Assessment of Environmental Stressors in the Indian Mill Creek Watershed

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Executive Summary

Indian Mill Creek is an agricultural/urban stream located in Kent County, Michigan. Its headwaters originate in the Fruitridge area of Alpine Township and flow through the City of Walker and the City of Grand Rapids before discharging into the Grand River. Indian Mill Creek is a tributary of the Lower Grand River and occupies a drainage area of 10,979 acres. Brandywine Creek, a major tributary of Indian Mill Creek, starts in the City of Walker and flows to the northeast to join Indian Mill Creek. The stream is listed as an impaired waterbody on the State of Michigan's 303(d) List due to its degraded fish community. A survey was conducted by the Michigan Department of Environmental Quality in 2009 and found that the lower reach of the creek did not meet coldwater fisheries community standards. The cause of the impairment was not identified in the survey. We conducted a detailed study of physical, biological, and chemical characteristics along with Geographic Information System characterization of land-use change to identify the sources and causes of environmental stressors impacting Indian Mill Creek. We installed scour chains and erosion pins to measure the rates of streambank erosion and sediment deposition. Temperature, bedload sediment transport, and suspended sediment concentration were measured to evaluate whether stream temperature was meeting the coldwater fisheries standards and if sedimentation was impacting the biota of the creek. The toxicity of the stormwater runoff was evaluated using the Microtox assay and Wolman pebble counts were performed to characterize the substrate composition of the river. Similarly, macroinvertebrate surveys and habitat assessments were conducted to evaluate the overall ecological health of the river. Our results showed that Indian Mill Creek appeared to be meeting the cold moderate or cold stable thermal regime, which was suitable for coldwater fish, such as brown trout, rainbow trout, and white sucker. Stormwater toxicity was determined not to be a factor impacting the biota. Our study showed that the land use was altered significantly since pre-settlement times. The Indian Mill Creek watershed has 12%

impervious surfaces and the impervious amount increases to 20% in the urban area below the I-96 highway. The increase in impervious surfaces in the watershed leads to more runoff which causes episodic high flows followed by lower baseflows. The episodic high flows have greater stream power, which increases bank erosion, bedload transport, and the export of woody debris. The filling of microhabitats of the stream by the sedimentation and loss of woody debris are detrimental to biota of the creek. Amphipod populations decreased by 94% from the stream section above the I-96 highway to Elizabeth Avenue (near the confluence of Grand River). Episodic high flow events also causes channel erosion and changes the morphology of the creek that negatively affects the habitat. Altered hydrology in Indian Mill Creek results in high bedload sediment transport (6680 kg/d) and bank erosion (>60 cm) in the lower reach of the stream and continual deposition of sediment in the channel (aggradation). Aggrading conditions (15-20 cm accumulation using scour chains) were observed at Richmond Park and below the confluence of Indian Mill Creek and Brandywine Creek. Since the temperature is within the cold-moderate category, our results suggest that sediment transport and deposition are the main stressors impacting the coldwater classification. Reducing stormwater inputs through best management practices, such as rain gardens, bioswales, and detention ponds would help maintain or improve the quality of the stream by promoting infiltration and reducing runoff. Decreasing the amount of impervious surfaces through green infrastructure would help maintain the natural flow regime of Indian Mill Creek. Various best management practices like pervious pavement, rain gardens and detention/retention ponds should be installed to increase infiltration of stormwater runoff. Similarly, reconnection of the creek with its floodplains and restoration of wetlands would provide more opportunities for water storage and reduce the negative impact altered hydrology has on the fish communities.

Introduction

A watershed is defined as an area of land that drains to a common rivers, lakes, or ponds. Watersheds play an important role in keeping the river system healthy by providing hydrologic functions such as collecting, storing, filtering, and discharging water in addition to providing habitats for organisms (Brauman et al., 2007; EPA, 2015). The quality of watersheds is impacted by various stressors including point and non-point sources of pollution and land use changes that destabilize hydrology (Meyer et al., 2005). The Environmental Protection Agency (EPA) estimates that even small areas of urban development can impact stream ecosystems because of the significant ecological footprint of impervious surfaces (EPA, 2012). Point source discharges and municipal stormwater discharges are regulated through the National Pollution Discharge Elimination System permit program under the Clean Water Act; however, non-point sources such as agricultural and other nonregulated runoff are difficult to control.

Urbanization and impervious surfaces alter stream hydrology and habitat resulting in a common pattern of impairments referred to as “urban stream syndrome” (Walsh et al., 2005). Most urban streams have elevated concentrations of anthropogenic chemicals, nutrients, and sediment. The runoff from impervious surfaces transport stormwater and associated pollutants to the water bodies, resulting in hydrologic and ecologic impairments (Grimm et al., 2008). The loss of the riparian zone and the increase in impervious areas with storm sewer systems accelerate the input of chemicals into the streams. The loss of the riparian vegetation also increases nutrient and sediment levels in streams. Riparian vegetation provides numerous advantages to stream environments including trapping sediments and chemicals (Daniels & Williams, 1996), exchanging of nutrients with the channel, and providing a nursery ground for fish (Junk et al., 1989). Altered hydrology and geomorphology have been observed in many urban rivers (Paul &

Meyer, 2001) and are detrimental to the biota. Urban streams also experience an increase in peak flows and a decrease in base flows, which change diel variation in dissolved oxygen and the erosive power of the water (Walsh et al., 2005). These streams may have higher summer water temperatures than non-urban streams due to the urban heat islands, point source discharges from wastewater, and removal of riparian vegetation (Wenger et al., 2009). Riparian/channel alteration and stormwater inputs also reduce water quality, destabilize hydrology, and increase suspended sediment and temperature, resulting in impairments to benthic macroinvertebrate and fish communities (Meyer et al., 2005). Stream quality also decreases as imperviousness increases (Klein, 1979). Heavy metals including lead, zinc, and copper in addition to hydrocarbons are transported by stormwater to the streams and rivers, degrading their water quality (Gobel et al., 2007). Rivers are linked to their surrounding landscapes and follow a logical progression from headwaters to the point of discharge (Vannotte et al., 1980). Inputs of runoff water, nutrients, and sediment in the headwaters and mid-reaches can alter both the local and downstream environments. Similarly, surrounding land use also can impact streams (Hardling et al., 1998). Urban stream water tends to have higher toxicity than that of non-urban streams due to the increase in load of pollutants like oil and grease that are discharged by hydrologically connected stormwater. Several researchers have used the Microtox assay to determine the toxicity of stormwater (eg., Pitt et al., 1995; Marsalek et al., 1999; Tang et al., 2013). This technique utilizes a photosynthetic bacterium as a surrogate for higher aquatic organisms and is highly correlated with standard aquatic toxicity assays (Bulich et al., 1981).

Many agricultural/urban streams are reported to be affected by sedimentation. Sediment is transported by suspension in the water column, which is referred to as suspended sediment, or transported along the bed by rolling, sliding, and/or saltation, which is referred to as bedload. Scour chains, erosions pins, and Helley Smith bedload sampler often are used to assess the sediment load in rivers (Turowski & Cook, 2016).

Urban streams tend to have higher temperatures than non-urban streams due to the urban heat island effect. The temperature of headwater streams is usually lower even in summer due to the forest canopy cover and influx of groundwater. The canopy blocks the sun radiation from reaching the stream and keeps the water cool. Temperature plays a major role in presence/absence of species and their life histories because different organisms are adapted to different water temperature. Most of the coldwater fish, such as trout and salmon, are poikilotherms and water temperature determines their metabolism and growth rate as dissolved oxygen concentrations are reduced in warm water (Wilkie et al., 1996).

The Clean Water Act is a federal statute that regulates surface water bodies of the United States. The objective of the act is "to restore and maintain the chemical, physical, and biological integrity of the Nation's water." The National Pollution Discharge Elimination System was established to regulate point sources of pollution. The Clean Water Act provides States with the authority to monitor the water bodies and classify them on the 303(d) list if they are not meeting their designated uses. Impaired waters need to have the sources and causes of the pollution identified to develop a Total Maximum Daily Load (TMDL) for contaminants that are impacting the designated use. The TMDL is the amount of pollutant load that streams can assimilate each day without being impaired for their designated uses.

Watershed descriptions/hydrology of study area

The Indian Mill Creek watershed (Hydrologic Unit Code 04050006 0504) is located in Kent County, MI and is an agricultural/urban sub-watershed of the Grand River (Figure 1). Indian

Mill Creek is a third order stream, with its headwaters beginning in the Fruitridge area of Alpine Township, and then flows through the City of Walker and the City of Grand Rapids, before discharging into the Grand River. A major tributary, Brandywine Creek, starts in the City of Walker and flows to the north to join Indian Mill Creek. The watershed occupies portions of the City of Grand Rapids, the City of Walker and Alpine Township. The Indian Mill Creek watershed has a drainage area of 10,979 acres. Five sampling locations were established for this project (Figure 1). These locations follow a gradient of stream conditions from the agricultural headwaters to the urban corridor. The elevation of the watershed ranges from about 800 feet to about 600 feet where it discharges into the Grand River (Figure 2). The reach from the headwaters to Station 2 is a low gradient stream (0.16%). A large change in slope occurs between Station 2 and Station 3 (0.36%) and the stream flattens out between Station 3 and Station 4 (0.12%). The slope increases rapidly between Station 4 and Station 5 and the confluence of Grand River (0.56%) (Figure 2). The stream power increases with increase in slope.

Water Quality Issues in Indian Mill Creek

Indian Mill Creek is included on the State of Michigan's 303(d) list of impaired water bodies because of a degraded coldwater fish community. A survey conducted by the Michigan Department of Environmental Quality (MDEQ) in 2009 found the lower section (North of Richmond Park) of Indian Mill Creek contained a fish community that was dominated by white suckers (16 individuals) and only 36 total organisms (MDEQ, 2011).

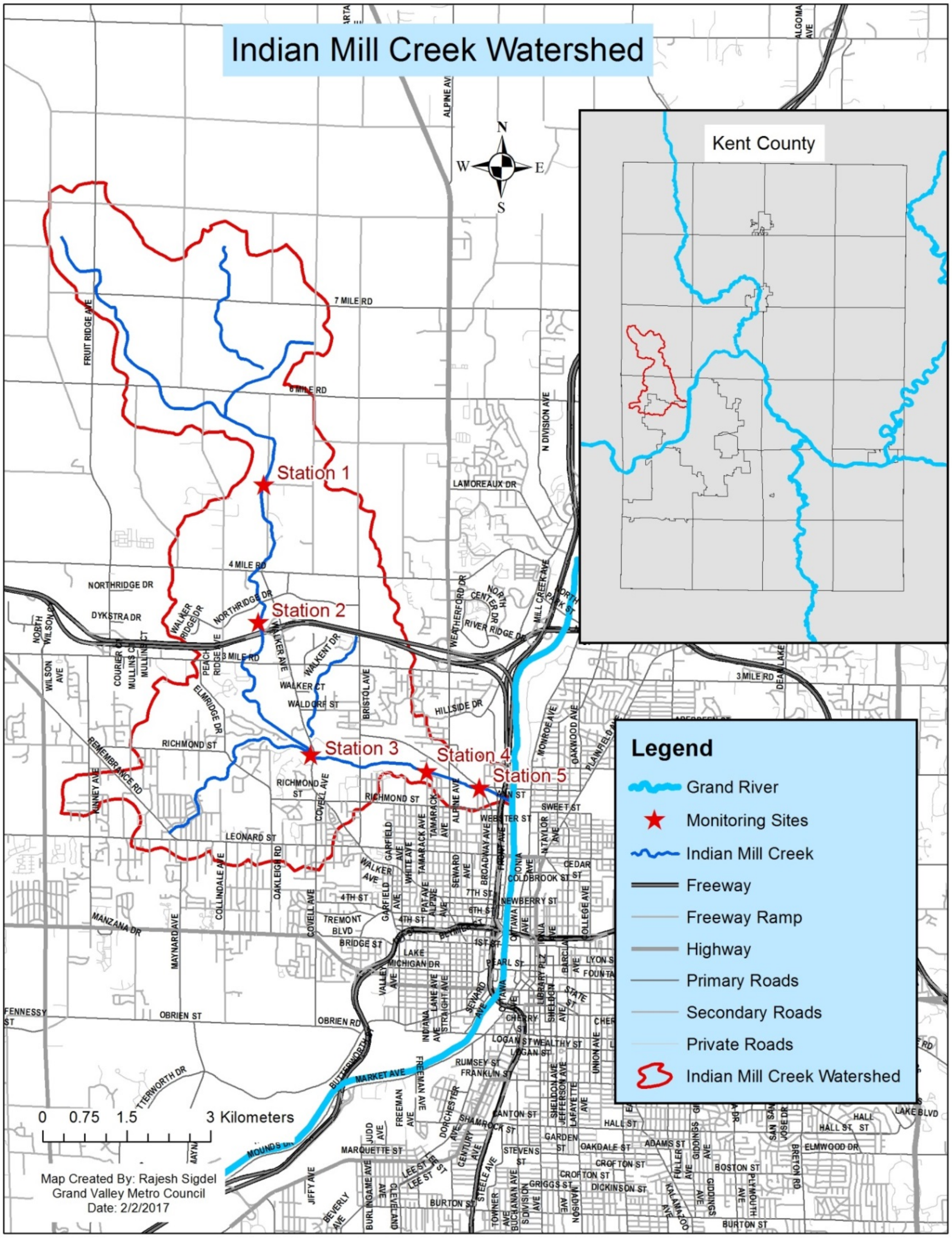


Figure 1. Indian Mill Creek Watershed located in Kent County, Michigan.

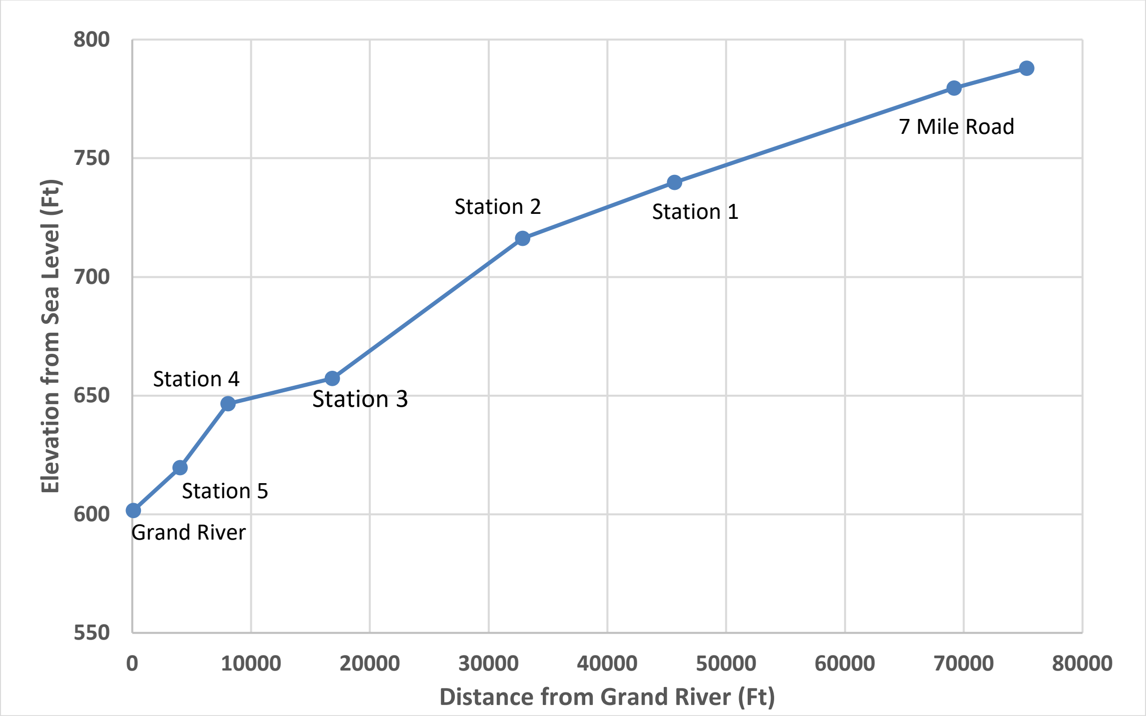


Figure 2. Elevation profile Indian Mill Creek as a function of distance from the Grand River.

The Richmond Park area of the stream did not meet the coldwater fisheries designation even though the benthic community and habitat scores were acceptable. At least 50 individual fish, including 1% salmonids, need to be collected to meet coldwater fisheries standards (MDEQ, 1996). Issues with respect to hydrologic connectivity were absent during the survey and the source of the impairment was not identified. The upper reaches of the stream contained >100 individuals (4% salmonids) and met the coldwater fisheries designated use. Based on limited survey data from the 2009 monitoring event, Indian Mill Creek appeared to meet coldwater temperature requirement; however, the corresponding fish community was not present.

PreSettlement Land Cover

The watershed was dominated by hardwood forest prior to 1800 (Figure 3). Beech-Sugar Maple forest was abundant and covered almost 65% of the area. Shrub swamp / emergent marsh was the second most dominant land cover with about 15% of land cover (Table 1) and was mostly in the upper portion of the watershed. Wetlands occupied 17.67% of the land in the watershed. The Creek is named for a sawmill constructed by Native Americans in 1834. There were considerable pine trees along the banks of Indian Mill Creek and saw mills were erected during the early settlement of Walker Township (Teelander, 2012).

Table 1: Indian Mill Creek Watershed Pre- Settlement Vegetation (State of Michigan, 2017)

No.	Cover Type	Area (sq. km)	Percentage
1	Beech-Sugar Maple Forest	32	64
2	Black Ash Swamp	0.18	0.37
3	Black Oak Barren	3.8	7.5
4	Mixed Hardwood Swamp	1.	2.
5	Mixed Oak Savanna	1.1	2.1
6	Shrub-Swamp/Emergent Marsh	1.7	15.
7	Wet Prairie	0.06	0.12
8	White Pine- Mixed Hardwood Forest	1.4	2.8
9	White Pine- White Oak Forest	3	6.0

1975 Land Cover

Walker Township was officially formed in late 1837 and the area experienced rapid population growth. The City of Walker was formed in 1962 with a population of approximately 11,000. A significant percentage of the area of the watershed was converted to either agricultural land or cities by 1975 (Table 2: Figure 4). The upper section of the watershed was dominated by the agricultural crops, pasture, and hay cultivation, and much of the lower section was developed for urban uses.

About 26% of the land of Indian Mill Creek was agricultural, 12% pasture/hay, 3.3% high density urban and 14% residential (Table 2). A significant loss of the forested land has occurred although some remnants of the forest remain. Deciduous forests dropped to 9.5% in the watershed.

Table 2. Indian Mill Creek Watershed Land Cover - 1975 and 2016 (Source: NOAA Office for Coastal Management, 2017).

No.	Land Class	1975		2016	
		Area sq.km	%	Area sq. km	%
1	Bare Land	0.3	0.7	0.1	0.4
2	Cultivated Crops	11	26	11	26
3	Deciduous Forest	4.4	9.8	4	9.2
4	Developed, High Intensity	1.4	3.3	2.1	4.9
5	Developed, Low Intensity	6.3	14	7.6	17
6	Developed, Medium Intensity	1.9	4.4	2.6	6
7	Developed, Open Space	5.5	13	6.6	15
8	Evergreen Forest	0.3	0.7	0.3	0.7
9	Grassland/Herbaceous	2.6	6	0.6	1.3
10	Mixed Forest	0.4	1	0.4	0.9
11	Open Water	0.03	0.08	0.05	0.1
12	Palustrine Emergent Wetland	0.4	0.9	0.4	0.9
13	Palustrine Forested Wetland	1.2	2.8	1.2	2.8
14	Palustrine Scrub/Shrub Wetland	0.9	2	0.8	2
15	Pasture/Hay	5.3	12	5.1	11
16	Scrub/Shrub	1.5	3.1	0.6	1.3

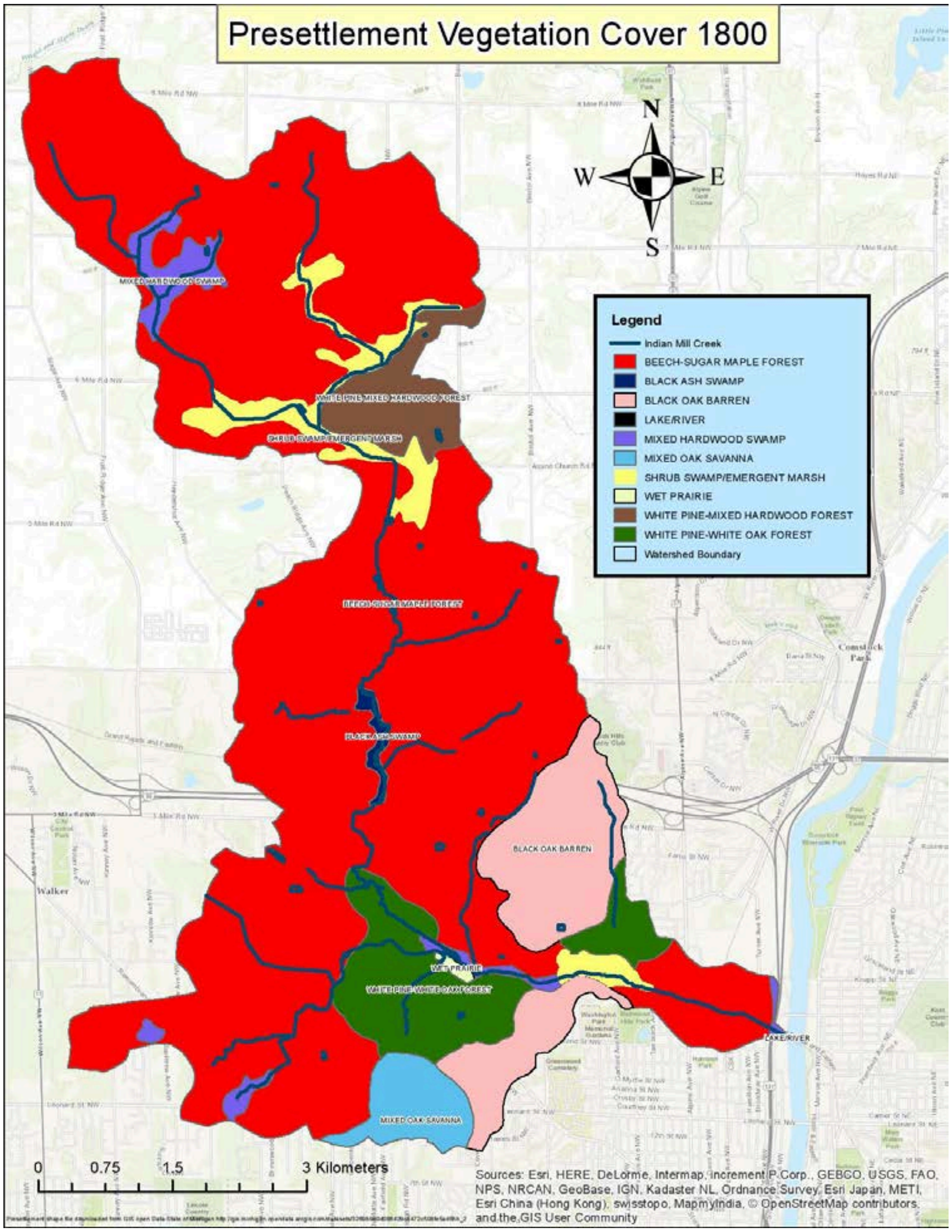


Figure 3. Indian Mill Creek Pre-Settlement Vegetation Cover (Source: State of Michigan, 2017)

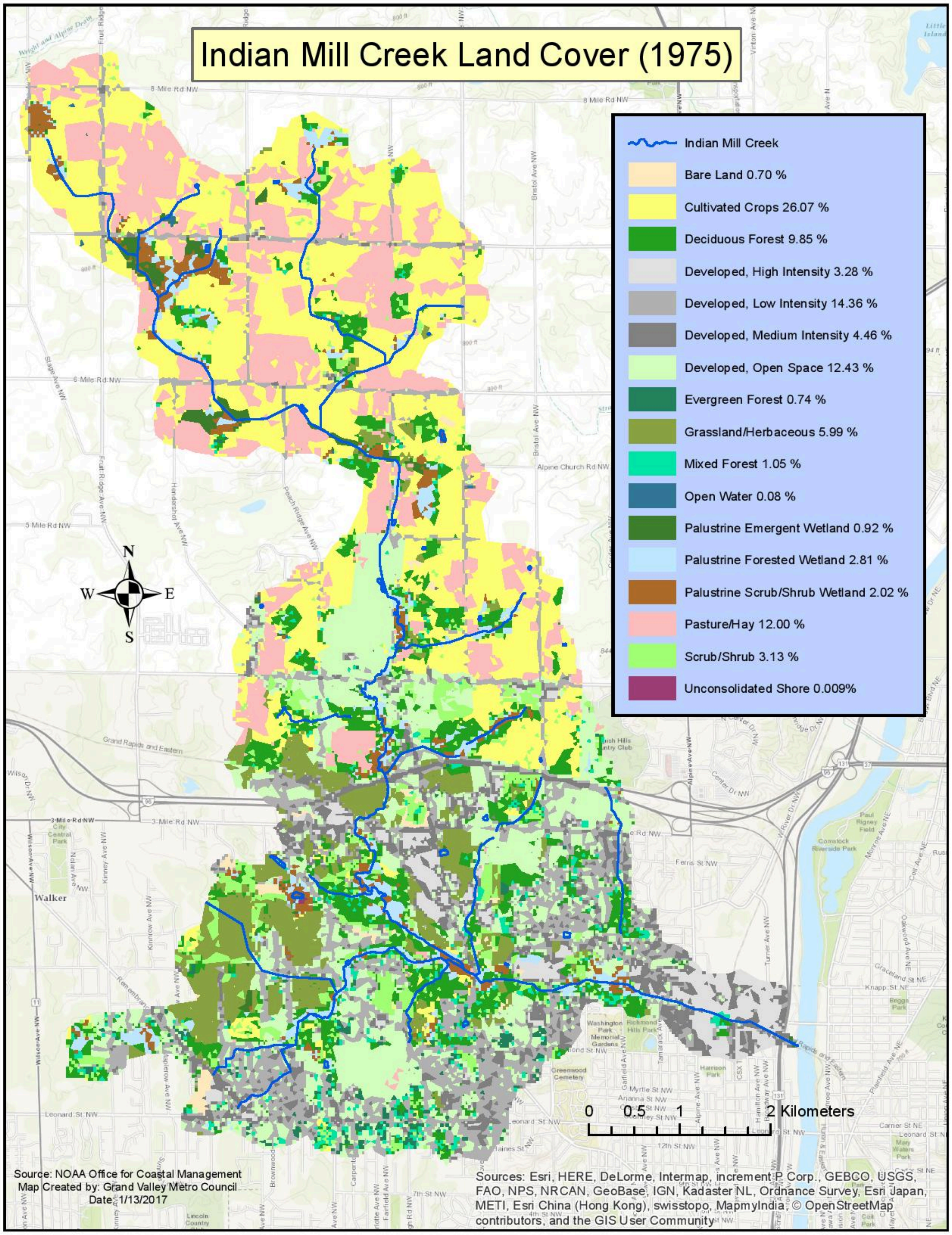


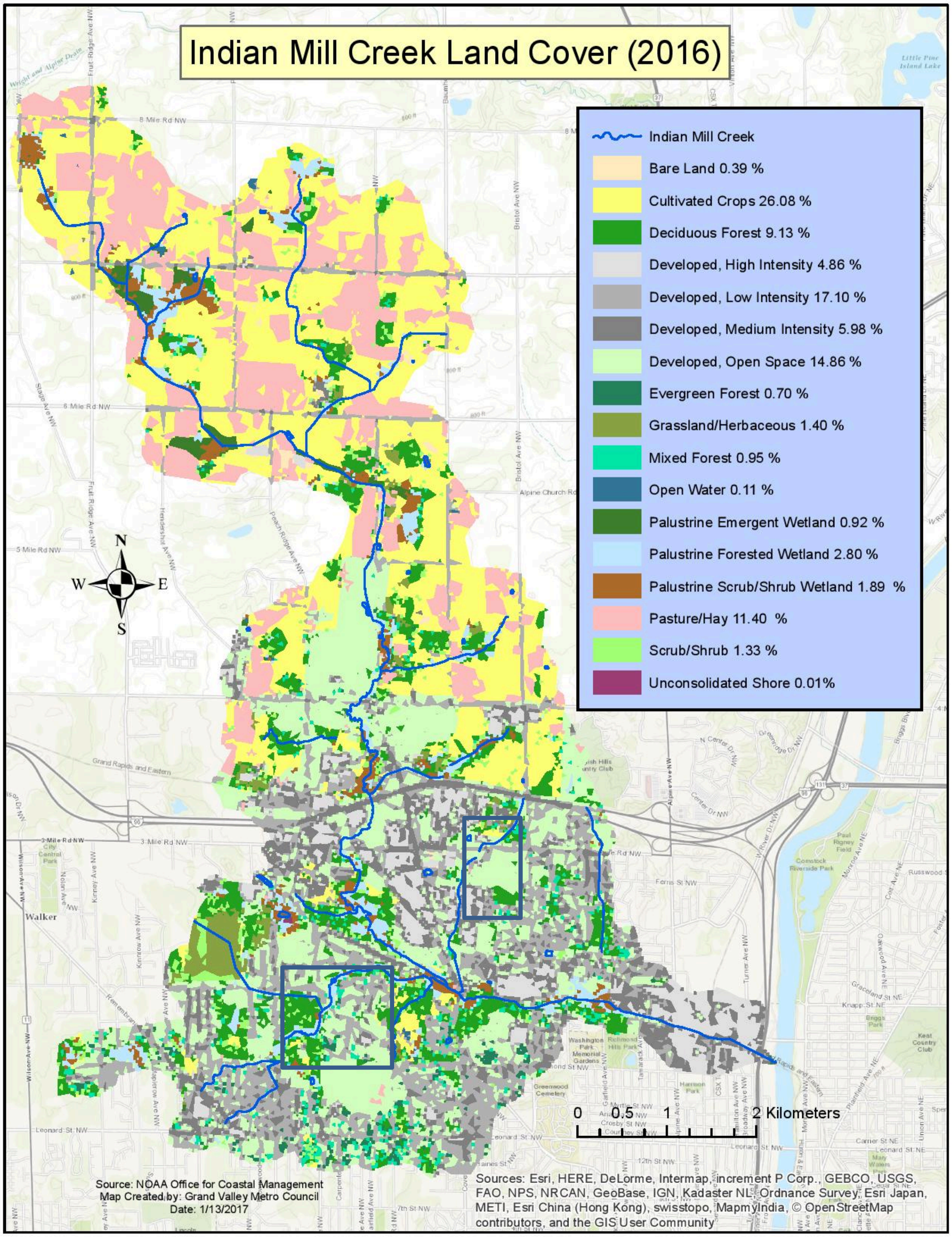
Figure 4. Indian Mill Creek Watershed Land Cover - 1975 (Source: NOAA Office for Coastal Management, 2017).

Current Land Cover

From 1975 to present, minimal changes to the land cover have occurred (Figure 5). Small increases in high, medium and low intensity development occurred (4.8% 5.9% and 17%, respectively). Most of the urban areas were developed by 1975. However, the area adjacent to Brandywine Creek (Figure 5) had a significant decrease in the herbaceous land that was converted to either developed open space or residential area.

Similarly, a portion of the land was converted from herbaceous to industrial in the areas adjacent to Walker Ditch (Northeast from Walker Avenue and Waldorf St). In the 1960s, 17 acres of land (near the Brandywine Creek) were donated to the Grand Rapids Public Museum to develop a nature center. The Blandford Nature Center was formed and the preserved land increased to 143 acres over time with more donations and acquisitions. Recently, the adjacent Highland Golf Course (122 acres) was donated to the Blandford Nature Center, which will double the amount of preserved land in the watershed.

Impervious surfaces act as hydrologically efficient mechanisms to deliver precipitation making the stream unstable and flashy. King et al. (2005) reported that the degradation of a stream beyond 10% impervious surface is highly likely. About 12.2% of the Indian Mill Creek is impervious (Figure 6). The watershed has more than 20% impervious surface in the urban areas below I-96.


Indian Mill Creek Land Cover (2016)

Source: NOAA Office for Coastal Management
Map Created by: Grand Valley Metro Council
Date: 1/13/2017

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 5. Indian Mill Creek Watershed Current Land Cover – 2016 (source: NOAA office for coastal management, 2017). (Boxes denote areas of significant land cover change.)

Hydrologic Soils of Indian Mill Creek

Soils are divided into 4 hydrologic groups based on their runoff and infiltration capacity (USDA, 2007). These soil groups are used to estimate direct runoff from rainfall. According to USDA, group of soils having similar runoff characters are assigned to the same Hydrologic Soil Group. Hydrologic soil groupings are important in predicting the runoff from surface and infiltration of water to the underground water table (USDA, 2007). The four hydrologic soil groups are Group A, B, C, and D.

Group A soils are mostly sand, gravel, loam, or sandy loam and have the lowest runoff potential and highest infiltration rate. These soils have less than 10% clay and more than 90% sand or gravel. Group B has a moderately low runoff potential and infiltration capacity. It is composed of 10% - 20% clay and 50% - 90% sand or gravel. Group C has moderately high runoff potential and low infiltration capacity. These soils are mostly sandy clay loam. Similarly, Group D soil has very high run off potential and very low infiltration capacity. These soils are mostly made of clay loam, silty clay loam, or clay. The dual hydrologic soil groups are placed based on the presence of water table within 24 inches of the surface (USDA, 2007). If the part of the soil is artificially drained and the part is undrained, then the soil is also classified as dual category.

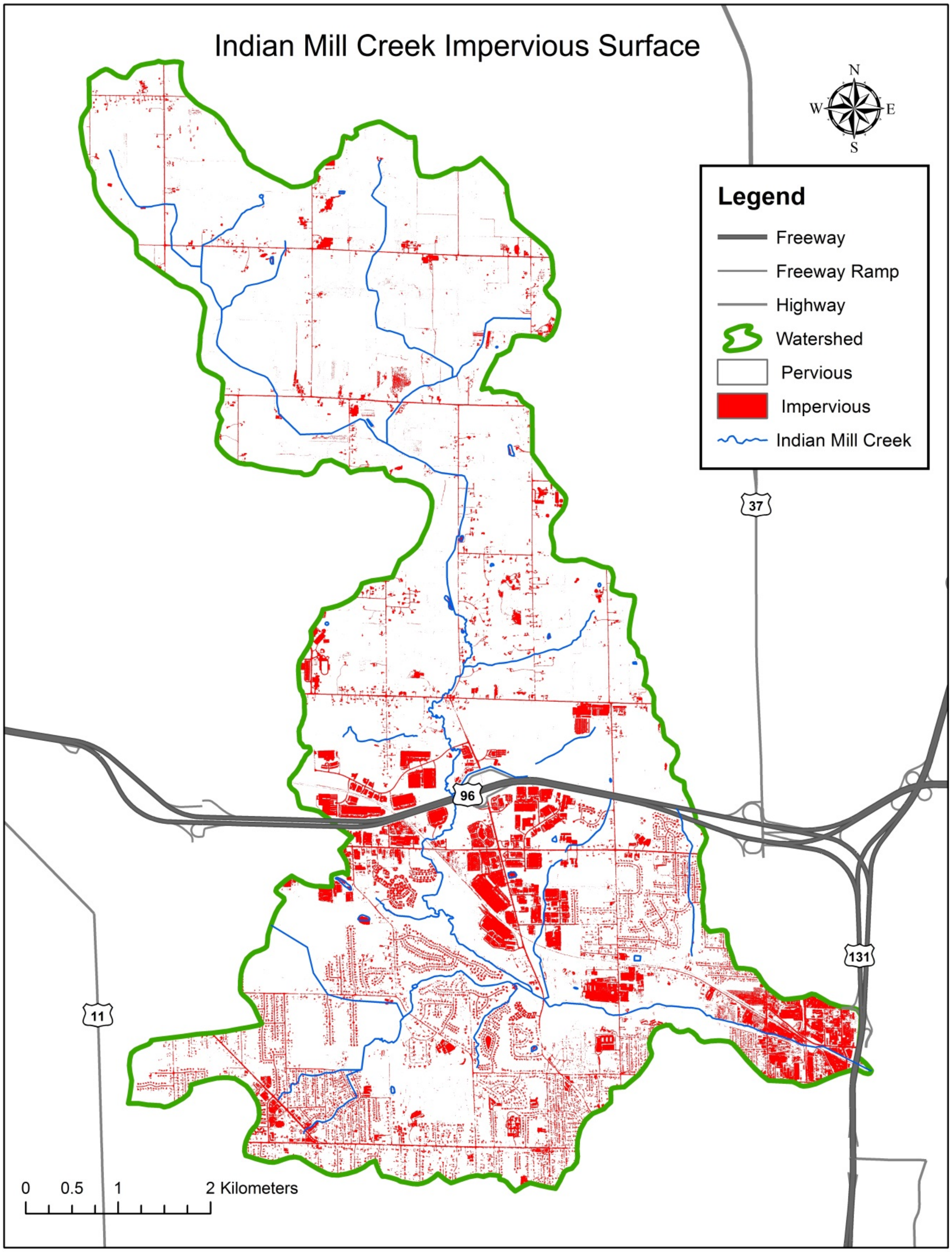


Figure 6. Indian Mill Creek Watershed Impervious Surface Cover (2016).

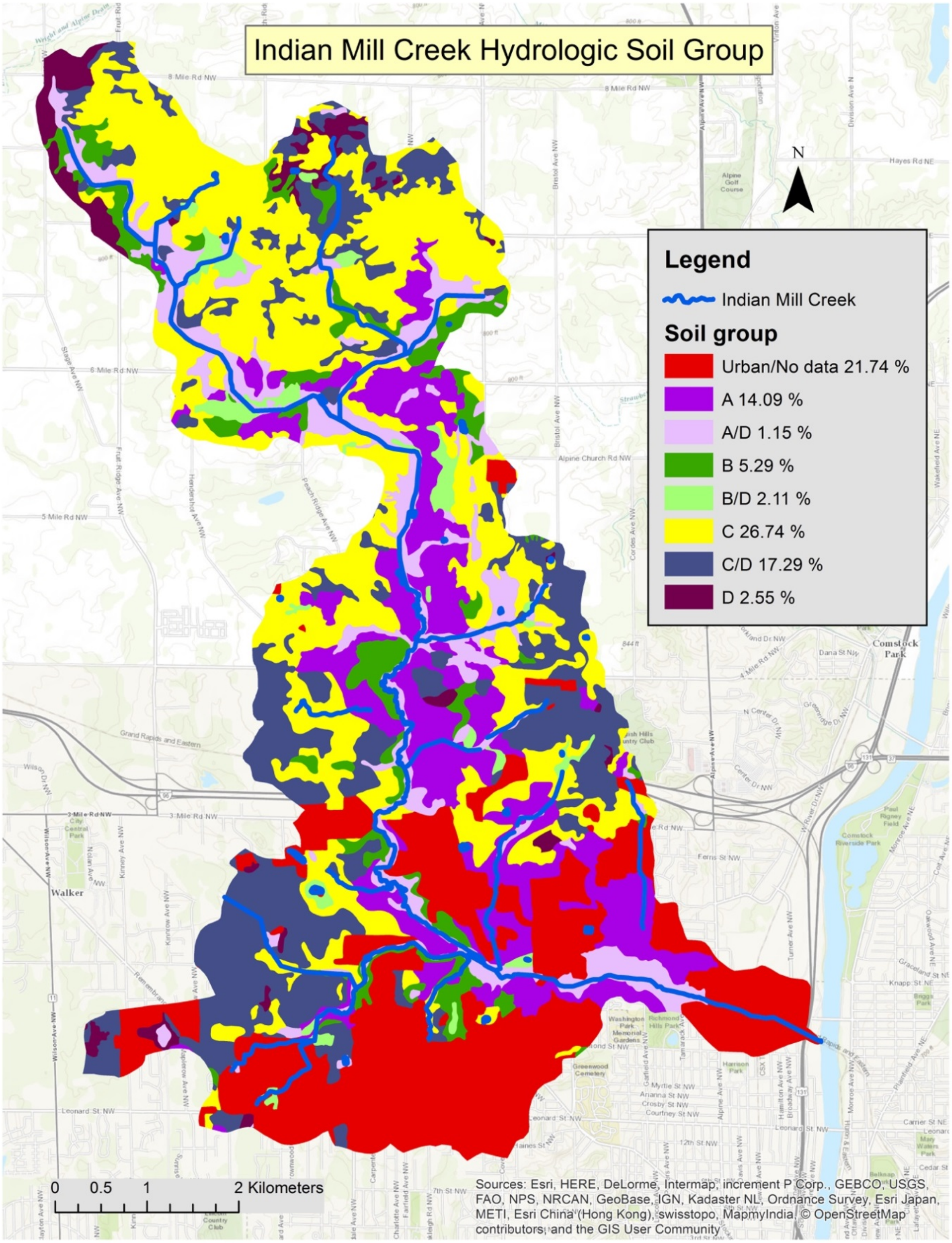
Indian Mill Creek watershed has a mixture of all hydrologic soil groups (Table 3; Figure 7). Group C is the highest percentage with about 26%. However, the lower portion of the watershed is all urbanized. Very little Group D soils exist in the Watershed with only 2.5%. Areas of Group C/D soils are concentrated in the Brandywine Creek subwatershed indicating a high potential for runoff. Sand deposits are located near the stream channel north of I-96 and also in the lower watershed. Sandy soils are highly erodible and will contribute to the stream's bedload.

Table 3. Indian Mill Creek Watershed Hydrologic Soil Groups (USDA, 2017).

No.	Rating	Acres (Sq. km)	Percentage
1	Urban/No Data	9.6	21.7
2	A	6.2	14.1
3	A/D	4.5	10.2
4	B	2.3	5.2
5	B/D	0.9	2.1
6	C	11.9	26.7
7	C/D	7.6	17.3
8	D	1.1	2.5

Summary of Historical Biological Assessments of the Indian Mill Creek Watershed

Biological assessments using benthic macroinvertebrates are often used to determine the ecological health of river systems (Lenat, 1988). Cairns and Pratt (1993) defined biological monitoring as "surveillance using the response of living organisms to determine whether the environment is favorable to living material." Early use of the macroinvertebrates focused on the detection of the organic pollution in water bodies (Richardson, 1925) and current assessments of these organisms are used to determine habitat quality and overall ecosystem health. Macroinvertebrate communities are highly abundant and their ubiquitous nature makes them



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 7. Indian Mill Creek Watershed Hydrologic Soil Groups (Source: Untied Stated Department of Agriculture, 2017).

suitable for bioassessment. Similarly, benthic communities are a very diverse group of organisms with a wide range of the tolerance to environmental stressors (Abel, 1989; Hellawell, 1986). They are sedentary species and often show strong reactions to human influences on aquatic ecosystems (Cairns & Pratt, 1993). Their distribution and populations also can help determine “synergistic or antagonistic effects” of stressors in the watershed (Gaufin, 1973; Wielderholm, 1980).

The biological integrity of Indian Mill Creek was assessed with Michigan Procedure 51 (P51). P51 is a rapid bioassessment method for wadable streams that examines the quality of stream habitat and the integrity of the macroinvertebrate and fish communities (MDEQ, 1990). The benthic macroinvertebrate portion of P51 uses 9 metrics: total number of taxa, total number of Mayfly taxa, total number of Caddisfly taxa, total numbers of Stonefly taxa, percent Mayfly composition, percent Caddisfly composition, percent contribution of the dominant taxon, percent Isopods, Snails, and Leeches, and percent surface dependent.

Each metric is scored between +1 and -1. The total score ranges from +9 to -9 and sites with scores of more than +5 are considered excellent, sites with scores between +5 to -5 are considered as acceptable, and sites scoring less than -5 are considered poor and categorized as impaired for the benthic macroinvertebrates community. MDEQ recommends taking the macroinvertebrate samples from all available habitats including low and high water velocity areas and all substrate types. The P51 procedure has undergone several revisions and the recent revisions (2005) recommend subsamples of approximately 300± 60 organisms should be collected for the enumeration (MDEQ, 2005). The designated coldwater streams are evaluated on the presence of at least 50 fish and minimum 1 % of the fish population collected should be salmonids (MDEQ, 1990)”.In addition to that, fish with anomalies (bent spine, open lesions, severely eroded fins, fungus patches, and growths on skins or fins, tumors, poor physical condition indicated by severe emaciation, excessive mucus coating, and hemorrhaging) should not exceed 2 percent (MDEQ, 1990). The habitat rating part of P51 uses metrics of Substrate and Instream Cover, Channel Morphology, Riparian and Bank Structure. Sites with a rank of >107 are considered excellent for habitat, sites scoring between 71-107 are ranked as good, sites scoring between 35-71 are classified as good, and sites scoring less than 35 are considered poor.

Biological assessments of the Indian Mill Creek watershed were conducted in 1991, 1998, 2005, 2009, and 2011. In 1991, the Michigan Department of Natural Resources (MDNR, 1993 [report year]) conducted a survey of stream habitat and macroinvertebrate and fish communities at three locations: downstream of 3 mile road, Alpine Avenue (near Richmond Park), and Broadway Avenue (near the confluence of the Grand River) (Figure 8). Additional assessments were made at 4 Mile and 6 Mile Roads.

The MDEQ reported the presence of steelhead ranging from 4 to 9 inches and the absence of self-sustaining populations of brown trout. They found 100 fish in 3 Mile Road Station 1) with 7 Salmonidae, 38 at the Alpine Avenue crossing (Station 2 near the Richmond Park) with 5 Salmonidae, and 59 at the Broadway Avenue crossing Station 3) with 6 trout. Minnows and carp were the most dominant species. They also found significant number of white suckers in the creek. Heptageniidae, Gerridae, Hydropsychidae and Athericidae were the dominant macroinvertebrate taxa in Station 1 and Chirnomonidae was dominant at Station 2 and 3. The macroinvertebrate population was rated as fair (moderately impaired) in all stations. Habitats in each station were fair with moderately impaired and they hypothesized the reduced habitat and lower scoring of stations could be due to the elevated siltation/deposition due to the unstable flow conditions causing bank erosions (MDNR, 1993).

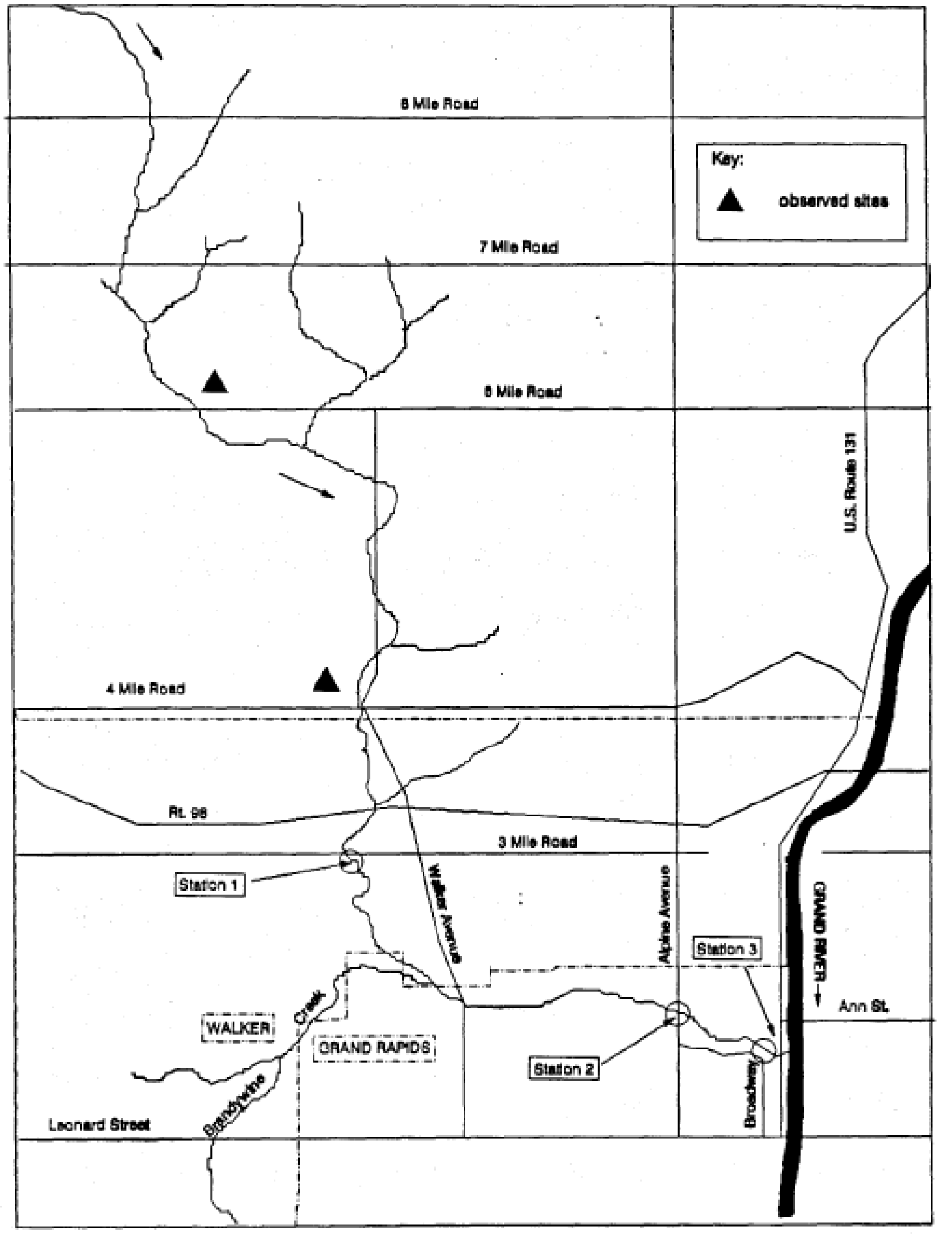


Figure 8. Locations of sites survey by MDNR in 1991. (Figure source: MDNR, 1993).

The 1998 survey by MDEQ (MDEQ, 1998) was conducted in response to a release of ammonia by Thornapple Valley Meat Company, which killed all the fish populations in the creek (Figure 9). A macroinvertebrate survey was conducted upstream of the industry and two samples downstream (Bristol Ave and Richmond Park) were collected. The upstream scored -1 (acceptable). The first downstream also scored -1 and was considered acceptable. The second downstream station scored -7 (poor). However, the results were influenced by the ammonia spill and were not representative of typical stream conditions.

The 2004 survey by MDEQ (MDEQ, 2005 [report year]) conducted north of Richmond Park (near Station 4 of this research) reported 41 individuals of fish species with 10 taxa and only 2 individuals of Salmonidae (Table 4). White sucker consisted significant portion (17 individuals) of the population. Macroinvertebrates were scored -5 and considered poor. Another qualitative fish sampling was conducted in north Richmond Park and 3 Mile Road by MDEQ in 2009 (MDEQ, 2011 [report year]). MDEQ found only 36 individuals with 10 Salmonidae north of Richmond Park and this section was considered as poor. At the 3 Mile Road location, 121 individuals were found with 5 Samlonidae. White Sucker dominated in Richmond Park (16 individuals) and Blacknose dace were the largest composition with 65 individuals at 3 Mile Road. Both Stations received -2 (acceptable) for the macroinvertebrate metric. Similarly, backpack electrofishing conducted by Streamside Ecological Services north of Richmond Park in 2011 (Streamside Ecological Services, 2011) also found Rainbow Trout, Brown Trout, White sucker, and Blacknose dace (Table 4).

Purpose of the Study

The Lower Grand River Watershed Management Plan (LGRWMP), approved by the EPA in 2011, was developed to improve the overall health of the Grand River and enhance water quality through of the implementation of best management practices (Fishbeck, 2011). The plan identified urbanization, bacteria (*E. coli*), stormwater, suspended sediment, loss of wetlands, and habitat destruction as significant concerns for the region. The Lower Grand River Organization of

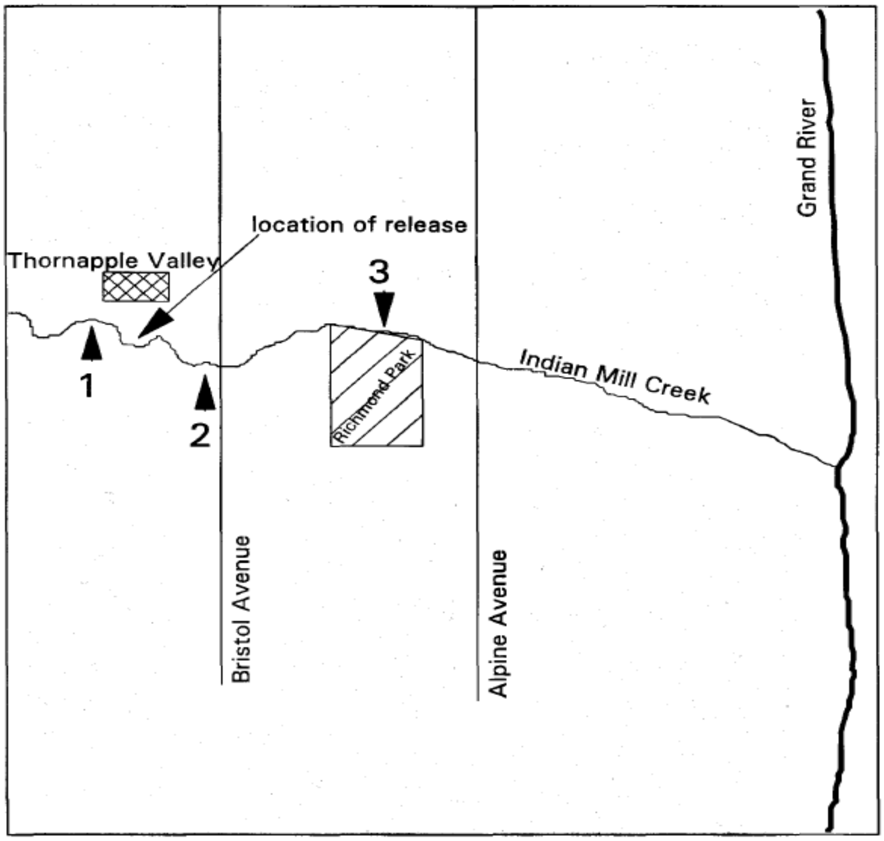


Figure 9. Locations of survey conducted by MDEQ in 1998. (Figure source: MDEQ, 1998).

Watersheds (LGROW) is responsible for overseeing the implementation of the LGRWMP. The LGRWMP prioritized the subwatersheds within the Lower Grand River Watershed based on five categories: estimated sediment loading, nutrient loading, Total Maximum Daily Loading nonattainment reaches, wetland restoration areas, and number of non-point sources sites that were identified through field visits.

Table 4. Fish survey conducted at Indian Mill Creek in 2004, 2009, and 2011. X represents present but not counted. North of Richmond Park is located is Station 4 of my research.

Name of Fish Species	**North of Richmond Park**			**3 Mile Rd**
	2005	**2009**	**2011**	**2009**
Salmonidae (trout)				
Oncorhynchus mykiss (Rainbow trout)	2	9	8	3
Salmo trutta (Brown trout)		1	5	2
Umbridae (mudminnows)				
Umbra limi (Central mudminnow)	1			
Cyprinidae (minnows and carp)				
Campostoma anomalum (Central stoneroller)				8
Pimephales notatus (Bluntose m.)	1			
Semotilus atromaculatus (Creek chub)	6		X	22
Rhinichthys atratulus (Blacknose dace)	6	1	X	65
Catostomidae (suckers)				
Catostomus commersoni (White sucker)	17	16	X	7
Gasterosteidae (sticklebacks)				
*Culaea inconstans (*Brook stickleback)				1
Centrarchidae (sunfish)				
Ambloplites rupestris (Rock bass)	2			
Micropterus dolomieu (Sm. Bass)	2			
Lepomis cyanellus (Green sunfish)	3	4	X	
Percidae (perch)				
Etheostoma nigrum (Johnny darter)	1	4	X	13
Lotidae (cod)				
Lota lota (Burbot)	0	1		
Total individuals	**41**	**36**		**121**

Based on these categories, the plan identified Indian Mill Creek as a high priority watershed for restoration. From the data collected in 2009 (MDEQ, 2011), Indian Mill Creek appeared to meet coldwater temperature requirements however the corresponding fish community was not present. Identification of the source of impairment is the initial step to determine Total Maximum Daily Load (TMDL). Establishment of a TMDL helps to set the target that the water body can handle without degrading their designated use. The source of impairment may be due to hydrologic instability, sedimentation, and/or the presence of toxic chemicals from industrial/stormwater sources.

In order to determine the source and nature of the impairment to coldwater fisheries, a preliminary assessment of stream hydrology, sedimentation, and toxicity was conducted in Indian Mill Creek. The assessment included the following components

- Stream temperature assessment using data loggers to determine coldwater fishery status.
- Suspended sediment Concentration (SSC) and bedload sediment monitoring to determine loadings and concentrations,
- Erosion pins, scours chains, and Wolman Pebble Count to examine bank erosion, aggradation, degradation, and stream bottom conditions.
- Benthic macroinvertebrate survey using MDEQ P51 methods to assess the status and overall health of the macroinvertebrate community.
- The Microtox assay to screen water samples for toxicity.
- Current land use update to examine landscape impacts to stream quality. (presented in Watershed Description)

Land use change was also updated to provide current information. Five Stations were identified for sampling purposes (Figure 1) for bedload, macroinvertebrates, SSC, and hydrology. These stations represent a variety of potential impacts including agriculture, golf course, residential, and industrial land use.

Research Questions and Hypotheses

The research questions I addressed concerning Indian Mill Creek included:

1) Is the temperature regime sufficient to support a coldwater fishery?

2) What are the amounts of suspended and bedload sediment impacting the stream?
3) Are there any stormwater sources of toxicity affecting the stream?

Three hypotheses were developed for this research to address the above questions:

H_1: The thermal regime of Indian Mill Creek may no longer be suitable for coldwater fisheries due urban runoff and decreases in the vegetative riparian zone.

Rationale: There are numerous breaks in the riparian vegetation of Indian Mill Creek which may impact the thermal regime and result in temperatures that will not support salmonids and other coldwater fish.

H_2: Toxic pollutants may be affecting Indian Mill Creek.

Rationale: The lower portion of the Indian Mill Creek is highly industrialized and contains numerous point and nonpoint discharges of stormwater that may contain toxic pollutants.

H_3: Erosion and Sedimentation have affected the lower reaches of the stream to the extent that benthic macroinvertebrates and fish populations are degraded.

Rationale: Previous biological survey indicated that Indian Mill Creek could be suffering from sedimentation/siltation. The stormwater runoff may be increasing the amount of bedload sediment transport and streambank erosion..

The proposed research will assist in the identification of hydrologic, geomorphic, and chemical impairments that may be affecting Indian Mill Creek and provide information to be used in remediation and restoration

Sampling Locations and Descriptions

The sampling locations are shown in Figure 1. Station 1 (Figure 11) was located off 5 Mile Road and Walker Avenue in Alpine Township (43.044188, -85.729805 [WGS 1984]). The station was highly influenced by the surrounding agricultural land. Upstream from Station 1, various crops like apples, peaches, and pumpkins are grown. The flow (velocity) of the water was low and did not change significantly during our field visits. The substrate consisted of loose muck and plant detritus. The riparian vegetation was present on both sides of the stream.

Station 2 (Figure 12) was located off the Walker Avenue on the Gerald R. Ford Council Boy Scouts of America building (43.021898, -85.730992 [WGS 1984]). This station was below the Highland Golf Course. The station had intact riparian vegetation and the flow was moderate. The stream channel width was 2.5 m and the substrate was medium gravel and sand.

Station 3 (Figure 13) was located south of Walker Avenue below the confluence with Brandywine Creek (43.000663, -85.718531 [WGS 1984]). Stream discharge and width increased at this station and the substrate consisted of gravel and sand. The north bank of Station 3 was cleared and vegetation consisted grasses whereas the south bank had riparian shrubs and trees. Plastic netting was present along the north bank to help control erosion (Figure 14). Walker Ditch empties into Indian Mill Creek below Station 3 and appears to be a significant source of bedload sand (Figure 15).

Figure 10. Station 1, 5 Mile Road and Walker Avenue in Alpine Township, MI.

Station 4 (Figure 16) was located north of Richmond Park (42.998049, -85.692500 [WGS 1984]). This site also was used by the MDEQ study in 2009 where they determined the stream did not meet the coldwater fisheries standard. The south bank of Station 4 had riparian trees and shrubs; however, the north bank had a fenced-in salvage yard with very little riparian vegetation. The substrate consisted of sand with some gravel.

Station 5 (Figure 17) was located off Elizabeth Avenue, 1 Km from the confluence of the Grand River (42.995708, -85.682006 [WGS 1984]). The north bank of Station 5 was a concrete wall and the south bank had some riparian shrubs. The velocity of the water was moderate at this site during all of our field visits and the substrate consisted of rocks and coarse gravel imbedded with sand.

Figure 11. Station 2, Boy Scouts of America property in the City of Walker, MI.

Figure 12. Station 3, Walker South (after the confluence with Brandywine Creek in the City of Walker, MI).

Figure 13. Plastic netting at Station 3 of Indian Mill Creek.

Figure 14. Sedimentation in Walker Ditch.

Figure 15. Station 4. North of Richmond Park.

Figure 16. Station 5 of Indian Mill Creek Watershed.

Eighteen sites were used for the Microtox assessment of stormwater toxicity (Figure 18). These locations represent tributaries, drains, and industrial locations where stormwater enters Indian Mill Creek.

Methods

Geographic Information System Data

The land use change of Indian Mill Creek was evaluated using Geographic Information System. The pre-settlement vegetation and 2016 land cover data were downloaded from NOAA

Office for Coastal Management website (www.coast.noaa.gov/digitalcoast/). The current aerial photography (2016) was acquired from the United States Department of Agricultural to calculate impervious surfaces of the Indian Mill Creek watershed. Spectral signatures of each class were collected and the signature was used to distinguish the impervious surfaces from pervious surfaces using maximum likelihood classification approach (Li et al., 2014) using ArcMap 10.1 (ESRI, 2016).

Stream Temperature

Temperature transducers were used to continuously monitor stream temperature during July and August. Wehrly et al., (2003) categorized the coldwater streams of Lower Peninsula of Michigan into three thermal categories: cold (<19°C), cool (19°C to <22°C), and warm (≥22°C) for average temperatures and stable (<5°C), moderate (5°C to <10°C), and extreme (≥10°C). The cold-moderate thermal category was optimal for brown and rainbow trout, blacknosed dace, and white sucker (Wehrly et al., 2003). Temperature loggers (Onset HOBO Model U20) were installed at Stations 2-4 (Figure 1) to measure stream temperature at 2 hour intervals during July and August 2016. Transducers were suspended within 5 cm of the sediment surface and attached to tree roots. Average temperatures and temperature ranges were divided into a 3 × 3 matrix with the following thermal categories: cold (<19°C), cool (19°C to <22°C), and warm (≥22°C) for average temperatures and stable (<5°C), moderate (5°C to <10°C), and extreme (≥10°C) for temperature ranges.

Scour chains and erosion pins

Scour chains assists in determining whether the stream bed is degrading or aggrading (Mistak et al., 2007). Researchers have used chains to determine the scour and fill of sediment (eg:

Figure 17. Microtox toxicity assessment sites in Indian Mill Creek Watershed (2016).

Leopold et al., 1966; Carling, 1987; Hassan, 1990) and have concluded that scour chains work well in many fluvial systems. Scour chains were installed with 10 cm of chains exposed according to Bigelow (2003) each station to measure depth of sediment deposition or scour over time. Scour chains were monitored for sediment deposition and/or scour during each monthly field visit. At the end of the sampling period, each scour chain was located using a metal detector and assessed for dynamic scour and fill, in which scour occurs first, exposing the chain, followed by burial by fill. This situation was demonstrated by a chain that was laid over 90 degrees under a layer of sediment. Scour chains found in this position were measured from the point at which they were bent to determine the depth of scour and the depth of fill was measured burial depth.

Erosions pins consist of rods that are inserted as a benchmark in the bank of a river. Erosion pins measure the process of erosion or sedimentation rather than the rate. They are very effective in a wide range of fluvial ecosystems (Lawler, 1993). Midgely (1975) found that they can be easily inserted in any type of soil, and can be used in meandering or straight channels (Haigh, (1977) which makes it suitable to use in Indian Mill Creek. Erosions pins are widely available and are inexpensive. Haigh (1977) reported that the erosions pins are the most effective tools for monitoring even small changes in the stream banks caused by erosion or deposition. Hansen (1971) studied sediment in Pine Creek located in the northwestern part of Michigan’s Lower Peninsula and determined that the stream bank erosion contributed significantly in the sediment budget of the stream. The use of erosion pins in the stream banks measures the lateral change in streams (Lawler, 1993).

At Stations 1-5, 60 cm erosion pins were (Hooke, 1979) inserted in the streambank and monitored. Erosion pins were set at water level and 30 cm above water level. Sites for the erosion pins were determined to represent wide range of the lotic habitats and stream banks. The pins were checked in each site visit. The differences in the length of the exposed pins were calculated to determine the erosion of the banks.

Discharge

Manual flow measurements were taken at permanently-marked transects over a range of stages from base flow to storm flow, with a minimum of 10 measurements per location. Water depth and velocity (at 0.6 depth from the surface) were measured at equally-spaced points along the transects using a Marsh-McBirney Flow Mate 2000 flow meter attached to a top-setting wading rod, according to USGS protocols (Rantz et al., 1982). Discharge was calculated as the sum of the flow recorded in each transect interval.

Macroinvertebrates and Habitat

Qualitative macroinvertebrate sampling of the creek using Michigan Procedure 51 (P51; MDEQ, 1990) was conducted on June 29, 2016. Representative stream habitats were sampled for about 45 minutes at each site. All the collected insects were put in a plastic tray and a subset of individuals were randomly selected from the sample and immediately placed in a jar containing 80 percent ethanol. Macroinvertebrate identification was conducted using taxonomic keys (Merritt and Cummins, 1996). The 9 metrics included in the P51 method were calculated for each site (MDEQ, 1990). Scoring was standardized by stream size and is ecoregion-specific. The proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT) also was calculated.

Bedload and Suspended Sediment Concentration

Sediment transport occurs in streams as suspended material and as bedload. The suspended sediments are transported at the same velocity of the fluid (Vanacker, 2014) whereas bedload travels by rolling, siltation or through sliding. The Helley- Smith bed load sampler (Figure 10) is designed to collect bedload in a basket type sampler through pressure difference (Helley-Smith, 1971). The sampler consists of a frame, sample bag and a nozzle. Bunte et al. (2008) studied

Figure 18. Helley- Smith bedload sampler.

transport rates in eight sites in coarse bedded Rocky Mountain stream using Helley- Smith bed load sampler. They found that the sampler is very effective in capturing fine gravel, even less than 4 mm. Emmett (1980) also studied the Helley Smith bed load sampling efficiency and concluded that the sampler has a near-perfect sediment trapping efficiency for the particles sizes between 0.50 to 16 millimeters. Similarly, the sampler also had a high efficiency for the particles smaller than 0.50 millimeters in their research.

Bedload was surveyed using the Helley-Smith bedload sampler. The stream was divided into the 5 equal compartments and the bedload was surveyed in each compartment. The sampler consists of the rod, nozzle and a sample bag. The sampler was placed perpendicular to the bed of the river for two minutes in each compartment. The sample bag was then refrigerated at 4^{o}C and then taken to the lab where it was dried to remove water and then analyzed. Bedload samples were dried at 105°C for 8 hrs and weighed to determine dry mass. Instantaneous bedload transport rate (Qb) in kg/s was calculated as:

$$Q = \frac{M}{T} \times \frac{1}{N} \times \frac{W}{0.076\,m}$$

Where,

Q is the instantaneous bedload sediment, M is the mass in kg, T is the sub sample duration (i.e. 120 seconds), N is the number of subsamples, W is the width of the width of the channel in meters and 0.076 represents the width of the opening of Helley-Smith sampler.

Grab samples for suspended sediment concentration (SSC) were collected in 1000-ml polyethylene bottles at all sites during the stream surveys. Samples were collected in the thalweg of the stream at mid-depth. All samples were stored at 4°C until analysis could be performed (Neff, 1983). To determine SSC, the entire water sample was vacuum filtered through pre-ashed glass fiber filters. Filters were dried at 105°C for 8 hrs and, weighed to determine sediment mass, suspended sediment load was calculated for each sample by multiplying SSC by discharge at the time of collection.

Wolman pebble count

Wolman pebble counts (Wolman, 1954) were performed in all stations except Station 1. Station 1 consisted of fine-grained muck with minor amounts of coarse woody debris. At the remaining stations, a reach was selected for the sediment size distribution quantification. Glides, riffles, and pools were sampled in the same proportion to characterize the stream. A transect was randomly selected along the edge of the stream and the first pebble was picked up while eyes were averted away. The length of the second longest axis of the pebble was determined using a gravelometer and recorded in a data book. Another step was taken and the procedure was repeated by walking in a zig-zag position. For those rocks that were too large to pick up, the second axis was measured as accurately as possible *in situ*. One hundred pebbles were measured at all four stations. The graphs were plotted to classify the particle size category as described by Wolman (1954).

Microtox Assay

The Microtox assay was used to screen samples for the presence of toxic chemical in stormwater samples collected from discharges entering Indian Mill Creek. The assay used the bioluminescent marine gram negative bacteria, *Vibrio fischeri* to determine the relative toxicity of water samples. Standardized bacteria aliquots were added to water samples and controls and the light output of the bacteria at specific time interval is used to compare to calculate the relative toxicity. Toxicity will result in the inhibition of bioluminescence. The assessment correlates well with other standard acute toxicity assays including Daphnia and fathead minnow. Zwart and Slooff (1983) compared the MicroTox Assay for 15 compounds with 20 freshwater species of different taxonomical groups (including fishes) and found that the MicroTox assessment results were comparable with those obtained from the standard bioassays. Parvez et al. (2006) also reported that the MicroTox assessment was useful for detecting toxicity across a wide spectrum of toxicants and the luminescence inhibition in the bacterium was representative of toxic effects on higher organisms. Previous research has demonstrated the toxicity of urban stormwater using the MicroTox assay (Pitt et al., 1995; Marsalek et al., 1999). This assay provides a toxicity assessment of the whole water sample and can be used as a screening tool to determine if more detailed chemical analyses are needed for toxicity assessments.

The toxicity of the stormwater to the marine bioluminescent bacteria *Vibrio fischeri* was determined using the Microtox® comparison test. Frozen samples were thawed on the day of the test in a water bath at 15 °C. The samples were centrifuged at 5,000 rpm for 10 minutes to remove particles. The samples and a control consisting of deionized water were adjusted to a salinity of 2 ppt and then adjusted to a pH of 7.5 with 3-N-morpholino propanesulfonic acid (MOPS) buffer by adding 50 µl of 0.12 M MOPS to 10 ml of the salinity-adjusted control or sample. The toxicity of the sample was tested according to the Microtox® manual (MicrotoxOmni™ Software, Azur Environmentals, USA). Light inhibition in the sample compared to the control was measured on 3 replicates after 5 and 15 minutes of incubation. The tested sample concentration in this test is 80 vol-%. A sample showing >20% light inhibition compared to the control was considered toxic. The sensitivity of bacteria was checked with $ZnSO_47H_2O$ and the IC_{50} was determined to be 1.5 ppm Zn^{+2}.

Results

Temperature

In the month of July, Station 2 had the highest average weekly temperature of 17.71°C (Figure 21). Station 3 had the average weekly temperature of 16.68°C and Station 4 had average weekly temperature of 16.98°C. Both the Station 2 and Station 3 had an average weekly temperature fluctuations range above 5°C (5.95°C and 5.21°C, respectively). Station 4 had an average weekly temperature fluctuation range below 5°C (4.08°C). Similarly, Station 2 had the highest mean weekly temperature in August 2016 with 18.24°C. Mean maximum weekly temperatures at Station 3 and Station 4 were 17.29°C and 17.63°C, respectively. Station 2 had the highest weekly temperature fluctuation range among all sites with 5.97°C. Both the Stations 3 and

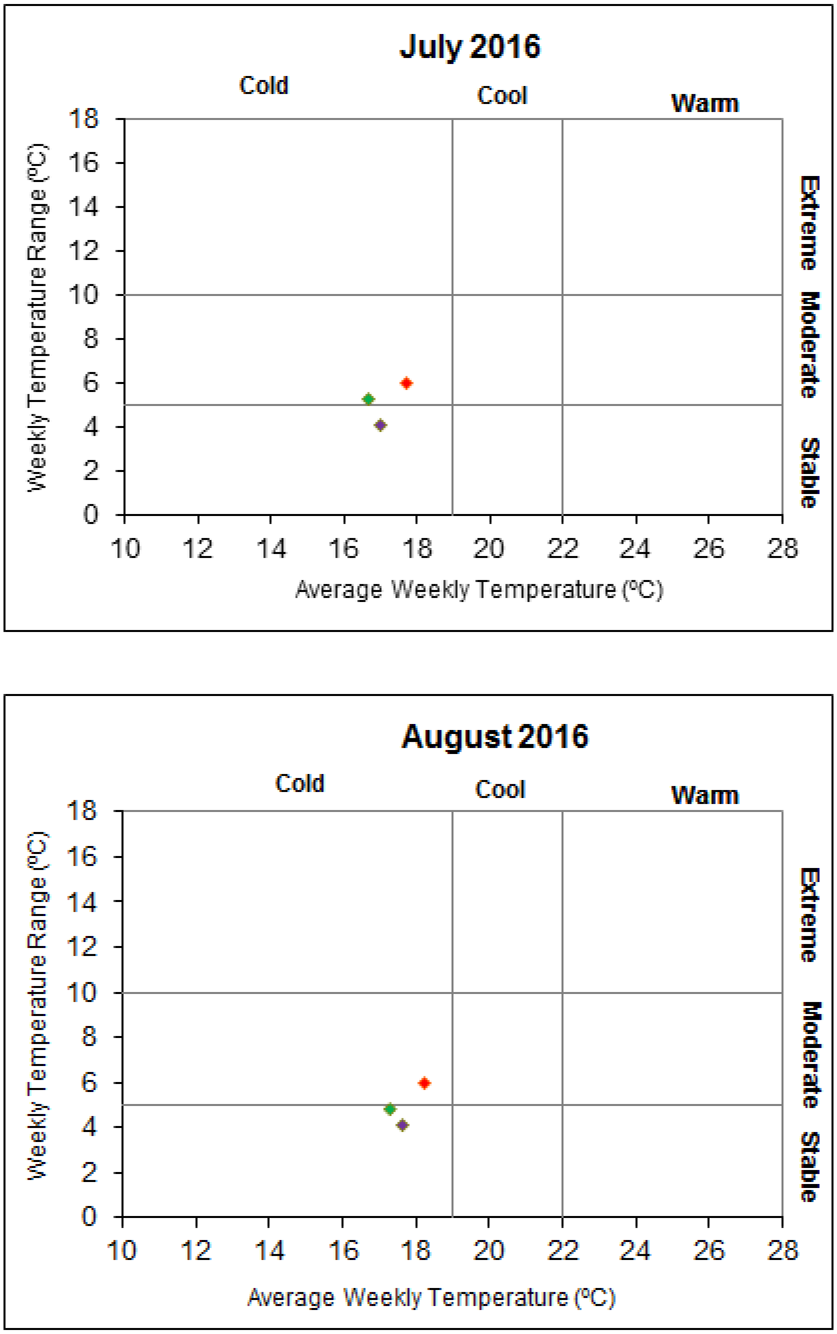


Figure 19. Average weekly temperature of Indian Mill Creek- July and August 2016. Site 2◆, Site 3◆, Site 4 ◆

Station 2 had average weekly temperature fluctuation range below 5^{o}C (4. 82^{o}C and 4.08^{o}C, respectively).

Brown and Rainbow trout, blacknosed dace, and white Sucker were found in Indian Mill Creek when surveyed by MDEQ and other organizations (Table 4). The cold-moderate thermal category is optimal for these fishes according to Wehrly et al., (2003).

Erosion pins and scour chains

There was no change in the exposed length of the erosion pins in Station 1 (Table 5). However, Station 2 showed both erosion and deposition in the upper and lower streambed sections, respectively. West top erosion pins at Station 3 were covered with sediment and other pins showed the channel erosion in the stream (Figure 20). All the erosion pins at Station 4 were knocked down due to the increased flow from storm and we estimated that the channel erosion was more than 60 cm at this station. The north side of the stream was all concrete at Station 5 and hence no pins were inserted. The south top and south bottom had erosion of 12 cm and 23 cm, respectively (Table 5).

Table 5. Scour chain and erosion pin results of Indian Mill Creek, 2016. Negative number represents erosion and positive number represents deposition.

Station	Location and Distance	Scour Chains			Erosion Pins			
		1	2	3	1	2	1	2
Station 1	Location	West	Center	East	West Top	West Bottom	East Top	East Bottom
	Distance (cm)	-4	-6	-3	0	0	0	0
Station 2	Location	West	Center	East	West Top	West Bottom	East Top	East Bottom
	Distance (cm)	15	20	-5	-12	-24	4	12
Station 3	Location	West	Center	East	West Top	West Bottom	East Top	East Bottom
	Distance (cm)	15	18	22	-10	-19	-32	-38
Station 4	Location	North	Center	South	North Top	North Bottom	South Top	South Bottom
	Distance (cm)	18	15	21	>-60	>-60	>-60	>-60
Station 5	Location	North	Center	South	North Top	North Bottom	South Top	South Bottom
	Distance (cm)	2	5	7	Concrete	Concrete	-12	-23

Station 1 had very little degradation (Table 5) as the scour chains were still exposed. Station 2 had both erosional and depositional zones indicating that the creek was trying to shift its course. Scour chain results the highest aggradation rates at Station 3 and Station 4.

Figure 20. Exposed erosion pins at Station 3.

The sedimentation deposition was greater than 15 cm in all the sites at Station 3 and Station 4 (Figure 21) which indicated that these locations are serving as depositional zones (aggradation) in the creek. The deposition was less in Station 5 due to more scouring and the cobble substrate.

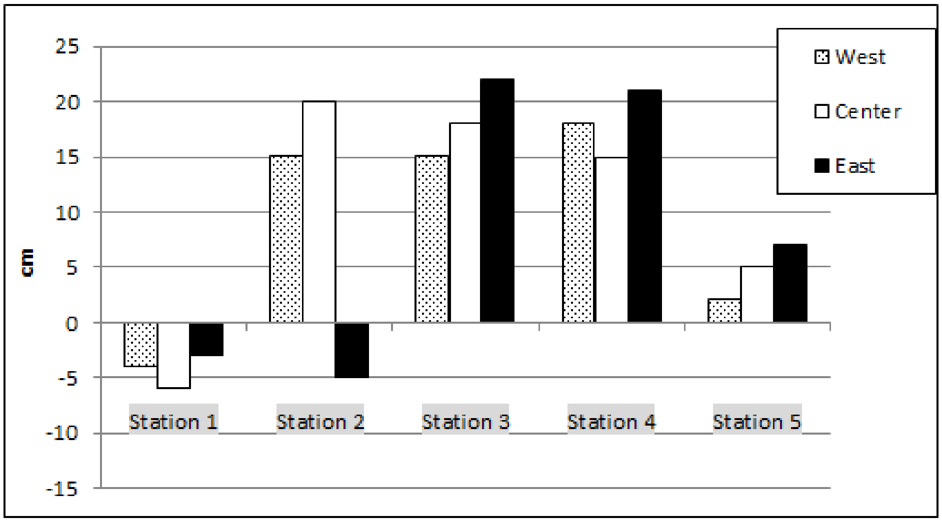


Figure 21. Scour chain results of Indian Mill Creek. 2016.

Discharge of Indian Mill Creek

Discharge was measured during 2016 on May 11/12 (May 11 in Station 1, Station 2, Station 3, and Station 4, and May 12 in Station 5), June 29, July 19, August 17, August 23 and September 9. The discharge of Indian Mill Creek increased from Station 1 to Station 5 suggesting that the groundwater influx also increased along the continuum (Figure 22). Brandywine Creek joins the Indian Mill Creek before Station 3. Three distinct flow regimes were observed in Indian Mill Creek. High flow occurred on May 11/12. During this time the corresponding discharge measurements at Station 1, Station 2, Station 3, Station 4, and Station 5 were 0.17 m^3/s, 0.22 m^3/s, 0.6 m^3/s, 0.97 m^3/s, and 0.58 m^3/s, respectively. Moderate flow occurred on June 29, August 17, August 23 and September 9.

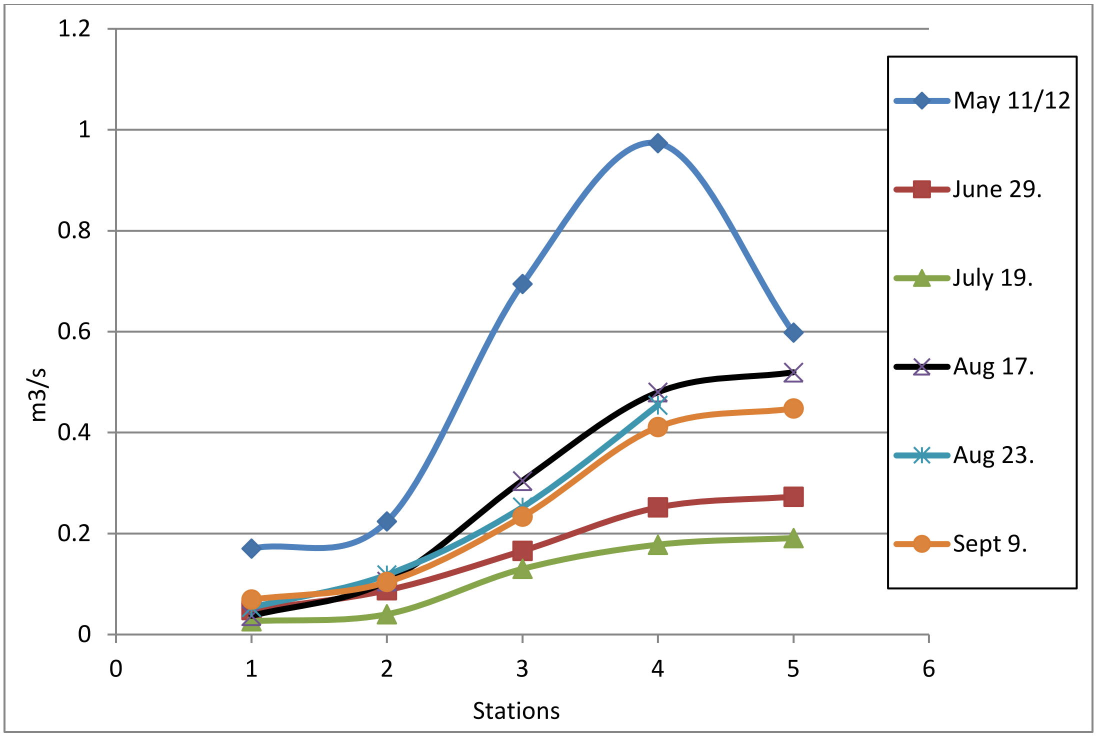


Figure 22. Measured discharge of Indian Mill Creek, 2016.

Station 1, Station 2, Station 3, and Station 4 were measured on May 11 within 24 hours of rain events (1.03 inch) (Figure 23). Station 5 was measured on May 12 within 48 hours of precipitation. June 29 measurement was done within 48 hours of precipitation (0.43 inch). July 19 sampling was conducted within 48 hours of precipitation (0.33 inches). August 17 discharge was measure within 24 hours of rain events (0.83 inch). August 23 measurement was done within 48 hours of major rain events 1.82 inches). September 9 measurement was done within 24 hours major precipitation (0.35 inches). The discharge measured at Indian Mill Creek was influenced by the amount of precipitation and time of the sampling after the rain event. The discharge measured also indicated that the creek is unstable and flashy. The flashiness is caused due to uncontrolled runoff from impervious surface and the elimination of vegetation cover (Hunsaker & Levine, 1995).

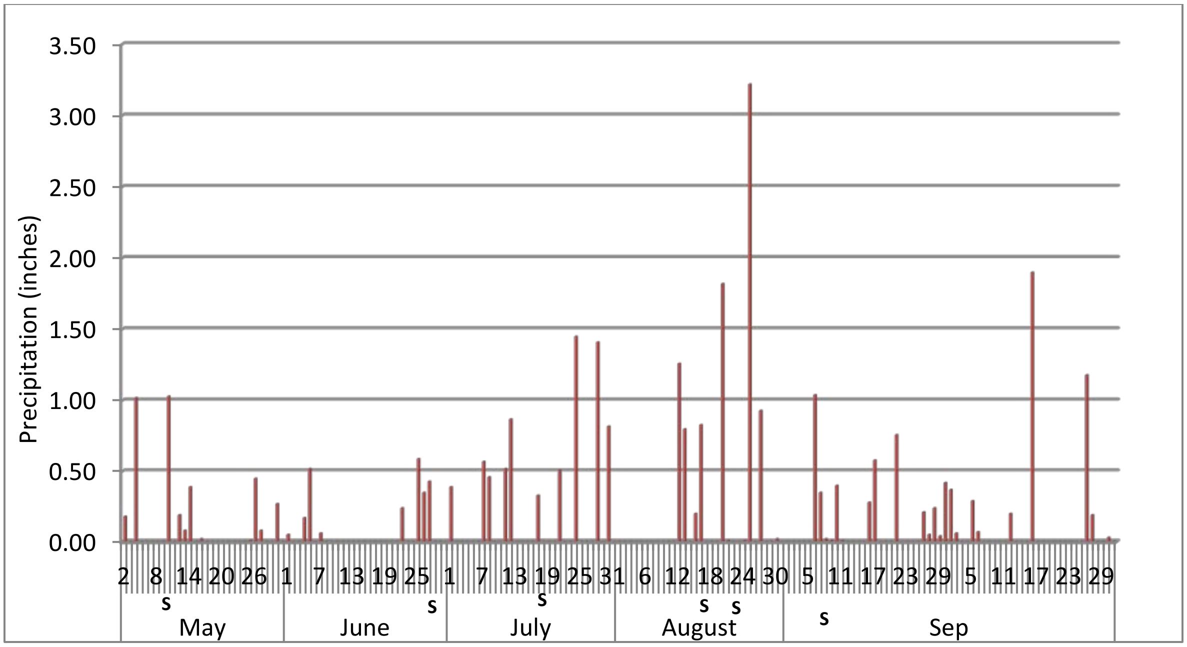


Figure 23. Precipitation accumulation measured at Walker by Kinney-Richmond. “S” in the graph denotes sampling dates.

Macroinvertebrates

We only found seven macroinvertebrates in 45 minutes of sampling time at Station 1 as the substrate was loose muck. Hence, we did not rate the macroinvertebrate community since the station lacked the minimum organism numbers required by P51 (MDEQ, 2005). Therefore, we ranked Station 1 as poor. All the other stations were rated acceptable (Table 6), however, tending towards poor quality. Station 3 scored the least with -4 score. Station 2 had the highest number of taxa with 16 different families in comparison to other stations. Station 5 had 13 families, Station 4 with 12 families and Station 3 with 12 families. Simuliidae was most common taxa in Station 5 (37%). Similarly, Baetidae was the most common in Station 4 at 35%. Isopods were common in Station 3 and made up 30% of the community. Amphipoda were most abundant at Station 2 and comprised 30% of the community (Table 7, Figure 24). Similarly, there is a gradual shift from shredders to filterer/collector macroinvertebrate community in Indian Mill Creek from Station 1 to Station 5.

Table 6. Macroinvertebrate scoring of Indian Mill Creek (July 2016).

	Station 2		Station 3		Station 4		Station 5	
Metric	Value	Score	Value	Score	Value	Score	Value	Score
Total no. of taxa	16	0	12	0	12	0	13	0
No of mayfly taxa	1	-1	1	-1	1	-1	1	-1
No. of caddisfly taxa	2	0	1	-1	1	-1	1	-1
No. of stonefly taxa	0	-1	0	-1	0	-1	0	-1
Percent mayfly comp.	1.6 %	-1	6.7 %	0	35 %	1	14 %	0
Percent caddisfly comp.	16 %	0	1.9 %	-1	6 %	0	5.3 %	0
Percent dominant taxon	30 %	0	30 %	0	35 %	0	37 %	0
Percent of isopods, snail, leech	25%	-1	59%	-1	19%	-1	7%	0
Percent surface air breathers	2%	1	1%	1	0.40%	1	0.50%	1
Total score		-3		-4		-2		-2
Rating		**Acceptable**		**Acceptable**		**Acceptable**		**Acceptable**

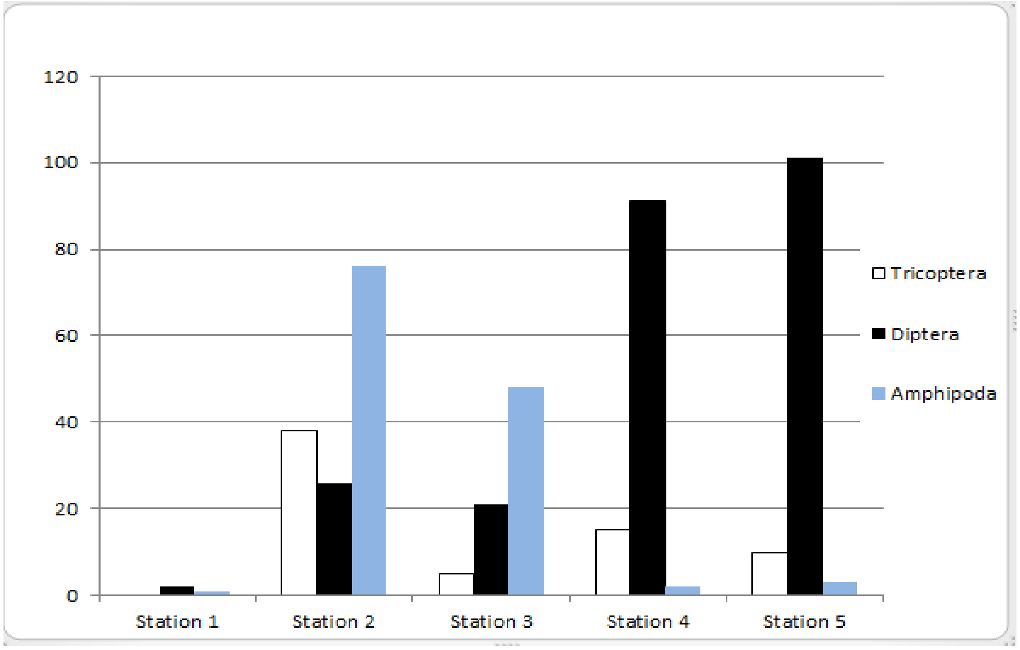


Figure 24. Total number of Tricoptera, Diptera, and Amphipoda enumerated in Indian Mill Creek (July 2016).

Table 7. Macroinvertebrates Populations in Indian Mill Creek (July 2016).

Taxa	Station 1	Station 2	Station 3	Station 4	Station 5
ANNELIDA					
Hirudinea (leeches)		10	76	2	3
Oligochaeta (worms)	2		8	2	10
ARTHROPODA					
Crustacea					
Amphipoda (scuds)	1	76	48	2	3
Decapoda (crayfish)		1			
Isopoda (sowbugs)	1	53	81	46	11
Arachnoidea					
Hydracarina				2	24
Insecta					
Ephemeroptera (mayflies)					
Baetiscidae		4			
Baetidae			18	89	26
Odonata					
Anisoptera (dragonflies)					
Aeshnidae	1			1	
Zygoptera (damselflies)					
Calopterygidae		9			
Hemiptera (true bugs)					
Corixidae			2		
Gerridae		5	1	1	
Trichoptera (caddisflies)					
Hydropsychidae		38	5	15	10
Uenoidae		4			
Coleoptera (beetles)					
Hydrophilidae (total)		1			
Elmidae		16	7		1
Diptera (flies)					
Athericidae		2	2	6	2
Chironomidae	2	21	16	13	27
Culicidae					1
Dixidae		1			
Simuliidae		2	3	72	70
Tipulidae					1
MOLLUSCA					
Pelecypoda (bivalves)					
Sphaeriidae (clams)		8			
TOTAL INDIVIDUALS	**7**	**251**	**267**	**251**	**189**

Habitat of Indian Mill Creek

All the stations of the Indian Mill Creek scored less than Marginal Score (Table 8) using the P51 Metric (MDEQ, 2005) except Station 2. Station 2 was slightly impaired placing it in “good” habitat category. Although Station 1 had the highest riparian vegetation value compared to other stations, it had the lowest epifaunal substrate cover. Station 2 had higher epifaunal substrate cover and higher pool substrate characterization. Station 3 scored as marginal due to the presence poor vegetative cover on the right side of the Station. The epifaunal substrate cover was acceptable however, there was evidence of bank erosion. Station 4 scored the lowest score and was characterized as poor habitat. No vegetation was on the right side of the station and there were signs of flashiness in the creek. Sediment bars were formed in the creek suggesting that the station is a depositional zone, and the banks also seemed unstable in the creek. Station 5 was also rated as poor habitat. Even though the epifaunal substrate cover scored high, there was no riparian vegetation on the right side of the station as it was all concrete wall.

Bedload and Suspended Solids Concentration

The bedload of Station 1 was lowest on June 29 with 2.20 kg/day and was highest on August 17 (56 kg/day) (Table 9 and Figure 25). Station 2 had its lowest bedload on August 23 (12 kg/day) and was highest on May 11/12 (142 kg/day). Similarly, the highest bedload measured at Stations 3 and 4 during the investigation time period was on May 11/12 (1,858kg/day and 6,680 kg/day, respectively). Bedload sediment at Station 4 consisted of sand and coarse cobble (Figure 26). Station 5 had the highest bedload on September 9 with 254 kg/day and lowest on June 29 with 24 kg/day. The lowest suspended sediment concentration value measured at Station 1 was on

Table 8. Habitat Survey of Indian Mill Creek.

HABITAT RATING	**STATION 1**	**STATION 2**	**STATION 3**	**STATION 4**	**STATION 5**
Substrate and Instream Cover					
Epifaunal Substrate/Avail. Cov.	4	17	12	8	15
Pool Substrate Characterization	5	17	10	7	8
Pool Variability	5	12	9	9	3
Channel Morphology					
Sediment Deposition	5	14	8	3	5
Flow Status- Maint. Flow Vol.	7	8	3	5	5
Flow Status-Flashiness	7	8	3	2	5
Channel Alternation	4	13	12	6	3
Channel Sinuosity	4	14	9	2	1
Riparian and Bank Structure					
Bank Stability (L)	7	7	7	7	6
Bank Stability (R)	7	7	7	2	1
Vegetative Protection (L)	7	7	7	5	7
Vegetative Protection (R)	7	7	7	2	1
Riparian Veg. Zone Width (L)	6	9	5	4	4
Riparian Veg. Zone Width (R)	12	7	4	1	1
Total Score	**87**	**147**	**103**	**63**	**65**
Habitat Rating	**Marginal (Poor)**	**Good (Slightly Impaired)**	**Marginal (Significantly Impaired)**	**Marginal (Poor)**	**Marginal (Poor)**

Table 9. Average bedload and suspended sediment concentration of Indian Mill Creek (2016). (The values are in kg/day).

Date	Station 1		Station 2		Station 3		Station 4		Station 5	
	Bedload	SSC	Bedload	SSC	Bedload	SSC	Bedload	SSC	Bedload	SSC
May 11/12	2.3	108	142	95	1858	612	6680	151	101	83
June 29.	2.2	25	61	70	73	52	290	123	24	143
July 19.	20.	8.9	47	28	53.4	106	129	51	17	48
Aug 17.	58	16	80	73.1	579	147	1659	271	157	450
Aug 23.	28	16	12	95	39	110	1820	201	*	*
Sept 9.	22	10	19	3.4	1198	54	2257	61	254	96
Mean	22	31	60	61	634	180.5	2139	143	111	137

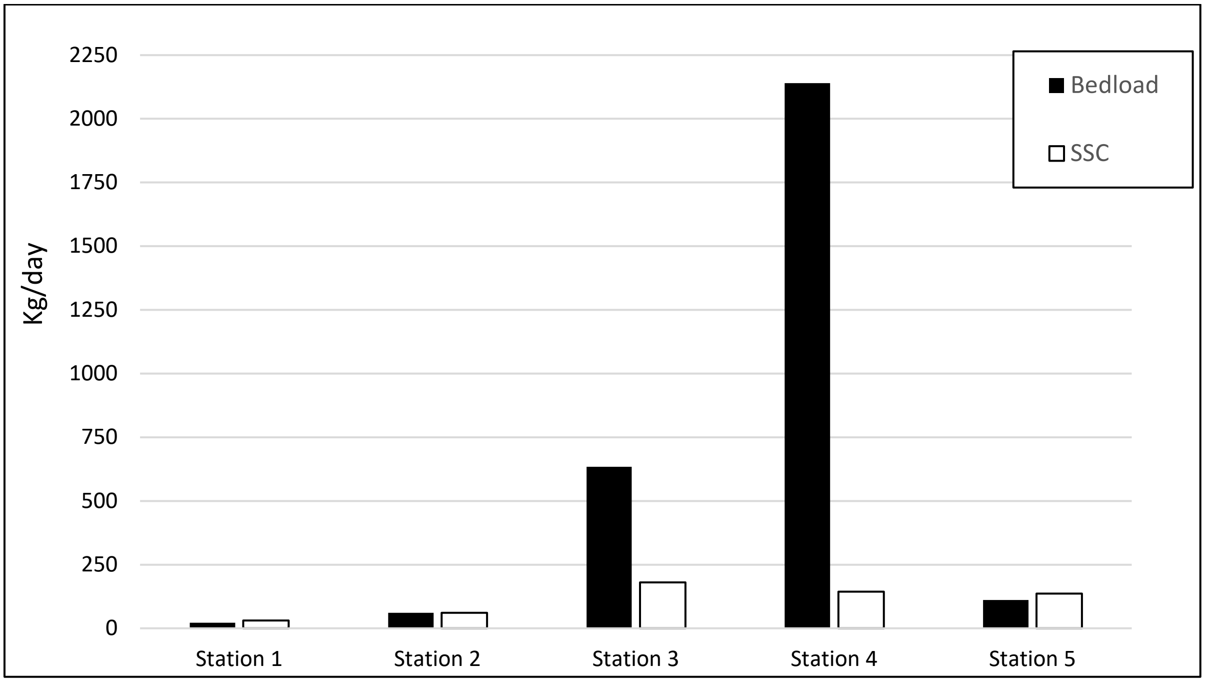


Figure 25. Average bedload and average suspended solids concentration of Indian Mill Creek (2016).

Figure 26. Bedload of Station 4 of Indian Mill Creek (September 8, 2016).

July 19 (9 kg/day). Station 2 lowest suspended sediment concentration recorded was on September 9 (3.4 kg/day). Both the Station 3 and Station 4 had the highest suspended sediment concentration on May 11/12. We measured lowest SSC at Station 3 on September 9 (54 kg/day) and at Station 4 on July 19 (51 kg/day). Station 5 highest SSC measured was on August 17 (450 kg/day) and lowest SSC value was 48 kg/day on July 19.

Wolman Pebble Count

Cumulative bed sediment size (substrate characteristics) of Indian Mill Creek is shown in Figure 27. Station 1 was all homogenous substrate with loose muck (less than 2 mm), hence not plotted in the figure. The substrate at Station 2 was fairly heterogeneous and had the lowest sand with 25%. The proportion of sand increases along the continuum of Indian Mill Creek. Station 3 had about 30% sand. Station 4 and Station 5 had similar proportion of sand (about 33%). Station 5 had the highest proportion of cobble and rocks than any other stations.

Microtox assessment

Eighteen different sites of Indian Mill Creek were assessed using Microtox assay. Station 3, Station 4, storm drains, the main channel of Indian Mill Creek, Brandywine Creek, and Walker Ditch were included in the study sites. The assay does not show any toxicity in the main watercourse of Indian Mill Creek, however, the seeps and stormwater drains might contain toxic chemicals (Table 10) as toxicity was detected.

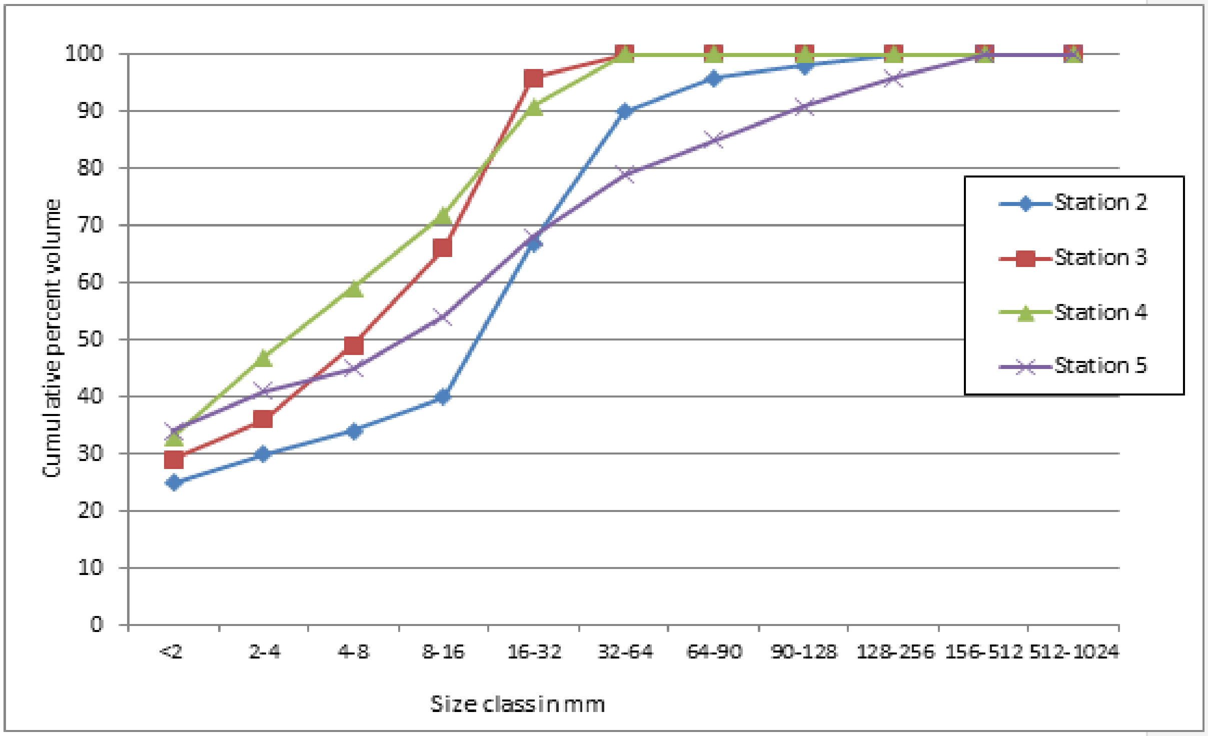


Figure 27. Cumulative percent volume of Wolman Pebble Count in Indian Mill Creek 2016. Size of less than 2 mm refers to sand.

No.	Location	Time	Lat	Long	Toxicity*			Mean*
1	WD 1	6:10	43.0187	-85.7095	5%	-5%	3%	1%
2	WD 2	6:20	43.0149	-85.715	4%	2%	-3%	1%
3	WD 3	6:35	43.0077	-85.7182	5%	6%	3%	5%
4	WD 4	6:50	43.006	-85.7192	8%	6%	4%	6%
5	WD 5	7:10	43.0004	-85.7182	9%	5%	5%	6%
6	IMC 6	7:25	43.0014	-85.7197	9%	8%	4%	7%
7	BC 1	7:40	43.0013	-85.7199	-1%	-3%	-2%	-2%
8	BC 2	8:00	42.9993	-85.7359	-1%	-3%	3%	0%
9	IMC 7	8:30	43.0153	-85.7341	8%	10%	9%	9%
10	IMC 8	8:45	43.0162	-85.7325	11%	6%	5%	7%
11	IMC 9	9:00	43.0162	-85.7325	9%	2%	2%	4%
12	IMC 10 Seep	9:15	43.0163	-85.7337	30%	22%	29%	27%
13	IMC 10	9:15	43.0161	-85.7337	7%	11%	5%	8%
14	IMC 11	9:40	43.0171	-85.7303	-4%	-4%	1%	-2%
15	IMC 13 Trib	10:00	42.9985	-85.6951	25%	21%	26%	24%
16	IMC 14 Trib	10:20	42.9997	-85.6982	23%	25%	24%	24%
17	Station 4	11:00	42.9979	-85.6923	10%	14%	11%	12%
18	Station 3	7:30	43.0009	-85.7189	3%	1%	7%	4%
***Light production inhibition relative to control, >20% indicate toxicity**								

Table 10. Microtox assessment of Indian Mill Creek in 10/27/2016. (WD=Walker Ditch, IMC= Indian Mill Creek. BC= Brandywine Creek). (Yellow indicates toxicity)

Discussion

Our research showed that the temperature of Indian Mill Creek was suitable for coldwater fisheries. All three stations measured fell in either the cold moderate or cold stable thermal category regime which is suitable for salmonids and white suckers and other coldwater fishes (Wehrly et al., 2003). Although some breaks and degradation of riparian vegetation occur at Stations 3 and 4, the ability to maintain a coldwater temperature regime indicates a strong and stable supply of groundwater is entering Indian Mill Creek. The discharge from groundwater provides stable cold temperature during the summer and overwintering habitat for fish, free of ice during winter seasons (Power et al., 1999; Hayashi & Rosenberry, 2002).

However, gravel substrate is also very important for salmonid and trout species for spawning (Bjornn & Reiser, 1991). The toxicity does not seems to be concerning for water sample from Indian Mill Creek. However, samples from some seeps and drains showed low toxicity greater than the reference samples. The MDEQ conducted a sediment study on 7/20/2016 and sampled above the dam at Richmond Park, above the woody debris dam near Station 4, and at Turner Street where Indian Mill Creek discharges at the Grand River. Polycyclic aromatic hydrocarbons (PAH), Diesel Range Organic compounds (DRO) and Oil Range Organics (ORO) were found at all locations (Appendix 1). An analysis of the data by Sam Noffke, MDEQ Toxicologist (Appendix 1) found that PAH and DRO/ORO may be at concentrations that could impact benthic invertebrates. Additional testing for a more expanded list of PAH compounds was recommended to determine the significance of the sediment test results. These locations were the only areas of organic sediment deposition found during our surveys. While the majority of the stream consisted of sand/gravel substrate and would not accumulate PAH and DRO/ORO organics, the sediment results show that these materials are entering Indian Mill Creek from unknown sources. The Microtox results may provide insight to the sources of these materials as PAH compounds would produce a toxic response in the assay. The solid phase Microtox assay can be useful to screen for the accumulation and sources of PAH compounds since they are retained in the sediment.

Station 1 has homogenous substrate of fine muck and little coarse woody debris. About 50% of the substrate was sand in Station 3 and 4. Similarly, results from the scour chains show that the upstream is degrading while the downstream is aggrading, which is changing the geomorphology of the creek. The bedload sediment transport results at Station 3 and Station 4 are very high. Excessive sedimentation affects the habitat of a creek (Lenat et al., 1988). Substrate and sediments are the two most important factors determining the macroinvertebrate community (Newlon & Rabe, 1977).

The macroinvertebrate community of the Indian Mill Creek at Station 1 was poor and other stations scores, although acceptable, were tending towards poor quality. Our habitat survey also showed us that the substrate of Station 1 was all loose muck, which supported only a few macroinvertebrates, although the riparian vegetation was intact. These data suggest that fine sediment is entering the stream from upstream sources. The discharge at Station 1 does not appear to be sufficient to transport fine sediment on a consistent basis. Station 2 has the greatest number of amphipods, consistent with the intact riparian vegetation and abundant woody debris present on the local environment. Amphipods belong to the shredder functional feeding group and their presence in large numbers indicates that there is adequate amount of allochthonous inputs (energy source outside the river: from the terrestrial environment) of coarse particulate organic matter (CPOM) from riparian zones (Cummins, 1989). However, the number of amphipods decreases at other stations and the Dipteran population increases. The decreasing Amphipods and increasing

Dipterans are indications that that there is a shortage of coarse allochthanous input and increase in fine suspended food particles for Dipterans like Simuliidae to consume. Woody debris are light and can scour readily compared to coarse sediments. Simullidae are attached to rocks in fast flowing river and depend on sestons (minute materials moving in water) instead of coarse leaves (Jonsson, 2003).

The diversity of macroinvertebrates is reduced (especially EPT) with an increase in sediment in streams (Ogbeibu & Victor, 1989; Zuellig et al., 2002; Gammon, 1970). The proportion of EPT in Indian Mill Creek is reduced due to sedimentation. Station 4 had the greatest abundance of Baetidae (Ephemeroptera) and also showed significant impacts from bedload sediment deposition. Populations of Baetidae are reported to increase in areas with sediment deposition (Angradi, 1999). Although the thermal regime is suitable for Plecoptera (coldstable), we were unable to find this taxa at at any of the stations. Plecoptera are sensitive to sedimentation ant most other macroinvertebrate orders (Relyea et al., 2000). Station 2 had the lowest bedload and has the highest number of Trichoptera. The excessive bedload leads to the mortality or drift of other macroinvertebrates (clinger, scrappers, etc.) making them less available for top predators (Culp, 1986). The macroinvertebrates are the primary source of food for the freshwater fish (Wallace & Webster, 1996). The benthic macroinvertebrate results plus the bedload and pebble count data suggest that food quality and quantity may be impacting the diversity of the coldwater fishery. Poor substrate quality and woody debris retention are known to impact fish communities (Bilby & Ward 1989).

The deposition of bedload sediment results in the aggradation of the river. Our study results are similar to previous research (Alexander & Hansen 1986) as fish populations of all sizes and ages in a Lower Michigan stream declined significantly with the influx of excessive bedload sediment and the resulting burial of microhabitat. Also, stream morphology changed considerably as the channel became wider and shallower. Scouring and channel erosion were the sources of sediment in the river studied by Alexander and Hansen (1986). Many any other studies have reported that Salmon embryo and egg survival rates decrease with an increase in sedimentation in the river (Shaw & Maga, 1943; Wells & McNeil, 1970; Willer, 1988; Wu, 2000). Indian Mill Creek is experiencing elevated amounts of sediment load during the higher flows that can affect the habitat and biota of the creek (Figure 28).

The significant change in exposed length of the erosion pins showed that channel erosion is a major source of sediment in Indian Mill Creek. Hassan (1971) studied sediment in Pine Creek and determined that stream bank erosion contributed significantly in the sediment budget of the stream. There are several factors contributing to this change (King et al., 2005; Figure 26). The water velocity, quantity (discharge), and gradient is low at the upstream segment of Indian Mill Creek. Groundwater influx increases along the continuum with increase in gradient increasing the stream power. Increased runoff of storm water from the catchment area is responsible for the pulsating flow of the water in the creek. The watershed has been compromised since the pre-settlement vegetation was removed and impervious surfaces have increased.

The habitat survey also showed there were several breaks in riparian vegetation along the bank of the creek at Station 3, Station 4 and Station 5, which could destabilize hydrology and increase sediment inputs resulting in impairments to benthic macroinvertebrate and fish communities (Meyer et al., 2005). Similarly, the channel sinuosity was reduced significantly to drain agricultural land and enhance stormwater removal. Urbanization and impervious surfaces alter stream hydrology and habitat resulting in a common pattern of impairments referred to as

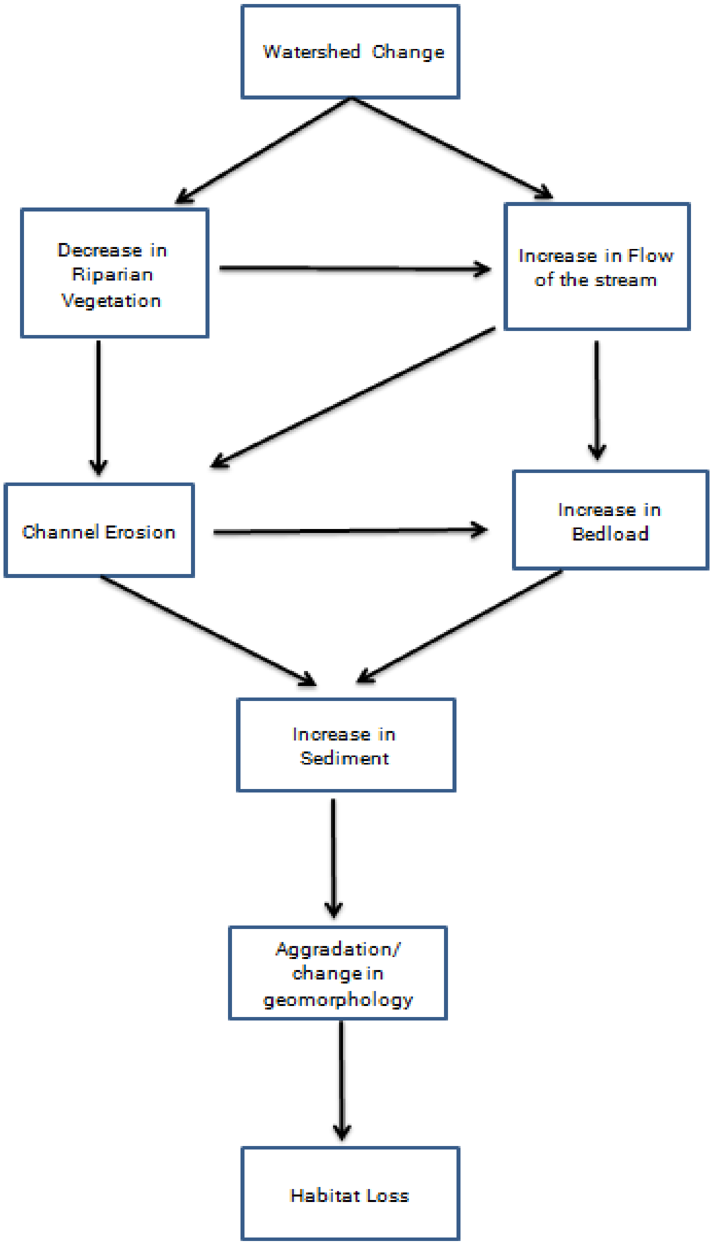


Figure 28. Schematic diagram of factors leading to habitat loss in Indian Mill Creek.

“urban stream syndrome” (Walsh et al., 2009). Changes in land use and an increase in urban density affect the water quality of streams (King et al., 2005).

There is a relationship between water discharge, sediment transport, gradient, sediment size (Lane, 1955) which is presented in following equation:

(Sediment Load) x (Sediment Size) ∝ (Stream Slope) x (Stream Discharge)

Stream power is related to gradient and discharge. Any change in one of the parameter of the river causes the river to change other parameter(s) to balance the equation. Exceedance of a 10% threshold of impervious surface in small watershed like Indian Mill Creek causes hydrologic instability and flashiness (King et al., 2005) and increases discharge.

The stormwater a stream receives from its catchment (runoff from parking lots, roads, and storm water pipes, and drains) changes the natural flow regime (Poff et al., 1997) and is responsible for increases in stream power during the episodic flows causing channel erosion. The stream can no longer efficiently transport the sediments when the flows decrease and aggradation occurs. Meyer et al. (2005) also reported riparian/channel alteration and stormwater inputs reduced water quality, destabilized hydrology, and increased suspended sediment resulting in impairment to benthic macroinvertebrate and fish communities. Decrease in channel sinuosity also leads to channel erosion as streams try to meander (Leopold et al., 1960). Thus, altered hydrology and geomorphology are detrimental to the biota of the creek (Paul, 2001).

The aim of this project was to determine the causes and sources of coldwater fisheries impairment in Indian Mill Creek. The temperature is within the cold-moderate category; however, results suggest that sediment transport and deposition are the main stressors impacting the coldwater classification. This is leading to the reduction in the amount of food quality and quantity to fish due to macroinvertebrate mortality and also directly affects the fish fry populations (Bisson & Bilby, 1982; Bilotta & Brazier, 2008; Kemp et al., 2011).

The results of erosion pins indicated that bank erosion is a source of sediment input to the creek. Considerable amount of sediments are being delivered between Station 2 to Station 4 based on erosion pin loss and bedload transport data. Further assessment is needed to determine if the banks are predominant sources of sediment and the contributions coming from the overland flow or small tributaries and storm drains. The creek is very flashy during the high precipitation events which result channel erosion and aggradation in the lower section of the creek and habitat loss (Meyer et al., 2005; Walsh et.al, 2009). Also, the sediment study conducted by MDEQ found that that PAH and DRO/ORO may be at concentrations that could impact benthic invertebrates of Indian Mill Creek. Further studies are need to determine the source of these hydrocarons.

Conclusion

A detailed study of physical, biological, and chemical analysis along with Geographic Information System characterization of land-use change was conducted to identify the sources and causes of environmental stressors impacting coldwater fisheries in Indian Mill Creek. Scour chains and erosion pins were installed to measure the rates of erosion and deposition. The temperature, bedload and suspended solids concentration were measured to evaluate whether stream temperature is meeting the coldwater fisheries standard and if sedimentation is impacting the biota of the creek. The toxicity of the stormwater was evaluated using the Microtox assay and Wolman pebble counts were performed to characterize the bed of the river. Similarly, macroinvertebrate surveys and habitat assessments were conducted to evaluate the overall health of the river. The results showed that Indian Mill Creek appeared to be meeting the cold moderate or cold stable thermal regimes which are suitable for coldwater fish like brown trout, rainbow trout, white sucker, etc. Hence, we rejected our first hypothesis. Stormwater toxicity was determined not to be a factor impacting the biota. Our study showed that the land use was significantly altered since pre-settlement times. Two different impacts can be seen in Indian Mill Creek. The upstream is affected by agriculture and downstream is influenced more by the urban and industrial landcover. Different approaches are needed to address these impacts in Indian Mill Creek. However, the key to river restoration is to focus on habitat requirements for stream organisms (Stanford, 1996).

Indian Mill Creek watershed has 12% impervious surfaces and the watershed has about 20% impervious surfaces below I-96 highway which exceeded the 10% threshold (King et al., 2005) for impervious surfaces. The increase in impervious surfaces in the watershed leads to more runoff which causes episodic high flows in the stream. The episodic flows have greater stream power increasing bank erosion and bedload and causing sedimentation and export of woody debris. The filling of microhabitats of the stream by the sedimentation and loss of woody debris are detrimental to biota of the creek. Amphipod populations were reduced by 94% from near I-96 highway to Elizabeth Avenue (near the confluence of Grand River). Although the temperature regime and substrate of Indian Mill Creek will support Plecoptera, the absence of this taxa can indicate stress from sedimentation and hydrologic instability. The increase in stream power due to the episodic flows exacerbated by the stormwater inputs and runoff from impervious surfaces caused channel erosion and changed the morphology of the creek that negatively affects the habitat of the creek. These factors contribute to high bedload (6680 kg/d) and bank erosion (>60 cm) observed in the lower reach of the stream and continual deposition of sediment in the channel (aggradation). Aggrading conditions (15-20 cm) were observed at Richmond Park and below the confluence of Indian Mill Creek and Brandywine Creek. Therefore, our third hypothesis was supported.

There was an intact riparian zone in Station 1, located at 5 Mile Road and Walker, but the substrate was homogenous with all loose muck. The upstream watershed of Station 1 was agricultural land and had numerous breaks in riparian zones upstream. Erosion from agricultural land upstream and the deposition of fine sediments at Station 1 appears to be the source of sedimentation. Any increase in the impervious surface in the watershed is likely to exasperate the problem in the creek. Several construction projects have recently been completed and others are being proposed that will add more stormwater to the creek unless best management practices (BMPs) are implemented. Station 3 has very flashy flows and action should be taken to reduce the flashiness in the creek. Station 3 and Station 4 are both severely affected by the bank erosion. Hence, installation of the bank erosion control measures in the area where there are breaks in the riparian zone and increasing riparian zone corridor would help improve the habitat. Also, the lower portion (Station 5) of the creek is highly impervious. Various structural, vegetative and managerial BMPs are recommended in the Lower Grand River Watershed Management Plan for the subwatersheds in the Lower Grand River (Table 11). These BMPs will help control sources and causes of pollution by improving the natural flow regime.

The Indian Mill Creek watershed is unique with respect to the number of corporate headquarters and environmental organizations located within the watershed. Participation of stakeholders in the river restoration processes improves the success of resource management (Carr, 2015) and helps achieve restoration goals (Heldt, 2016). A Friends of Indian Mill Creek (FIMC) organization was established with the aid of Grand Valley Metro Council as a part of this project. This group can take a leading role in the management and restoration of the creek. Various stakeholders (Table 12) are actively engaged in the promotion and preservation of biodiversity in Indian Mill Creek

Table 11. Recommended best management practices (BMPs) in Lower Grand River Watershed Management Plan that apply to the Indian Mill Creek Watershed (Fishbeck, 2004).

Objectives	**Recommended BMPs**
Implement vegetation buffering practices	Buffer/filter strips; native plantings
Implement Low Impact Development	Bio retention (Rain gardens)
	Capture/ reuse (rain barrels, cisterns)
	Vegetated roof
	Vegetated swale
	Infiltration practices (dry wells, infiltration basins, infiltration berms, infiltration beds, bio retention, level spreader, leaching basins)
	Pervious pavement
Implement cropland management practices	Crop residue management, cover crop; field tile management, critical area planting; wetland restoration
Implement channel stabilization and erosion control technique	LID storm water criteria or ordinance for new development/redevelopment projects/capital improvement projects
Reduce and control gully erosion	Slope stabilizations
	Grassed waterways
Restore and protect wetlands	Wetland restoration; constructed wetlands
Minimize the impact of tiles and drainage networks on hydrology	Field tile management
	Tile outlet repair
Restore and protect floodplains	Floodplain management strategies
	Reconnect floodplains

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Table 12. Stakeholders of Indian Mill Creek (as of 7/19/2017)

Kent County Road Commission	Grand Rapids White Water
City of Walker	Grand Valley State University
Friends of Grand Rapids Parks	Indian Trails Golf Course
Boy Scouts of America	Izaak Walton League
Blandford Nature Center	Kenowa Hills High School
West Catholic High School	Land Conservancy of West Michigan
CA Frost Environmental Science Academy	Michigan Department of Environmental Quality
Alpine Township	Quiet Water Society
West Michigan Environmental Action Council	Schrem's Trout Unlimited
City of Grand Rapids	Davey Resource Group
Grand Valley Metropolitan Council	Residents/Community members
Bissell	

The FIMC has a critical role in enhancing the aesthetic values and protecting the watershed. Clean up campaigns have been organized and implemented in the watershed. CA Frost Environmental Science Academy, West Catholic High School students and various organizations have been conducting volunteer stream monitoring programs in Brandywine Creek and Indian Mill Creek. Community based institutions can effectively achieve “desired ecological outcomes” (Habron, 2003) which in the case of Indian Mill Creek is restoring the trout fishery.

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Appendix 1.

MDEQ 2016 Sediment Study

STATE OF MICHIGAN
DEQ
DEPARTMENT OF ENVIRONMENTAL QUALITY

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
ENVIRONMENTAL LABORATORY

P.O. Box 30270
Lansing, MI 48909
TEL: (517) 335-9800
FAX: (517) 335-9600

22 August 2016

Work Order: 1607226

Price: $1,251.00

Aaron Parker
MDEQ-WRD-LANSING
525 W. Allegan, P.O. Box 30242
Lansing, MI 48909-7742

RE: INDIAN MILL CREEK

I certify that the analyses performed by the MDEQ Environmental Laboratory were conducted by methods approved by the U.S. Environmental Protection Agency and other appropriate regulatory agencies.

Sincerely,

George Krisztian
Laboratory Director

MDEQ-WRD-LANSING
525 W. Allegan, P.O. Box 30242
Lansing MI, 48909-7742

Project: INDIAN MILL CREEK
Site Code: LB041708
Project Manager: Aaron Parker

Reported:
08/22/2016

Analytical Report for Samples

Sample ID	Laboratory ID	Matrix	Date Sampled	Date Received	Qualifier
Indian Mill Dam	1607226-01	Soil/Sediment	07/20/2016	07/20/2016	
Indian Mill Tamarack	1607226-02	Soil/Sediment	07/20/2016	07/20/2016	
Indian Mill Turner St.	1607226-03	Soil/Sediment	07/20/2016	07/20/2016	

Notes and Definitions

Y30	ORO results may also include non-oil organic compounds.
Y29	DRO results may also include non-diesel organic compounds.
Y20	Reporting Limits (RL) raised due to matrix.
N	Result is estimated due to Non-homogeneous sample.
ND	Indicates compound analyzed for but not detected
RL	Reporting Limit
NA	Not Applicable
dry	Sample results reported on a dry weight basis

Client ID: Indian Mill Dam
Lab ID: 1607226-01

CAS #	Analyte	Result	RL	Units	Dilution	Analyzed Date	QC Batch	Method	Qualifier
Organics-DRO/ORO									
DRO	**Diesel Range Org(C10-C20)**	**55000**	40000	ug/kg dry	1	07/30/16	B6G2121	8015	Y29
ORO	**Oil Range Organics (C20-C34)**	**310000**	160000	ug/kg dry	1	07/30/16	B6G2121	8015	Y30
Organics-Semivolatiles									**See note Y20**
91-57-6	2-Methylnaphthalene	ND	790	ug/kg dry	1	08/03/16	B6G2603	8270	
83-32-9	Acenaphthene	ND	320	ug/kg dry	1	08/03/16	B6G2603	8270	
208-96-8	Acenaphthylene	ND	320	ug/kg dry	1	08/03/16	B6G2603	8270	
120-12-7	Anthracene	ND	320	ug/kg dry	1	08/03/16	B6G2603	8270	
56-55-3	**Benz[a]anthracene**	**320**	320	ug/kg dry	1	08/03/16	B6G2603	8270	
50-32-8	Benzo[a]pyrene	ND	630	ug/kg dry	1	08/03/16	B6G2603	8270	
205-99-2	**Benzo[b]fluoranthene**	**750**	630	ug/kg dry	1	08/03/16	B6G2603	8270	
191-24-2	Benzo[g,h,i]perylene	ND	630	ug/kg dry	1	08/03/16	B6G2603	8270	
207-08-9	Benzo[k]fluoranthene	ND	630	ug/kg dry	1	08/03/16	B6G2603	8270	
218-01-9	**Chrysene**	**510**	320	ug/kg dry	1	08/03/16	B6G2603	8270	
53-70-3	Dibenz[a,h]anthracene	ND	630	ug/kg dry	1	08/03/16	B6G2603	8270	
206-44-0	**Fluoranthene**	**1200**	320	ug/kg dry	1	08/03/16	B6G2603	8270	
86-73-7	Fluorene	ND	320	ug/kg dry	1	08/03/16	B6G2603	8270	
193-39-5	Indeno(1,2,3-c,d)pyrene	ND	630	ug/kg dry	1	08/03/16	B6G2603	8270	
91-20-3	Naphthalene	ND	320	ug/kg dry	1	08/03/16	B6G2603	8270	
85-01-8	**Phenanthrene**	**420**	320	ug/kg dry	1	08/03/16	B6G2603	8270	
129-00-0	**Pyrene**	**810**	320	ug/kg dry	1	08/03/16	B6G2603	8270	
Surrogate: 2-Fluorobiphenyl			*71.4 %*	*32.9-115*		*08/03/16*	B6G2603	*8270*	
Surrogate: Nitrobenzene-d5			*52.9 %*	*31.8-115*		*08/03/16*	B6G2603	*8270*	
Surrogate: p-Terphenyl-d14			*76.9 %*	*38.5-115*		*08/03/16*	B6G2603	*8270*	

Client ID: Indian Mill Dam

Lab ID: 1607226-01

CAS #	Analyte	Result	RL	Units	Dilution	Analyzed Date	QC Batch	Method	Qualifier
Inorganics-General Chemistry									
TS	**% Total Solids**	**63.0**	0.1	%	1	07/25/16	B6G2506	2540 B	
Inorganics-Metals									
7440-38-2	**Arsenic**	**2.0**	0.5	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-39-3	**Barium**	**32**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-43-9	Cadmium	ND	0.2	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-47-3	**Chromium**	**6.7**	2.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-50-8	**Copper**	**6.7**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7439-92-1	**Lead**	**8.4**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7439-97-6	Mercury	ND	0.08	mg/kg dry	1	07/27/16	B6G2528	7471/245.5	
7782-49-2	Selenium	ND	0.2	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-22-4	Silver	ND	0.1	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-66-6	**Zinc**	**39**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	

Client ID: Indian Mill Tamarack

Lab ID: 1607226-02

CAS #	Analyte	Result	RL	Units	Dilution	Analyzed Date	QC Batch	Method	Qualifier
Organics-DRO/ORO									
DRO	Diesel Range Org(C10-C20)	ND	31000	ug/kg dry	1	07/30/16	B6G2121	8015	
ORO	Oil Range Organics (C20-C34)	ND	120000	ug/kg dry	1	07/30/16	B6G2121	8015	
Organics-Semivolatiles									**See note Y20**
91-57-6	2-Methylnaphthalene	ND	620	ug/kg dry	1	08/03/16	B6G2603	8270	
83-32-9	Acenaphthene	ND	250	ug/kg dry	1	08/03/16	B6G2603	8270	
208-96-8	Acenaphthylene	ND	250	ug/kg dry	1	08/03/16	B6G2603	8270	
120-12-7	Anthracene	ND	250	ug/kg dry	1	08/03/16	B6G2603	8270	
56-55-3	Benz[a]anthracene	ND	250	ug/kg dry	1	08/03/16	B6G2603	8270	
50-32-8	Benzo[a]pyrene	ND	500	ug/kg dry	1	08/03/16	B6G2603	8270	
205-99-2	Benzo[b]fluoranthene	ND	500	ug/kg dry	1	08/03/16	B6G2603	8270	
191-24-2	Benzo[g,h,i]perylene	ND	500	ug/kg dry	1	08/03/16	B6G2603	8270	
207-08-9	Benzo[k]fluoranthene	ND	500	ug/kg dry	1	08/03/16	B6G2603	8270	
218-01-9	**Chrysene**	**290**	250	ug/kg dry	1	08/03/16	B6G2603	8270	
53-70-3	Dibenz[a,h]anthracene	ND	500	ug/kg dry	1	08/03/16	B6G2603	8270	
206-44-0	**Fluoranthene**	**480**	250	ug/kg dry	1	08/03/16	B6G2603	8270	
86-73-7	Fluorene	ND	250	ug/kg dry	1	08/03/16	B6G2603	8270	
193-39-5	Indeno(1,2,3-c,d)pyrene	ND	500	ug/kg dry	1	08/03/16	B6G2603	8270	
91-20-3	Naphthalene	ND	250	ug/kg dry	1	08/03/16	B6G2603	8270	
85-01-8	Phenanthrene	ND	250	ug/kg dry	1	08/03/16	B6G2603	8270	
129-00-0	**Pyrene**	**350**	250	ug/kg dry	1	08/03/16	B6G2603	8270	
Surrogate: 2-Fluorobiphenyl			*66.1 %*	*32.9-115*		*08/03/16*	B6G2603	*8270*	
Surrogate: Nitrobenzene-d5			*49.3 %*	*31.8-115*		*08/03/16*	B6G2603	*8270*	
Surrogate: p-Terphenyl-d14			*78.7 %*	*38.5-115*		*08/03/16*	B6G2603	*8270*	

Client ID: Indian Mill Tamarack

Lab ID: 1607226-02

CAS #	Analyte	Result	RL	Units	Dilution	Analyzed Date	QC Batch	Method	Qualifier
Inorganics-General Chemistry									
TS	**% Total Solids**	**80.4**	0.1	%	1	07/25/16	B6G2506	2540 B	N
Inorganics-Metals									
7440-38-2	**Arsenic**	**2.5**	0.5	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-39-3	**Barium**	**24**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-43-9	Cadmium	ND	0.2	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-47-3	**Chromium**	**5.4**	2.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-50-8	**Copper**	**4.3**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7439-92-1	**Lead**	**22**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7439-97-6	Mercury	ND	0.06	mg/kg dry	1	07/27/16	B6G2528	7471/245.5	
7782-49-2	Selenium	ND	0.2	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-22-4	Silver	ND	0.1	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-66-6	**Zinc**	**32**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	

Client ID: Indian Mill Turner St.

Lab ID: 1607226-03

CAS #	Analyte	Result	RL	Units	Dilution	Analyzed Date	QC Batch	Method	Qualifier
Organics-DRO/ORO									
DRO	**Diesel Range Org(C10-C20)**	**52000**	37000	ug/kg dry	1	07/30/16	B6G2121	8015	Y29
ORO	**Oil Range Organics (C20-C34)**	**400000**	150000	ug/kg dry	1	07/30/16	B6G2121	8015	Y30
Organics-Semivolatiles									**See note Y20**
91-57-6	2-Methylnaphthalene	ND	740	ug/kg dry	1	08/03/16	B6G2603	8270	
83-32-9	Acenaphthene	ND	300	ug/kg dry	1	08/03/16	B6G2603	8270	
208-96-8	Acenaphthylene	ND	300	ug/kg dry	1	08/03/16	B6G2603	8270	
120-12-7	Anthracene	ND	300	ug/kg dry	1	08/03/16	B6G2603	8270	
56-55-3	**Benz[a]anthracene**	**360**	300	ug/kg dry	1	08/03/16	B6G2603	8270	
50-32-8	Benzo[a]pyrene	ND	600	ug/kg dry	1	08/03/16	B6G2603	8270	
205-99-2	**Benzo[b]fluoranthene**	**820**	600	ug/kg dry	1	08/03/16	B6G2603	8270	
191-24-2	Benzo[g,h,i]perylene	ND	600	ug/kg dry	1	08/03/16	B6G2603	8270	
207-08-9	Benzo[k]fluoranthene	ND	600	ug/kg dry	1	08/03/16	B6G2603	8270	
218-01-9	**Chrysene**	**550**	300	ug/kg dry	1	08/03/16	B6G2603	8270	
53-70-3	Dibenz[a,h]anthracene	ND	600	ug/kg dry	1	08/03/16	B6G2603	8270	
206-44-0	**Fluoranthene**	**1300**	300	ug/kg dry	1	08/03/16	B6G2603	8270	
86-73-7	Fluorene	ND	300	ug/kg dry	1	08/03/16	B6G2603	8270	
193-39-5	Indeno(1,2,3-c,d)pyrene	ND	600	ug/kg dry	1	08/03/16	B6G2603	8270	
91-20-3	Naphthalene	ND	300	ug/kg dry	1	08/03/16	B6G2603	8270	
85-01-8	**Phenanthrene**	**460**	300	ug/kg dry	1	08/03/16	B6G2603	8270	
129-00-0	**Pyrene**	**980**	300	ug/kg dry	1	08/03/16	B6G2603	8270	
Surrogate: 2-Fluorobiphenyl			*76.7 %*	*32.9-115*		*08/03/16*	B6G2603	*8270*	
Surrogate: Nitrobenzene-d5			*59.7 %*	*31.8-115*		*08/03/16*	B6G2603	*8270*	
Surrogate: p-Terphenyl-d14			*91.8 %*	*38.5-115*		*08/03/16*	B6G2603	*8270*	

Client ID: Indian Mill Turner St.
Lab ID: 1607226-03

CAS #	Analyte	Result	RL	Units	Dilution	Analyzed Date	QC Batch	Method	Qualifier
Inorganics-General Chemistry									
TS	**% Total Solids**	**67.1**	0.1	%	1	07/25/16	B6G2506	2540 B	
Inorganics-Metals									
7440-38-2	**Arsenic**	**2.3**	0.5	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-39-3	**Barium**	**30**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-43-9	Cadmium	ND	0.2	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-47-3	**Chromium**	**9.2**	2.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-50-8	**Copper**	**9.5**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7439-92-1	**Lead**	**13**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7439-97-6	Mercury	ND	0.07	mg/kg dry	1	07/27/16	B6G2528	7471/245.5	
7782-49-2	**Selenium**	**0.3**	0.2	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-22-4	Silver	ND	0.1	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	
7440-66-6	**Zinc**	**49**	1.0	mg/kg dry	10	08/11/16	B6H0201	6020/200.8	

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY

ENVIRONMENTAL LABORATORY - ANALYSIS REQUEST SHEET

Lab Work Order Number: 1607226
Project Name: Indian Mill Creek
Matrix: **SOIL/SEDIMENT**

Site Code/Project Number:
AY:
CC Email 1:
Project TAT Days:
Sample Collector: Aaron Parker
Dept-Division-District: WRD-SWAS
Index:
CC Email 2:
Project Due Date:
Sample Collector Phone: 517-284-5484
State Project Manager: Aaron Parker
PCA:
CC Email 3:
Contract Firm:
State Project Manager Email: parkera7@michigan.gov
Project:
Overflow Lab Choice 1: Tri Matrix
Accept Analysis hold time codes:
Contract Firm Primary Contact:
State Project Manager Phone: 517-284-5484
Phase:
Overflow Lab Choice 2:
Primary Contact Phone:

	Lab Use Only	Field Sample Identification	Collection Date	Collection Time	Container Count	Comments
1	01	Indian Mill Dam	7/20/16	10:00AM	1	TOC Sent to TriMatrix
2	02	Indian Mill Tamarack	7/20/16	10:30AM	1	7/21/16
3	03	Indian Mill Turner St	7/20/16	11:00AM	1	
4						
5						
6						
7						
8						
9						
10						

ORGANIC CHEMISTRY

VOA - Volatile Organic Acidic	
Volatiles - Full List	1 2 3 4 5 6 7 8 9 10
BTEX/MTBE/TMB only	1 2 3 4 5 6 7 8 9 10
Chlorinated only	1 2 3 4 5 6 7 8 9 10
GRO.	1 2 3 4 5 6 7 8 9 10
1,4 Dioxane	1 2 3 4 5 6 7 8 9 10

OS - Pesticides, PCBs	
Pesticides & PCBs	1 2 3 4 5 6 7 8 9 10
Pesticides only	1 2 3 4 5 6 7 8 9 10
PCBs only	1 2 3 4 5 6 7 8 9 10
Toxaphene	1 2 3 4 5 6 7 8 9 10

BNA - Base Neutral Acids	
BNAs	1 2 3 4 5 6 7 8 9 10
PNAs only	[✓ 1 2 3] 4 5 6 7 8 9 10
BNs only	1 2 3 4 5 6 7 8 9 10

Organic Specialty Requests	
Library search - Volatiles	1 2 3 4 5 6 7 8 9 10
Library Search - SemiVols	1 2 3 4 5 6 7 8 9 10
Finger Print	1 2 3 4 5 6 7 8 9 10
DRO / ORO	[✓ 1 2 3] 4 5 6 7 8 9 10

METALS CHEMISTRY PACKAGES

OpMemo2 - Total (Sb,As,Ba,Be,Cd,Cr,Cu,Co,Fe,Pb,Mn,Hg,Mo,Ni,Se,Ag,Tl,V,Zn)	1 2 3 4 5 6 7 8 9 10
Michigan10 - Total (As,Ba,Cd,Cr,Cu,Pb,Hg,Se,Ag,Zn)	[✓ 1 2 3] 4 5 6 7 8 9 10

MS - TOTAL METALS

Silver - Ag	1 2 3 4 5 6 7 8 9 10
Aluminum - Al	1 2 3 4 5 6 7 8 9 10
Arsenic - As	1 2 3 4 5 6 7 8 9 10
Barium - Ba	1 2 3 4 5 6 7 8 9 10
Beryllium - Be	1 2 3 4 5 6 7 8 9 10
Cadmium - Cd	1 2 3 4 5 6 7 8 9 10
Cobalt - Co	1 2 3 4 5 6 7 8 9 10
Chromium - Cr	1 2 3 4 5 6 7 8 9 10
Copper - Cu	1 2 3 4 5 6 7 8 9 10
Iron - Fe	1 2 3 4 5 6 7 8 9 10
Mercury - Hg	1 2 3 4 5 6 7 8 9 10
Lithium - Li	1 2 3 4 5 6 7 8 9 10
Manganese - Mn	1 2 3 4 5 6 7 8 9 10
Molybdenum - Mo	1 2 3 4 5 6 7 8 9 10
Nickel - Ni	1 2 3 4 5 6 7 8 9 10
Lead - Pb	1 2 3 4 5 6 7 8 9 10
Antimony - Sb	1 2 3 4 5 6 7 8 9 10
Selenium - Se	1 2 3 4 5 6 7 8 9 10
Strontium - Sr	1 2 3 4 5 6 7 8 9 10
Titanium - Ti	1 2 3 4 5 6 7 8 9 10
Thallium - Tl	1 2 3 4 5 6 7 8 9 10
Vanadium - V	1 2 3 4 5 6 7 8 9 10
Zinc - Zn	1 2 3 4 5 6 7 8 9 10
Calcium - Ca	1 2 3 4 5 6 7 8 9 10
Potassium - K	1 2 3 4 5 6 7 8 9 10
Magnesium - Mg	1 2 3 4 5 6 7 8 9 10
Sodium - Na	1 2 3 4 5 6 7 8 9 10

GENERAL CHEMISTRY

GS - General Chemistry	
Total Cyanide - CN	1 2 3 4 5 6 7 8 9 10
Available Cyanide - CN	1 2 3 4 5 6 7 8 9 10
Chem Oxyg Dem - COD	1 2 3 4 5 6 7 8 9 10
Total Org Carbon - TOC	[✓ 1 2 3] 4 5 6 7 8 9 10
Kjeldahl Nitrogen - KN	1 2 3 4 5 6 7 8 9 10
Total Phosphorus - TP	1 2 3 4 5 6 7 8 9 10

Chain of Custody

Relinquished by	Received By	Date / Time
Print Name & Org. Aaron Parker, MDEQ WRD	Melissa Smith	7/20/16 1400
Signature:		
Print Name & Org.		
Signature:		
Print Name & Org.		
Signature:		

From: Noffke, Sam (DEQ)
Sent: Monday, September 12, 2016 11:08 AM
To: Parker, Aaron (DEQ)
Cc: Carpenter, Koren (DEQ)
Subject: RE: Michigan DEQ-Laboratory Report 1607226

I analyzed the data three different ways to provide several lines of evidence. I evaluated the Equilibrium Partitioning Sediment Benchmark Toxicity Units (ESBTU), Probable Effects Concentration Quotient (PEC-Q) and the Sediment Toxicity of Petroleum Hydrocarbon Fractions using the DRO & ORO data. All of these lines of evidence are normalized based on the total organic carbon in the sediments which were 1.1 for Dam and Tamarack and 1.0 for Turner. These are low TOC numbers. PAH's normally are more bioavailable and toxic to benthic organisms in systems with low organics.

ESBTU

ESBTU for the 17 PAH's for the Dam, Tamarack and Turner street sites were 0.85, 0.48 and 0.97, respectively. Typically, a PAH ESBTU less than or equal to 1 indicates that benthic organisms are not expected to be harmed by contamination present in the sediments (EPA 2003a). However, because the total 34 scan of PAH's was not carried out a correction factor to determine the 95% confidence level is applied to the summation of the 17 hydrocarbons. Therefore the ESBTU's after the correction factor are 7.29, 4.17 and 8.35. This would suggest that the current concentrations of PAH's **may be having** detrimental effects on the benthic community.

PEC-Q's

The PEC-Q calculation results in a risk if the value is greater than 0.5 which is equivalent of 64% to 94% of the organisms not showing a toxic effect. The PEC_{PAH} values for the Dam, Tamarack and Turner sites were 0.25, 0.14 and 0.29, respectively. Therefore **not** having a detrimental effect on the benthic community. Also, when the metals were analyzed using the PEC-Q analysis the Dam, Tamarack and Turner sites were found to have results of 0.05, 0.06 and 0.06, respectively. Again suggesting no detrimental benthic community effects from metals.

Sediment Toxicity of Petroleum Hydrocarbon Fractions

When analyzing the DRO/ORO data a Sample Specific Risk Screening Level (SSRSL) was developed based on the Battelle 2007 sediment benchmark recommendations. The DRO SSRSL was exceeded at both the Dam and Turner Street site while the ORO SSRSL was exceeded at all three sites, suggesting there may be a potential risk to the benthic communities.

When looking at all three lines of evidence, two suggests detrimental effects based on low (1%) TOC. I would recommend more data be collected, maybe down stream further where more sediment may collect in depositional areas since you mentioned that the creek was rocky with very little sediment material to sample. I would also suggest a toxicity study to see exactly how the sediments affect benthic organisms.

Also, the analysis of the 17PAH's may be an issue since the correction factor is being applied. If the total 34 PAH's were analyzed for, it would give a better representation of what PAH's (parent and alkylated) are in the system without a correction factor. If you look at the ESBTU's by themselves from the 17 analyzed they do not look too bad so I am expecting the 34 may show different results.

Samuel T. Noffke

Senior Aquatic Biologist

Michigan Department of Environmental Quality

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