1-1-2012

The Effectiveness of Constructed Wetlands

Jessica L. Franks
Grand Valley State University

Eric B. Snyder
Grand Valley State University

Megan M. Woller-Skar
Grand Valley State University

THE EFFECTIVENESS OF CONSTRUCTED WETLANDS

Grand Valley State University, Biology Department, Allendale, MI

Franks, J.L., E.B. Snyder, M.M. Woller-Skar

Wetland construction represents a vital tool to increase the number and extent of wetlands in the United States. However, there is uncertainty as to how effective constructed wetlands actually are and if they continue to function efficiently as they age. This study's objective was to evaluate the constructed wetlands on Grand Valley State University's Allendale campus. The wetlands studied were constructed in both 2009 (n=3) and 2011 (n=5), not specifically to mitigate for wetland loss; rather they are a proactive attempt to reduce erosion from excessive stormwater runoff in the GVSU ravines. We compared these to wetlands constructed in the mid 1980's (n=3) located at the near-by Bass River Recreation Area. Specifically, aquatic macroinvertebrates were sampled throughout May 2012, following rapid bioassessment protocols used by the Michigan DNR, while water chemistry parameters (specific conductivity, pH, dissolved oxygen, temperature, turbidity, riparian coverage, chloride, and total dissolved solids) were measured bi-weekly throughout the summer. The macroinvertebrate Family richness and diversity were significantly different ($p<0.05$, ANOVA) and values for each metric ranged from 21.3, 20.67, and 6.6 and 2.31, 2.13, and 1.01 between 1980's, 2009, and 2011 sites, respectively. These differences in the insect community assemblages were evident in a multivariate test as well (NMDS). Thus, at a community level there was a rapid improvement in the aquatic insects in just three years suggesting these constructed wetlands will rapidly develop into healthier communities.

INTRODUCTION

The main campus at Grand Valley State University (GVSU) has rapidly expanded in the last twenty years, and this expansion has resulted in a significant increase in impermeable surfaces and decline in available surfaces for water to infiltrate, resulting in increased erosion. Much of this erosion has occurred in the geologically and biologically unique ravine ecosystems around which is built much of the campus infrastructure. Often, ponds are placed next to parking lots to catch this run-off. In 2009, GVSU went the extra mile and created three storm-water wetlands and re-routed a significant portion of the campus storm drains to feed into these systems versus the ravines. These wetlands have established plant life and are now home to many tree swallows, eastern bluebirds, and an abundance of water fowl. Five additional wetlands were constructed in 2011.

In this project, we sought to compare the macroinvertebrate communities in these storm-water retention wetlands on campus and to wetlands constructed in the early to mid 1980's at Bass River Recreation. These three reference wetlands were constructed as a result of gravel excavation and are now well-established and appear to be in ecological dynamic equilibrium.

Wetlands provide a number of benefits, including habitat for fish and wildlife, beautiful scenery for nature enthusiasts, a natural water filter that reduces contaminant and nutrient load, and a natural storage zone for flood water (Turner et al. 2000). Unfortunately, the number of natural wetlands has decreased drastically due to human activity (Turner et al. 2000). Historically, wetlands were destroyed to make way for fields, and though the brunt of the agricultural revolution has passed, wetlands are still being destroyed today with ongoing urbanization (Mitsch and Gosselink 2011). There are guidelines now for wetland mitigation if a

natural wetland were to be destroyed, but the question is how effective are manmade wetlands? Does their ecological function approximate natural systems? There is much literature about mitigated wetlands and their lack of effectiveness, but the idea of using wetlands as a storm-water retention area is relatively new and primary literature on the topic is scarce. This project in part seeks to contribute to this body of knowledge.

When assessing the health of aquatic environments it is important to look at physical, chemical, and biological factors (Voshell, 2002). In addition, the living organisms present in an ecosystem can provide a solid indication of ecosystem integrity or health. As such, the organisms serve as biological indicators and the advantage or their use in ecosystem assessment is their ability to integrate conditions over their life-span. This provides a significant increase in the temporal resolution of a biological assessment beyond that obtained for example from synoptic grab samples for water chemistry.

In our study we used aquatic macroinvertebrates as biological indicators of aquatic health. These aquatic insects prove to be excellent indicators of their environment because they have a short lifespan, spending all, if not most of their lives in water. With each family having different tolerances and sensitivities, looking at biodiversity, taxa richness, and patterns in dominance tells a great deal about the water quality (Stepenuck et al. 2008). This assessment approach has proved to be very useful for several reasons. First, the method is fast. More sites can be sampled and it is inexpensive. Second, it does not require extensive background experience. Third, this method includes an assessment of the surrounding environment. This is important because the condition of the watershed can directly and indirectly affect the health of the wetland. Fourth, the organisms being sampled are known for their sensitivities and are only found in specific conditions (Hannaford & Resh 1995).

METHODS

The three "natural" or reference wetlands were located in Bass River Recreation Area, Ottawa County, Michigan (Figure X). These sites used to be gravel excavation areas, but haven't experienced significant anthropogenic disturbances since the 1980's. We selected these sites as a temporal control given that they were constructed, or man-made, and have been established for much longer (ca. twenty-seven years) than the campus wetlands (three years and one year). The eight storm-water wetlands on campus (Figure 1) were constructed in two phases: the first three sites (what we called sites A, B, and C) were constructed in 2009. Five additional sites (sites D through G) were constructed in 2011).

Chemical-Physical Characteristics

Water chemistry was measured biweekly from May 2012 through August 2012. Temperature, specific conductivity, pH, dissolved oxygen, and total dissolved solids were measured using a YSI 650 MDS sonde. At each site, three replicate turbidity samples were taken and measured using a HACH 2100P Turbidimeter. Turbidity is a measure of water quality and provides a measure of how much singlight can penetrate the water allowing for plant growth.. Riparian shade was measured using a spherical densitometer. For each sampling three chloride samples were gathered and brought back to the laboratory for analysis using an ORION ion specific chloride probe.

At the reference sites, water samples were collected during one storm event on July 31st, 2012, to measure wetland response. Sample retrieval was delayed until August 10th therefore data from this analysis is suspect, particularly for ortho-phosphorus. The phosphate samples were

refrigerated until analysis on August 16th and analyzed following standard methods (Spectro following proper EPA method #365.3). Water chemistry from campus retention wetlands was monitored in another ongoing research project (Wampler and Krum 2012). Water temperature was monitored continuously at the largest site (site I) and several of the on-campus sites (Wampler and Krum 2012) using submersible temperature loggers (ONSET, model Pro v2). This allows for some comparison to be made between the 1985 wetlands and the 2011 wetlands.

Invertebrate Sampling

Invertebrates were collected mainly during May with the last two reference sites sampled on June 1st. Three replicate samples were taken from each type of vegetation zone present following the methods outlined in Burton and Uzarski (2009). The vegetation zones we encountered were open water, emergent, and floating. Although each wetlands represented a statistical experimental unit, the samples from each zone were kept separate enumeration and taxa identification. Each sample was collected with a D-frame kick nets with 0.5-mm mesh and sampling depths varied depending on overall water depth. For example, in deeper water, sampling was stratified and included a near surface, mid, and benthic sample, with care taken to avoid digging into too much sediment resulting in clogged nets and inefficient collection. Collectively, sampling effort was approximately 15 minutes per vegetation zone.

Macroinvertebrates were field sorted using white plastic trays (17x30 cm) divided into eight grids with permanent marker. Invertebrates from each replicate were sorted for 30 minutes a person or once 150 invertebrates had been collected. At the end of the allotted time if 150 specimens had not been collected, sorting continued as follows: less than 50 individuals would result in continued sorting effort until 50 had been collected; >50-100 resulted in continued

soring to 100; and >100-150 resulted in continued sampling to 150. This way, each replicate contained 50, 100, or 150 invertebrates. Collected invertebrates were immediately placed in 70% ethanol. After ~24 hours, the ethanol in each sample was replaced with fresh 70% ethanol.

In the lab invertebrates were identified to their taxonomic families using a Nikon SMZ645 C-FMBN dissecting microscope at 10x-50x magnification and using Merritt et al. (2008) as taxonomic key. Later, once macroinvertebrates were identified to family they were assigned tolerance values based on values from Barbour et al. 1999. These tolerance values are macroinvertebrates' tolerance to organic pollution. These values are ranked from 0-10, zero being extremely sensitive.

Data Analysis

Macroinvertebrate and physical/chemical data were analyzed in two ways. Firstly, a comparison of the similarities and differences between vegetation zones was conducted, although this was relatively superficial given that there was a large degree of variation between wetlands and year-classes and the number and type of vegetation zones present. However, we deemed that this might be an interesting comparison and would allow for possible future analyses to be conducted on the changes in vegetation zones. The bulk of our analysis involved a comparison between wetlands, where the data from the vegetation zones within a given wetland were pooled. As such, each wetland represented an experimental unit, and our replicates included the other wetlands within the particular year (e.g 1985, n=3; 2009, n=3; 2011, n=5).

Diversity was calculated using the Shannon-Wiener diversity index (H');

Diversity: $H' = \sum(pi * logpi)$

where pi represents the proportion of individuals in the ith species, genera, or family. Relative abundance was calculated as;

Relative abundance: $\left(\frac{\#\text{ individuals in the ith family or genus}}{\#\text{ total number of individuals}}\right)$

Richness is the sum of total taxa found within a wetland. Replicate samples from each wetlands were pooled for comparisons between wetlands and richness and diversity values were calculated and compared using an analysis of variance (ANOVA). Patterns in macroinvertebrates were assess using multivariate statistics, which allowed us to look for patterns in a complex data set. Specifically, we used Nonmetric Multi-Dimensional Scaling (NMDS) using the software package PC-ORD (McCune and Grace 2002). NMDS is a particularly well-suited for complex ecological data sets where the data matrix is populated by many empty cells or zeroes. Results of the NMDS looked promising and therefore similarity percentage of SIMPER analysis (Clarke 1993) was conducted to identify macroinvertebrate taxa that were strongly associated with the three different wetlands year classes (1985, 2009, 2011). This analysis was done in R.

RESULTS

Macroinvertebrates

Taxa richness and diversity were highest in the 1980's wetlands with a value of 21.3 for richness and 2.31 for diversity (Figure 2). The 2009 wetlands were slightly lower, 20.7 and 2.13 for richness and diversity, respectively. The most recently constructed wetlands (2011) were lowest (6.6 and 1.01 for richness and diversity). Differences (ANOVA) between year classes were significant for both richness ($p=0.003$) and diversity ($p=0.001$).

Patterns in macroinvertebrates between vegetation zones indicated the diversity values overall tended to be higher in the 1985 wetlands and diversity values were lower in open water, although these data were not analyzed statistically due to issues with pseudoreplication and non-independence and the fact that the presence or absence of vegetation zones was variable (Table 1).

The multivariate analysis indicated that sites were grouped based on date of construction (figure 2). The final stress value was 0.053, and an analysis of similarity (ANOSIM) was significant ($p=0.0001$), and $R=0.80$. Thus, site groupings were statistically significant. Plot A shows the groupings, plot B shows the groupings with the macroinvertebrate overlay showing the taxa that best describe the similarities within and differences between site groupings.

Relative abundance of taxa revealed that Chironomidae were the most prevalent and the only taxa found in all eleven sites (table 3). The more sensitive taxa (Aeshnidate and Baetidae) are only found in the 2009 and 1985 sites. The tolerance values for all the sites never went below a 3.

Physical/chemical

The 2011 wetlands generally had higher chloride content, specific conductivity, total dissolved solids, and were more turbid than the 2009 and 1985 wetlands (table 2). It is noteworthy that the dissolved oxygen values were lowest in the Bass River Recreation sites and highest in the 2009 wetlands. We expected to see the highest dissolved oxygen values at the Bass River sites.

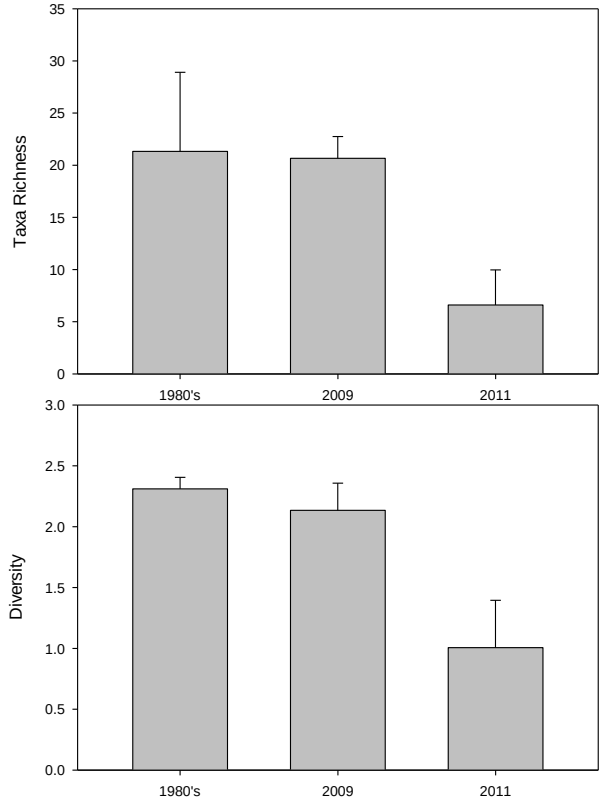


Figure 1. Diversity (p=0.001) and richness (p=0.003) (+1 SD) of macroinvertebrates in wetlands constructed on GVSU's campus in 2009 and 2011, and the Bass River Recreation Area in the 1980's.

Table 1. Macroinvertebrate diversity for each vegetation zone present in 2009 wetlands (A, B, C), 2011 wetlands (D, E, F, G, H), and 1985 wetlands (I, J, K) collected May 2012.

	1985			2009			2011				
	Site I	Site J	Site K	Site A	Site B	Site C	Site D	Site E	Site F	Site G	Site H
open				1.69		1.83	1.59	0.96	1.07	0.88	0.52
emergent		2.33		2.21	2.44						
floating	2.40		2.21		2.23	1.92					

Table 2. Average environmental characteristics from all eleven sites: 2009 wetlands (A, B, C), 2011 wetlands (D, E, F, G, H), and 1985 wetlands (I, J, K) from May 2012 through August 2012.

	1985			2009			2011				
	Site I	Site J	Site K	Site A	Site B	Site C	Site D	Site E	Site F	Site G	Site H
Temp	24.91	21.26	22.67	24.35	21.09	23.74	23.99	24.72	23.95	24.08	23.92
SC	257.43	214.41	349.83	469.00	491.25	433.17	850.40	968.00	1120.40	865.20	1008.00
DO%	89.94	63.25	52.58	130.54	110.13	110.92	108.94	101.82	100.58	100.92	95.63
DOmg/L	7.39	5.71	4.31	11.10	9.20	9.57	9.43	8.47	8.43	8.44	7.89
pH	8.36	8.17	8.12	8.40	8.47	8.45	8.60	8.35	8.37	8.70	8.06
NTU	3.14	13.82	2.86	20.07	26.93	5.59	6.68	37.25	26.24	113.06	66.15
TDS	0.18	0.27	0.23	0.32	0.32	0.29	0.55	1.92	0.70	0.56	0.66
Cl-	40.48	42.92	47.63	190.15	108.64	92.99	254.13	282.60	291.33	232.56	236.92

Table 3. Relative abundance of macroinvertebrate taxa and tolerance values for 2009 wetlands (A, B, C), 2011 wetlands (D, E, F, G, H), and 1985 wetlands (I, J, K) collected in May 2012.

	1985				2009			2011				
	Site I	Site K	Site J	tolerance	Site A	Site B	Site C	Site D	Site E	Site F	Site G	Site H
Chironomidae	0.09	0.07	0.01	6	0.30	0.15	0.12	0.48	0.48	0.51	0.73	0.88
Corixidae			0.01	7	0.09	0.10	0.02	0.15	0.41	0.33	0.18	0.04
Caenidae	0.10	0.28		7	0.02	0.14	0.43	0.04			0.01	
Libellulidae	0.03	0.14		9	0.06	0.02	0.01					
Lestidae		0.01	0.13			0.01	0.03					
Dytiscidae	0.02		0.04	5		0.01				0.02	0.02	
Baetidae	0.03	0.04	0.01	4		0.02	0.01					
Ceratopogonidae	0.02	0.01		5.7	0.03	0.02	0.02					
Haliplidae	0.02			7	0.01	0.02	0.01	0.02				
Aeshnidae	0.01		0.04	3	0.01							
Oligochaete		0.01		5								0.03
Hydrophilidae			0.03	5								
Chaoboridae			0.01	8				0.01				

A: Without insect overlay

B. With insect overlay

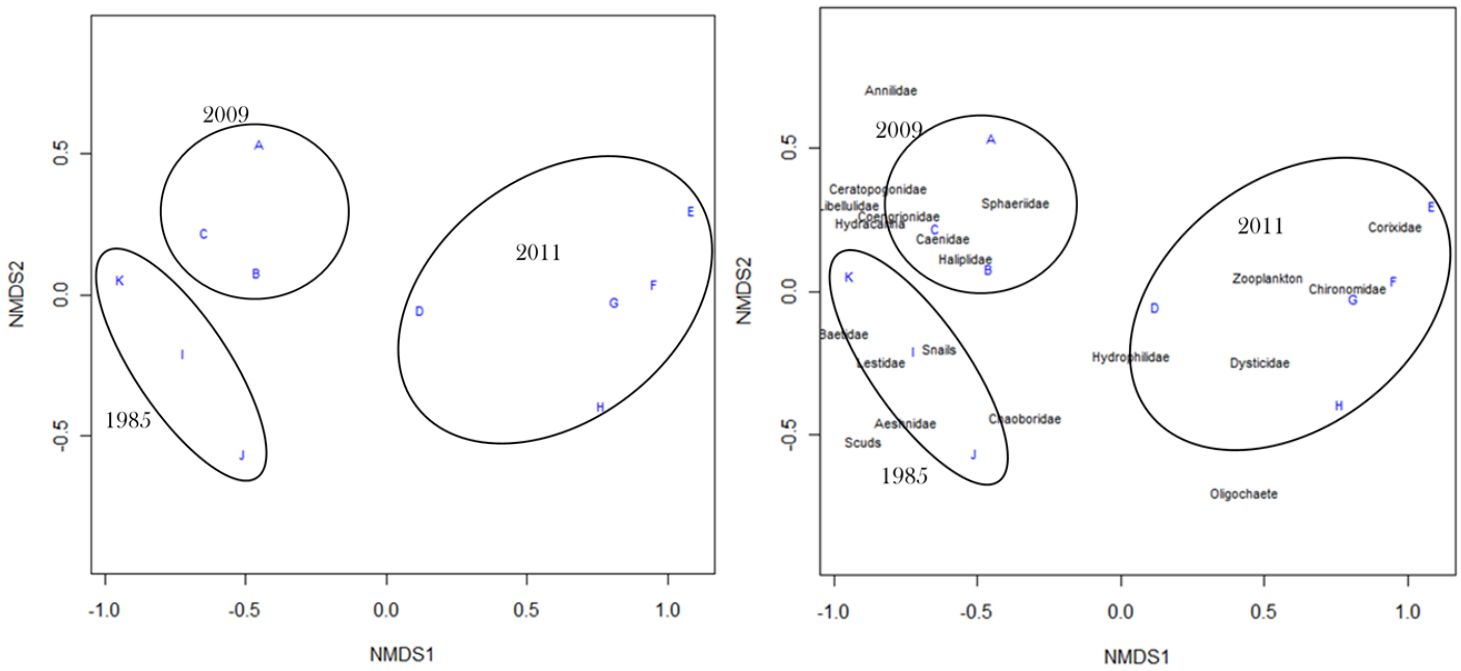


Figure 2. Non-metric multidimensional scaling (NMDS) data represents macroinvertebrate relative abundance for sites constructed in 2009 (A, B, C), 2011 (D, E, F, G, H), and 1985 (I, J, K). Plot A is without the macroinvertebrate overlay. Plot B, includes the macroinvertebrate overlay on plot A (weighted averaging).

DISCUSSION:

We found that macroinvertebrate richness and diversity values were highest in the reference wetlands, followed closely behind by the 2009 wetlands. This suggests that in just three short years, wetland function, as assessed by the macroinvertebrate community, had improved drastically. Higher richness and more diversity suggest a more complex environment, which is always better from an ecological stand point (Molles, 2010). The greater diversity present, the more resilient and resistant an ecosystem is the disturbance. It is not known how low is "too low" for diversity before an ecosystem unravels (Elmqvist et al. 2003).

Though there was greater richness and diversity found in the 2009 and 1985 wetlands, the macroinvertebrate tolerance values were all quite high (table 3). The lowest tolerance values were 3 (Aeshnidae) and 4 (Baetidae) found in sites A and I and sites B, C, I, J, and K respectively. The fact that the majority of taxa found in all wetlands were relatively tolerant of pollution suggests a couple of things: one, insects were only identified down to family where species and genus tolerance values may have provided greater insight; and two, these tolerance values came from Barbour et al. (1999), which are tolerance values designed for lotic (stream) systems and not lentic systems. Rapid bioassessment for wetlands and tolerance values for wetlands are still being researched; therefore the higher richness and diversity may provide a more robust assessment of wetland function or health than using tolerance values. Improved diversity and richness may also be related to wetland habitat complexity. For example, the 1985 wetlands have floating or emergent vegetation zones, and the 2009 wetlands have at least two vegetation zones. At the time of sampling, the 2011 wetlands each had only an open vegetation zone. Balcombe et al. (2005) discussed habitat fragmentation and how emergent zone to open zone ratios accounted for greater diversity which could explain the trends observed.

When looking at the environmental data, due to the lack of plants surrounding the wetlands and the amount of run-off received we expected the specific conductivity (SC) values to be highest in the 2011 wetlands, then the 2009, and lowest in the 1985 wetlands---this pattern did appear, but within those wetlands (2009 and 2011 specifically) we expected to see additional patterns which were not present. For example, wetlands A, B, and C act as a filtration system; wetland A receives the parking lot run off, then flows into B, which then flows into C. This being the case, we expected to find the specific conductivity values in parking lot A to be highest and C to be lowest. This was not the case. Wetland B had the highest specific conductivity value, followed by A and then C. Similarly, the 2011 wetlands are structured such that D receives initial run-off followed by E through H in series. So like our 2009 specific conductivity value predictions, we expect a similar pattern in the 2011 wetlands, but once again, this is not what we found. Likely reasons include the following: Firstly, we often sampled on multiple days and at variable times of the day. Secondly, our analysis was based on a pooled or averaged data from the summer, thus, any temporal patterns are masked. Finally, we were not trying to sample during/after rain events, which is the period of time when the wetlands receiving run-off directly would be expected to show the greatest environmental signal.

Dissolved oxygen values were generally lowest in the Bass River Recreation sites and highest in the 2009 sites (table 2). This may be due to the severe rain shortage over the summer. The 2011 sites (with the exception of site D) and the Bass River Recreation sites (especially sites J and K) were hit the hardest and suffered the lowest water levels with some of the sites drying up completely. At Bass River the low water levels desiccated a lot of the wetland plants and algae and the high levels of bacterial decomposition would lead to low amounts of dissolved oxygen.

In our study, areas that contained emergent zones had higher diversity values. This is similar to reports by Balcombe et al. 2003, Wolcox and Meeker 1992, and Streever et al. 1995 who also found wetland plant diversity positively correlated to macroinvertebrate diversity.

The NMDS analysis indicated that the three sets of wetlands were temporally grouped and those three groups were significantly different from one another. Interestingly, wetland D was grouped slightly closer to the 2009 and 1985 wetlands than the other 2011 wetlands. This site, as mentioned previously, had a most stable hydrologic regime relative to E-H and had significantly improved emergent vegetation. As discussed earlier, the presence of plants allows for more insect diversity (Balcombe et al. 2003, Wolcox and Meeker 1992, and Streever et al. 1995). Site D offers an interesting glimpse of a transition from a newly established wetland to well established wetland and suggests the presence of plants can really improve wetland function (as inferred from the macroinvertebrates) in a short period of time.

As mentioned previously, when assessing the health of aquatic environments it is important to look at physical, chemical, and biological factors (Voshell, 2002). In our study we used aquatic macroinvertebrates as a biological indicator of aquatic health. These aquatic insects prove to be excellent indicators of their environment because they have a relatively long lifespan, spending all, if not most of their lives in water. With each family having different tolerances and sensitivities, looking at biodiversity, taxa richness, and the dominance tells a great deal about the water quality (Stepenuck et al. 2008). Our study mainly emphasized these final three ideas: biodiversity, taxa richness, and dominance. Our data on diversity and richness suggests that wetland health can improve in a relatively short period of time. In addition, there are many parameters that could be assessed and some of these are being examined by another research team. For example, Wampler and Kneeshaw (2012) found that wetlands D, E, F, and G were

efficient at cycling out and reducing phosphorus and nitrogen, suggesting that they carry out proper wetlands functions.

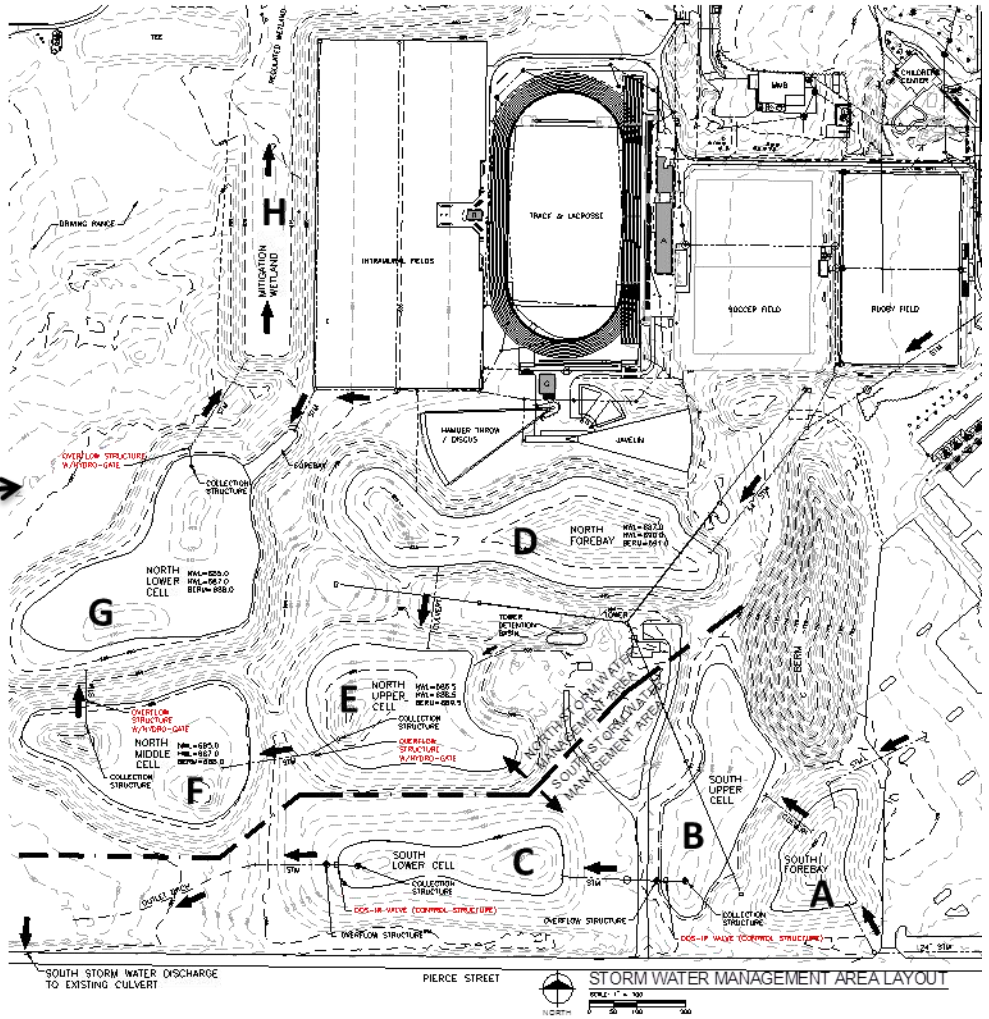
Further studies need to be conducted. The richness and diversity found in the 2009 wetlands are encouraging. Plants seem to be a driving force in establishing a healthy macroinvertebrate community and Grand Valley has already planted significant amounts of vegetation around the 2011 wetlands. Wetland D by the end of the summer already had an emergent zone established. Continuing research next summer to create a wetland succession timeline could help found better construction guidelines for storm-water retention wetlands. Erosion is not a problem unique to Grand Valley. In our growing world it is a growing threat. The creation of wetlands as storm-water retention vessels should become a common practice. If proper guidelines and maintenance are established the ecological benefits would be unparalleled.

Acknowledgements

A huge thanks to Melissa Overweg and Nate Morrison for their unbelievable dedication and enthusiasm for this project. I cannot express how much I appreciate your hard work and friendship. Thank you to Matt Krause, Alynn Martin, Ken Poczekaj, and Sara Leonard for their help out in the field. Thank you to Shaughn Barnett, and Travis Foster for showing me the ropes in lab. Thank you to Peter Wampler, Tara Kneeshaw, and their crew for their nutrient help, their input, and their collaboration. Thank you to Lauren Villalobos and Edward Krynak for not only repeated help in the field, but also for your incredible patience and guidance. Thank you to the DNR for allowing us to work so easily out at Bass River. And a big thank you to Susan Mendoza and Shelley (Student Summer Scholar) for funding and for making this all possible.


Grand River Greenway Corridor
State land
Ottawa County land
Ottawa County parks
Private preserves
Owashtanong Islands Sanctuary (Audubon)
Minnie Skwarek Preserve
Land Conservancy
Grand Haven
Grand Haven State Game Area
Crockery Creek
Jubb Bayou
Bur Oak Landing
Riverside Park
Eastmanville Farm
Eastmanville Bayou
Deer Creek Park
Connor Bayou
Conservation Easement Land Conservancy
Bass River State Recreation Area
West Eastmanville Bayou
Ripps Bayou
The Bend Area Mining Reclamation
Grand River Park
Lake Michigan
96
31
45
N
PRESS GRAPHIC


K
J
I
© 2012 Google
Google earth


H
MITIGATION WETLAND
DRIVING RANGE
INTRAMURAL FIELDS
TRACK & LACROSSE
SOCCER FIELD
RUGBY FIELD
HAMMER THROW / DISCUS
JAVELIN
D
NORTH FOREBAY
G
NORTH LOWER CELL
E
NORTH UPPER CELL
F
NORTH MIDDLE CELL
C
SOUTH LOWER CELL
B
SOUTH UPPER CELL
A
SOUTH FOREBAY
OVERFLOW STRUCTURE W/HYDRO-GATE
COLLECTION STRUCTURE
NORTH STORMWATER MANAGEMENT AREA
SOUTH STORMWATER MANAGEMENT AREA
SOUTH STORM WATER DISCHARGE TO EXISTING CULVERT
PIERCE STREET
STORM WATER MANAGEMENT AREA LAYOUT

Work Cited

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Balcombe, C.K., J.T. Anderson, R.H. Fortney, W.S. Kordek. 2005. Aquatic macroinvertebrate assemblages in mitigated and natural wetlands. Hydrobiologia 541: 175-188.

Burton, T.M., D.G. Uzarski, and D.A. Albert. 2009. Ecology and bioassessment of Michigan's inland wetlands. Manual 2 (of 2), Wetland, Lakes and Stream Unit, MDEQ. 69 pp.

Elmqvist, T., C. Folke, M. Nystrom, G. Peterson, J. Bengtsson, B. Walker, J. Norberg. 2003. Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment* **1**: 488–494.

EPA (n.d.) Wetland Bioassessment Methods. In: *Environmental Protection Agency, Water: Monitoring & Assessment.* Retrieved December 14, 2011, from http://water.epa.gov/type/wetlands/assessment/oh1macro.cfm

Hannaford M.J. & V.H. Resh. 1995. Variability in macroinvertebrate rapid-bioassessment surveys and habitat assessment in a northern California stream. Journal of the North American Benthological Society. 14:430-439.

Merrit, R.W., and K.W. Cummins. 1996. An introduction to the aquatic insects of North America, 3rd ed. Kendall/Hunt Publishing Company.

Mitsch, W.J., and J.G. Gosselink. 2011. Wetlands (4th ed.). John Wiley & Sons, Inc.

Stepenuck K.F., R.L. Crunkiltion, M.A. Bozek, L. Wang. 2008. Comparison of macroinvertebrate-derived stream quality metrics between snag and riffle habitats. Journal of the American Water Resources Association. 44:670-678.

Streever, W. J., D.L. Evans, C.M. Keenan, & T.L. Crisman. 1995. Chironomidae (Diptera) and vegetation in a created wetland and implications for sampling. Wetlands 16: 416-428.

Turner R.K., J.C.J.M. van den Bergh, T. Söderqvist, A. Barendregt, J. van der Straaten, E. Maltby, E.C. van Ierland. 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35: 7-23.

Voshell J. R. 2002. A Guide to Common Freshwater Invertebrates of North America. McDonald and Woodward Publishing Company.

Wampler P., T. Kneeshaw. 2012. Storm Water Management Complex 2012 Monitoring Executive Summary.

Wolcox, D. A., J.E. Meeker. 1992. Implications for faunal habitat related to altered macrophyte structure in regulated lakes in northern Minnesota. Wetlands. 12: 192-203.

Appendix 1

	CF1 (2009)	CF2 (2009)	CF3 (2009)	CO1 (2009)	CO2 (2009)	CO3 (2009)	BE1 (2009)	BE2 (2009)	BE3 (2009)	BF1 (2009)	BF2 (2009)	BF3 (2009)	AO1 (2009)	AO2 (2009)	AO3 (2009)	AE1 (2009)	AE2 (2009)	AE3 (2009)	DO1 (2011)	DO2 (2011)	DO3 (2011)	FO1 (2011)	FO2 (2011)	FO3 (2011)	EO1 (2011)	E02 (2011)	E03 (2011)	HO1 (2011)	HO2 (2011)	HO3 (2011)	GO1 (2011)	GO2 (2011)	GO3 (2011)	KF1 (1985)	KF2 (1985)	KF3 (1985)	JE1 (1985)	JE2 (1985)	JE3 (1985)	IF1 (1985)	IF2 (1985)	IF3 (1985)
Aeshnidae	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	5	3	3	0	0
Lestidae	22	1	0	0	0	0	5	0	0	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	19	33	0	1	0	0
Coengrionidae	1	17	21	7	7	18	5	12	11	27	36	31	0	2	9	13	13	18	1	5	3	0	0	0	0	0	0	0	0	0	0	0	0	18	21	11	1	0	0	0	1	24
Libellulidae	2	3	0	0	0	1	5	0	0	3	6	1	0	2	21	1	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	9	32	0	1	0	2	1	5
Caenidae	104	64	40	41	27	49	10	3	12	18	7	45	0	2	1	0	2	6	11	1	1	0	0	0	0	0	0	0	0	0	0	2	1	36	19	45	0	1	0	4	2	18
Chironomidae	8	12	18	17	22	12	12	1	12	46	7	21	50	65	18	3	4	23	39	54	58	59	60	67	19	51	51	143	130	96	54	84	18	2	13	9	2	1	0	12	6	5
Haliplidae	1	2	3	0	0	0	1	0	0	1	12	1	0	0	1	2	2	3	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	5	0	0
Dysticidae	1	0	0	0	0	0	0	0	5	0	0	1	0	0	0	1	0	0	0	0	1	5	2	0	0	0	0	1	0	1	0	3	2	0	0	0	8	2	7	3	0	2
Curculionidae	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptlidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poduridae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corixidae	1	13	0	0	0	0	5	21	4	7	21	10	2	7	13	8	11	6	26	20	1	45	42	35	33	30	39	4	3	9	6	9	24	0	0	0	0	5	0	0	0	0
Annilidae	3	10	2	0	0	1	2	0	16	2	0	0	22	13	0	4	3	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0
Snails	2	4	7	17	21	8	0	3	3	0	1	0	0	0	0	0	0	1	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	5	6	27	15	28	8
Hydracarina	4	14	14	7	20	9	2	1	0	0	11	6	0	3	4	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	11	23	1	1	0	3	0	3
Baetidae	0	3	2	1	0	1	2	1	1	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	11	5	1	0	6	1	0
Ceratopogonidae	0	2	2	6	4	2	4	2	2	0	0	3	0	1	2	8	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1	0	3	1	0
Zooplankton	0	12	7	17	14	2	26	13	19	43	16	10	0	0	0	0	0	2	8	39	5	3	46	1	4	19	5	5	0	9	1	3	6	5	23	7	12	34	2	6	1	2
Plecoptera	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sminthuridae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Isotomidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeriidae	0	0	0	0	0	0	0	0	7	0	0	0	49	7	8	14	59	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	2	3	2	1	0
Hydrophilidae	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	7	3	2	0	0	0
Mackenziellidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Saldidae	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Scuds	0	0	0	0	0	0	0	3	0	3	1	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	3	11	35	54	46	13	8	27
Hebridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Nepidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Notonectidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	5	0	0	0
Culicidae	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	20	0	0	0
Hirudinae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Chaoboridae	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0
Pleidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	16	0	0
Platyhelmenthes	0	0	0	0	0	0	0	4	2	14	6	1	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Oligochaete	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	1	2	0	1	0	0	0	0	0
Veliidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Gerridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	1	0	0	0	0
Helophoridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Entomobrydae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Leptoceridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3
total	152	158	119	114	115	103	80	66	95	170	129	137	123	104	78	55	105	87	89	126	101	113	150	103	56	100	95	156	146	115	62	102	51	90	111	158	120	159	122	95	52	97

Appendix 2

Site C 3/7/2012 Eric & Nate

Site C 3/7/2012

Site B 3/7/2012 Eric & Nate

Site B 3/7/2012

Site A 3/7/2012 Eric & Nate

Site A 3/7/2012

Site H 3/7/2012 Eric & Nate

Site H 3/7/2012

Site G 3/7/2012 Eric & Nate

Site G 3/7/2012

Site F 3/7/2012 Eric & Nate

Site F 3/7/2012

Site E 3/7/2012 Eric & Nate

Site E 3/7/2012

Site D 3/7/2012 Eric & Nate

Site D 3/7/2012

Site K 6/1/2012 Eric, Melissa, Jessie

Site K 6/1/2012

Site J 6/1/2012 Eric, Melissa, Jessie

Site J 6/1/2012 Eric, Melissa, Jessie

Site J 6/1/2012 Melissa


Site J 6/1/2012 Ed

Site J 6/1/2012 Eric

Site J 6/1/2012 Eric, Melissa, Jessie

Bass River Recreation 6/1/2012 Eric, Melissa, Jessie

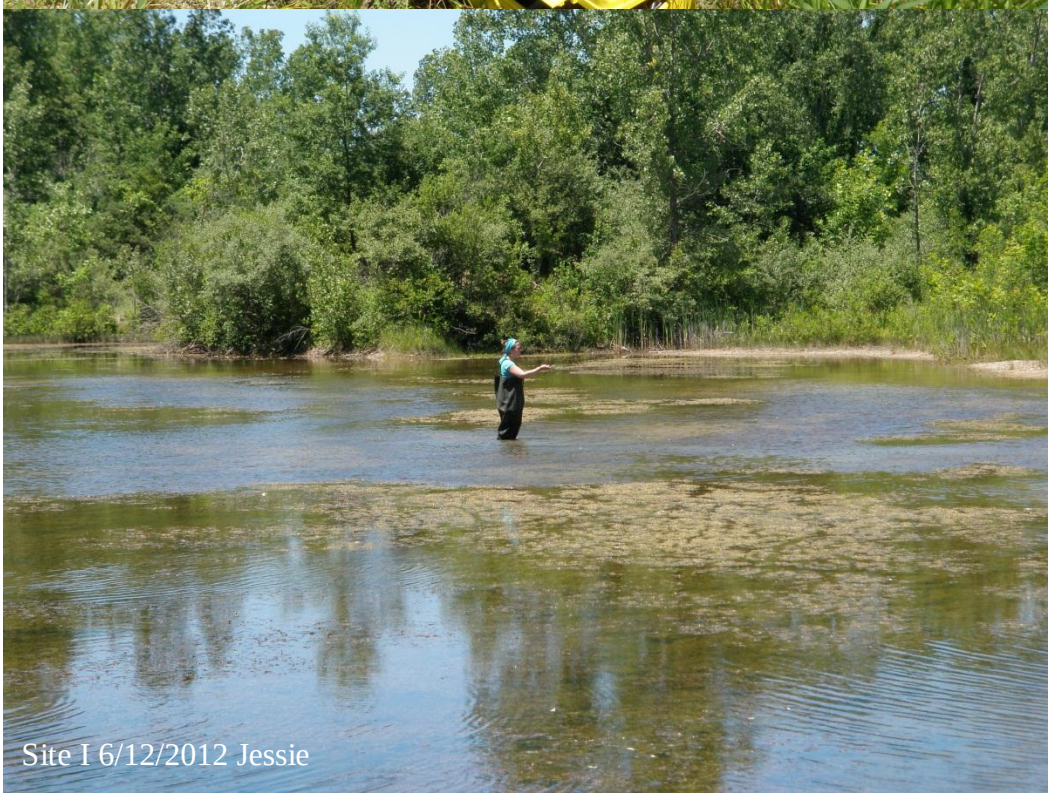
Site K 6/1/2012 Eric, Melissa, Jessie

Site G 6/1/2012 Jessie

Site G 6/1/2012 Nate

Site G 6/12/2012 Nate & Jessie

Site B 6/12/2012 Nate



Site I 6/12/2012 Jessie

Site I 6/12/2012 Jessie

Site I 6/12/2012 Jessie


Site I 6/12/2012 Jessie

Site D 6/12/2012 Nate

Site D 6/12/2012 Nate