, the distance to the center of the 50 meter transect. We used a linear regression to quantify our hypothesis that seeps are more frequent closer to the dam (negative correlation). Linear regression tests were performed in Microsoft Excel with plotted trendlines, and all other tests were performed in IBM SPSS Statistics program.

RESULTS

Our general measurements showed an increase in river discharge further downstream from the dam, and an increase in phosphate, ammonium, silicate, and total nitrogen further downstream in site 3 (Table 2.).

Table 2. The river discharge and general water quality analysis of the Maple River, Pellston, Michigan, all taken downstream of the Maple River dam. 7/30/15.

Site	Discharge (m^3s^{-1})	PO_4 (ug P/L)	NH_4 (ug N/L)	NO_3 (ug N/L)	Alkalinity (mg $CaCO_3$/L)	SiO_2 (mg Si/L)	TN (ug N/L)	TP (ug P/L)
1	1.20	4.09	9.50	208.60	67.47	4.99	341.80	8.70
2	1.30							
3	1.65	4.24	13.10	201.60	66.97	5.25	379.40	6.80

According to our linear regression there was no significant correlation between the frequency of seeps and the distance downstream of the dam (t Stat=-1.277, P-Value=0.224, R^2=0.111, Figure 3.).

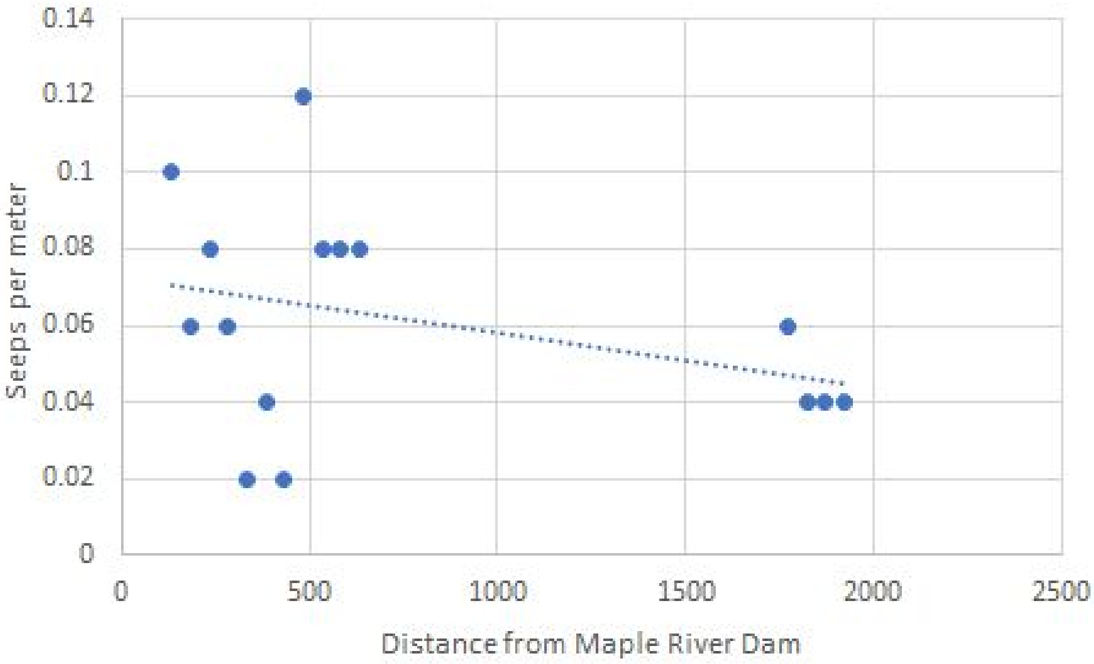


Figure 3. Frequency of groundwater inputs as seeps into the Maple River downstream from the dam.

The mean hyporheic temperature 20 centimeters below *Chara* hummocks was significantly lower the then mean temperature at the surface of the hummocks. (T=3.13, df=51, p=0.0028, Figure 4.). In contrast, there was no difference in the mean temperature between the surface and hyporheic zone outside *Chara* hummocks (Figure 4.). Likewise, average surface and hyporheic (20 cm depth) temperatures within *Chara* hummocks were not significantly different from surrounding substrate surface or hyporheic mean temperature (T=1.069, p=0.29, R^2=0.038, Figure 5.).

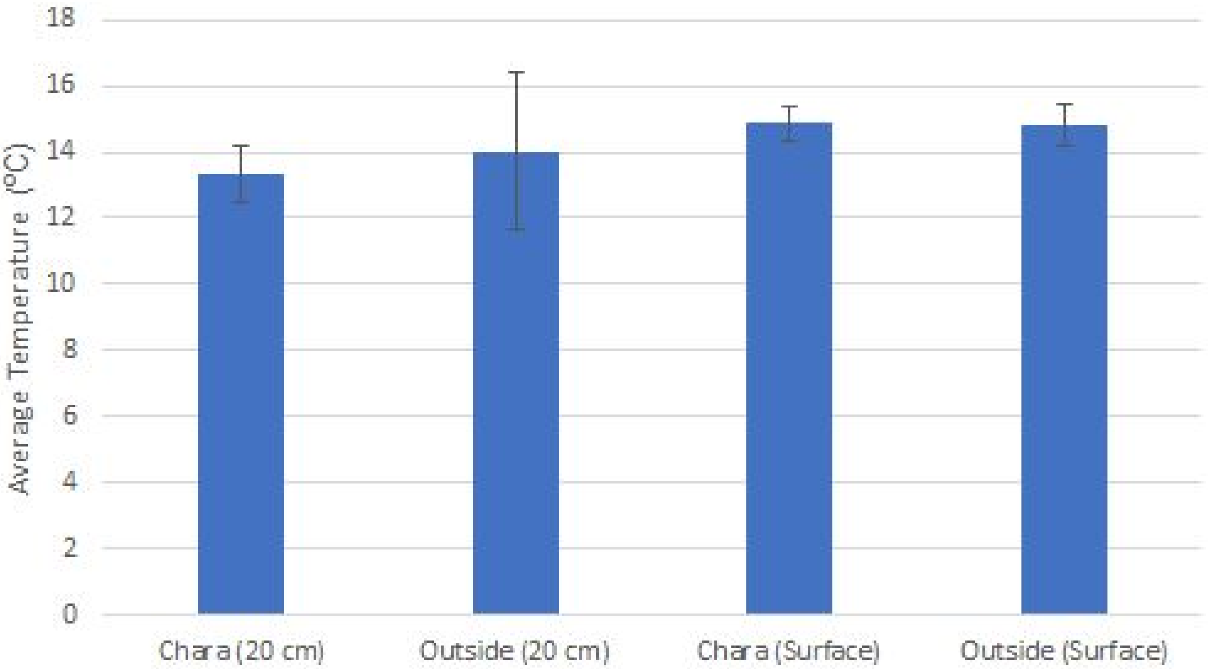


Figure 4. Comparison of average temperatures inside and outside of *Chara* hummocks, with the prediction of groundwater inputs affecting temperature differences under the beds of *Chara*.

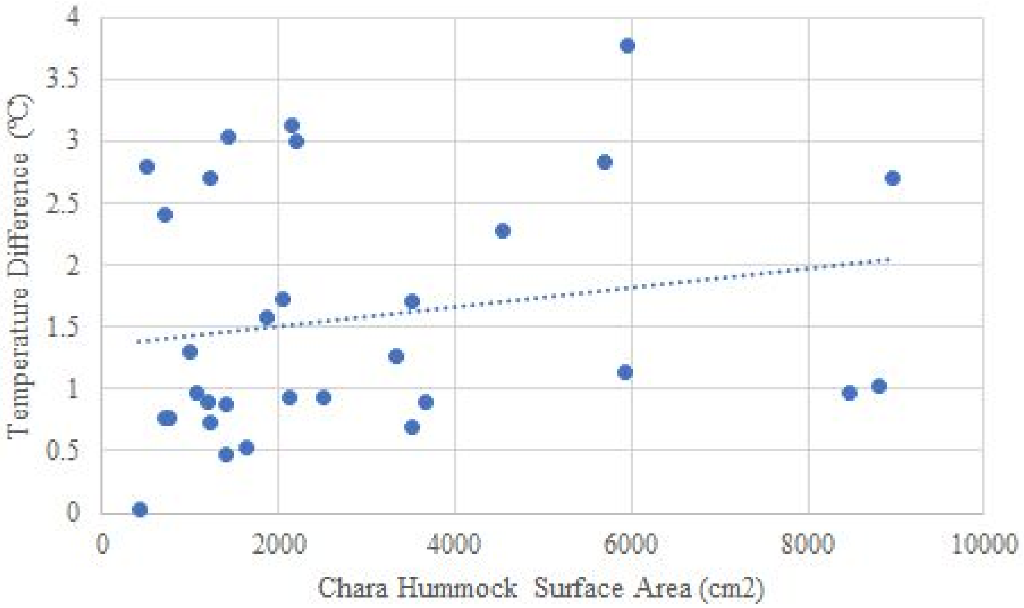


Figure 5. Relationship between difference in temperature of surface and hyporheic zone, and the surface area of *Chara* hummocks.

Our data comparing average level of embeddedness to average distance to groundwater inputs was not significant at the 0.05 alpha level, however it showed a negative trend that was opposite of our expected hypothesis (t Stat=-1.925, P-Value=0.064, R^2=0.116, Figure 6.).

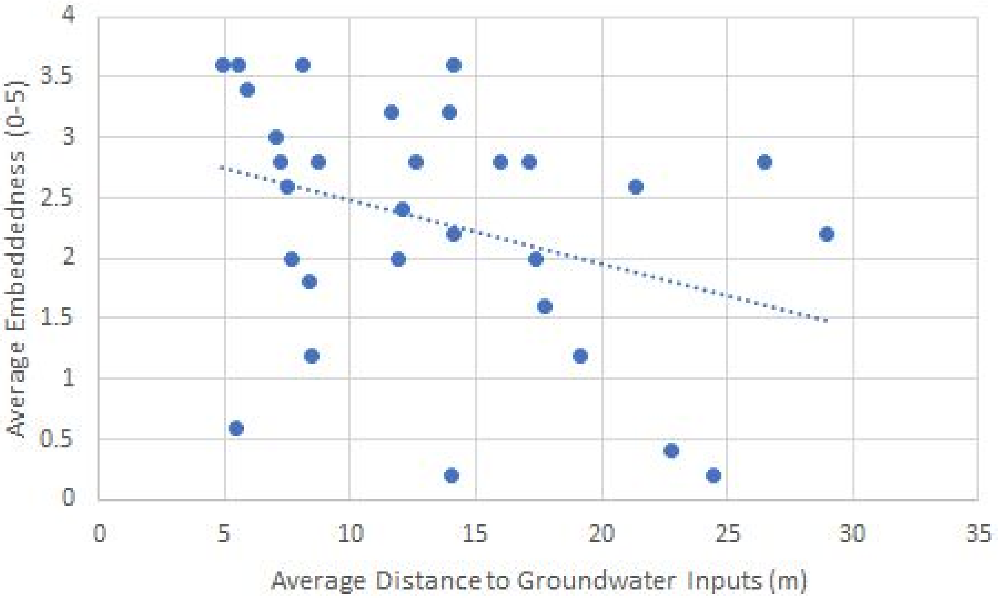


Figure 6. Relationship between average embeddedness of river substrate and average distance to groundwater inputs of *Chara*, seeps, or riffles.

Our prediction that there will be a variation in substrate composition was significant only in the variance between sites with more cobble upstream (f Stat=8.09, df=2, P-Value=0.000, Figure 7.). While cobble had a significant change in distribution downstream, sand, gravel, and pebble had no significant variation (Figure 7.).

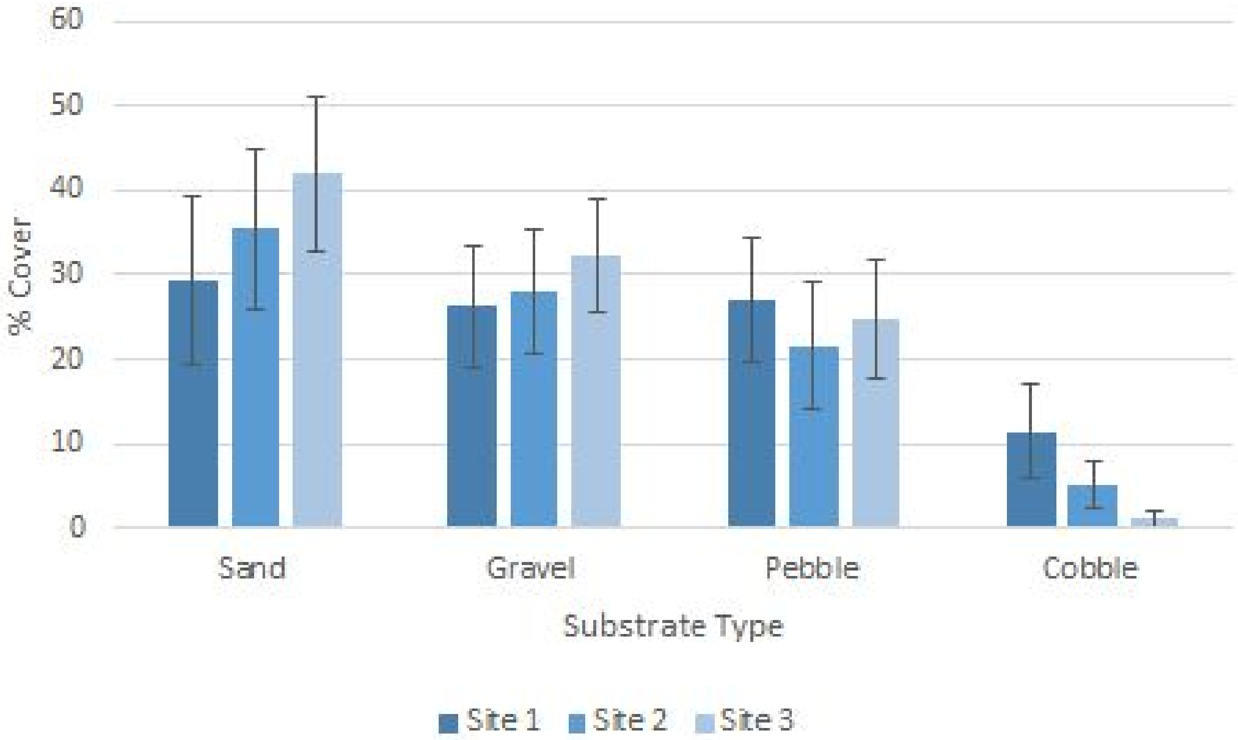


Figure 7. A comparison of substrate composition according to the Wentworth scale across three sites below the Maple River Dam. The error bars represent two standard deviations.

DISCUSSION

We found a higher flow downstream from the dam, which could potentially be slow velocity inputs of groundwater to the river upstream that gain momentum (Table 2.). We know from previous studies of groundwater, with accurate measurements using chlorofluorocarbons (CFCs), inputs are more abundant directly below a dam than downstream (Zhang, 2014). Our insignificant results might be explained by differences in the Maple River's geological history from the rivers in other literature. The variables we have measured may not have affected the Maple River groundwater, simply due to the small size of the dam and river system.

One of the most easily measured indicators of groundwater is temperature that we identified with *Chara* beds. Our measurements of temperature inside and outside of *Chara* beds did not yield significant results, except for the difference between temperature at the surface and at depth in the hyporheic zone under *Chara* (Figure 2.). The difference between surface and hyporheic temperatures under *Chara* could be indicative of upwelling, as stated in the literature. Possibilities for the insignificance of other tests may have been that we found no variance in outside temperatures because of 50 cm being too close in proximity. Our data also may suggest a different finding than in Hendricks et. al. (1988), they imply *chara* flourishes from nutrients in groundwater. If there is no true difference in temperature in and out of *Chara* beds the only way to replicate this experiment would be to use precise methods of nutrient sampling from interstitial waters.

We found that *Chara* hummock size did influence magnitude of the temperature differential between the surface and groundwater beneath the hummocks. This is in contrast to a previous study which suggested these results may have been due to the fact that our analysis of linear regression was run on surface area of *Chara* hummocks instead of on length alone (Hendricks, 1988). We chose to use surface area in hopes to have a more complete and accurate measurement of *Chara* beds for analysis. For the purposes of our study, it may have been possible to find significant results with a greater sample size of *Chara* beds and interstitial temperature differences. This is assumed because of a slight positive correlation in the trendline comparing both variables (Figure 3.).

We concluded that level of embeddedness related to distance from groundwater inputs was not significant at the 0.05 alpha level, but it did have a P-Value of 0.064 which is just below a 94% confidence level. This slight skew could have again been attributed to human subjectivity on judging substrate composition. If the P-Value and negatively correlated trendline are in fact an explanation for changes in benthic habitat, then our findings are opposite of expected from the literature (Figure 4.). These implications mean as the benthic substrate becomes more embedded, there is a shorter distance to groundwater inputs of *Chara* beds, seeps, or riffles.

Our hypothesis that there will be a change in substrate further downstream of the dam was significant for cobble (Figure 5.). This is concurrent with the idea of embeddedness being lower, closer to the dam. However more cobble upstream is a confounding variable with all of our other measurements, as flow increased downstream (Table 1.), and the level of embeddedness was more negatively correlated with distance to groundwater inputs (Figure 4.). For further study on the effects of the dam on benthic substrates, it would be beneficial to incorporate data on macroinvertebrates to describe the dam's overall effect on the downstream habitats.

Implications of this study show the potential for study on damming effects in a river ecosystem. Dams create disturbance to benthic organisms and fish spawning areas and often can be harmful to adult fish with zones of oxygen supersaturation, resulting in the bends. Little is known on effects of dam removal, but previous studies have already explained the high costs dams incur economically, but upon removal, they open the way for exotic species and completely alter the downstream habitats (Stanley, 2003).

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