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**SEDIMENT SURVEY
OF THREE TRIBUTARIES OF MUSKEGON LAKE**

PROJECT #39644.000

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1.0 INTRODUCTION AND BACKGROUND

The Michigan Department of Environmental Quality (MDEQ) retained Gannett Fleming of Michigan, Inc. (Gannett Fleming) under the Level of Effort, Remediation and Redevelopment Division (RRD) Contract No. 2014 File No.: 761/99215.AGY, to evaluate sediment contamination in three tributaries of the Muskegon Lake Area of Concern (Study Areas, Figure 1). Funding for this project was provided by the United States Environmental Protection Agency (USEPA) Grant Award Number GL97561201-0, accepted by the MDEQ on October 18, 2001 for the Sediment Survey of Three Tributaries of the Muskegon Lake Area of Concern.

The main objective for this project was to identify potentially impacted sediments in the three study areas. The following project-specific objectives were developed:

- Review available data from previous investigations in the study areas;
- Identify preferred sampling stations;
- Vertically sample sediments for target chemicals of potential concern;
- Perform whole sediment toxicity tests on sediments from selected stations; and,
- Assess the impact of contamination at the sampling stations.

1.1 Survey Location Characteristics

The sediment survey was conducted in Muskegon, Michigan, and consists of three tributaries to Muskegon Lake (Figure 1). The survey area has been divided into three separate Study Areas. They include:

- Muskegon River;
- Fourmile Creek; and,
- Ryerson Creek.

The Muskegon River Study Area extends about three and a half miles from its mouth, in the vicinity of Veteran's Memorial and Richards Parks, up the South Channel of the Muskegon River to east of US-31 (Figure 1). This study area is bounded to the south by BR-31 and wetlands to the north.

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The Fourmile Creek Study Area is about three and a half miles long and less than one quarter mile wide. It extends from 300 feet east of Sheridan Road westward to its confluence with the South Branch of the Muskegon River 2,000 feet west of BR-31 (Figure 1). This study area is generally bounded to the north by the former Teledyne facility and to the south by Marquette Avenue.

The Ryerson Creek Study Area is about three and six-tenths miles long and about one third mile wide. It extends from Quarterline Road westward to its mouth at Muskegon Lake (Figure 1). This study area is bounded to the north by Marquette Avenue and to the south by Apple Avenue.

1.1.1 Survey Area Geology

The majority of the survey area is underlain by 100 to 200 feet of Pleistocene lacustrine sand and gravel deposits (Western Michigan University, 1981). The eastern end of the Ryerson Creek Study Area is underlain by Pleistocene sand dune deposits. The lacustrine deposits consist primarily of fine to medium-grained sand, with occasional gravel lenses. These deposits often originated in beach and near-offshore environments. The dune sands consist primarily of fine to medium-grained quartz sands which formed as sand dunes immediately inland of the former beaches (Farrand, 1982).

The bedrock underlying the Pleistocene deposits consists of the Mississippian-aged Marshall Sandstone (MDEQ, 1987). The Marshall Sandstone is predominantly composed of sandstones and siltstones (Catacosinos and others, 2001).

1.1.2 Study Area Hydrology

The study areas lie within the Muskegon River watershed. Fourmile Creek flows into the Southern Branch of the Muskegon River approximately 4,000 feet upstream from the mouth of the Southern Branch of the Muskegon River (Figure 1). Ryerson Creek empties into Muskegon Lake approximately 2,600 feet south of the mouth of the South Branch of the Muskegon River. Muskegon Lake empties into Lake Michigan approximately five miles west of the study areas.

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Fourmile Creek and Ryerson Creek drain the northern and eastern portions of the City of Muskegon, including storm water from city streets. The Muskegon River in the vicinity of the study areas receives most of its water from upstream portions of the watershed.

Based on the presence of the creeks, river branches, and lakes, regional ground water flow in the vicinity of the study areas would be expected to be generally towards the west. However, ground water flow at any particular sampling station may be highly variable, depending on local elevations, water bodies, etc.

1.1.3 Sediment Quality Guidelines (SQGs)

The pollutant levels in the sediment were compared to the consensus-based sediment quality guidelines (SQGs), specifically the threshold effect concentration (TEC) and the probable effect concentration (PEC) (MacDonald and others, 2000). The TEC describes a level of contamination in the sediment below which adverse effects are not expected to occur. The PEC describes a level of contamination in the sediment above which adverse effects are more likely to occur.

The results of the chemical specific sediment analyses and the SQG comparisons guided where additional sampling was necessary for whole sediment toxicity testing. The whole sediment toxicity testing was conducted to identify areas where the sediments were impacting aquatic organisms.

Some sampling stations were near public parks or other areas where the public may enter the water for recreational purposes. Therefore, the analytical results were compared to the MDEQ-RRD Generic Residential Direct Contact cleanup criteria for dry soils. Direct contact cleanup criteria are protective of dermal (skin) exposure to dry contaminated soils. The direct contact cleanup criteria are being used as an initial screening tool to determine the need for a site specific, wet sediment, direct contact cleanup criteria.

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1.2 Previous Investigations

Gannett Fleming contacted supporting divisions of the MDEQ to identify any previous investigations of the three Muskegon Lake tributaries. No previous MDEQ sediment investigations covering Fourmile Creek, Ryerson Creek, or Muskegon River are available.

Gannett Fleming also contacted academic researchers reported as having performed research in the study areas. Dr. Richard R. Rediske of the Annis Water Resources Institute at Grand Valley State University, Muskegon, Michigan (AWRI), supplied Gannett Fleming with two reports containing information on sediment sampling activities in the Muskegon River and Ryerson Creek. The first report (West Michigan Shoreline Regional Development Commission, 1982) reported metals, volatile organic compounds (VOCs), and polynuclear aromatic hydrocarbons (PAHs) above method detection limits (MDLs) in sediments from the Muskegon River and Ryerson Creek. Some of the reported concentrations were above TECs and PECs. In addition, polychlorinated biphenyls (PCBs) were reported in sediments from the Muskegon River. Sample locations from the historical reports are shown on Figure 2. Analytical results from the historical reports are summarized in Table 1.

Arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc, benzo(a)pyrene, chrysene, fluorene, naphthalene, pyrene, and PCBs were greater than the respective TECs and PECs in sediment samples collected from Ryerson Creek. Cadmium, copper, lead, anthracene, fluoranthene, fluorene, naphthalene, and pyrene were greater than the respective PECs in sediment samples collected from the Muskegon River. During the sediment sampling in 1982, no sediment samples were collected from Fourmile Creek (West Michigan Shoreline Regional Development Commission, 1982).

Rediske (1995) reported elevated concentrations of metals, total oil and grease, and PCBs in sediments from Ryerson Creek (Table 1). The reported concentrations of pollutants within the sediments were compared to the respective TECs and PECs. Cadmium, lead, and mercury were above the respective TECs in one or more sediment samples, but only lead was above the PEC. The sediments of the Muskegon River and Fourmile Creek were not sampled during the 1995 study.

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1.3 Project Objectives

Contamination had been reported within the Muskegon Lake Area of Concern prior to the present project (MDNR, 1987). Numerous potential sources of contamination were reported in the vicinities of all three study areas. The potential contaminants include VOCs, PAHs, PCBs, pesticides, and metals.

The main objective of the present study was to identify potentially contaminated sediments in the three study areas. The following project-specific objectives were developed for the three tributaries of the Muskegon Lake Area of Concern sediment survey:

- Review available data from previous investigations conducted in the study areas;
- Conduct preliminary site walks to identify preferred sampling stations; and,
- Vertically sample sediments for target chemicals of potential concern.

After the initial sediment survey was conducted, the project objectives were expanded to include:

- Collect sediment samples from selected sampling stations for whole sediment toxicity analyses.

The results of the investigation were used to evaluate the potential for contamination to impact the environment at each sampling station and to make recommendations for further work (this report).

2.0 SAMPLING METHODOLOGY

2.1 Station Identification

Members of the Public Advisory Committee (PAC) along with other concerned citizens from the area gathered to help identify potential sediment sampling locations that would be located in proximity to historic and on-going sources of contamination to the Muskegon River Watershed within the study area. Sampling stations were selected based on historic land uses and the presence of nearby potential sources of contamination and areas where the public may enter the water. Twenty-seven sampling stations were investigated during this sediment survey.

2.1.1 Initial Station Identification

On December 21, 2001 and January 10, 2002, Gannett Fleming and MDEQ-Surface Water Quality Division (SWQD) conducted kick-off meetings and station identification walks to observe the proposed sampling stations. The participants of the December 21, 2001, kick-off meeting and station identification walk included:

- Mr. Roger Jones – MDEQ-SWQD;
- Mr. Thomas Berdinski – MDEQ-SWQD;
- Ms. Heather Hopkins – MDEQ-ERD;
- Ms. Kathy Evans – Muskegon Conservation District;
- Mr. Greg Mund – United States Department of Agriculture (USDA)-Natural Resource Conservation Service (NRCS);
- Ms. Terri Boschi – formerly of Gannett Fleming; and,
- Mr. R. Bruce Rust – formerly of Gannett Fleming.

The January 10, 2002, station identification walk was attended by:

- Mr. Thomas Berdinski – MDEQ-SWQD;
- Ms. Terri Boschi – formerly of Gannett Fleming; and,
- Mr. R. Bruce Rust – formerly of Gannett Fleming.

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All of the proposed sampling stations were visited or viewed from a distance except for MR-6, which was inaccessible due to wetlands and heavy tree cover along the riverbank. After combining information obtained during the kick-off meeting, the historical file review, and the station identification walks, the proposed sampling stations were finalized. Twenty-five proposed sampling stations were selected. The section rationale for each sampling station is summarized in Table 2.

2.1.2 Final Sampling Station Locations

Several sampling stations were moved from the proposed locations due to field conditions or at the request of the MDEQ-SWQD Project Manager. MR-7 and MR-9 were moved because shallow water prevented the Vibrocore boat from reaching the proposed location. MR-7 was selected as a sampling station because it is downstream of an outfall from the Teledyne facility. Due to the presence of a sandbar at the mouth of the outfall channel, the sampling location for MR-7 was moved approximately 30 feet downstream of the mouth of the channel. The Muskegon River became too shallow for the boat to reach the proposed MR-9 sampling station location. Therefore, MR-9 was collected as far upstream as the boat could travel, which was approximately 2,000 feet west of the proposed location. FMC-6 was moved to the east side of Sheridan Road at the request of Mr. Jones and Mr. Berdinski. One additional sampling station (RYC-1A) was added to investigate the deeper sediments in the vicinity of RYC-1 and RYC-2. The additional sampling depth was required because contamination was visible at the base of the six-foot cores from RYC-1 and RYC-2. A second sampling station (RYC-2A) was added for whole sediment toxicity analysis at the suggestion of Dr. Rediske. RYC-2A is located between RYC-2 and RYC-3 east of the Ottawa Street bridge over Ryerson Creek.

Final sampling station locations were determined in the field using a global positioning system (GPS) to obtain the latitude and longitude of each sampling station. The horizontal accuracy was generally +/- 20 to 25 feet. For each sampling station, the approximate depth to sediment from the water surface was also measured (Table 3). Photographs of the final sampling stations are included in Appendix B.

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2.2 Field Sampling Plan

Gannett Fleming prepared a Field Sampling Plan (FSP) prior to initiating field sampling activities (Appendix B of Work Plan, dated April 2002). Gannett Fleming followed the procedures outlined in the FSP except where noted below.

2.2.1 Modifications to the FSP

Originally three samples from each sampling station were to be collected. However, during discussions in the field between Gannett Fleming employees and Mr. Jones and Mr. Berdinski of the MDEQ-SWQD, the FSP was modified so that only one sample would be collected from locations with sand and no organic muck or peat when sampling with the manual direct push sampling device. Due to the Vibrocore sampling method requiring one sample tube to be advanced to the desired depth without discrete sampling (further described in Section 2.3), three samples could be, and were, collected from each sample station per the FSP regardless of sediments encountered.

Field conditions at two sampling stations (RYC-3 and RYC-4) prevented sufficient sample recovery to collect the proposed three samples. The sediments consisted of very loose organic material, which did not have sufficient cohesion to be pushed past the sediment trap in the manual Geoprobe. Once the shoe of the manual Geoprobe was full, the sampler acted as a solid rod and pushed additional sediment to the sides. At these locations, sufficient sediment for one sample was obtained by repeatedly pushing the sampling device into the sediment by hand and collecting the sediment trapped in the shoe.

Also, one additional Vibrocore sample (RYC-1a) was collected between RYC-1 and RYC-2 to a depth of 10.5 feet below the sediment-water interface to investigate the vertical distribution of sediments and contamination.

During the fall of 2002, Mr. Michael Alexander of the MDEQ-Water Division (WD, formerly the SWQD) was assigned as the new MDEQ project manager. On November 20, 2002, Mr. Alexander requested Gannett Fleming to collect samples from selected locations for whole sediment toxicity testing. Three rounds of whole sediment toxicity sampling were performed.

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The first round was collected on December 3 and 3, 2002; the second round was collected on April 9 and 10, 2003; and the third round was collected on November 18 and 19, 2003. The samples were collected using either a petite ponar sampler dropped from a boat or by using a shovel, depending on the water depth. Samples were first placed into a large plastic bag for homogenization, and then placed into the appropriate laboratory-supplied containers. Based on unpublished data indicating sediment contamination between RYC-2 and RYC-3, RYC-2A was added to the study at the suggestion of Dr. Rediske for the November 2003 sampling event. RYC-2A is located east of the Ottawa Street bridge over Ryerson Creek.

2.2.2 Sampling and Analyses

Samples were collected from the zero to one half foot, one half to two foot, and two to four foot intervals from each sampling station, except as noted below. If organic muck was encountered, the sampling intervals were zero to one half foot, two to four foot, and four to six foot (Table 4). The zero to one half foot interval sample was analyzed for VOCs using USEPA SW-846 Method 8260, PAHs using USEPA SW-846 Method 8270, target metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc) using USEPA SW-846 Methods from the 6000/7000 series, PCBs using USEPA SW-846 Method 8082, and pesticides using USEPA SW-846 Method 8081. The VOC samples were weighed and field-preserved in methanol. The deeper intervals were analyzed for PAHs using USEPA SW-846 Method 8270, target metals using USEPA SW-846 Method from the 6000/7000 series, PCBs using USEPA SW-846 Method 8082, and pesticides using USEPA SW-846 Method 8081. The analytical parameters analyzed for each sample are listed in Table 4. The individual methods are described in USEPA (1996).

Whole sediment toxicity samples were collected from the zero to one foot interval. Samples were analyzed for whole sediment toxicity (USEPA, 1999; ASTM, 1999), sediment grain size (Plumb, 1981), and total organic carbon using the Walkley-Black method. In addition, the samples were analyzed for PAHs using USEPA SW-846 Method 8270 and Michigan 10 Metals using USEPA SW-846 Methods from the 6000/7000 series (USEPA, 1996).

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2.3 Vibrocore Sampling

Gannett Fleming contracted AScI Corporation of Sterling Heights, Michigan (ASCI) for Vibrocore sampling services. AScI operates a pontoon boat-mounted Vibrocore rig which uses disposable plastic corers. The AScI Vibrocore boat required access to the study area using a boat ramp and water depths of 18 inches. During this study, the Vibrocore boat accessed areas with water depths of approximately 10 inches.

As described in the FSP, the Vibrocore sampling was accomplished by attaching a disposable plastic corer to a vibrator head. The corer was then lowered to the sediment-water interface and the vibrator activated. After the desired depth was reached or refusal was encountered, the vibrator was turned off and the corer was raised. A plastic cap was placed on the bottom of the core and any water present was drained from the top. The corer was then cut opened at the desired interval(s), the samples were field screened with a photoionization detector (PID) and logged, and the laboratory samples collected.

Corers were pre-cut to six foot lengths, which limited the maximum length of recovered cores to six feet. At sampling stations with thick river sands (MR-1, MR-4, MR-6, MR-7, MR-8, and MR-9), sample refusal occurred between three and a half and four feet below the sediment surface. Refusal occurred because the tightly packed sand grains could not vibrate enough to become fluidized. One 12-foot core was collected between RYC-1 and RYC-2 to further investigate suspected contamination observed in RYC-1 and RYC-2. The Vibrocore was used to collect samples from a total of 13 sampling stations (Figure 3 and 4).

2.4 Manual Direct Push Sampling

Manual direct push equipment was used to collect sediment samples at sample stations inaccessible by the Vibrocore boat. The manual direct push sampling device consists of a standard two inch diameter, four feet long macrocore and extensions which are hammered into the sediment using an anvil attachment and a 30-pound slide hammer, and is manufactured by Geoprobe®. As described in the FSP, a disposable plastic liner was inserted into the macrocore prior to advancing the macrocore. To collect sediments from intervals below four feet beneath the sediment surface, a discrete sampling unit was inserted into the macrocore. The macrocore

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was then advanced to the desired beginning depth, the discrete sampling unit was removed from the macrocore using special extension rods, and then the macrocore was advanced to the desired ending depth. The macrocore was extracted from the sediment using a jack. The plastic liner was then cut open, the sample screened with a PID and described, and the laboratory samples collected. The manual Geoprobe® was used to collect samples at 13 sampling stations (Figures 3 and 4)

Due to field conditions at two sampling stations (RYC-3 and RYC-4), the anvil was not used to advance the macrocore and only the zero to four foot interval was sampled. The sediments at these sampling stations consisted of very loose organic muck, which did not allow a firm enough base for extracting the macrocore from deeper intervals. At these sampling stations, the macrocore was advanced and extracted by pushing directly on an extension rod attached to the macrocore.

2.5 Whole Sediment Toxicity Analyses

The whole sediment toxicity analyses were performed in accordance with USEPA (1999) and ASTM (1995). *Chironomus tentans* and *Hyalella azteca* were the invertebrates selected to perform the analyses. Additional analyses included sediment grain-size analysis, total organic carbon (TOC), PAHs, and metals. A biological census of the samples collected during the third round of toxicity sampling was also conducted at the request of Mr. Alexander. The biological census consisted of identifying and enumerating the macroscopic organisms living in the sediment.

Three rounds of whole sediment toxicity sampling were performed. The first round of whole sediment toxicity was performed in December 2003. The quality assurance/quality control (QA/QC) requirements of the test were not met. Therefore, the data gathered during this first test was unusable. However, the sediment chemistry data, which did meet the QA/QC requirements, have been included in Table 6. The second round of samples was collected on April 9 and 10, 2003, from FMC-1, FMC-2, MR-1, RYC-1, RYC-2, RYC-7, and RYC-8. The whole sediment toxicity samples were submitted to Great Lakes Environmental Center in Traverse City, Michigan (GLEC) and the PAH and metals samples were submitted to the MDEQ laboratory.

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The third round of samples was collected on November 18 and 19, 2003. Samples were collected from RYC-1, RYC-2, RYC-2A, RYC-3, RYC-4, and RYC-7. The whole sediment toxicity and benthic census samples were submitted to AWRI and the PAH and metals samples were submitted to the MDEQ laboratory. Triplicate samples were collected at each station for the biological census. To evaluate the benthic census, each sample was sieved at the laboratory using a 150-micrometer (μm) sieve. The sample was then preserved using rose Bengal stain and 10% buffered formalin. Benthic macroinvertebrates were then removed from the sample and preserved using 70% ethanol until identification and enumeration. After the organisms had been identified and enumerated, the density for each taxon was calculated and ecological analyses performed to determine if the benthic community was degraded.

3.0 ANALYTICAL RESULTS

All of the chemical analytical results were compared to TECs, PECs, and dry soil direct contact cleanup levels (Table 5). The whole sediment toxicity samples were examined statistically to determine if contaminants in the sample had a significant effect on the organisms. The whole sediment toxicity results were then compared with the PAH and metal analytical results to determine if any correlations existed between the toxicity results and potential contaminants. PAH and metal analytical results for samples collected for the toxicity analyses were compared to the TECs, PECs, and dry soil direct contact cleanup levels.

3.1 Data Quality Evaluation

The reproducibility of laboratory analytical results varied with the analyte group and sediment type. PAHs analyzed from sands tended to have good reproducibility. PAHs analyzed from organic muck tended to have poor reproducibility (Tables 3 and 6). Metals generally had better reproducibility than PAHs, although not in samples from two sampling stations (RYC-5 and RYC-7). Matrix interference and/or dilution factors may account for the majority of the variability.

The MDLs for nine of the PAHs (anthracene, benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluorene, naphthalene, phenanthrene and pyrene) were greater than the respective TECs. The MDL for anthracene was also greater than the PEC (845 micrograms per kilogram (ug/kg)). During the review of the data, comparisons of analytical results to criteria were conducted when a concentration value was reported.

The MDLs for PCBs generally ranged from 130 to 540 ug/kg, which were above the TEC for total PCBs (59.8 ug/kg), but were below the PEC for total PCBs of 676 ug/kg. A variation in the MDLs was observed in many samples. This variation is believed to be the result of matrix interference as a result of the high carbon content (i.e. muck) observed in these samples. In 28 samples, the elevated MDLs also were above the PECs of one or more PAHs. None of the MDLs for samples analyzed for metals were above the TECs.

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The procedures for whole sediment toxicity analysis and biological census require the use of replicates. Any divergences between replicates were taken into account during the statistical analysis.

3.2 Analytical Results by Study Area

The sediment study consisted of three representative study areas: Four Mile Creek, Muskegon River, and, the Ryerson Creek.

PCBs and pesticides were not detected above MDLs in samples collected during this sediment survey. One sample, MR-3 0-0.5', contained the VOCs n-propylbenzene, 1,2,4-trimethylbenzene, and 1,3,5-trimethylbenzene in concentrations above MDLs. VOCs were not detected in any other samples. No TECs have been formulated for VOCs and the reported VOC concentrations were below the respective dry soil direct contact criteria. Samples collected from all three-study areas contained PAHs and target metals above the respective TECs. The laboratory analytical results for measurable (i.e. above MDLs) analytes are summarized in Table 5. Laboratory analytical reports are included in Appendix C. PAH concentrations were above TECs and PECs are shown on Figure 3. Target metal concentrations above TECs and PECs are shown on Figure 4. Contaminant concentrations for samples collected for the whole sediment toxicity analyses are discussed in Section 3.3.

3.2.1 Muskegon River Study Area

3.2.1.1 PAH Analytical Results

The following PAHs were above the respective TECs: benzo(a)anthracene, benzo(a)pyrene, and fluoranthene in sediment sample MR-7 0.5-2' and benzo(a)anthracene in sediment sample MR-7 2-4'. PAH concentrations above TECs are shown on Figure 3. All other PAHs were below the respective TEC.

PAHs were not above the respective PECs or dry soil direct contact criteria within the Muskegon River Study Area.

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3.2.1.2 Target Metals Analytical Results

The levels of cadmium, chromium, copper, lead, nickel, and zinc in sediment sample MR-3 0-0.5' were above the TECs established for the respective parameter as indicated in Table 5. The remaining sediment samples collected from the Muskegon River study area did not document any levels of target metals above the respective TECs.

The levels of chromium and nickel in sediment sample MR-3 0-0.5' were above the PECs established for these metals as indicated in Table 5. The remaining sediment samples collected from the Muskegon River study area did not document any levels of target metals above the respective PECs.

Arsenic was identified in sediment sample MR-3 0-0.5' at a concentration greater than the dry soil direct contact criterion, as indicated in Table 5.

3.2.2 Four Mile Creek Study Area

3.2.2.1 PAH Analytical Results

Sediment samples FMC-3 0-0.5', FMC-3 0-0.5' DUP, FMC-3 2-4', and FMC-5 0-0.5' were above TECs for one or more of the following parameters: benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene. PAH concentrations above TECs are shown on Figure 3 and in Table 5.

Sediment sample FMC-3 0-0.5' contained levels of PAHs that were above the respective PECs as indicated on Figure 3.

3.2.2.2 Target Metals Analytical Results

One or more of the following target metals were above the TEC concentrations in sediment samples FMC-1 0-0.5', FMC-1 2-4', FMC-2 0-0.5', FMC-2 2'-4', FMC-3 2-4', FMC-5 0-0.5' and FMC-6 0-0.5: cadmium, chromium, copper, lead, mercury and zinc. Target metal concentrations are shown on Figure 4 and in Table 5.

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Sediment sampling locations FMC-1 0-0.5', FMC-2 0-0.5' and FMC-2 2-4' contained levels of lead which were above the PEC established for this parameter. The remaining sediment sampling locations within the Fourmile Creek study area did not contain levels of target metals above the respective PECs.

3.2.3 Ryerson Creek Study Area

3.2.3.1 PAH Analytical Results

Stations RYC-1, RYC-2, RYC-3, RYC-4, RYC-7, and RYC-8 contained levels of one or more of the following compounds that were above the respective TEC and/or PEC: anthracene, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene. PAH concentrations above TECs and PECs are shown on Figure 3 and in Table 5.

3.2.3.2 Target Metals Analytical Results

Stations RYC-1, RYC-2, RYC-3, RYC-4, RYC-5, and RYC-7 contained levels of one or more of the following compounds that were above the respective TEC and/or PEC: arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Stations RYC-1, RYC-2, RYC-3, and RYC-5 contained at least one target metal that was present in excess of the established PEC for the respective parameter. Figure 4 graphically displays the sampling results for the Ryerson Creek study area. Table 5 presents the analytical data and indicates where contaminants were above the TECs and PECs in Ryerson Creek.

One or more target metals were above the respective PEC concentrations for arsenic, cadmium, chromium, copper, lead, nickel, and zinc in sediment samples RYC-1 0-0.5', RYC-1 2-4', RYC-1 4-6', RYC-2 0-0.5', RYC-2 0-0.5' DUP, RYC-2 2-4', RYC-2 4-6', RYC-3 0-4', RYC-5 2-4', RYC-5 4-6'. The following target metals were above the respective PECs: lead in RYC-1 0-0.5', arsenic, cadmium, chromium, copper, lead, nickel, and zinc in RYC-1 2-4' and RYC-1 4-6'; lead and zinc in RYC-2 0-0.5' and RYC-2 0-0.5' DUP; cadmium, chromium, copper, lead, nickel, and zinc in RYC-2 2-4'; cadmium, chromium, copper, lead, and zinc in RYC-2 2-4' and RYC-2 4-6'; lead and zinc in RYC-3 0-4'; copper and nickel in RYC-5 2-4'; and lead and zinc in RYC-5 4-6'. Concentrations above PECs are shown on Figure 4.

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Arsenic was above the direct contact cleanup criterion for dry sediment samples at three sediment sampling locations on Ryerson Creek. Lead was above the direct contact cleanup criterion for dry sediment samples at two sediment sampling locations on Ryerson Creek.

3.3 Whole Sediment Toxicity Analyses and Benthic Survey

During December 2002, an initial sediment toxicity test was conducted and sediment samples were also collected for chemical analyses. However, the sediment toxicity test did not meet the quality assurance/quality control requirements. Therefore, the toxicity data has not been included with this report. The chemical analytical results are included in Table 6.

Based on the contaminant distributions identified during the initial sediment sampling activities, the whole sediment toxicity sampling focused primarily on Ryerson Creek. During the second round of sediment toxicity sampling, two samples were also collected from Fourmile Creek (FMC-1 and FMC-2) and a background sample was collected from the Muskegon River (MR-1). All of the samples collected during the third round of sediment toxicity sampling were collected from Ryerson Creek and a laboratory sample was used to establish background. The chemical analytical results are summarized in Table 6. The toxicity analysis results are summarized in Table 7 and the laboratory reports are included in Appendix D (GLEC, 2003; Rediske, 2004).

3.3.1 April 2003 Toxicity Sampling

Sampling location FMC-1 contained levels of lead that were greater than the PEC. The levels of cadmium, copper, mercury, and zinc were greater than the respective TECs. The sediments analyzed from stations FMC-2 and MR-1 did not contain any target metals or PAHs at levels above the establish TECs. In RYC-1 and/or RYC-1 Dup, fluoranthene, pyrene, lead, and zinc were present at levels greater than the respective PECs; cadmium, chromium, copper, and mercury were present at levels greater than the respective TECs. Sampling location RYC-2 contained levels of chrysene, fluoranthene, phenanthrene, pyrene, copper, lead, and zinc that were greater than the respective PECs; cadmium, chromium, and mercury levels were greater than the respective TECs. Sediments from station RYC-7 contained levels of benzo(a)anthracene, chrysene, fluoranthene, phenanthrene, pyrene, copper, lead, and zinc that were above the respective PECs and cadmium, chromium, and mercury levels that were above

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the respective TECs. Sampling location RYC-8 contained elevated levels of anthracene, benzo(a)anthracene, chrysene, fluoranthene, phenanthrene, and pyrene when compared to the respective PECs; levels of copper, lead, and zinc were elevated when compared to the respective TECs. Table 6 summarizes the above information and highlights any values that are elevated when compared to the respective PEC and/or TEC.

The control survival rates for *H. azteca* and *C. tentans* (greater than 80% and 70%, respectively), growth criteria, and the water quality data were within the acceptable guidance established by the USEPA. Therefore, the tests are considered valid assessments of sediment toxicity.

RYC-1 and RYC-7 had a statistically significant reduction in survival of *H. azteca*. RYC-1 had 28.8% survival and RYC-7 had 45% survival. Growth, as determined by average dry weight, was not significantly reduced in any of the samples. These results indicate that the sediments from stations RYC-1 and RYC-7 were acutely toxic to *H. azteca* after 10 days of exposure (Table 7).

RYC-1 and RYC-7 had a statistically significant reduction in survival of *C. tentans*. RYC-1 had 62.5% survival and RYC-7 had 32.5% survival. Growth, as determined by ash free dry weight, was significantly reduced in one of the samples (RYC-7). These results indicate that the sediments from stations RYC-1 and RYC-7 were acutely toxic to *C. tentans* after 10 days of exposure and the sediments were also impacting the growth of *C. tentans* at RYC-7 after 10 days of exposure (Table 7).

3.3.2 November 2003 Toxicity Sampling

Sediments collected from station RYC-1 contained elevated levels of benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, pyrene, copper, lead, mercury, and zinc when compared to the respective PECs; cadmium and chromium were present at elevated levels when compared to the TECs. The sediment at station RYC-2 (RYC-2 0-1' and RYC-2 Dup 0-1') contained levels of anthracene, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, pyrene, and mercury that were greater than the respective PECs; fluorene, copper, and zinc were elevated when compared to the TECs. The sediments from RYC-2A contained

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levels of benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, pyrene, lead, and zinc that were greater than the respective PECs; cadmium, chromium, copper, and mercury were present at levels greater than the respective TECs. Sediment sampling at RYC-3 revealed elevated levels of chrysene, fluoranthene, pyrene, copper, lead, and zinc when compared to the respective PECs; benzo(a)anthracene, phenanthrene, cadmium, and chromium were present at levels greater than the corresponding TECs. Sediments collected from Ryerson Creek at RYC-4 contained elevated levels of chrysene, fluoranthene, phenanthrene, pyrene, copper, lead, and zinc when compared to the PECs established for these parameters; benzo(a)anthracene, benzo(a)pyrene, cadmium, and chromium were present at levels in excess of the TECs established for the respective parameter. Sediments at station RYC-7 contained levels of benzo(a)anthracene, chrysene, fluoranthene, phenanthrene, pyrene, copper, lead, and zinc that were greater than the respective PECs. Cadmium was present at a greater concentration than the TEC but was below the PEC. Table 6 summarizes the above information and highlights any values that are elevated when compared to the respective PEC and/or TEC.

The control survival rates for *H. azteca* and *C. tentans* (greater than 80% and 70%, respectively), growth criteria, and the water quality data were within the acceptable guidance established by the USEPA. Therefore, both tests are considered valid assessments of sediment toxicity.

RYC-1, RYC-2, and RYC-3 had a statistically significant reduction in survival of *H. azteca*. RYC-1 had 61% survival, RYC-2 had 66% survival, and RYC-3 had 62.5% survival. Growth, as determined by dry weight, was significantly reduced in RYC-1 and RYC-2. These results indicate sediments from RYC-1, RYC-2, and RYC-3 were acutely toxic to *H. azteca* after 10 days of exposure and the sediments were also significantly impacting the growth of *H. azteca* at stations RYC-1 and RYC-2 (Table 7).

None of the samples caused a significant reduction in mortality of *C. tentans*. Growth, as determined by ash free dry weight, was significantly reduced in RYC-1 after 10 days of exposure (Table 7); however, none of the sediment samples were acutely toxic to *C. tentans* after 10 days of exposure.

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3.3.3 Benthic Survey

All sediment samples from Ryerson Creek contained benthic macroinvertebrate assemblages that indicated degraded conditions. In all of the samples, oligochaetes, chironomids, and leaches were the dominant taxa. High oligochaete densities and the predominance of the oligochaete *Limnodrilus hoffmeisteri*, such as identified in RYC-1 and RYC-2, indicate highly enriched conditions. Amphipods, a relatively pollution intolerant taxon, were absent from RYC-1 but present in the remaining samples.

RYC-3 and RYC-4, both collected from the lagoon adjacent to the Farmer's Market, contained very different benthic populations. RYC-3 contained lower amphipod, chironomid, and isopod densities than RYC-4. Diversity and density were also lower in RYC-3 when compared to RYC-4.

4.0 SUMMARY

This survey was undertaken to assess contamination of the study areas from a variety of sources. The survey identified target metals and PAH contamination throughout the study areas. The initial objective was to identify locations where the sediments may be impacting the benthic communities based on contaminant concentrations greater than the SQGs. In addition, target metals were reported in all three-study areas above the PECs for one or more analytes. PAHs were reported in the Fourmile Creek and Ryerson Creek Study Areas above the PECs for one or more analytes. Target metals were detected in every sample submitted for laboratory analysis. However, most of the reported concentrations were below the MDEQ Statewide Default Backgrounds for soils (Table 5).

Elevated levels of PAHs were identified in some sediment samples from Fourmile Creek and Ryerson Creek. Target metals were present in all three-study areas; however, Fourmile Creek and Ryerson Creek had the highest levels of target metals.

4.1 Muskegon River Study Area

Target metals at concentrations above TECs and petroleum hydrocarbons were reported at two sampling stations (MR-3 and MR-7) in the Muskegon River Study Area. Target metal concentrations were not above the dry soil direct contact criteria.

MR-3 was selected as a sampling station due to the presence of a Marathon petroleum bulk storage facility to the northwest. Numerous monitoring wells and recovery wells on the Marathon property were visible from a public drive located southeast of the Marathon facility, indicating ground water monitoring for petroleum releases. Three VOCs were reported at concentrations above the MDLs at MR-3; however, TECs and PECs have not been established for VOCs (MacDonald and others, 2000). The reported VOC concentrations were below the dry soil direct contact criteria. The vertical extent of VOC contamination at MR-3 is not known due to VOCs being analyzed only in the uppermost sample. No PAHs were reported in samples collected at MR-3. Target metals concentrations at MR-3 were above TECs, with chromium and nickel concentrations above the respective PECs. Arsenic and chromium concentrations were

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identified at MR-3 above the direct contact criteria. The metal concentrations decreased with depth.

MR-7 was selected as a sampling station due to its location directly downstream of an outfall from the Teledyne facility. Three PAHs were reported at MR-7 at concentrations above TECs but below PECs. Due to the presence of a sandbar at the mouth of the outfall channel, the sampling location for MR-7 was moved approximately 30 feet downstream from the mouth of the outfall channel. Sediments at MR-7 consisted entirely of sand. MR-7 0-0.5' contained no detectable levels of PAHs, possibly due to the swifter water flow in areas with sand deposition which may prevent the analytes from settling. MR-7 0.5-2' contained higher concentrations of PAHs than MR-7 2-4'. One potential source of the PAHs reported in MR-7 0.5-2' and MR-7 2-4' is petroleum hydrocarbons from the outfall. Another potential source of the PAHs is contamination from ground water discharging into the Muskegon River. However, the higher concentrations of PAHs in MR-7 0.5-2', compared to the deeper sample, do not directly support contaminated ground water as the potential source.

4.2 Fourmile Creek Study Area

Analytes above TECs were reported at five sampling stations (FMC-1, FMC-2, FMC-3, FMC-5, and FMC-6) in the Fourmile Creek Study Area.

FMC-1 was selected as a sampling station to assess potential contamination in an area potentially receiving discharge from the Teledyne facility. Metals were reported at FMC-1, with lead above the PEC in FMC-1 0-0.5'. A significant concentration gradient is present at FMC-1 0-0.5' and FMC-1 2-4'. However, the analyte concentrations are lower in FMC-1 4-6' to the extent that none of the analytes were in excess of the TEC.

FMC-2 was selected as a sampling station to assess any contamination in an area potentially receiving discharge from the Teledyne facility. Metals were also reported at FMC-2 at concentrations above TECs, with lead above the PEC in FMC-2 0-0.5' and FMC-2 2-4'. Metal concentrations decrease between FMC-2 0-0.5' and FMC-2 2-4'. The metal concentrations are

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much lower in FMC-2 4-6' to the extent that none of the analytes are above the TEC. The metal concentrations are higher at FMC-2 than the same intervals at FMC-1 or FMC-3.

FMC-3 was selected as a sampling station due to the downstream location from the Planck facility. PAHs were reported at FMC-3 at concentrations above the TECs and PECs. The reported concentrations are highest in FMC-3 0-0.5' and decrease vertically. No PAHs were reported above method detection limits in FMC-3 4-6'.

FMC-1, FMC-2, and FMC-3 are located in the Sanford Bayou. FMC-1 and FMC-2 are located in the open-water portion of the bayou (western and eastern ends, respectively) and FMC-3 is located in the shallow creek in the wetlands portion of the bayou. FMC-2, located close to where the shallow creek flows into the open water, contained the highest concentrations of metals. Metal concentrations were generally lower at FMC-1 and were much lower at FMC-3. One explanation for this distribution is that the swifter water flow at FMC-3 may prevent the analytes from settling as readily.

FMC-5 was selected as a sampling station to assess potential contamination in an area receiving discharge from the Teledyne facility. Two PAHs and copper were reported at FMC-5 at concentrations above the TECs but not the PECs. Only one sample was collected at FMC-5 per the modified sampling plan (refer to Section 2.2.1); therefore, the vertical extent of contamination is not known. The reported analytes and their concentrations differ between Sanford Bayou (FMC-1 and FMC-2) and FMC-5.

FMC-6 was selected as a sampling station to collect samples that would represent background conditions. Target metals were reported at FMC-6 at concentrations above the TECs. The highest metal concentrations were reported in FMC-6 0-0.5' and decrease with depth. In FMC-6 0.5-2', the metal concentrations are below the TECs.

4.3 Ryerson Creek Study Area

More contaminants were detected in the Ryerson Creek study area than the other two study areas. PAHs and target metals were reported at concentrations above TECs at eight of the nine

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sampling stations in the Ryerson Creek Study Area. Target metals were reported at concentrations above the dry soil direct contact criteria at three sampling stations. The Ryerson Creek study area samples had the highest PAH and target metal concentrations when compared to the other study areas.

RYC-1 and RYC-2 were selected as sampling stations to assess historical contamination in a heavily industrialized area. Target metals and PAHs in RYC-1 2-4' and RYC-1 4-6' were above the TECs, PECs, and dry soil direct contact criteria. The deeper sample at RYC-1a at 9.5-10.5' did not have any detectable PAHs and metals were below statewide Default Background Concentrations. The sediment at RYC-1 is organic muck for the entire six-foot length of the core.

Target metal concentrations above the TECs and PECs were reported in all three samples at RYC-2. The metal concentrations generally increase with depth. The PAH concentrations show a slight increase with depth. The sediment at RYC-2 is organic material for the entire six-foot length of the core.

In order to assess the lithology and analyte concentrations to a greater depth, RYC-1a was advanced between RYC-1 and RYC-2. Approximately eight feet of organic muck overlies one half foot of silt. Underlying the silt is a sand layer. One sample (RYC-1a 9.5-10.5') was collected from the sand layer and submitted for laboratory analysis. PAHs were not reported above MDLs and the detected metal concentrations were below the respective TECs and Statewide Default Background Concentrations. Therefore, the contamination at RYC-1 and RYC-2 is confined to the interval between zero and nine and a half feet below the sediment-water surface. The silt layer may be acting as a barrier to the migration of contaminants.

RYC-3 and RYC-4 were selected as sampling stations to assess potential contamination from a sewer main break. Some PAHs were reported at concentrations above TECs and some target metals above TECs and PECs at RYC-3. Only one sample was collected at RYC-3 and consisted primarily of muck and sand. PAHs were reported at concentrations above TECs and PECs (pyrene only) and lead was reported at a concentration above the TEC at RYC-4. No

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analyte concentrations were above dry soil direct contact criteria. RYC-4 appears to have been impacted more by PAHs than RYC-3, whereas RYC-3 appears to have been impacted more by metals. However, the elevated MDLs for PAHs in both samples may mask the actual PAH concentrations in the samples.

RYC-5 and RYC-6 were selected as sampling stations to assess contamination from another sewer main break. Target metals at RYC-5 (cadmium, copper, lead, nickel, and zinc) were reported at concentrations above the respective TECs. Copper, lead, nickel and zinc were identified at concentrations greater than the respective PECs. Some of the metal concentrations increase with depth (lead and zinc). However, copper concentrations are greatest in RYC-5 2-4' and decrease markedly in RYC-5 4-6'. Arsenic was reported in RYC-6 at a concentration above the TEC but below the PEC. The arsenic concentration in RYC-6 0-0.5' was above the dry soil direct contact criteria. Arsenic was reported in all three samples from RYC-5, but at concentrations below the TEC. The difference in analyte distributions indicates different sources may be involved for the contamination at the two locations.

RYC-7 was selected as a sampling station to assess contamination from multiple nearby leaking underground storage tanks (LUST) sites. Target metals were reported at concentrations above TECs but below PECs at RYC-7. PAHs were reported at concentrations above TECs and PECs at RYC-7. The concentrations of both metals and PAHs decrease with depth, with no analyte concentrations reported above TECs in RYC-7 4-6'.

RYC-8 was selected as a sampling station to assess potential contamination from a nearby LUST site. A monitoring well, probably associated with the LUST site investigation was located approximately 30 feet west of RYC-8. PAHs were reported at concentrations above TECs, PECs at RYC-8. Metals were not reported at concentrations above TECs. The PAHs were reported only in RYC-8 0-0.5'.

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4.4 Whole Sediment Toxicity Analyses and Benthic Survey

4.4.1 April 2003 Toxicity Sampling

The whole sediment toxicity tests indicate contaminated sediments at RYC-1 and RYC-7 impact organisms at those locations. The impacts included increased mortality and decreased growth. MR-1 was collected as a background sample, so no toxic effects were anticipated nor observed. Additional contaminants were identified at the remaining sampling stations on Fourmile Creek and Ryerson Creek; however, they do not appear to be affecting organisms. One possible explanation is that the contaminants are bound to organic matter in the sediments.

The toxicity and sediment chemistry results (using only the chemistry results from the second round of toxicity sampling) were statistically analyzed to determine if significant correlations were present. All of the contaminants with concentrations greater than the PECs in multiple samples were analyzed. No significant correlations were identified.

4.4.2 November 2003 Toxicity Sampling

The whole sediment toxicity tests indicate contaminated sediments at RYC-1, RYC-2, and RYC-3 are impacting organisms at these locations. The impacts included increased mortality and reduced growth and community diversity. Additional contaminants were identified at the remaining sampling stations on Ryerson Creek; however, they do not appear to be affecting organisms. One possible explanation is that the contaminants are bound to organic matter in the sediments.

The toxicity and sediment chemistry results (using only the chemistry results from the third round of toxicity sampling) were statistically analyzed to determine if significant correlations were present. All of the contaminants with concentrations above the PECs in multiple samples were analyzed. No significant correlations were identified. In addition, the benthic census and sediment chemistry results were similarly analyzed, with no significant correlations found.

The results of the sediment chemistry, toxicity tests, and benthic census were then analyzed using a sediment quality assessment matrix (Table 8, Rediske, 2004). This matrix uses the results of the different tests to assess the likelihood of contaminant impact to the environment.

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The possible results range from impact highly unlikely to impact highly likely. Contaminant concentrations above PECs, observed sediment toxicity, and benthic community degradation were observed in RYC-1, RYC2, and RYC-3, indicating that impact is highly likely at these locations and that the impact is affecting sediment-dwelling organisms. Although contaminant concentrations above PECs were observed at RYC-2A, RYC-4, and RYC-7, sediment toxicity and excessive benthic community degradation were not observed, indicating the contaminants are unavailable to the sediment-dwelling organisms.

4.5 General Observations

4.5.1 Sediment Survey General Observations

Due to the distances between sampling stations, area mapping of contaminants is not possible. At sampling stations with reported contaminants and two or more analyzed samples (a total of 19 sampling stations), no overall contaminant concentration gradient was apparent. At eleven stations, a general trend of decreasing contaminant concentrations with depth was noted, although individual contaminant concentrations often countered the trend at any single sampling station. At eight of the sampling stations, either no discernable trend was evident or contaminant concentrations increased with depth.

In general, metal concentrations were higher in samples consisting of muck than in samples consisting of sand, with some exceptions. PAHs showed a slight trend for samples from muck to have more PAHs than samples from sand. These trends may be due to PAH adsorption by the organic matter in the muck. Another possibility is that the swifter water flow in areas with sand deposition may prevent the analytes from settling.

Sampling stations investigating contamination from the same potential source often exhibited different chemical profiles. FMC-1 and FMC-2 exhibited target metal contamination, whereas FMC-5 and FMC-7 exhibited PAH contamination, even though all four sampling stations were investigating potential impact from the Teledyne facility. RYC-3 and RYC-4 were selected to investigate the same sewer main break, yet RYC-3 contained more target metals contamination and RYC-4 contained more PAH contamination. RYC-5 and RYC-6 were selected to investigate

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another sewer main break, yet RYC-5 contained several target metals (but not arsenic) above TECs whereas RYC-6 contained only arsenic above the TEC.

RYC-8 and RYC-9 were selected to investigate potential contamination from LUST sites. PAH concentrations above PECs were reported at RYC-8 in one of the two samples collected (RYC-8 0-0.5'). No PAH contamination was reported at RYC-9.

4.5.2 Comparisons with Previous Studies

Samples were collected during this study from the vicinity of 11 sampling stations previously sampled (West Michigan Shoreline Regional Development Commission, 1982; Rediske, 1995). In some locations, the previous studies reported higher analyte concentrations; in other locations the current sediment survey reported higher analyte concentrations. Metal concentrations were similar at other locations. The sample lithologies were not reported in the previous studies. The PAH and selected metals concentrations are shown in Table 9. The sampling locations for the previous studies are shown on Figure 2 and the sampling stations for this survey are shown on Figure 1.

MR-4 was collected in the vicinity of the 1982 stations L-3 and L-4. The metal analytical results are similar among these samples, except for an elevated zinc concentration in L-4. PAHs were not analyzed in L-3 and L-4.

According to the text of West Michigan Shoreline Regional Development Commission (1982), the 1982 station B-1 was near the location selected for MR-7 in this study. However, the 1982 location map shows that B-1 is more than two miles downstream of MR-7. The analyte concentrations in MR-7 are generally one to two orders of magnitude less than the concentrations in B-1 for both metals and PAHs.

MR-10 was collected in the general vicinity of the 1982 station M-1. The metal concentrations reported from MR-10 are generally an order of magnitude less than those reported from M-1.

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RYC-1 and RYC-2 were collected in the general vicinity of the 1982 station K and the 1995 station MRY-1. Some of the reported metal concentrations from RYC-1 and RYC-2 are higher than the same analyte concentrations in K and MRY-1, whereas others are lower. Concentrations of analytes that were greater than PECs in a previous study sample generally were greater than PECs in this current sediment survey sample.

RYC-3 and RYC-4 were collected in the vicinity of the 1995 station MRY-2. Metal concentrations are generally similar in RYC-3 and MRY-2. As discussed above, the metal concentrations are lower in RYC-4. PAHs were not analyzed in MRY-2.

RYC-6 was collected in the vicinity of the 1982 station K-1. Metal concentrations are generally higher in RYC-6 0-0.5' than reported from K-1; however, the concentrations in RYC-6 2-4' and RYC-6 4-6' are similar to the concentrations reported from K-1. PAHs were not detected in any of the samples; however, the MDLs are not known for K-1 and the MDLs are elevated in all samples from RYC-6.

RYC-7 was collected in the vicinity of the 1995 station MRY-3. Metal concentrations are higher in RYC-7 0-0.5' than in MRY-3. Metal concentrations are similar in RYC-7 2-4', RYC-7 4-6', and MRY-3. PAHs were not analyzed in MRY-3.

RYC-8 was collected in the vicinity of the 1995 station MRY-4. Metal concentrations are generally similar, except for lead, which is approximately four times higher in RYC-8 0-0.5' than in MRY-4. PAHs were not analyzed in MRY-4.

RYC-9 was collected in the vicinity of the 1995 station MRY-5. Metal concentrations are slightly lower in RYC-9 than in MRY-5. PAHs were not analyzed in MRY-5.

5.0 RECOMMENDATIONS

5.1 Summary

Target metals and PAHs were the primary contaminants detected at the study areas during this sediment survey. VOCs were reported at one sampling station (MR-3). **No PCBs or pesticides were reported at any of the sampling stations.**

The Muskegon River Study Area had two sampling stations where contaminant concentrations were above the TECs. PAHs were present at concentrations above the respective TECs at MR-7 and sampling station MR-3 had target metals greater than the respective TECs. Arsenic levels were greater than the dry soil direct contact criterion at MR-3.

The Fourmile Creek Study Area had three sampling stations where contaminant concentrations were elevated when compared to the PECs. Target metals and PAHs were greater than the TECs at FMC-3 and FMC-5. Target metal concentrations were also greater than the TECs at FMC-1, FMC-2, and FMC-6 (background location). The most elevated levels of PAHs were located at FMC-3.

The Ryerson Creek Study Area had eight sampling stations where contaminant concentrations were elevated when compared to the TECs. Seven of the sampling locations had levels of contaminants that were elevated when compared to the PECs. Target metals and PAHs were elevated when compared to the TECs at RYC-1, RYC-2, RYC-3, RYC-4, and RYC-7. Target metals were above TECs at RYC-5 and RYC-6. PAHs were above TECs at RYC-8. Benzo(a)pyrene was present at levels above the dry soil direct contact criterion at RYC-2 and RYC-7. Arsenic was present at levels above the dry soil direct contact criterion at RYC-1, RYC-2, and RYC-6. Lead was present at levels above the dry soil direct contact criterion at RYC-1 and RYC-2.

After reviewing the initial analytical data, the MDEQ requested two rounds of whole sediment toxicity analyses at selected locations. Statistically significant toxic effects were observed at RYC-1 and RYC-7 during the April 2003 sediment toxicity testing. Statistically significant toxic

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effects were observed in samples from RYC-1, RYC-2, and RYC-3 during the November 2003 sediment toxicity testing. A biological census was also conducted for the second round samples. The census indicated community degradation at all sample locations, although only RYC-1, RYC-2, and RYC-3 exhibit excessive degradation. Factors other than contaminants can influence the biological community, affecting the community structure at the other sampling stations.

5.2 Recommendations

Based upon the data collected during this investigation, the contaminants within sediments of Ryerson Creek are impacting localized populations of aquatic organisms. Further studies should focus primarily on Ryerson Creek from Getty Street (RYC-7) downstream to the mouth.

Further sediment toxicity studies along with more specialized sediment analytical tests may be necessary to correlate sediment toxicity to a specific pollutant(s). For example, pore water testing may be used to more specifically evaluate the impact of PAHs to the biological community within the sediment. Acid volatile sulfide (AVS) sediment testing may be useful to predict the toxicity of divalent metals within the sediment. Therefore, further sediment toxicity testing and analytical testing may be necessary to determine in what areas sediments are impacting the benthic community.

Locations where additional investigation may occur include:

- RYC-1 and RYC-2 vicinity for target metals and PAHs. The sediment quality assessment matrix indicates the contaminants are affecting organisms at these stations.
- RYC-3 and RYC-4 vicinity for target metals and PAHs. The sediment quality assessment matrix indicates the contaminants are affecting organisms at RYC-3.
- RYC-5 vicinity for target metals. Samples should be collected downstream of RYC-5 because RYC-6 provides an upstream sampling station.
- RYC-7 vicinity for target metals and PAHs. The whole sediment toxicity tests indicate the contaminants could affect organisms at this station.

6.0 REFERENCES

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APPENDICES

APPENDIX A

**“DEVELOPMENT AND EVALUATION OF CONSENSUS-BASED SEDIMENT
QUALITY GUIDELINES FOR FRESHWATER ECOSYSTEMS”**

MacDONALD AND OTHERS, 2000

APPENDIX B
PHOTOGRAPHIC RECORD

APPENDIX C
LABORATORY ANALYTICAL REPORTS

APPENDIX D

WHOLE SEDIMENT TOXICITY LABORATORY REPORTS