# *GeoMorph*® Pilot Site Characterization Report

# Upper Tittabawassee River and Floodplain Soils
# Midland, Michigan

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*February 1, 2007*

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# 1. INTRODUCTION

This *GeoMorph*® Pilot Site Characterization Report (SCR) has been prepared for the Study Area consisting of river channels and floodplains of the upper 6.4 miles of the Tittabawassee River (TR) downstream of the confluence with the Chippewa River. This Report for the Upper Tittabawassee River (UTR) has been prepared pursuant to Section 1.1 of the UTR *GeoMorph*® Sampling and Analysis Plan (SAP) dated July 7, 2006. The UTR *GeoMorph*® SAP, approved by the Michigan Department of Environmental Quality (MDEQ) on a pilot basis with limitations on July 12, 2006 and incorporated herein by reference, describes the sampling strategy, sampling locations, and procedures to determine the horizontal and vertical extent of constituents of interest (COI) contamination in the upper 6.4 miles of the Study Area (ATS, 2006b). A map showing the location of the Study Area is provided in Attachment A.

The Tittabawassee and Saginaw Rivers have been the focus of several investigations over the past several decades. These studies have primarily been directed towards gaining an understanding of flows and solids transport in the rivers and their floodplains over a range of flow conditions, and the distribution of contaminants in the river water, sediments, fish, and more recently floodplain soils.

The comprehensive Remedial Investigation Work Plan for the Tittabawassee River and Upper Saginaw River and Floodplain Soils dated December 2006 (RIWP) (ATS, 2006a) includes within its scope the investigative work along the UTR. Early findings from the *GeoMorph*® investigative work on the UTR during the summer and fall of 2006 are reported in the RIWP (ATS, 2006a), incorporated herein by reference. The UTR *GeoMorph*® Pilot Site Characterization report builds upon the information presented in the RIWP (ATS, 2006a); and includes, in summary form, the information that has become available through January 15, 2007 from the UTR SAP (ATS, 2006b)investigation activities.

## 1.1 UTR *GEOMORPH*® SAP OBJECTIVES

This Report is intended to provide a description of the geomorphic approach used to investigate and evaluate the COI present in sediments and soils along the UTR. These COI include chlorinated dioxins, chlorinated furans, and other chemicals. The objective of this document is to provide a preliminary understanding of in-channel sediments containing COI and present a comprehensive characterization of floodplain sediments and soils along the UTR.

## 1.2 UTR *GEOMORPH*® SITE CHARACTERIZATION REPORT DELIVERABLES

Deliverables in this document include:

- An assessment of the relevant physical and chemical properties of the potential constituents of interest (PCOI);
- Detailed topographic mapping of the project area with geomorphic features;
- Historical aerial photographic analysis for the relevant period;
- Detailed geomorphic feature mapping;
- Preliminary in-channel sediment inventory, confirmatory sediment poling, and core sampling; and
- Summary tables and concentration maps of the sediment and soil sampling information, with all locations described by reach and stationing coordinates.

## 1.3 REPORT ORGANIZATION

This Report is organized into the following sections:

Section 1 – Introduction: presents the general objectives, deliverables and organization for this report.

Section 2 – Background: summarizes the UTR and overall Project Study Areas and introduces the *GeoMorph*® investigation process used to investigate the UTR.

Section 3 – Conceptual Site Model (CSM) Update: provides an update of the CSM that integrates the information necessary to understand how furans, dioxins, and other COI move through the Study Area and come into contact with the environment.

Section 4 – UTR SAP Procedures: identifies the data collection needs and procedures used to implement the *GeoMorph*® SAP and address the investigation objectives.

Section 5 – *GeoMorph*® Pilot Site Characterization Summary and Discussion: provides an overview of the investigation process, data presentation, and discussion of findings.

Section 6 – Conclusions and Supplemental Site Characterization Work: provides the *GeoMorph*® Pilot SCR conclusions and a description of supplemental site characterization work.

Section 7 – References: lists the references cited in this report.

Section 8 – Glossary:  lists terms and related definitions used in this report.

Section 9 – Acronyms and Abbreviations: lists the acronyms and abbreviations used in this report.

# 2. BACKGROUND

This section provides an overview of the UTR SAP Study Area and where it is spatially oriented within the overall December 2006 RIWP (ATS, 2006a) project study area.

## 2.1 PROJECT AREA OVERVIEW

### 2.1.1 Tittabawassee River

The Tittabawassee River is a tributary to the Saginaw River, draining 2,600 square miles of land in the Saginaw River Watershed. The Tittabawassee River, along with the Shiawassee, Flint, and Cass Rivers, comprise approximately 84 percent of the total Saginaw River drainage area (MDNR, 1988). The Tittabawassee has the largest drainage area covering 39 percent of the total area draining to the Saginaw River.

There are a number of dams on the upstream portion of the Tittabawassee River. The dams are located at Secord, Smallwood, Edenville, Sanford, and The Dow Chemical Company Midland Plant (Midland Plant). The dams upstream of Midland were constructed in 1925 to generate hydroelectric power and provide limited storage and flood control during storm events for the Cities of Midland and Saginaw. In addition, a Beaverton hydroelectric dam was installed further upstream in 1918. The current operation of the hydroelectric station at Sanford results in water releases from Sanford Dam during peak electricity usage periods to provide peaking power to Consumer's Energy. Sanford Lake has limited flood storage capacity due to a narrow range of permitted lake levels. Below the Dow Dam, the river is free flowing to the confluence with the Shiawassee and Saginaw Rivers.

The Tittabawassee River is the receiving water for various industrial and municipal wastewater discharges. Some discharge directly into the river, and some discharge into the major tributaries of the Tittabawassee River: the Salt, Tobacco, and Chippewa Rivers. Past industrial inputs include wastes from chemical, plastics, can manufacturing, and photographic industries (Rossman, et al., 1983). A significant smaller tributary is Lingle Drain, located south of the Midland Plant, which has been a receiving stream for both municipal and industrial discharges over time.

### 2.1.2 2006 UTR SAP Study Area

The study area encompasses the section of the Tittabawassee River commencing at the confluence of the Tittabawassee and Chippewa Rivers and extending approximately 6.4 miles downstream. A figure depicting the Study Area is provided in Attachment A.

For communication purposes, a numerical stationing system was established for the Tittabawassee and Upper Saginaw Rivers. The numerical stationing was established down the middle of these Rivers at 50 foot intervals. In addition, reach designations based on channel slope, channel width, geomorphic features, and sinuosity have been established for the UTR Study Area. These are summarized in the following table and presented in the Reach Overview figure in Attachment A.

**UTR Reach Summary**

| Reach Designation | Stationing | Reach Length (ft) |
|---|---|---|
| Upstream of Dow Dam | | |
| Reach A | 0+00 to 12+00 | 1,200 |
| Reach B | 12+00 to 37+50 | 2,550 |
| Reach C | 37+50 to 46+50 | 900 |
| Reach D | 46+50 to 59+25 | 1,275 |
| Near Plant Area | | |
| Reach E | 59+25 to 81+00 | 2,175 |
| Reach F | 81+00 to 115+00 | 3,400 |
| Reach G | 115+00 to 141+00 | 2,600 |
| Reach H | 141+00 to 163+50 | 2,250 |
| Natural River Setting | | |
| Reach I | 163+50 to 185+50 | 2,200 |
| Reach J | 185+50 to 196+50 | 1,100 |
| Reach K | 196+50 to 233+50 | 3,700 |
| Reach L | 233+50 to 261+50 | 2,800 |
| Reach M | 261+50 to 286+00 | 2,450 |
| Reach N | 286+00 to 320+00 | 3,400 |
| Reach O | 320+00 to 335+50 | 1,550 |

# 3. CONCEPTUAL SITE MODEL UPDATE

The Conceptual Site Model is described in the December 2006 RIWP. (ATS, 2006a) The following sections provide updates to the CSM based on the *GeoMorph*® Pilot Site Characterization.

## 3.1 RIVER AND FLOODPLAIN MORPHOLOGY

The majority of the Tittabawassee River valley between Midland and Saginaw is characterized by relatively flat floodplains extending to a steep scarp rising to the upland. The floodplain extends from the top of the current channel banks to the base of the upland scarp and is periodically inundated by episodic flooding of the Tittabawassee River. The floodplain includes a number of geomorphic features that have developed over time by lateral and vertical movement of the river. The upland scarp likely represents the glacial period channel banks of the Tittabawassee River, typically rising 20 to 30 feet above the valley floor. As it approaches the City of Saginaw the Tittabawassee River is characterized by a less prominent upland scarp and a broadening of the floodplain. A figure depicting the approximate extent of the Tittabawassee River 100-year floodplain is provided in Attachment A.

The river valley has a relatively subdued topographic relief along the length of the river, with water elevations dropping from approximately 595 feet mean sea level (msl) near Midland to 560 feet msl at the confluence with the Saginaw River. The overall longitudinal profile of the Tittabawassee River is equivalent to approximately 1.6 feet of elevation drop per river mile. When accounting for impact of the Dow Dam, the longitudinal profile decreases to approximately 1.4 feet of elevation drop per river mile. A figure depicting the longitudinal profile of the Tittabawassee River is provided in Attachment B.

The Tittabawassee River channel varies from relatively straight reaches upstream of Freeland, to a more sinuous river system downstream, with sinuosity increasing significantly as the river approaches Imerman Park in the lower portion of the Tittabawassee River. Typical of a meandering river, erosion generally occurs on the downstream outside bank of the Tittabawassee River forming cut banks. Deposition tends to occur on the downstream inside bank, forming point bars.

The Tittabawassee River has moved laterally and incised since glacial times. Channel comparisons using 1937 and 2004 aerial photographs show that the river has been relatively stable in its current channel since 1937. The estimated maximum lateral movement in the 6.4 miles downstream from the confluence with the Chippewa River since 1937 is approximately 25 feet based on aerial photograph interpretations. Overlays of the 1937 and 2004 aerial photographs are provided in Attachment C.

The Tittabawassee River is a high-energy system that undergoes a rapid increase in flow during periods of precipitation, as indicated by the high ratio of flood discharge to long-term average discharge. The dynamic flow of the Tittabawassee River influences deposition and erosion in and adjacent to the river channel. The depositional and erosional patterns create the geomorphic features or "river landscape" along the river banks and floodplain. Water velocity, sediment load and distance from the river channel are factors that influence the grain size distribution of sediments present in geomorphic features. Coarse-grained sediment deposits (e.g., point bars), formed through lateral accretion processes, are present in features adjacent to the river. Finer-grained sediment deposits, formed through vertical accretion processes, are present in features in the floodplains away from the river channel. Analyses of in-channel sediments indicate that they are composed of approximately 87 percent medium/fine sand. During the 2006 UTR poling and coring work, areas of surficial fine-grained sediments, suggestive of low-energy depositional areas, were encountered at depth in wetlands approximately 200 feet away from the river channel.

The river valley in the upper portion of the UTR is characterized by relatively abrupt valley walls due to topographic modifications to accommodate the Midland Plant, Midland Cogeneration Venture (MCV) facility, and a significant number of other anthropogenic influences. Anthropogenic features in this area include extensive sheet piling along the river bank, steeply constructed banks along the Midland Plant and MCV facility, cooling ponds, several locations with rip-rap armoring, numerous bridges, and the Dow Dam. These anthropogenic features have altered the natural river development through the upper portion of the UTR by constraining the natural lateral channel movement and channelizing the water flow and river energy during high flow and flood conditions.

The river valley in the lower portion of the UTR is characterized by a natural river setting with a slight increase in sinuosity, well developed geomorphic features, and a broad river floodplain. Depositional features common in this portion of the river valley include a double series of levees ("pre-industrial" and "post-industrial") along much of the UTR, especially along inside bends with advanced terrace development in the overbank or floodplain. The levees have formed along the river bank where floodwaters overtop the channel banks and deposit coarse-grained sediments. A series of terraces have formed in the overbank where floodwaters overtop the channel banks, water velocities decrease, and finer-grained sediments are deposited.

## 3.2 SEDIMENT TRANSPORT

Soil and sediment transport processes include in-river solids transport through the water column, erosion and deposition of solids in the floodplain, and exchange between the river channel and floodplain under flood conditions. These processes are described in greater detail below based on recent work on the Tittabawassee River.

### 3.2.1 In-River Solids Transport

Solid particles may be transported in the water column as suspended solids or as bedload along the river bottom. Suspended solids are generally fine-grained materials such as silt and clay that may be transported considerable distances once suspended. Larger particles such as coarser sand and gravel generally move along the bottom of the river as bedload, traveling for relatively short distances per-event. The movement of larger particles depends on the water velocity and therefore such particles may move largely during high-energy flood events. Finer sands may move either in suspension or as bed load. On average, the Tittabawassee River has a suspended solids concentration of 30 milligrams per liter (mg/L), which is consistent with suspended solids concentrations in other tributaries of the Saginaw River (MDNR, 1988; MDNR, 1994). Concentrations as high as 85 mg/L have been observed during and after heavy precipitation events (LTI, 2004a). In October 2003, flow and solids monitoring of the river was initiated to improve the understanding of erosion, transport, and deposition throughout the river system (LTI, 2004a). These data provide a preliminary indication of solids transport (and therefore adsorbed COIs) through the system and allow construction of a preliminary conceptual model of solids transport. Preliminary results indicate that most of the solids transported through the river originate in the watershed upstream of Midland. In the three high flow events measured in 2003-2004 and a smaller event observed in March/April 2005, no discernable net gain or loss of suspended solids load occurred between the Midland Plant and the confluence of the Tittabawassee and Shiawassee Rivers.

The sediment bed may be episodically affected by scour induced by winter ice formation and breakup. The Tittabawassee River typically experiences significant ice formation during the winter months, with periodic ice breakup during mid-winter thaws that elevate river flows. Ice breakup and movement might affect the sediment bed in several ways: by individual ice floes impacting the sediment bed, banks, and near-bank areas; by the formation of ice jams; and by the enhanced scour that can occur as river flow is diverted around or under ice jams. Ice jams can also cause overbank flooding and sediment deposition. All of these factors may affect the stability of the sediment bed and bank areas on the Tittabawassee River.

### 3.2.2 Floodplain Erosion and Deposition Processes

The majority of erosion and deposition is episodic in nature; consequently, sediment and floodplain soil movement is believed to occur primarily during periodic flood events. The amount or rate of erosion and deposition is dependent on the intensity of the flood event, with large events resulting in correspondingly larger amounts of floodplain soil and sediment movement. Higher flow events result in increased erosion and transport for two reasons: first, the increased shear stress exerted on surficial soils or sediments increases the rate of erosion, and second, the increased flow energy has a correspondingly greater capacity to move solids downstream by keeping them in suspension.

Pilot studies were conducted to evaluate the potential effectiveness of geochronologic (i.e. radiological age dating) and dendrogeomorphic techniques to evaluate net rates of floodplain soil deposition at various representative locations in the floodplain. Dendrogeomorphology consists of the measurement of soil accumulation above the root systems of trees. Geochronology relies on the evaluation of the relative abundance of naturally occurring and man-made radioactive elements in the soil column. These methods are complementary, providing multiple lines of evidence. The results of these studies are provided in the pilot study reports (LTI, 2005a; LTI, 2005b).

The dendrogeomorphology and geochronology results indicate that soil accretion rates along the Tittabawassee River floodplain are on the order of 0.1 to 0.5 inches per year with an average of 0.17 inches per year, which equates to a range of approximately 1 to 4 feet of soil accumulation over the past 100 years. The geochronologic and dendrogeomorphic results are in close agreement. Accretion rates vary locally, and preliminary analyses suggest that they appear to be influenced by local geomorphic features, including topography, proximity to the river, and channeling.

The accretion rates described above are net rates, reflecting the results of erosion and deposition operating over many years. While the measurements to date show net accretion in the floodplain, it is likely that localized erosion has also occurred. For example, after the March 2004 flood event, recently eroded areas were visually apparent such as scour around fence posts, downstream of trees, and around other obstructions to flow. However, available measurements suggest a general tendency of the floodplain to gain solids rather than lose them, and localized scour likely results primarily in local redistribution of soils and limited export from the floodplain.

Available measurements of solids loads to date are limited. Observations of solids transport in the river under flood events in 2003 and 2004 showed that the in-river solids loads measured at the upstream and downstream ends of the study area were not sufficiently different to indicate a clear gain or loss of load across the study area. This is consistent with observations of relatively slow floodplain accretion described above.

Bank undercutting, overhanging vegetation and lateral retreat can be observed at a number of locations between Midland and the Saginaw River confluence. The steep banks and ongoing lateral retreat are a product of several factors, including: the post-glacial rebound of the land surface in mid-Michigan and subsequent incising of the river; the "flashiness" of the river as evidenced by the high peak to average discharge ratio; and likely historical increases in peak discharge caused by land development changes in the watershed, including extensive logging in the 19th century.

Human activities have disrupted the natural fluvial system through the construction of various structures and the creation of cut-and-fill areas. These features alter river flow patterns, restricting erosion and deposition in some areas while causing erosion and deposition in others. Examples of man-made features that affect the natural fluvial system include bridges, elevated roadways, and railroads where fill was used to elevate them above the floodplain; other areas that were filled to elevate the land surface above the floodplain; erosion control features used to stabilize riverbanks, dams, and cut areas where floodplain materials were removed; hydrologic inputs from surface water discharge, water releases from dams and power plants; and agriculture fields where ridges are leveled and depressions filled over the years by plowing and tilling.

### 3.2.3 River-Floodplain Exchange

As described above, measurements of in-river suspended sediment load and floodplain accretion in the Tittabawassee River valley show (1) a significant load of suspended solids that is transported by the river, primarily under high flow conditions, and (2) positive rates of accretion in the adjacent floodplain over time that suggest flood-driven net solids movement from the river to the floodplain. The process by which flow and solids pass from the river channel to the floodplain during the rise, peak, and recession of a typical flood event is complex and depends on many factors, including the magnitude of flow, the bathymetry of the river and topography of the floodplain, the amount of vegetation in the floodplain and its tendency to slow down the flow, and the characteristics of the solid particles themselves, including density, cohesiveness, particle size, and tendency to settle.

A study of floodplain, bank, and sediment bed elevation changes was conducted between November 2004 and November/December 2005, to observe erosion and accretion of solids during this time period. Elevations were surveyed at fixed stations along transects aligned perpendicular to the Tittabawassee River, spanning the river from bank to bank and including adjacent shoreline and upland floodplain areas.

Three parallel transects were surveyed in each of three locations, including Dow property near RO-332+00 (historically referred to as River Mile 17.5); near RII-812+50 (Imerman Park); and near RVV-1165+50 (Shiawassee Wildlife Refuge). Each transect location included steep banks separating the river from the upland floodplain.

In general, the greatest measured changes between the two survey rounds were in sediment bed elevations. These ranged in magnitude from a localized decrease of 2.0 feet, at a mid-channel station along one of the RM 17.5 transects, located near RO-332+00, to increases as large as 1.8 feet within 50 to 75 feet of the bank at Imerman Park, near RII-812+00. In general, more sediment bed stations were characterized by elevation decreases than increases.

Measured bank elevation changes fell within a narrower range, from an increase of 0.9 feet at the top of the bank along one of the Imerman Park transects, near RII-812+50, to a decrease of 1.1 feet near water's edge along another of the Imerman Park transects, near RII-813+00. In general, more bank stations were characterized by elevation increases than decreases.

Measured upland floodplain elevation changes fell within the narrowest range, from an increase as high as 0.3 feet along one of the RM 17.5 transects, near RO-332+50, to a decrease of 0.4 feet along another of the RM 17.5 transects near RO-332+00. In general, more upland floodplain stations were characterized by elevation increases than decreases.

These estimates of elevation change over a single year at three locations generally support the observation that banks and floodplains were areas of net solids accretion. Sources of uncertainty common to the river, bank, and floodplain elevation changes measured in this study include the vertical and horizontal error components inherent in the elevation surveys, plus natural factors including leaf accumulation and frost heave. Cumulative elevation changes of larger magnitude that may occur over longer time periods could be estimated by repeat surveys at the same locations, without a commensurate increase in uncertainty of the estimates.

# 4. UTR *GeoMorph®* SAMPLING AND ANALYSIS PROCEDURES

The following sections provide an overview of the sample location rationale, sampling and sample handling procedures, recordkeeping, and analytical plan used during implementation of the UTR SAP.

## 4.1 GEOMORPHIC DEVELOPMENT OF SAMPLING LOCATIONS

This section provides an overview of the sampling location selection process used for the UTR from the Tridge in Midland at the beginning of Reach A to Orr Road near the end of Reach O. Geomorphic characteristics, a summary of previous investigations, and a description of the proposed sampling locations are provided for each reach in the UTR SAP (ATS, 2006b).

Sample locations were selected based on fluvial geomorphic features representing fluvial transport, erosion and deposition processes. These included channel alignment, proximity to channel, and proximity to anthropogenic influences/structures. Specifically the primary features were:

- Adjacent to channel;
- Away from channel;
- Straight channel segment;
- Inside meander bend;
- Outside meander bend;
- Upstream or downstream of a bridge or culvert.

The geomorphic features were mapped from the Midland Tridge downstream to near Orr Road on April 18-21, 2006. The UTR was segmented from Reach A through Reach O and the relative geomorphic features from upstream to downstream were initially described using Light Detection and Ranging (LiDAR) topographic map data and either direct field inspection, when property access was possible, or best possible visual observation.

Geomorphic descriptive summaries for the reaches and the sampling locations are presented in the approved UTR SAP (ATS, 2006b) and incorporated herein by reference (ATS, 2006b). A UTR reach overview figure is provided in Attachment A.

## 4.2 SAMPLING EQUIPMENT AND PROCEDURES FOR SITE CHARACTERIZATION

### 4.2.1 Sample Identification

A systematic process for identifying sample locations was built upon the numerical river stationing system (described in Section 2.1.2). This process results in unique labels for each sample location and assists in identifying the sample location along the river when reviewing data. The QAPP (ATS, 2006c) provides details of the complete sample identification system. The following sections provide the sample identification system used for soil and sediment samples and field duplicate samples which are used for laboratory quality assurance.

#### *4.2.1.1 Soil and Sediment Samples*

Each sample identification label includes five descriptors:

**Reach – Station Number – Orientation – Distance from Channel – Sample Depth**

where:

**Reach** = Two letter designation indicating the reach of the stream channel. Fifteen reaches, alphabetically, RA through RO, were established for the Upper Tittabawassee River study area.

**Station Number** = Approximate location of sample downriver from initial station at 0+00 ft.

**Sample Orientation** = For overbank soil samples, the sample orientation depicts which side of the river the sample was collected from, with NE for Northeast or SW for Southwest. Samples collected within the channel are denoted “IC” for In-Channel, samples collected from the UTR tributaries are denoted “T” and samples collected from the eroded channel banks are denoted “ES” for Erosion Scar.

**Distance From Channel** = The approximate distance of an overbank sample from the channel bank in feet is designated but is not included for in-channel, pond or tributary samples.

**Sample Depth** = Depth of the sample interval in feet below ground surface. Sediment samples (IC and Pond Samples) were measured from the sediment surface and do not include the water depth above the sediments. A sediment sample with an initial sample depth of zero indicates that the sample was collected from the sediment surface. For erosion scar samples, the depth indicates the depth horizontally into the bank, not below ground surface.

The following examples illustrate this identification system:

**Example (Overbank Location): RE-59+50-SW35-1.1-1.4**

The sample was collected from Reach E near station 59+50. The sample point is located approximately 35 feet southwest of the channel bank and the sample depth is 1.1 to 1.4 feet below ground surface (bgs).

**Example (In-channel Location): RE-59+50-IC-0.0-1.0**

The sample was collected from Reach E, near station 59+50. The in-channel sample is a surface sediment sample taken from the interval 0.0 to 1.0 feet below sediment surface.

#### *4.2.1.2 Field Duplicates*

Field duplicate samples were named according to the nomenclature described above with the addition of the letters "DUP" added as a suffix yielding the following scheme:

**Reach – Station Number – Orientation – Distance from Channel – Sample Depth – DUP**

For example, the sample ID for a duplicate sample collected along with the overbank the sample used in the example above would be as follows:

**Example: RE-59+50-SW35-1.1-1.4-DUP**

### 4.2.2 Field Positioning

Overbank soil sample locations, including the tributary and fixed interval sample locations but excluding pond samples, were staked, flagged and surveyed during the UTR project to the extent practicable. An experienced fluvial geomorphologist or soil scientist located the overbank and tributary sample locations to ensure they were positioned along the appropriate geomorphic feature. Global Positioning System (GPS) coordinate locations were obtained using a high zephyr antenna mounted Differential Global Positioning System (DGPS) receiver. The horizontal coordinate system was recorded in Michigan State Plane Coordinate System, South Zone, NAD 83, in international feet using the vertical datum NAVD 88. In initial sampling, the field teams collected 10 differential points per location. However, to increase accuracy, the field team increased the number of differential points collected to 20 per location. Sample locations with the corresponding field positioning data is provided in Attachment D.

Of the 523 overbank and tributary GPS surveyed sample locations, 76 percent of the locations have a horizontal accuracy of <1 meter, 12 percent have an accuracy between 1 and 2 meters, and 12 percent have >2 meter accuracy. Tree canopy or areas where the GPS antenna could not read the satellites contributed to reduced accuracy (>2 meter accuracy) at some sample locations.

In-channel sediment, erosion scar, pond, and off-set sampling locations were not surveyed during the UTR project. The positioning of these sampling locations on site maps is estimated based upon field measurements and observations.

### 4.2.3 Sediment and Soil Sampling

In-channel sediment, overbank soil, tributary, and erosion scar samples were collected to characterize soil profiles and establish primary COI concentrations. Methods are summarized in the following sections. In most cases, sampling was conducted in transects perpendicular to the stream and included in-channel and overbank samples to determine the depositional environment in that sub-reach of the river. When supported by the geomorphological setting, data collected from these transect locations were extrapolated upstream and downstream into similar segments of the river.

#### *4.2.3.1 Sediment/Soil Profile Descriptions*

Soil and sediment profile descriptions were performed for the in-channel, overbank, tributary, and erosion scar sampling. Soil profile descriptions were completed for each horizon and were recorded by an experienced fluvial geomorphologist or soil scientist. Soil horizons were determined from pedogenic processes or vertical or lateral accretion sediment deposition characteristics. Soil/sediment descriptions were completed either in the field at the time of sampling or later at the ATS field staging area in Midland, Michigan. Soil profile descriptions included soil color (Munsell Color Chart), USCS soil texture, USDA-SCS soil texture, moisture, root content, mottling, clay skin development, and other soil features such as the presence of shell fragments, sand, sand/gravel lenses, iron concretions, or odors. Sediment/soil profile descriptions are presented in Attachments R and S.

#### *4.2.3.2 In-Channel Sediment Poling, Inventory and Sampling*

Field personnel in boats located the in-channel sample and pond sample locations using distances from known landforms or overbank flags in the study area. Once the transects were identified, buoys were placed in the river for reference. Field personnel then poled sediment thickness along the transects. Once poling was complete, sample locations were selected based upon the presence and thickness of soft sediment. Location identification, poling and sampling occurred on the same day.

In-channel sediment poling/inventory was conducted to assess the location and extent of significant soft sediment deposits and the placement for the in-channel sample locations along each sampling transect. The sediment poling/inventory was conducted using a metal pole marked in 1 foot increments to measure the water depth and sediment thickness. Water depth was obtained by placing the metal pole at the top of the sediment and recording the depth on the metal pole. The metal pole was then pushed into the sediment until refusal. The total depth, minus water depth provided an estimate of the soft sediment depth. Water and sediment depths were recorded on a field form to the nearest 0.1 foot.

In-channel sample locations were based on sediment thicknesses and nature of sediment. The in-channel sediment sampling was conducted from the top of the sediment into the underlying denser and more resistant soil. Depending on sediment thicknesses, either a check valve sampler or a soggy bottom sampler was used for sample collection. The check valve sampler was used to sample sediment thicknesses less than or equal to 4 feet. It was fitted with a 2 foot or 4 foot acetate liner that is open on the leading end. The check valve sampler was driven to the sediment thickness depth and/or refusal either by hand or by using a slide hammer. The sampler was advanced to the necessary depth and then retrieved back to the boat. Each sample core was capped, labeled, and brought back to the ATS field staging area in Midland for future logging.

The soggy bottom sampler was used to collect samples below 4 feet following the check valve sampler. It consists of a 4 foot acetate liner inside a sampling tube. The leading edge of the sampling tube can be closed during advancement. The sampler was advanced slowly (to minimize compaction) into the sediment to the desired depth of the top of the core (4ft, 8ft, 12ft, etc.). Once the desired depth was reached the leading end of the sampling tube was opened. The open ended sampler was then advanced 4 feet either to refusal or the desired sampling depth and then extracted, either by hand or by using a slide hammer. The sample core was retrieved, capped, labeled, and transported to the ATS field staging area for future logging.

Sediment core logging was conducted at the ATS field staging area under a controlled environment. Distinct sediment horizons observed in the sediment cores were subsampled for analysis. A sediment profile description for each horizon was made and recorded by a geomorphologist. Subsamples collected from each horizon were stored at the ATS field staging area until shipment/delivery to the laboratory for analysis. Refer to Section 4.2.6 Field Documentation and Recordkeeping for logging procedures. The preliminary UTR In-Channel Sediment Inventory is presented in Attachment Q.

#### *4.2.3.3 Floodplain, Overbank, and Tributary Sampling*

Floodplain, overbank and tributary sample locations were selected in the field based on the appropriate geomorphic feature by an experienced fluvial geomorphologist or soil scientist. Once the locations were selected, they were marked with survey flagging and a labeled pin-flag. Locations were labeled using the sample identification system and surveyed following the procedures in Section 4.2.2 Field Positioning. Floodplain, overbank and tributary sampling methods used for the UTR study area included hand sampling and direct push methods.

*4.2.3.3.1* *Hand Sampling Methods*

Hand sampling methods were used by field crews to develop a greater understanding of the soils and geomorphic features, and to collect samples for quantitative chemical analysis. A 1 foot stainless steel sampling tube, equipped with a new acetate liner, was pushed vertically into the ground to a depth of 1 foot either by hand or by using a rubber hammer. The sampling tube was then extracted and the acetate liner removed. After retrieval of the interval sample (e.g., 0.0-1.0 ft), a bucket auger was used to auger down over this interval allowing passage of a clean tube for sampling the next 1 foot interval (e.g. 1.0-2.0 ft, 2.0-3.0 ft, etc.) without interference from the sidewall of the previous interval. Measurements were taken after each step to verify interval depths. This process was repeated to terminal (final) depth, as determined by the on-site experienced fluvial geomorphologist or soil scientist, or until collapse of the borehole. Used equipment was stored in a plastic container, away from clean equipment, until decontamination.

Upon reaching terminal depth the sample cores were cut open for logging. Distinct soil types were logged and subsampled for chemical analysis. Distinct soil horizons significantly greater that 1 foot were divided into smaller intervals and subsampled for laboratory analysis. Subsamples were placed into laboratory-approved containers, labeled and placed on ice in a cooler. Samples were transferred to the ATS field staging area in Midland, Michigan, where they were stored at 4°C until shipment/delivery to an approved laboratory for chemical analysis. Refer to Section 4.2.6 Field Documentation and Recordkeeping for logging procedures.

On two occasions, MDEQ personnel collected split samples along with the field crew. Split samples were collected from each sample horizon at predetermined locations. Once the split sample interval was identified, the entire interval was placed into a clean stainless steel bowl, composited, quartered and divided equally into the appropriate laboratory approved containers. Dow split samples were placed into laboratory approved containers, labeled and placed on ice in a cooler. Dow samples were transferred to the ATS field staging area in Midland, Michigan, where they were stored at 4 °C until shipment/delivery to an approved laboratory for chemical analysis. MDEQ samples were managed by the MDEQ personnel.

*4.2.3.3.2* *Direct Push Sampling Methods*

Direct push drilling methods were utilized for three different purposes: 1) to reach deeper depths than the hand sampling; 2) verify analytical results from hand sampling; and 3) collect overbank samples on MCV property. A 4 foot long Macrocore sampling barrel, equipped with a new acetate liner, was advanced into the ground to a depth of approximately 4 feet. The sampling barrel was then extracted from the ground and the acetate liner removed. After retrieval of the sample core interval (e.g., 0.0-4.0 ft), the sampling barrel (decontaminated and equipped with a new acetate liner) was advanced into the next 4 foot interval (e.g. 4.0-8.0 ft, 8.0-12.0 ft, etc.). Measurements were taken after each step to verify interval depths. This process was repeated to terminal (final) depth, as determined by the on-site experienced fluvial geomorphologist or soil scientist. Sample cores were capped, labeled, and transferred to the ATS field staging area in Midland, Michigan, for logging under a controlled environment.

Distinct soil types were subsampled for analysis. Distinct soil horizons significantly greater than 1 foot were divided into smaller intervals and subsampled for laboratory analysis. Subsamples were placed into laboratory-approved containers, labeled and stored on-site at 4°C until shipment/delivery to an approved laboratory for analysis. Soil profile descriptions for each soil horizon were described and recorded by an experienced fluvial geomorphologist or soil scientist. Refer to Section 4.2.6 Field Documentation and Recordkeeping for logging procedures.

#### *4.2.3.4 Erosion Scar Sampling*

Erosion scars along the river banks were observed in areas where erosion may be caused by high river velocities and shear stress along the river bank face during storm events, or by undercutting of river banks due to daily river level fluctuations. The erosion scar face represents the soil present in the feature deposit that has not yet eroded but has been disturbed through the erosion process.

Erosion scar sampling was conducted from a boat at locations identified by the MDEQ and field personnel. Erosion scar samples were collected on two different days using two different sampling methods. On November 29th, 2006, soil samples were collected from the surface of the erosion scars using a disposable plastic spoon. The soil interval sample (e.g., 0.0–0.2 feet horizontally into the scar) was placed into a laboratory approved container, labeled and placed on ice in a cooler. The samples were transferred to the ATS field staging area in Midland, Michigan, where they were stored at 4°C until delivery to an approved laboratory for chemical analysis.

On November 30th, 2006, additional soil samples were collected at the same locations. At each location, a 1 foot stainless steel sampling tube, equipped with a new acetate liner, was pushed horizontally into the river bank to a depth of 1 foot. The sample tube was then extracted from the bank and the acetate liner removed. The acetate liner was capped, labeled, and transferred to the ATS field staging area for logging.

A decontaminated sampling tube with a new acetate liner was then pushed into the same hole to collect the next 1 foot interval (e.g. 1.0-2.0 ft, 2.0-3.0 ft, 3.0-4.0 ft, 4.0-5.0 ft into the bank). This process was repeated until the pre-determined 5 foot terminal depth was reached. Used equipment was stored in a plastic container, away from the clean equipment, until decontamination.

Logging of the soil cores took place at the ATS field staging area under a controlled environment. Distinct soil types were subsampled for analysis. Distinct soil horizons significantly greater than 1 foot were divided into smaller intervals and subsampled for laboratory analysis. Subsamples were placed into laboratory-approved containers, labeled and stored at the ATS field staging area at 4°C until shipment/delivery to the approved laboratory for analysis. Soil profile descriptions for each soil horizon were described and recorded by an experienced fluvial geomorphologist or soil scientist. Refer to Section 4.2.6 Field Documentation and Recordkeeping for logging procedures.

### 4.2.4 Field Duplicates

Field duplicate samples were collected and analyzed to check for sampling reproducibility and site homogeneity. Duplicate samples were collected and submitted to the laboratory at a frequency of approximately one duplicate per 20 samples. Once a duplicate interval was identified, the entire interval was placed into a clean stainless-steel bowl, composited, quartered and equally deposited into two appropriate laboratory approved containers. Subsamples were labeled using the sample identification system and placed on ice in a cooler or inside a refrigerator. Samples were stored at the ATS field staging area at 4°C until shipment/delivery to an approved laboratory for analysis.

### 4.2.5 Decontamination and Sample Handling

The equipment used in the sampling process, including the one inch sample tubes, stainless steel bowls and utensils were decontaminated prior to initial use, between sample intervals, and between sampling locations. Hand augers were decontaminated prior to initial use and between sample locations. Decontamination procedures included washing and scrubbing of the equipment with a laboratory grade soap solution, double rinsing with distilled water and air-drying. Rinsate water was containerized and stored on site for proper disposal.

To preserve sample integrity, samples were placed on ice in a cooler while in the field and during shipping/delivery to the analytical laboratory and stored in refrigerators at the ATS field staging area in Midland, Michigan. Sample handling procedures varied slightly for samples collected in the field versus samples collected at the ATS field staging area. Upon sample collection in the field, great care was taken to protect the sample jars from damage during transportation. After collection in the field, sample jars were labeled, placed into plastic bags, sealed and placed on ice inside insulated coolers. These samples were carefully transferred back to the ATS field staging area where they were placed into refrigerators until they were delivered to the appropriate laboratory for chemical analysis. Subsamples were labeled, placed into plastic bags, sealed and transferred to refrigerators until shipment/delivery to the appropriate laboratory for chemical analysis. In all cases, sample labels included the project number, unique sample identification number, date and time of collection and type of sample. When ready for analysis, samples were packed on ice, and delivered to or shipped via overnight courier to the appropriate laboratory for analysis following chain of custody procedures.

### 4.2.6 Field Documentation and Recordkeeping

#### *4.2.6.1 Field Sample Data Collection*

Sample data were recorded real-time using a GPS-based system as field crews collected soil cores and samples. GPS coordinates were recorded at all sample locations prior to soil sampling and linked to a base map created using ESRI ArcPad software. At each location, logs of soil cores, sample method, geographic features, sample anomalies, or problems encountered during sample collection were entered into the field computer and tied to the sample location GPS coordinates. Data were merged into the database daily. A second automated data transfer was used to query the database for sample information and incorporate the data into an electronic chain of custody. Twice per week specific database and map records were copied from all field computers and uploaded to the secured project FTP site for post-processing.

Post-processing of GPS data compared field collected GPS data with X,Y coordinates of known base stations. Using "Trimble GPS Analyst Extension for ArcGIS" software, field GPS coordinates were paired with GPS coordinates recorded from multiple base stations in the area. This comparison resulted in an overall positional error in field GPS readings that was used to adjust the GPS collected points to a higher accuracy. Post-processed data were then resaved to the project FTP site in a separate folder for incorporation into the central database.

Observations, measurements, sample information, and GPS location data were recorded using field specific computer equipment. Project-specific forms and dropdown lists were custom programmed into the ESRI ArcPad software for electronic data acquisition. All information relevant to sampling activities was recorded on these forms and stored electronically in an Access Database format. Entries on these forms included:

- Names of field crew member logging the soil cores
- Date and time of soil logging
- Date and time of sample collection
- Number and volume of samples collected
- Location of sampling activity
- Sampling method
- Date and time of sample collection
- Sample identification number
- Soil horizon descriptions
- Field measurements
- Field observations

Information collected using the electronic forms was compiled into a single database and was periodically reviewed for quality assurance purposes. As appropriate, field quality assurance corrective actions were recorded in the Corrective Action Logbook maintained for the project. Electronic field records were chosen as the preferred means for data collection to eliminate transcription errors as field data was transferred to the database. Additionally, the use of standardized forms and drop-down menus provided continuity to the field data across field crews. These records are part of the permanent project file.

Xplore tablet PCs and a Trimble Recon handheld PC were utilized in the field to record sample data and observations. These devices, when paired with a Trimble GPS Pathfinder ProXH receiver, were also used to collect the GPS coordinates for the sample locations. Additionally, in areas of dense tree canopy a Trimble Zepher antenna was utilized in conjunction with the Pathfinder ProXH receiver. The Trimble Zepher antenna provided increased accuracy in areas with an unobstructed view of the open sky.

#### *4.2.6.2 Chain of Custody, Sample Shipping, and Long-Term Storage*

A designated sample custodian was responsible for the care and custody of samples until they were transferred to the appropriate laboratory. To minimize sample handling errors as few people as possible handled the samples. Chain of custody (COC) records were initiated electronically and populated by the sample custodian. COCs contained the following information:

- Laboratory identification, address, and contact;
- Sample custodian's name, date, and time of shipment;
- Method of shipment, carrier, and tracking number (if applicable);
- Sample identification, date, and time;
- Sample type (composite or grab);
- Number of containers;
- Priority number;
- Applicable analytical method; and
- Sample matrix.

When the sample custodian transferred possession of the samples, the COC was signed, dated and the time was noted.

An electronic version of the COC was distributed via email to the appropriate laboratory, designated lab personnel, and the ATS *GeoMorph*® team senior staff. A signed hard copy version of the COC followed each lot of samples from initial shipment, through the laboratories, and until samples were received at the ATS field staging area for archiving.

The sample custodian properly packaged the samples for shipment in strong, tamper-proof coolers that were uniquely identified. Individual sample containers were isolated from contamination by placing them in re-sealable, liquid-tight bags. Each sample container was placed into appropriate sized bubble wrap bags to protect against breakage. Ice bags, double bagged to prevent leakage, were added to the coolers to maintain a temperature of 4°C. Ice bags were added to each cooler at the approximate ratio of one bag per ten samples. Free space within the cooler was consumed with additional packing materials to prevent breakage. A hard copy of the COC was placed in the appropriate cooler during shipment/delivery. Each cooler was sealed with packing tape and two signed and dated custody seals. Samples sent by commercial carrier included a bill of lading with a unique record number for computer tracking. Tracking numbers were recorded as part of the permanent custody documentation. Upon receipt of the samples at the laboratory, a Sample Receipt Form (SRF) was completed in addition to the chain of custody record. The SRF documented the condition of the chain of custody seal, time of receipt and the laboratory storage location.

All unconsumed samples were shipped, according to the procedure stated above, from the laboratory back to the ATS field staging area for archiving. Upon receipt, samples were verified against the appropriate COC and the record was signed and closed. Individual sample containers were inspected for integrity and defects. Samples were sorted, cataloged, and referenced according to reach, transect, and COC number. Finally the samples were boxed, labeled with indelible ink and stored at -10°C.

#### 4.2.7 Sample Analysis

The UTR SAP (ATS, 2006b) identifies seventeen, federally regulated, 2,3,7,8-substituted, chlorinated furan and dioxin congeners as the primary COI for the *GeoMorph*® site characterization of the UTR. All in-channel sediment and floodplain soil samples collected for chemical analysis for this study were analyzed for primary COI using Method 1613-TRP/RT.

Method 1613-TRP/RT was developed to quantify specific indicator congeners on a rapid turnaround basis. A review of CDF/CDD data from earlier investigations, including 400+ samples collected from the Tittabawassee River in 2005, found that certain congeners predominated in the dioxin-furan congener mixture in the UTR downstream of Midland. Most of the Total TEQ in site samples is attributable to these specific congeners. Method 1613-TRP/RT, a performance validated, rapid turnaround, HRGC/MS procedure was derived from USEPA Method 1613B. It targets the analysis of specific UTR indicator congeners and uses them to predict the total CDF/CDD TEQ in UTR sediment and soil samples.

Method 1613B is a performance validated, standard turnaround analysis for all seventeen 2,3,7,8 substituted CDF/CDD congeners. Both Method 1613-TRP/RT and USEPA Method 1613B utilize isotope dilution calibration for maximum sensitivity. Complete descriptions of both methods including laboratory SOPs can be found in the July 2006 Quality Assurance Project Plan (QAPP) (ATS, 2006c) for the UTR SAP (ATS, 2006b).

To establish the comparability of Method 1613-TRP/RT and USEPA Method 1613B, a set of sixty (60) UTR samples were analyzed by both methods. The samples were chosen to represent a low (<1,000 ppt ETEQ), medium (1,000-5,000 ppt ETEQ) and high (>5,000 ppt ETEQ) range of CDF/CDD, as well as a variety of soil/sediment types and geomorphological locations, to insure that the evaluation was made over the broadest range of contaminant concentrations and soil/sediment physical characteristics. The data from the comparability testing is provided in Attachment E. Results of this comparability study will be discussed in a technical memorandum prepared in the first quarter of 2007.

As described in the PCOI/COI/TAL Technical Memorandum (ATS, 2006a, Attachment G) secondary COI parameters for the UTR study area include a long list of chlorinated hydrocarbons, pesticides, herbicides, polynuclear aromatic hydrocarbons, metals and other chemical substances. Select samples from channel and overbank areas chosen collaboratively with MDEQ were analyzed for the complete USEPA Appendix IX list of constituents, to address the secondary COI needs of the study. Multi-compound analytical methods utilizing mass spectrometric detection (i.e., USEPA 8260 and 8270) for Appendix IX parameters were conducted such that Tentatively Identified Compounds (TICs) also reflective of secondary COI are included in the UTR project data reports.

#### *4.2.7.1 Analytical Plan*

All project analyses were performed by ATS, or an ATS and Dow approved contractor. In accordance with the QAPP (ATS, 2006c), such laboratories were either certified in the State of Michigan and/or had performance-demonstrated method proficiency for the test protocols they performed. The following laboratories were used to provide data for the 2006 UTR study:

Alta Analytical, El Dorado Hills, California

Ann Arbor Technical Services, Inc., Ann Arbor, Michigan

Environmental Analytical Services Group, The Dow Chemical Company, Midland, Michigan

TriMatrix Laboratories, Inc., Grand Rapids, Michigan

Dow Chemical and Alta Analytical both provided CDF/CDD data using Method 1613-TRP/RT, with the choice of laboratories depending on available capacity and project turnaround requirements. Alta performed all USEPA Method 1613B analyses for CDF/CDD, including those for the Appendix IX samples. The balance of the Appendix IX parameters were analyzed by TriMatrix and ATS.

All laboratory data reports were issued as fully validated electronic data deliverable packages (EDDs). Each package included a summary of the analytical methods used, quality control data (including method blanks, sample duplicates, surrogate recoveries, MS/MSD, and LCS), executed COCs, and case narratives. Corrective action forms were utilized to document and correct discrepancies and errors in these reports. The quality assurance data and corrective action records will be summarized in a quality assurance audit report prepared in the first quarter of 2007.

Throughout the study, ATS reviewed the EDD supplied by the labs on a near-real time basis, comparing QC data against the SOP/QAPP performance objectives. Validated data were incorporated into data summary reports distributed to *GeoMorph*® team members, Dow, and MDEQ. The reports were organized by Reach and included collection date, interval depth, moisture content and CDF/CDD levels expressed both as discrete indicator congener concentrations as well as total TEQ for each sample location.

The majority of the CDF/CDD analyses performed for this study were conducted on a rapid turnaround basis (results available 48-96 hour after submittal to laboratory). The information was conveyed to the field staff and other team members on a similar fast track. The rapid, reliable and conservative characterization of the geomorphological units within Reach areas allowed sampling locations and depths to be adjusted in the field. This, in turn, assured that the nature and extent of COI in those areas were fully delineated and understood before sampling crews demobilized or moved on.

#### *4.2.7.2 Analytical Parameters*

Analytical parameters and reporting limits for the study were as follows:

**Method 1613-TRP/RT**

| Target Analyte | CAS # | RL |
|---|---|---|
| 2,3,7,8-TCDD | 1746-01-6 | 4 ng/kg |
| 2,3,7,8-TCDF | 51207-31-9 | 4 ng/kg |
| 1,2,3,7,8-PeCDF | 57117-41-6 | 4 ng/kg |
| 2,3,4,7,8-PeCDF | 57117-31-4 | 4 ng/kg |
| 1,2,3,4,7,8+1,2,3,6,7,8-HxCDF | 70648-26-9 & 57117-44-9 | 4 ng/kg |
| E-TEQ | -- | 10 ppt TEQ |

The reporting limit (RL) for Method 1613-TRP/RT is 4 ng/kg per congener and 10 ppt estimated total TEQ on dry weight basis, except in cases where limited sample volume, matrix interferences or low internal standard recovery precluded attainment of this objective. Discrete indicator congener concentrations and the aggregate indicator congener concentration, defined as the sum of all positive indicator concentrations, are reported for samples analyzed by Method 1613-TRP/RT. In cases where at least one positive indicator is detected, the aggregate indicator is flagged as estimated. Because the indicator congeners selected for Method 1613-TRP/RT constitute approximately 90 percent of the total

TEQ, a correlation factor multiplier of 1.1 is applied to the total indicator TEQ value to give an estimated total TEQ based on 2005 WHO-TEF factors.

**Method 1613B**

| Target Analyte | CAS # | RL |
|---|---|---|
| 2,3,7,8-TCDD | 1746-01-6 | 1 ng/kg |
| 1,2,3,7,8-PeCDD | 40321-76-4 | 1 ng/kg |
| 1,2,3,4,7,8-HxCDD | 39227-28-6 | 1 ng/kg |
| 1,2,3,6,7,8-HxCDD | 57653-85-7 | 1 ng/kg |
| 1,2,3,7,8,9-HxCDD | 19408-74-3 | 1 ng/kg |
| 1,2,3,4,6,7,8-HpCDD | 35822-46-9 | 1 ng/kg |
| OCDD | 3268-87-9 | 1 ng/kg |
| 2,3,7,8-TCDF | 51207-31-9 | 1 ng/kg |
| 1,2,3,7,8-PeCDF | 57117-41-6 | 1 ng/kg |
| 2,3,4,7,8-PeCDF | 57117-31-4 | 1 ng/kg |
| 1,2,3,4,7,8-HxCDF | 70648-26-9 | 1 ng/kg |
| 1,2,3,6,7,8-HxCDF | 57117-44-9 | 1 ng/kg |
| 2,3,4,6,7,8-HxCDF | 60851-34-5 | 1 ng/kg |
| 1,2,3,7,8,9-HxCDF | 72918-21-9 | 1 ng/kg |
| 1,2,3,4,6,7,8-HpCDF | 67562-39-4 | 1 ng/kg |
| 1,2,3,4,7,8,9-HpCDF | 55673-89-7 | 1 ng/kg |
| OCDF | 39001-02-0 | 1 ng/kg |
| TEQ | -- | 3.16 ppt TEQ |

The RL for USEPA 1613B in this study is 1 ng/kg per congener and 3.16 ppt total TEQ on a dry weight basis, based on 2005 WHO-TEF factors.

Appendix IX

Parameters for Appendix IX analyses are given in Attachment F. The analytical methods for Appendix IX analyses in this study were:

**Appendix IX Analytical Methods**

| | |
|---|---|
| Methods 8260B | Volatile Organics |
| Method 8270C | Semivolatile Organics |
| Method 8081A | Chlorinated Pesticides |
| Method 8082 | PCB |
| Method 8151A | Chlorinated Herbicides |
| Method 1664 | 1,4-Dioxane |
| Method 1613B | Chlorinated Dioxins and Furans |
| Method 6000/7000 | Total Metals |
| Method 9014 | Cyanide |
| Method 9034 | Sulfide |
| Method 3550B | Total Solids |

The RLs for Appendix IX standard target parameters for this study are defined as 3.33 times the current, laboratory specific, statistically based method detection limit, using the USEPA approved procedure found in 40 CFR Part 136 Appendix B.

Qualitative and quantitative information from non-target peaks in the chromatograms of multi-compound volatile and semi-volatile methods (e.g., USEPA 8260 and USEPA 8270) of Appendix IX analyses was handled according to the specifications developed collaboratively with MDEQ for the PCOI/COI/TAL technical memorandum (ATS, 2006a, Attachment G).

# 5. *GEOMORPH®* PILOT SITE CHARACTERIZATION SUMMARY AND DISCUSSION

## 5.1 ITERATIVE *GEOMORPH®* INVESTIGATION APPROACH FOR SITE CHARACTERIZATION

The root technology of *the GeoMorph®* process is geomorphology, which is the study of landforms on the surface of the Earth, and the processes that create and shape them. Fluvial geomorphology, a subspecialty profession, is the focused study of those landforms that are specifically created or influenced by moving water, such as rivers or streams. The science of fluvial geomorphology has been used to define, characterize, map, and predict depositional and erosional areas on river systems ranging in size from small streams to the Mississippi River. A fluvial geomorphological characterization is the process of determining depositional and erosional environments within a river to understand the storage and transport of sediments through the river system. The *GeoMorph®* process is used to identify areas of sediment deposition and erosion based on stream gradient, water velocity, thalweg location, sinuosity of the stream, and morphology of the floodplain and terraces. The process identifies similar sediment morphologies and focuses sampling to characterize these units.

A fundamental element of the *GeoMorph®* site investigation approach to site characterization is that sampling activities are guided by near-real-time (NRT) feedback from the laboratory analyses. By having high quality data flowing back to the *GeoMorph®* Project Team on a NRT basis, sampling locations and depths can be adjusted or "iterated in the field" to assure that an adequate number of representative samples are collected and the nature and extent of COIs are understood before sampling crews demobilize from a study area. A series of statistical tools is integrated into the iterative process to aid decision making related to the adequacy of geomorphic feature and site characterization.

## 5.2 GEOMORPHOLOGICAL CHARACTERIZATION AND MULTIPLE LINES OF EVIDENCE

The UTR SAP (ATS, 2006b) describes the sampling strategy, sampling locations, and procedures to determine the horizontal and vertical extent of COI contamination in the upper 6.4 miles of the Study Area (ATS, 2006b). The depositional environments in UTR have been mapped and a sampling strategy presented in the UTR SAP (ATS, 2006b) to define the concentration and extent of COI in contaminated channel sediments and floodplain soils in the upper section of the river.

The purpose of the geomorphologic characterization is to determine the sediment depositional environments within the river channel, floodplains, and terraces of the rivers and understand the storage and transport of COI contaminated sediments and soils. This characterization is important to understand the history of the geomorphology of the rivers in particular as it relates to contaminated sediment deposition patterns in the last 100 years. Geomorphological characterization includes defining parameters that influence river system dynamics. The parameters included in the geomorphological characterization of in-channel and overbank deposits are discussed in the following sections.

### 5.2.1 High Resolution Topographic Mapping, Longitudinal Profile, and Determination of River Reaches

The purpose of the high resolution topographic mapping is to establish an accurate information base map upon which the *GeoMorph*® layers, or multiple lines of evidence, are built. The longitudinal profile, river reaches, channel comparison of historic aerial photography to the present-day river configuration, and preliminary geomorphic feature mapping of the overbank floodplain and terraces are examples of the layers added to the detailed topographic mapping. The longitudinal profile is established to identify changes in the channel gradient along the length of the river. The changes in the channel gradient have an effect on the velocity and sediment deposition patterns in the river channel. The channel gradient can also affect the overbank sediment deposition pattern. The updated high resolution topographic mapping and longitudinal profile for the UTR is presented in Attachment G and Attachment B, respectively.

A longitudinal profile is developed by surveying the elevation of the channel bed in a downstream direction along the deepest part of the channel. The longitudinal profile can show the number of pools, depths of pools, pool-riffle spacing, and the spatial pattern of pool distribution. Successive thalweg profiles can document trends in deposition or erosion. Thalweg profiles are useful in combination with river cross-section profiles to determine the vertical dimension of channel morphologic features.

The channel gradient, thalweg profile, channel width, channel bed material, and sinuosity are used to establish the breakpoints between the reaches of the river. Discrete river segments or reaches were defined to provide a means to analyze and describe conditions along the river. Reach boundaries were defined to include river segments with similar geomorphologic and/or hydraulic characteristics to assess existing features (landforms) and the potential for sediment accretion (deposition) or degradation (erosion and transport) for a specific reach.

### 5.2.2 Aerial Photographic Review

Historic aerial photographs provided a rich source of information on the natural development of the river and of the anthropogenic changes to the river system dating back to 1937. Aerial photograph interpretation and geomorphic feature comparison at different points in time constitute a basic element, or "layer," of the *GeoMorph®* process and contribute to the "lines of evidence" evaluation. The analysis of the historical aerial photographs was integrated into the other layers of the *GeoMorph®* evaluation, including the analysis of the geomorphic features and the sample locations.

The 1937-1938 series of aerial photographs along the Tittabawassee River represent the earliest aerial photo coverage of the study area. As an element of the work planning effort during the preparation of the UTR SAP (ATS, 2006b), the 1937-1938 river channel alignment was derived using ArcGIS from a digitally ortho-rectified version of the 1937-1938 aerial photography. This 1937-1938 alignment was then digitally superimposed on the 2004 aerial photography and is presented in Attachment C. The information derived from this overlay was used to make an initial assessment of the lateral movement of the river channel over this 67 year period at selected transects, interpret depositional and erosion areas, and relocate sediment and soil sampling locations. The comparison between 1937-1938 and 2004 aerial photographs documented that the banks of the river have either been relatively stable or have expanded certain parts of the Study Area. This comparison also identified some areas where around 100 feet of lateral bank accretion has occurred, such as the Sand Bar area on northeast side of Reach G, and the natural levies on the SW side of Reach L.

During the development of the UTR SAP (ATS, 2006b), it was determined that more detailed contour information was required, and ATS commissioned additional aerial photography of the Tittabawassee River and Upper Saginaw River study area in April 2006. This aerial photography utilized a 0.25 ft horizontal accuracy, which is needed to develop 1 foot contour intervals and supplement the aerial photo history. This high-resolution topographic mapping, along with field verification, was used to refine the geomorphic features. The updated topographic maps developed from the April 2006 aerial photography, and the revised geomorphic feature mapping, are presented in Attachment G.

### 5.2.3 Anthropogenic Influences Analysis

Human activities have modified the Tittabawassee River prior to and during the Midland Plant production operations. These activities range from broad changes in the watershed that affected the hydrology of the entire river system to localized changes along the bank of the river that affect deposition and erosion within a specific area. This section summarizes the major anthropogenic activities that have influenced the Tittabawassee River over the first 6.4 miles downstream of the confluence with the Chippewa River. Anthropogenic influences on the remainder of the TR and the USR will be evaluated during the *GeoMorph®* investigations planned for 2007 and 2008.

### *5.2.3.1 Logging and Salt Manufacturing Prior to The Dow Chemical Company's Operations*

Prior to the production of chemicals at The Dow Chemical Company Midland Plant, logging activities created substantial adverse impacts on the watershed, the hydrology of the river and the floodplain ecology. In the early 1800's, the headwaters of the Tittabawassee River, north of Midland, and the area around the first 6.4 miles downstream of the confluence of the Chippewa River with the Tittabawassee River were dominantly forested with Hemlock, White Pine, and Sugar Maple. (MNFI, 1998) This forest was logged intensively beginning in about 1847 up through the late 1800's. Saw logs were rafted down the Tittabawassee River system to mills in Saginaw, where much of the wood was "wasted" into the local environment due to wide saw blades in the early years and defects in the lumber. In later years, saw widths were reduced and the slab wood and reject boards were processed into wood lath, roofing shingles, cedar blocks and other commercial products, with a large volume of the sawmill wastes also being burned to supply power to the sawmills and to the brine mining/salt making operations that developed to take advantage of this excess fuel supply and the readily available brine underlying the area.

During this period, logging and major forest fires removed vegetation across most of the watershed and sterilized much of the soil. This significantly changed the hydrology and erosion and sedimentation patterns in the Tittabawassee River watershed through increased runoff and decreased baseflow. The first major "shore to shore" forest fire occurred in 1871, followed by lesser fires throughout the 1870's and 1880's. A large storm combined with the denuded watershed created unprecedented flooding in Midland and Saginaw in 1886.

Also during this period, the Tittabawassee River was used to raft logs to milling operations along the Tittabawassee and Saginaw Rivers. Occasionally log jams would occur that significantly impacted river flow, erosion, deposition, and aquatic and riparian habitat. In 1873, a log jam on the Tittabawassee River was reported to have been two to five logs deep and extended up river approximately 130 miles. Activities were taken to manage and remove these log jams, including clearing the river channel and dynamiting the jams. The preparation of the river for log rafting, significantly affected habitat along the river by altering the course and hydrodynamics of the river channel. In addition, the presence of the logs in the river and the subsequent log jams led to significant scouring in the river and altered the hydraulics (AIM, undated).

Lumber production from the Saginaw River peaked at over one billion board feet of lumber being produced from 70 mills in 1882. The Tittabawassee Boom Company was formed to move the lumber down the Tittabawassee River, and rafted 11,800,000,000 board feet of logs down the Tittabawassee

River system prior to going out of business in 1894 (AIM, undated). Salt production was integrated into most of the mills, and it is estimated that 0.25 of the wage earners in the mills around Saginaw worked producing salt. Wells were installed in the area that produced brine from underground formations. The scrap wood from the milling operations was used as an economic source of heat to evaporate the brine and form salt. Michigan became a major producer of salt, and by 1883 accounted for one half of the salt production in the United Sates (AIM, undated).

Waste materials from the logging and salt production were often discharged into the river system. In addition to the scrap wood and saw dust, the salt production operations released residual brine with other minerals that may have contained common inorganic salts such as calcium and magnesium carbonate and magnesium hydroxides. Iron was also present in the lime and gave the salt a reddish color if not removed. To eliminate the red tint in the salt, the brine was treated to precipitate out the iron, and the removed solids were also wasted out of the system (AIM, undated).

The log rafting on the Tittabawassee River ended prior to the end of the 19$^{th}$ century, and the Tittabawassee Boom Company went out of business in 1894. The mills in Saginaw continued to cut wood imported from as far away as Canada, but these operations were also in decline at the start of the 20$^{th}$ century. While the waste wood was no longer available as cheap fuel for evaporating brine, salt production in Michigan continued into the 1900's, and Michigan was still among the leading producers of salt in 1911 (JIEC, 1911).

#### *5.2.3.2 Dams*

Dams have been placed across the Tittabawassee River to control flow and to harness the flowing water. These dams significantly affect the hydrology and hydraulics of the Tittabawassee River. During the logging period, dams were built to control the flow of water during log rafting periods. In 1866, dams were built on the Salt and Chippewa Rivers by the Tittabawassee Boom Company (AIM, undated).

The Sanford, Edenville, Smallwood, and Secord dams were constructed on the Tittabawassee River in 1925 to provide hydroelectric power. The Sanford Dam is the last dam in the sequence up river from Midland and has the largest impact on river flows in the Tittabawassee River downriver from Midland. The Sanford Dam is used to generate power during peak periods of the day, and the turbine is typically run for 7 hours per day, five days per week (AIM, 2006).

This series of historic upstream dams continues to control the flow along the Tittabawassee River near the Midland Plant under normal flow conditions. During peak flow periods, these dams retain a portion of flood flows and aid in reducing the frequency of downstream peak flows. During lower flow periods, the Sanford Dam (the southern dam and most downstream in the series) discharges 210 cubic feet per second, which is the minimal flow maintained in the Tittabawassee River except under severe drought conditions (AIM, 2006).

The present daily schedule for hydroelectric turbine operations at the Sanford Dam leads to diurnal fluctuations in the river level at Midland. These fluctuations can typically be observed in the river stage measurements at the USGS gauging station in Midland, Michigan. Preliminary analysis suggest that this diurnal fluctuation of river water level may be causing undercutting and accelerated erosion in cut banks by repeatedly saturating and then draining the soils at the waters edge and thereby making these soils more susceptible to erosive forces during small to medium size storm events. Further study of this apparent undercutting process will be conducted during work in 2007 and 2008 to determine whether this apparent undercutting adversely affects the stability of cut banks along natural levees having elevated concentrations of COI.

The Dow Dam was installed within the plant area at the Midland Plant between 1939 and 1945 to provide sufficient water depth behind the dam to supply a reliable flow of water to Dow for process operations.

#### *5.2.3.3 Berms*

The floodplain of the Tittabawassee River has been narrowed through the first few miles downstream of the confluence with the Chippewa River through the construction of a series of berms. These berms extend over thousands of feet along the river and border ponds and fill areas adjacent to the river. The series of berms reduces the floodway of the Tittabawassee River over approximately a three mile stretch from Station 30+00 through Station 210+00. Within parts of this section, the constructed berms have reduced the width of the floodplain from approximately 5,000 feet across prior to the berm construction to a current width of approximately 500 feet across. This reduction in the width of the floodplain affects the hydrology of the river during flood events by restricting the cross-sectional area of the floodway, thereby increasing flow velocities, and reducing the amount of overbank storage available during a storm. The following berms are present in the upper section of the Study Area:

- The berm for the ash pond extends approximately 1,300 feet along the southwest side of the Tittabawassee River north of the Dow Dam, from Station 30+00 through Station 46+00. Based on a review of historical aerial photographs, this berm was not present in 1945 and was completed by 1956; it is still present today.

- The brine pond berm extends approximately 4,500 feet along the southwest side of the river south of the Dow Dam, from Station 70+00 through Station 115+00. This berm was constructed before 1938. A series of ponds and a filled area are present behind this berm, including the No. 6 Brine Pond which is used for storage of spent brine, and the Tertiary Pond (T-Pond) system which is used for polishing of treated wastewater. Bullock Creek was re-routed when this berm was created. Bullock Creek currently enters the Tittabawassee River at the south end of this berm, while the original channel of Bullock Creek is now occupied by the T-Pond.

- Farther south on the southwest side of the Tittabawassee River, the berm for the MCV cooling pond extends for approximately 8,000 feet from Station 130+00 through Station 210+00. Based on historical aerial photograph review, the cooling pond was constructed beginning in the early 1970's and was completed by 1972. This berm is still present and maintained today.

- On the northeast side of the Tittabawassee River, a long berm now borders a Dow fill area that extends along 8,800 feet of the river from Station 70+00 to 158+00. The berm was constructed some time prior to 1938 and currently borders a series of fill areas along the northeast bank of the river.

#### *5.2.3.4 Sheet Piling*

Sheet piling has been used to stabilize the banks of the Tittabawassee River along numerous stretches within the Midland Plant area and in several downstream locations. This type of bank stabilization increases channel velocity in the immediate area during flood stage by restricting the cross-sectional area of the river and, depending on the local cross-section, may increase downstream flood elevations and erosive forces by increasing the flows and velocities of water that can no longer be stored on the overbank above the stabilized banks.

The northeast edge of the river is contained by sheet pile through the entire Midland Plant area for approximately 2 miles, from Station 25+00 through Station 158+00. This sequence of sheet pile is part of the revetment groundwater interception system (RGIS) that is used to intercept the flow of groundwater from the plant flowing toward the Tittabawassee River by reversing the hydraulic gradient along the river. Within this area, approximately 1,700 feet has a second sheet pile located farther into the former river channel to stabilize a sand bar deposit (Station 121+00 through Station 138+00). The RGIS was installed through a series of construction stages and improvements starting in 1979 and was largely completed by 1987. Upgrades, improvements and maintenance of the system has continued to the present through the addition of purge wells, improved drain tiles and system repairs and cleaning. One section of the RGIS underdrain system was recently repaired, and notice has recently been given to MDEQ of one other section that will likely require repair and/or cleaning in the near future.

Sheet pile was also installed around the current location of the Dow Dam prior to and related to the Dam. The rectangular embayment on the west side of the river just north of the Dow Dam was present in 1938 prior to the installation of the Dow Dam, and there was sheet piling present north of the Dow Dam leading up to the dam as early as 1945. Sheet piling is also present in front of the MCV facility near Station 130+00 on the southwest side of the river.

#### *5.2.3.5 Bridges*

Many bridges have been constructed across the Tittabawassee River, along its entire 22 mile length. These bridges affect the flow direction and velocities around the supports and also around the approach ramps constructed for the bridges. Some of these bridges significantly constrict flow through a narrow channel during flood events (e.g. the Gordonville Road Bridge) creating orifice effects that increase erosional turbulent eddy currents below the bridges and backwater effects upstream. The following bridges are or have been present in the Upper Tittabawassee Study Area:

**UTR Bridge Summary**

| Bridge | Station | Constructed | Status |
|---|---|---|---|
| Tridge (walking bridge) | 0+00 | 1981 | Still present |
| Benson Street Bridge | 11+00 | Prior to 1938 | Removed approximately 1967 |
| Poseyville Road Bridge | 18+00 | 1967 - 1968 | Still present |
| Dow Rail Pipe Bridge | 50+00 | 1959 | Still present |
| Dow Rail Bridge | 52+00 | 1929 | Still present |
| Pipe Bridge | 114+00 | 1973 - 1979 | Still present |
| Consumers Rail Bridge | 164+00 | 1970 | Still present |
| Gordonville Road Bridge | 233+00 | 1976 | Still present |
| Smith’s Crossing | 261+50 | Prior to 1938 | Closed but still present |

The effects of these bridges on deposition and erosion patterns in the UTR are discussed in Section 5xxx of this report.

For the lower Tittabawassee River and Upper Saginaw Rivers, an inventory and assessment of the effects of bridges, utility crossings, shoreline armoring and other anthropogenic features will be performed during the *GeoMorph*® site characterization investigations planned in 2007 and 2008, and will be presented in the Final Tittabawassee River Site Characterization Report.

#### *5.2.3.6 Pipe Bridges in the Upper Tittabawassee River*

The pipeline from the wastewater treatment plant to the T-Pond system presently passes overhead on the Pipe Bridge. A series of pipes were historically laid beneath the Tittabawassee River to connect the southwest and northeast sides of Dow's Midland plant. To the best of The Dow Chemical Company's knowledge, these pipes have been abandoned and plugged. The installation of these pipes likely disturbed the bottom of the Tittabawassee River channel and may have had transitory effects on sediment load in the river.

#### *5.2.3.7 Discharges into the Tittabawassee River Watershed*

Direct discharges to surface waters within the Tittabawassee River watershed have been, and continue to be, a part of the anthropogenic influences on the watershed. There are a number of cities that lie completely within the Tittabawassee River watershed and discharge their treated wastewater effluent into the river system, including Midland, Mt. Pleasant, Alma, and Clare, Michigan. In addition, there are a number of industrial facilities within the watershed of the Tittabawassee River that currently have, or have had, discharges which go to the Tittabawassee River. These industrial facilities include Dow Chemical in Midland, Dow Corning in Midland, Velsicol Chemical and Michigan Chemical Company in St. Louis, and Total Petroleum in Alma.

Dow Chemical has discharged wastewater into the Tittabawassee River since the early years of its operations, and continues to treat wastewater in their on-site wastewater treatment plant and discharge it through an NPDES permitted outfall. Former historical discharge locations have been identified from previous NPDES permits and historical aerial photographs.

A copy of the draft Special Conditions for The Dow Chemical Company's 1973 NPDES Permit (# MI 070 0X5 2 710109) documents the historical presence of 11 discharge points. These discharge points were labeled 1 through 6 and 11 through 15. Brief descriptions and approximate river-station location references for the outfalls are presented in below. Nine of the 11 outfalls discharged into the Tittabawassee River; the remaining two outfalls discharged into Lingle Drain. Of the nine outfalls that discharged directly into the Tittabawassee River, seven can be observed on historic aerial photographs.

**1973 NPDES Permit Special Conditions Outfalls**

| Outfall No. (1973 Permit) | Description (1973 Permit) | Flow (MGD) (1973 Permit) | Station | Side of River |
|---|---|---|---|---|
| 1 | WWTP | 46 | 128+00 | northeast |
| 2 | 54" CWS | 6 | Lingle | northeast |
| 3 | 60" CWS | 27.4 | 81+00 | northeast |
| 4 | 84" CWS | 3.5 | Lingle | northeast |
| 5 | Asby Ditch | 1 | 30+00 | southwest |
| 6 | 24" WSS | 1 | 61+50 | southwest |
| 11 | E fl-60" | 42.8 | 46+00 | northeast |
| 12 | H fl-96" | 30 | 61+00 | southwest |
| 13 | 12"ST-47 Bldg | 0.144 | 27+00 | northeast |
| 14 | 8"CI-47 Bldg | 0.432 | 29+00 | northeast |
| 15 | 8"ST-47 Bldg | 0.27 | 31+00 | northeast |

The RIWP listed an additional nine outfalls observed on aerial photographs of the Tittabawassee River between its confluence with the Chippewa River and the confluence with Lingle Drain (ATS, 2006a). Two locations that were previously reported are no longer included on the list of additional outfalls. These locations were at station 58+00 on the NE side of the river and at 71+00 on the NE side of the river and are described further below.

The Dow Dam is located at 58+00 NE. In the RIWP (ATS, 2006a), an outfall was listed as being present on the NE side of the river at this location based upon the review of historical aerial photographs. Upon further review of the data, it was determined that there was not an outfall at this location. Instead, the observations are attributed to an upstream outfall. The outfall at 46+00 NE (historically referred to as the E flume outfall) discharged along the NE side of the Tittabawassee River behind a sheet pile wall. The effluent from this outfall was restricted to the far NE portion of the Tittabawassee River by the E flume until the water cascade over the Dow Dam (Reach D). The previous observations related to the end of the E flume, not a separate outfall, and the outfall at station 58+00 NE was removed from the list of additional outfalls.

Earth work for pipe runs has been documented at station 71+00 where a pipe line historically ran to the No. 6 Brine Pond area. The older aerial photographs are at a low resolution, and the disturbance from the earth work was originally categorized as an outfall in the RIWP (ATS, 2006a) at station 71+00 NE. Based upon a more thorough review of the aerial photographs from other years, discussions with Dow employees, and review of the MDEQ files, this location is no longer categorized as an outfall.

The updated list of additional outfalls is provided below:

**Additional Outfalls Observed in Aerial Photographs**

| Station | Side of River |
|---|---|
| 20+00 | northeast |
| 24+00 | northeast |
| 34+50 | northeast |
| 36+00 | northeast |
| 42+00 | northeast |
| 58+00 | southwest |
| 106+00 | southwest |

A figure depicting the locations of these outfalls is provided in Attachment H.

### 5.2.4 Geomorphic Feature Mapping

Preliminary geomorphic mapping was conducted to define specific landform and channel features that result from and/or influence fluvial geomorphologic processes. For this study, geomorphic features (e.g. floodplain, low terrace, intermediate terrace, high terrace, upland), which often are distinguished by elevation differences, were predominantly mapped for each specific reach on detailed topographic maps. Based on this method, the defined geomorphic features are relative to similar features observed in each specific reach and have not, at this time, been tied to a flood elevation-based classification for the river system.

The reach was used as the basis for geomorphic mapping to provide a practical means to evaluate the river system since reaches were defined to include river segments with similar geomorphologic and/or hydraulic characteristics. This method provides a means to define predominant geomorphic features, many of which are correlated throughout the river system study area. The preliminary geomorphic mapping was then used to establish soil and sediment sample locations on the base map. Most overbank soil samples are associated with transects that were developed on a base map. The overbank transects are perpendicular to river flow and extend away from each bank. Sample locations were typically selected to represent each geomorphic feature type. Geomorphic features with the same classification were not always considered similar since proximity to the river and to adjacent geomorphic features is a factor. Therefore, more than one sample was collected from a specific geomorphic feature type in a reach. For example, an intermediate terrace adjacent to a river channel is distinguished as a separate feature from an intermediate terrace separated from the river channel by a low terrace.

In-channel mapping included delineation of bank erosion scars on the base map and limited characterization of channel sediment thickness to assess channel deposition and erosion within each reach. Additional channel characterization is required in the future during the pre-design field investigation to further define in-channel deposition and erosion areas. Soil and sediment profile descriptions that were obtained during the field investigation were used to confirm or revise the pre-field geomorphic feature delineation and/or classification.

#### 5.2.5 Soil and Sediment Profiling

Overbank (soil) core samples were described to characterize profiles with regards to soil horizon (e.g. A, E, B, C) and specific horizon physical properties. The physical properties that were described included texture estimates (particle size distribution), color, rupture resistance, plasticity, and distinguishable matter in the soil/sediment matrix. Distinguishable matter included formations (nodules of iron, manganese, or sulfate), deposits that were not apparent products of soil processes (construction debris, possibly graphite), and plant matter (roots, leaves, woody tissue, mollusk shells). The sediment cores were also described to characterize layers with regard to physical properties, as listed previously. Terminology used by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) was used to describe soil/sediment layers in each sample core (Schoenberger et al., 2002).

Soil horizon and physical description data is used to verify the geomorphic feature classification based on preliminary mapping, to support the evaluation regarding the nature and extent of contamination along the river corridor, and to assist with pre-design remediation evaluations. Soil horizon/sediment layer descriptions provide insight into a number of pertinent factors regarding river valley morphology and transport. The soil horizon descriptions were used to verify or revise geomorphic features that were defined through preliminary mapping.

The degree of soil horizon development is related to time, which indicates stability of the soil profile. Therefore the soil horizon data can be used to determine if the profile formed in a relatively stable environment, an environment subject to change (erosion, deposition), and in some cases the depth interval of stable/unstable conditions. Limited soil horizon development or channel sediment accumulation may indicate erosion or scouring, respectively. Soil horizon/sediment layer physical properties, such as texture provide insights into the depositional environment of the soil/sediment layer. Coarse-grained deposits (sand) are typically associated with high energy depositional environments (e.g. glacial outwash, point bars from fluvial transport, natural levees) as compared to fine-grained deposits which are typically associated with low energy depositional environments (lacustrine, fluvial backwater areas, wetlands, river pools). Unique soil horizon/sediment layer characteristics may provide insights regarding contaminant fate and transport. For example, organic compounds may have an affinity to accumulate (adsorb) in soil horizons/layers with higher organic matter content (A horizon, organic layer from tree or herbaceous plants) or may be restricted from downward vertical transport in low hydraulic conductivity clay layers. Unique soil horizon/sediment layer characteristics may also provide useful markers to assess the vertical extent of contamination (e.g. lacustrine clays that formed prior to existence of Midland Plant).

## 5.3 CONSTITUENTS OF INTEREST

### 5.3.1 Primary Constituents of Interest

Seventeen chlorinated dibenzofurans and dibenzodioxins used to calculate TEQ are the primary Constituents of Interest (COI) in this investigation. These substances are known to be environmentally persistent and have relatively low threshold concentrations for environmental concern. Certain furan congeners predominate in the mixture of dioxin-furan congeners present in Tittabawassee and Saginaw River sediments and floodplain soils downstream of Midland. Most of the Total TEQ is attributable to these furan congeners. As a result, a selected subset of selected furans and dioxins constitutes a useful suite of contaminants to assess the presence of sediment and soil impact.

### 5.3.2 PCOI Evaluation and Secondary Constituents of Interest

Because of the long and complex history of the Midland Plant as a manufacturer of chemicals, and the potential for additional contributors of chemicals to the Tittabawassee and Saginaw River watershed, other PCOI have been evaluated in a collaborative effort by Dow, ATS, MDEQ and USEPA. The evaluation process is described in detail in a Technical Memorandum prepared by ATS and submitted to MDEQ on December 1, 2006 as part of the RIWP (ATS, 2006a, Attachment G). This document identified the secondary COI substances in Target Analyte Lists (TALs) for near-plant and downstream portions of the UTR investigation. These TALs, and their corresponding analytical method SOPs, have been incorporated into the project Quality Assurance Project Plan (QAPP) (ATS 2006c). Secondary COI were analyzed at a lesser frequency than furans and dioxins, on samples selected by Dow, ATS and MDEQ.

### 5.3.3 COI Release History

Contaminant release histories constitute an important layer in the *GeoMorph*® investigation process. The potential periods of release for furans, dioxins and other COI from the Midland Plant have been established, and have been summarized in an industrial history timeline included in the RIWP (ATS, 2006a, Attachment F).

### 5.3.4 Sediment Geochemistry

Understanding the relationship of grain size, mineralogy and other factors that influence the occurrence of furans and dioxins is fundamental to the GeoMorph site characterization. At present it is unclear whether furan and dioxin contamination in sediment and soil can be associated with a particular grain size, the presence of carbon-rich fractions, or some other soil property. An initial geochemistry study was conducted in 2006 to investigate this possibility. Two particle fractionation protocols were developed and evaluated on representative samples from the TR. These are provided in Attachment I. The dry-sieving protocol was found to give an incomplete separation of the desired size fractions, leaving appreciable fine material in the coarse fractions, and thereby substantially confounding interpretation of furan and dioxin data. The wet-sieving protocol yielded an acceptable separation of the size fractions, and was utilized in the analysis of 15 samples from the site chosen collaboratively with MDEQ. Analyses are on-going and will be summarized in a Technical Memorandum.

Final results and interpretation of the 2006 geochemistry study will be presented in a technical memorandum issued on or before April 1, 2007. If the results of this study indicate there is a relationship between contaminant concentrations and grains size and/or mineralogy, this relationship will be incorporated into the fluvial geomorphic analysis of contaminant distribution. Further, if such a relationship exists, Stokes Law settling studies will be conducted in 2007 to support calibration and verification of the particle transport components of the TR and USR hydrodynamic models, and the sediment trap efficiency studies currently underway in the USR.

## 5.4 FATE AND TRANSPORT

Because of the hydrophobic and highly sorptive nature of chlorinated furans and dioxins, movement of these compounds within a riverine setting is typically dominated by the transport and deposition of solids. Soil and sediment transport processes include in-channel solids transport through the water column as bedload and suspended sediment, erosion and deposition of solids in the banks and floodplain, and exchange between the river channel and floodplain under flood conditions. A hydrodynamic model of the

Tittabawassee River has been developed to better understand the role of varying flow conditions in soil and sediment transport. The hydrodynamic model will also be used to develop particle transport simulations. The development of the hydrodynamic model and particle transport simulations is discussed below, and a summary of specific transport mechanisms that are relevant to the Tittabawassee and Upper Saginaw River systems is also presented in the following sections.

### 5.4.1 Hydrodynamic Model – Tittabawassee River

A two-dimensional model of the Tittabawassee River from its confluence with the Chippewa River in Midland, Michigan to its confluence with the Shiawassee River in Saginaw, Michigan was developed to provide an understanding of the hydrodynamic forces and sediment transport pathways operating in this portion of the river. The model was developed in the Environmental Fluid Dynamics Code (EFDC), an EPA modeling framework that has been applied to many riverine sites in the United States. In its recent review of an EFDC application to the Housatonic River and floodplain (Hayter, 2006), EPA found EFDC to be a "robust modeling system that can be successfully implemented at other contaminated sediment sites." The Tittabawassee River model spans the 100-year floodplain, and consists of 174,000 curvilinear grid cells with typical dimensions 11 m (longitudinal) by 22 m (transverse). Floodplain grid topography was generated with 1 foot resolution in most areas and 2 foot resolution in others, and channel bathymetry from bathymetric surveys performed in 2003 by LTI.

The model consists of two submodels, linked at Dow Dam. Each submodel is driven by upstream flows and constrained by downstream water levels. For the submodel above Dow Dam, upstream boundary flows are based on USGS monitored flows just downstream of Dow Dam and drainage area relationships for the Chippewa River and Upper Tittabawassee River. The downstream water level boundary is based on a stage-discharge relationship at Dow Dam. The upstream boundary flows for the submodel below Dow Dam, are also given by the USGS gauge just downstream of Dow Dam, and the downstream water level boundary is based on a one-dimensional model of the Saginaw River.

The model was used to predict hydrodynamic outcomes, including velocity, shear stress, water depth, flooding extent, and flooding duration, for four recent storm events, including November 2003, March 2004, May 2004, and March 2006. Peak flows for these events ranged from 3250 to 23,940 cfs, and recurrence intervals from 0.4 to 7.9 years. In the table below is a summary of peak flows and recurrence intervals for the four events. Channel and floodplain roughness were the primary calibration parameters, and were calibrated using water level and velocity monitoring data as targets. The close match between actual and predicted water levels and velocities for a wide range of events indicates that the model reliably predicts hydrodynamic outcomes over a wide range of flow conditions. The model was also simulated for the very large 1986 storm event (approximately 96-year recurrence interval). Details of model development are given in Attachment J.

**Summary of Monitored Events Used for Model Calibration**

| Month and Year | Dates | Peak Flow | Recurrence Interval |
|---|---|---|---|
| November 2003 | 11/18 – 11/22 | 3,250 | 0.4 |
| March 2004 | 3/3 - 3/11 | 23,940 | 7.9 |
| May 2004 | 5/8 – 5/13 | 17,550 | 3.1 |
| March 2006 | 3/9 – 3/18 | 23,030 | 6.9 |

### 5.4.2 Particle Transport Simulations

The path and distance traveled by a resuspended particle before redepositing depends on flow direction and velocity, and on the settling characteristics of the particle. To better understand the movement of particles under varying flow conditions, the hydrodynamic model has been used to simulate the settling of particles, when released from locations of potential erosion and contaminant transport. For example, the model can be used to predict whether coarse particles eroded from levees under very high flows would deposit in floodplains or terraces, or return to the channel. Test particle tracking runs have been successfully performed, and it is expected that this tool will be used in future remedial planning.

### 5.4.3 River-Floodplain Exchange

Transport of solids between the river and floodplain (solids exchange) depends on the configuration of the river, local geomorphic features, and the amount of flow and solids transported during any given event. As described above, the Tittabawassee River channel at the north end of the Study Area is generally straighter, while the middle portion of the river is more sinuous. This is illustrated in the CH2M Hill Scoping Study Area 1 and Area 2 (CH2M Hill, 2005a). In both areas, transport of solids between the river and floodplain occurs as the river flow leaves the main channel during flood events. In both the upstream and downstream portions of the river, this river-floodplain interaction results in the transport of some river sediment into the floodplain, creating formations such as natural levees and splays.

The 2005 Scoping Study on the Tittabawassee River included an investigation of floodplain soil characteristics including organic content, particle size distribution, and associated furan and dioxin concentrations (CH2M Hill, 2005a). Particle size distributions differ in the two areas. In Area 1, sandy materials predominate at most locations, with the exception of a line of more silty samples located on the inside of a shallow river bend. Higher TEQ concentrations appear to be associated with these silty samples, as well as with more sandy samples located in the natural levee area adjacent to the river. In Area 2, silty samples are more broadly distributed throughout the floodplain, and are generally associated with relatively high TEQ concentrations.

A comparison of the silty samples in both areas with estimates of their predicted streamline distances shows that most of these samples are at floodplain locations a short distance downstream from the river channel during flood conditions (that is, locations that have short streamline distances to the river under flood conditions). The observed gradient of relatively coarse sands in levee areas adjacent to the river and finer materials a short distance downstream in the floodplain is consistent with the sorting that would be expected during a flooding and sediment transport event. This suggests that transport of sediments from river to floodplain under flooding conditions may be a predictable phenomenon, and may also be a vector for historic and present-day transport of solids-associated furans and dioxins. The data available to date suggest that furans and dioxins may be preferentially associated with floodplain geomorphic features such as splays and levees that are formed by short-range sediment transport from river to floodplain. Elevated TEQ concentrations observed across broader areas of the floodplain may be related to deposition of finer-grained suspended sediment transported greater distances from the river channel during flood events.

The sediment transport observations described above were supported by the “influencing factor” evaluation performed in the Scoping Study, which showed that streamline distance was the strongest predictor of TEQ concentration in the floodplain. The streamline distance serves as a simplified surrogate for the complex suite of processes that result in the erosion and transport of sediment particles, and subsequent redeposition in the floodplain. In general, low streamline distance implies a strong transport link to sediments in the river, and a greater probability of transport and deposition of river sediments to a given location.

As noted above, chlorinated dioxin and furan concentrations and thicknesses of deposited solids were measured in the Tittabawassee River floodplain after the March 2006 flood event. Total chlorinated dioxin and furan concentrations ranged from 25 - 5,120 ppt (TEQ), and the thickness of measured solids deposition ranged from zero to as much as 70 mm deposition.

The transport processes governing solids transport are illustrated in Attachment K, which display a conceptual model of solids movement in the Tittabawassee River, its floodplain, tributaries, and downstream waters. These processes include in-river transport of solids, exchange between river and floodplain due to processes that may include both overland flows during flood events and bank erosion, and deposition and/or erosion of the floodplain during flood events. Because of the hydrophobic nature of chlorinated furans and, dioxins these compounds associate strongly with solids in aquatic environments, and their presence in rivers and floodplains is highly dependent on the movement of solids between these environmental compartments.

Recent hydrodynamic modeling results have extended our understanding of flows during flood events and their potential effects on river-flood plain solids exchange. Figures 5.3a to 5.3l in Attachment J how simulated velocities, shear stresses, and flow paths from 3-year and 8-year flood events and for the very large (approximately 96 year) 1986 event, for reach J, K, and L, and M, N, and O.

Shear stress governs the erosion of surface sediments and solids, and shear stress reductions along flow paths dictate subsequent deposition patters. In general, the figures show the highest shear stresses occur along near-shore levees during high-flow events and that flood plain shear stresses decline with distance from the river bank. The shear stress figures also show flow paths during peak flood, so that potential transport pathways from levees to floodplains can be identified.

Comparisons of the three simulated flow events illustrate the differences between flood events with higher and lower flows. In general, the shear stresses experienced by the sediment bed are insensitive to the size of the event, because the effect of higher velocity is attenuated by greater water depth. This can be seen in a comparison of figures 5.3b, d, and figures 5.3h, j and l of Attachment J. The same comparisons show that the most prominent differences between larger and smaller events are the extent of flooding and magnitude of shear stresses experienced in the flood plains. Simulated flow paths for the larger events shows greater potential for particle transport from the river bed to the floodplain and higher floodplain sheer stresses for the larger events suggest greater transport distances prior to floodplain deposition.

## 5.5 UTR CHARACTERIZATION

A river is a dynamic system that strives toward equilibrium in terms of energy associated with flow and sediment transport. River patterns and channel shapes and the associated landforms or geomorphic features associated with the fluvial landscape are products of this process of striving towards equilibrium and are influenced by many variables including discharge, longitudinal slope, sediment load, bank resistance, vegetation, and geology. Following are summary discussions of the geomorphology, analytical results, horizontal and vertical extent of contamination, and the nature of contamination in relation to the predominant geomorphologic features and hydrodynamic conditions. These summaries are best read while referring to the Maximum TEQ Concentration Maps contained in Attachment L, the Surface TEQ Concentration Maps contained in Attachment M and the Cross-Sections prepared for eleven UTR transects presented in Attachment N. In addition, the Site Characterization Data Summary reports, contain soil profile descriptions for each sampling location, the geomorphic setting of each location, and the analytical results for each soil horizon sampled are presented in Attachment R and S. These attachments and the following discussion taken together provide a comprehensive narrative and graphical description of the database presently available for the UTR.

### 5.5.1 Upstream of Dow Dam (Reaches A through D)

#### *5.5.1.1 River Geomorphology*

The "Upstream of Dow Dam" river segment includes Reach A through Reach D. This river segment extends from the City of Midland Tridge at the confluence of the Chippewa and Tittabawassee Rivers (Station 0+00) downstream to the Dow Dam (Station 57+50). This river segment is relatively stable with minimal evidence of erosion, scour, and/or deposition, presumably due to the backwater influence from the Dow Dam.

The river channel associated with Reach A and Reach B is relatively natural. Downstream from Reach B, the river channel is influenced by anthropogenic structures including embankments, rip-rap, and sheet pile. The channel hydraulic gradient is less than 0.001 ft/ft or less than 1 ft of vertical change over the entire 5,750 ft channel length. The channel is relatively straight, except for a meander towards the south in Reach B, resulting in low channel sinuosity, or ratio of channel length to valley length, which is representative of a stable river. The channel width is relatively uniform and ranges from about 200 ft to 400 ft.

The predominant geomorphic features in this river segment include low terrace and upland. Floodplain and intermediate terrace areas do occur, but to a much lesser extent. Throughout most of the river segment, overbank flow is contained within a relatively narrow corridor due to embankments and upland. The most significant land uses are associated with industrial and commercial facilities including buildings, roads, surface water impoundments, and grass areas along the river and adjacent to the surface water impoundments. Prominent anthropogenic modifications adjacent to or near the river include the Poseyville Road Bridge, a drainage channel that discharges into the west bank of the river near Station 30+00, the water intake basin (constructed channel expansion) upstream of the Dow Dam on the west bank, and the Dow Dam.

### *5.5.1.2 Contaminant Distribution - Summary*

The area of the UTR "Upstream of Dow Dam" is highly channelized by the berms and armoring on both sides of the river as it passes between the Dow Midland Plant operations to the northeast and the T-Ponds to the southwest. All samples collected in this area are from in-channel or from southwest overbank locations. Sampling in the overbank was not performed on City of Midland property or in areas of the Dow Midland plant on-site corrective action activities. In addition, the highly industrialized nature and historic construction activities along the downstream end of this river segment has narrowed the floodplain and resulted in limited geomorphic feature development.

The river upstream of the Dow Dam has been migrating to the northeast, based on comparison of aerial photographs (1937 to 2004), with erosion and accretion occurring on the outside and inside of the meander bend, respectively. The ponding or backwater from the dam is evident from the contrast in channel configuration beginning in Reach B and continuing through Reach D. Lateral channel migration is not observed downstream of RB-30+00 in Reach B. The present channel width based on the 2004 aerial is greater than 1937 channel width starting about midway through Reach B, due to backwater from the downstream dam, which was installed sometime between 1937 and 1945.

All in-channel samples upstream of the Dow Dam are <100 ppt TEQ except for two sampling locations situated within an historic wastewater flume. These locations are discussed below. All overbank samples upstream of the Dow Dam are <200 ppt TEQ.

<u>*Historic Wastewater Flume Locations*</u>

Elevated TEQ concentrations were identified at two sampling locations (RD-55+05-IC-NE and RD-55+10-IC-NE) between sheet piling walls of a historic wastewater flume located within the channel in Reach D. The soft sediment deposits at these two locations are 3.0 and 2.5 feet in thickness, respectively. Furan and dioxin concentrations in the eight discrete intervals collected from these locations ranged from 2,600 to 69,000 ppt TEQ. The congener pattern in these sediments, principally consisting of the higher chlorinated furans, is consistent with discharge of waste brines from the production of chlorine by the electrolysis of salt brine. The historic flume was created with sheet piling installed parallel to and approximately 20 feet from the northeastern bank of the river. The purpose of the flume was to constrain wastewater discharges to flow adjacent to the northeastern side of the river, bypassing the industrial water intake located on the southwestern side of the river just above the dam. The flume was used prior to the construction of the Tertiary Ponds in the early 1970's. The sediment within this historic flume is currently contained on three sides by sheet piling, and on the downstream end by the Dow dam. The sheeting on the east side of this deposit is a component of the RGIS system, and serves as the Tittabawassee River bank.

### *5.5.1.3 Chemistry Data – Summary*

*In-Channel Samples*

Findings from the preliminary in-channel characterization of furan and dioxin concentrations are reported on 144 samples (including replicates) from 32 in-channel sample locations upstream of the Dow Dam. Although originally proposed in the SAP (ATS, 2006b), samples were not collected from the proposed sampling location Reach A (RA-4+25-SW) because half of the channel bed consisted of gravel and cobbles. A summary of the soil profiles and analytical results is presented in Attachment R.

Ten samples (including two duplicates) from two locations are located inside a historic wastewater discharge flume, within the current river channel, created with sheet piling installed parallel to and approximately 20 feet from the northeastern bank of the river just upstream from the Dow Dam (RD-55+05-IC-NE and RD-55+10-IC-NE). This deposit is protected by the sheet piling installed in the river channel. The maximum furan and dioxin concentration observed within the flume is 69,000 ppt TEQ at RD-55+10-IC-NE (1.9-2.5 ft). The surface concentration at this location is 18,000 ppt TEQ. The highest surface concentration observed is 26,000 ppt TEQ at RD-55+05-IC-NE.

Vertical extent of contamination in this area is defined at 3.0 ft bss based on an observed concentration of 10,000 ppt TEQ at RD-55+05-NE. The horizontal extent of contamination is bounded on the northeast by the RGIS system sheet piling along the river channel bank and on the southwest (river side) of the historic flume by the submerged historic sheet piling. Based on historical aerial photographs, the downstream boundary of the flume is the Dow Dam and the upstream boundary is near the location of a historic Midland Plant wastewater discharge point.

The remaining 134 samples collected from the 30 other in-channel sampling locations have furan and dioxin concentrations <100 ppt TEQ. The highest observed TEQ is 76 ppt located at depth at RD-55+00-IC-SW2 (10.7-12.0 ft).

*Overbank Samples*

Sixty-three overbank samples were collected from 14 locations. All sampling locations were on the southwest side of the river and had furan and dioxin concentrations <100 ppt TEQ with the exception of four samples located at depth. The maximum concentration of 190 ppt TEQ was detected at RB-30+50-SW905 (0.4-1.1 ft). A summary of the soil profiles and analytical results is presented in Attachment R.

The primary overbank deposition area is in Reach C on the low terrace on the southwest side of the river. This terrace is bounded on the west by a pond berm and on the east by floodplain and the river. The maximum TEQ concentrations ranging from 130 to 150 ppt TEQ, at three sample locations [RC-45+00-SW20 (1.7-2.1 ft), RC-38+50-SW60 (0.9-1.5 ft), and RC 45+00-SW65 (1.2-1.6 ft)]. Surface samples at the three locations have concentrations <100 ppt TEQ. The northern extent of contamination on the low terrace is represented by location RB-37+00-SW60 where the highest concentration is <100 ppt TEQ and is located in the surface horizon. The southern extent of contamination is the facility berm located approximately 200 ft south of the RC-45+00 transect. The vertical extent of contamination is 2.1 ft. All three sample locations are bounded vertically with concentrations <10 ppt TEQ below the highest concentration horizon. The deposition is caused by vertical accretion of sediment during flood events. In the remaining overbank locations, all concentrations are <100 ppt TEQ.

The Reach A and upper Reach B overbank areas along the northeast side of the river are located on properties within the City of Midland and were not sampled. Also, the overbank areas northeast of the river (Reaches B though D) were not sampled. These areas are located on the Dow Chemical Company Midland Plant property and are part of the On-site Corrective Action program.

*Tributary Samples*

A small tributary ditch runs parallel to the berm for the ash pond on the southwest side of the river at station RB-29+50. One tributary location and two associated wetland locations were sample and analyzed for primary COI. A summary of the soil profiles and analytical results is presented in Attachment R.

All four intervals of the tributary samples have furan and dioxin concentrations <100 ppt TEQ. One sample from a depositional area within a wetland (RB-30+50-SW905) has a concentration of 190 ppt TEQ from 0.4 to 1.1 feet. Concentrations at the surface are <100 ppt TEQ. The soil horizon below 1.1 feet also has a concentration of <100 ppt TEQ. The horizontal extent of contamination is bounded by the berm and property boundary 150 feet to the north and the berm for Poseyville Road to the west. The horizontal extent of contamination on the east is bounded by the active tributary with the highest concentration <100 ppt TEQ at RB-29+50-T-SW180. The horizontal extent of contamination on the south is sample location RB-32+00-SW1000 with the highest concentration <100 ppt TEQ in the surface horizon.

<u>*Secondary COI*</u>

Six in-channel locations upstream of the Dow Dam area were sampled and analyzed for Appendix IX constituents. Five of the samples were collected within the normal channel, and one location (RD-55+05-IC-NE) was collected within the historic wastewater flume located in Reach D. The RD-55+05-IC-NE sample contains higher concentrations of chlorinated organic compounds, metals, and PNAs than the other five samples. The concentrations of metals in this sample are outside the range typically observed in Michigan soils (MDEQ, 2005; Page 3, Table 1; column {c}). The other five samples located in-channel but outside of the sheet piling contained two volatile organic compounds at low concentrations (2-butanone, and toluene) and low but detectable concentrations of PNAs, 4-4'-DDD, 4-4'-DDE, 4-4'-DDT, and naturally occurring metals. The concentrations of the naturally occurring metals in these five samples are within the concentration range typically observed in Michigan soils (MDEQ, 2005; Page 3, Table 1; column {c}). A summary of the Appendix IX analytical results is presented in Attachment T.

### 5.5.2 Near Plant Area (Reaches E through H)

#### *5.5.2.1 River Geomorphology*

The "Near Plant Area" river segment includes Reach E through Reach H. This river segment extends from the Dow Dam (Station 57+50) to the facility Pipe Bridge (Station 163+50). The entire river channel is adjacent to either the Midland Plant or MCV properties.

The river channel is relatively stable with minimal evidence of erosion, scour, and/or deposition. The most significant indication of bank erosion occurs along the southwest outside bank of the meander, with respect to downstream flow, just downstream of the Dow Dam. An erosion scar was observed along this outside bank, which experiences greater hydraulic forces as compared to the inside bank. Energy associated with the dam and the sheet pile located along the northeast bank of the river are the likely sources of the erosion along this unarmored bank segment.

The river channel is influenced by anthropogenic structures including the Dow Dam, embankments, rip-rap, sheet pile, and surface water impoundment drainage channels. The channel hydraulic gradient is less than 0.001 ft/ft or less than 2 ft of vertical change over the entire 10,600 ft channel length. The channel is relatively straight, except for a meander downstream of the Dow Dam and a meander near the boundary between Reach G and Reach H. Therefore, the channel sinuosity, or ratio of channel length to valley length, is relatively low and representative of a stable river. The channel width is relatively uniform and ranges from about 200 ft to 350 ft.

Geomorphic features include floodplain, wetland, tributaries, natural levee, low terrace, low intermediate terrace, intermediate terrace, high terrace and upland. Throughout most of the river segment, overbank flow is contained within a relatively narrow corridor due to embankments and upland. The most significant land uses are associated with industrial and commercial facilities (Dow, MCV) including buildings, roads, surface water impoundments, drainage channels, and grass areas along the river and adjacent to surface water impoundments. Prominent anthropogenic modifications adjacent to or near the river include the Dow Dam, large surface water impoundments greater than 40 acres in size along most of the southwest bank, and significant drainage channels that discharge from the southwest bank (Reach F/G boundary) and northeast bank (Reach H/I).

#### *5.5.2.2 Contaminant Distribution - Summary*

The “Near Plant” area downstream of the Dow Dam is a highly channelized river segment with the presence of steep slopes along both sides of the river. Dow Midland Plant property exists on the northeast side of the river. Dow Midland Plant property also exists on the southwest side in Reaches E and F; with MCV property on the southwest side through Reaches G and H. The highly industrialized land use and historic construction activities along this river segment has narrowed the floodplain, increased channel velocities, and resulted in limited geomorphic feature development.

The channel width in the Near Plant portion of the UTR has increased along the entire length (Reaches E through H) based on comparisons of 1937 to 2004 aerial photographs. The increase in channel width is attributed to anthropogenic influences including the Dow Dam, sheet pile, rip rap, and the water discharge locations (Bullock Creek, Dow Midland Plant, and Lingle Drain). Downstream from the Dow Dam, the river has widened to the northeast due to increased water velocity from the dam. Erosion has occurred in Reach F and H, on the southwest bank, due to the sheet pile and rip rap installed along the northeast bank adjacent to the Dow Plant. The river channel has shifted to the southwest in Reach G due to the former Dow wastewater treatment plant discharge, the RGIS system installation, and the sheet pile along the northeast bank.

In this river segment, samples of buried deposits were identified at three locations in Reach G with concentrations >1,000 ppt TEQ: RG-130+50-NE30 (7.9-8.8 ft), RG-130+55-NE80 (4.7-5.4 ft, 5.4-6.2 ft and 6.2-7.8 ft), and RG-135+50-NE30 (3.3-4.1 ft). The highest buried concentration was identified at

RG-135+50-NE30 (3.3-3.7 ft) at a concentration of 4,500 ppt TEQ. These soil horizons are overlain and underlain by cleaner deposits. Horizontally, these locations are bounded on the north and south by the RGIS system sheet piling and upstream and downstream by rip rap adjacent to the river and a service road. This area between the sheet piling is predominantly comprised of river deposited material between the sheet piling. Deposition is caused by vertical accretion of sediment during flood events. Along the northeast bank, no samples were taken where the RGIS extends to the river's edge.

All in-channel results in the Near Plant area are <1,000 ppt TEQ with the exception of three locations in buried deposits. The maximum Near Plant in-channel concentration of 2,900 ppt TEQ was identified in a buried deposit at RF-103+50-IC-NE at a depth of 2.5-3.0 ft bss. All results in the overbank area were <5,000 ppt TEQ with the exception of one location in a buried deposit. The maximum overbank concentration of 9,400 ppt TEQ was identified in a buried deposit at RE-66+05-SW65 at a depth of 1.1-2.5 ft bgs.

#### *5.5.2.3 Chemistry Data – Summary*

*In-Channel Samples*

Findings from the preliminary in-channel characterization of furan and dioxin concentrations are reported on 136 samples from 39 in-channel locations taken in the Near Plant Area. Concentrations of all samples are <100 ppt TEQ except for eight samples located in buried deposits, three of which have concentrations above 1,000 ppt TEQ. The three results above 1,000 ppt TEQ are buried in-channel deposits along transects RF-103+50-IC and RF-162+00-IC. The nature and extent of both areas are discussed below. A summary of the soil profiles and analytical results is presented in Attachment R.

RF-103+50-IC-NE is located in the northeast portion of the river with rip rap armoring along the northeast bank and a narrow floodplain and a high terrace along the southwest bank. The maximum concentration detected at this location is 2,900 ppt TEQ between 2.5-3.0 ft bss. The sediment layers above and below this interval have concentrations <100 ppt TEQ. The sediment profile at RF-103+50-IC-NE shows well sorted sand in the clean sediment layers above the 2,900 ppt TEQ layer. Sediments at and below this layer are poorly sorted. The bottom sediment layer contains burnt wood and gravel within the sand matrix.

RH-162+00-IC is located 200 feet upstream of the Midland Plant Pipe Bridge. The bridge abutments collect a significant amount of debris causing localized ponding upstream of the bridge and sediment deposition. The highest concentrations are found at RH-162+00-IC-NE (2.6-3.0 ft) with a concentration of 1,300 ppt TEQ, and at RH-162+00-IC-SW (1.1-1.4 ft) with a concentration of 2,300 ppt TEQ. All surface sediment samples exhibit concentrations <100 ppt TEQ. Contamination does not extend to RH-162+00-IC-C, where all sediment intervals contain concentrations <100 ppt TEQ. The sediment profile at RH-162+00-IC-NE shows well sorted sand in the clean sediment layers, and mixed/poorly sorted materials in layers with higher TEQ concentrations. The higher concentration layers in RH-162+00-IC-SW contain wood and burnt wood material and the lower concentration layers are predominantly sand.

*Overbank Samples*

Four hundred and thirty-six overbank samples were collected at 103 locations within the Near Plant Area, 84 sample locations on the southwest side of the river and 19 locations on the northeast side of the river. Three depositional areas were identified in the Near Plant Area: along the southwest bank on the intermediate terrace at RE-66+00, along the northeast bank on the low terrace and floodplain in Reach G at RG-135+50, and along both banks in Reach H at RH-158+00. The following discussion presents a more detailed description of the horizontal and vertical extent of contamination at each of these areas. A summary of the soil profiles and analytical results is presented in Attachment R.

Along the southwest side of the river, the majority of the samples contain <100 ppt TEQ. All surface samples in this area report concentrations <100 ppt TEQ. Analyses of 69 samples show concentrations at depth <100 ppt TEQ with six samples of buried deposits reporting >1,000 ppt TEQ. The highest concentration is 9,400 ppt TEQ at RE-66+05-SW65 (1.1-2.5 ft). Analysis of the soil profiles from these six locations with elevated concentration reveal underlying sediments with concentrations less than 100 ppt TEQ. The samples collected from the southwest side of the river in this area are associated with a vertically accreting intermediate terrace. This intermediate terrace is bounded on the east by the river bank which includes sheet pile and rip rap, along the north and south by pond berms for the industrial ponds located on Dow Chemical Company and MCV properties, and along the west by an elevated road system. This intermediate terrace area is predominantly fill material from the creation and management of the sedimentation ponds. The bottom sample of the soil profile in each sampling location in this terrace indicates a concentration of 10 ppt TEQ or less.

Along the northeast side of the river, samples were taken at 15 locations within a sand bar located between the RGIS system sheet piling and a line of sheet piling which is the northeast bank of the river. Surface concentrations at all locations within this area are <100 ppt TEQ. Samples of buried deposits at three locations have concentrations >1,000 ppt TEQ: RG-130+50-NE30 (7.9-8.8 ft), RG-130+55-NE80 (4.7-5.4 ft, 5.4-6.2 ft and 6.2-7.8 ft), and RG-135+50-NE30 (3.3-3.7 and 3.7 to 4.1 ft). The highest concentration identified at any of these locations was 4,500 ppt. These soil horizons are overlain and underlain by cleaner deposits. Horizontally, these locations are bounded on the northeast and southwest by the RGIS system sheet piling and upstream and downstream by rip rap adjacent to the river and a service road. This area is predominantly material deposited between the sheet piling walls during flood events. Along the northeast bank, no samples were collected where the RGIS extends to the river's edge.

Twenty-three samples were also collected from four locations in a small overbank area on the northeast side of the river near the confluence of Lingle Drain and the Tittabawassee River in Reach H. All samples contained <1,000 ppt TEQ except for one sample, a buried deposit, at RH-158+00-NE20 (1.9-2.8 ft) with a concentration of 3,200 ppt TEQ.

Buried deposits with concentrations >1,000 ppt TEQ are also found along Reach H at RH-158+00 in the floodplain on the northeast side of the river and on an intermediate terrace on the southwest side of the river. The floodplain on the northeast side of the river at RH-158+00-NE20 is bounded on the north by the low terrace scarp and sample location RH-158+00-NE70; to the east by Lingle Drain; to the west by a service road; and to the south by the river. The highest concentration is found in a buried deposit at RH-158+00-NE20 (1.9-2.8 ft), with a concentration of 3,200 ppt TEQ. This interval is overlain and underlain by cleaner deposits, <500 ppt TEQ. Samples from RH-158+00-NE70 50 feet away show concentrations <500 ppt TEQ. All surface samples in this area are <100 ppt TEQ. The floodplain contains primarily fine grained material. Deposition is due to vertical and lateral accretion. The floodplain is heavily vegetated which limits the reworking of sediment deposits.

The intermediate terrace along the southwest side of Reach H at RH-158+00 contains buried deposits at two locations with concentrations >1,000 ppt TEQ: RH-158+00-SW25 (2.1-2.5 ft) with a concentration of 2,300 ppt TEQ and RH-158+00-SW175 (4.2-5.4 ft) with a concentration of 1,700 ppt TEQ. The terrace is bounded on the north by the river, on the east by the embankment of the Pipe Bridge, on the south boundary by a low terrace, and on the west by a man made drainage ditch. Surface concentrations in the intermediate terrace are all <1000 ppt TEQ with the highest reported concentration of 310 ppt TEQ. Cleaner deposits underlie both elevated intervals that have elevated concentration. The contamination is limited horizontally to the southwest by the low terrace station RH-158+00-SW235, which has a high concentration of 210 ppt TEQ at the surface and a bottom horizon concentration of <100 ppt TEQ. The soil profile at RH-158+00-SW25 shows well sorted sands in the top five feet underlain by fine grained material. Deposition on the intermediate terrace is by vertical accretion. The accretion rates on this terrace are accelerated by the ponding affect resulting from constricted flow of floodwater upstream of the Pipe Bridge

<u>*Tributary Samples*</u>

Two locations were sampled in Lingle Drain, a tributary to Reach H. Surface samples from the Lingle Drain tributary in Reach H contain <100 ppt TEQ. A buried deposit at RH-161+50-T-NE265 (0.8-1.1 ft) contains the highest concentration of 200 ppt TEQ. Lingle Drain is a wastewater discharge point for the City of Midland and a backwater area for the Tittabawassee River. A second tributary, Bullock Creek, enters Reach H from the MCV property. Analyses of samples from Bullock Creek were not complete at the time of the writing of this report. A summary of the soil profiles and analytical results is presented in Attachment R.

<u>*Secondary COI*</u>

Twelve samples from the "Near Plant" area were analyzed for Appendix IX constituents. Six of these twelve samples were in-channel sediments, four were from overbank soil locations in the sand bar located on the northeast side of the river in Reach G, and two were from the tributary, Lingle Drain. VOCs were present in some of the samples at low concentrations. The six in-channel samples did not contain detectable chlorinated volatile organic compounds, and contained only low concentrations of benzene (maximum of 0.14 mg/kg). The overbank samples in Reach G had low concentrations of benzene, 2-butanone, tetrachloroethene, toluene, trichloroethene, and trichlorofluoromethane. The two tributary samples in Lingle Drain contained low concentrations of benzene (maximum of 0.026 mg/kg) and toluene (one sample at 0.024 mg/kg). A summary of the Appendix IX analytical results is presented in Attachment T.

All of the samples contained some PNAs and naturally occurring metals. The concentrations of the naturally occurring metals detected in these samples are within the concentration range typically found in Michigan soils (MDEQ, 2005; Page 3, Table 1; column {c}) with the exception of copper in one tributary sample at 77 mg/kg which is slightly higher than the typical range of data for copper in Michigan soil samples (1 to 58 mg/kg).

Of the twelve samples, two of the in-channel samples and two of the overbank samples in Reach G contained detectable concentrations of 4-4'-DDD all under 0.01 mg/kg, and a single overbank sample in Reach G contained 4-4'-DDE and 4-4'-DDT. Nine of the twelve samples contained detectable concentrations of some chlorinated benzenes.

### 5.5.3 Natural River Setting (Reaches I though O)

#### *5.5.3.1 River Geomorphology*

The "Natural River" setting includes Reach I through Reach O. This river segment extends from the facility Pipe Bridge over the river (Station 163+50) to downstream from Rodgers Road at Station 335+50. Most of the river channel is adjacent to Midland Plant, MCV, or privately owned properties that are undeveloped. Throughout the majority of this river segment, overbank flow is not contained with in a relatively narrow corridor by embankments and upland as in the case of the upstream river segments discussed above.

There is some evidence of erosion, scour, and/or deposition along portions of this river segment. Erosion scars occur throughout this segment and are common along both channel banks within and downstream from lower Reach K. The river segment has fewer anthropogenic structures, as compared to the previously discussed upstream river segments. The channel hydraulic gradient is less than 0.001 ft/ft or less than 2 ft of vertical change over the entire 17,200 ft channel length. There are several gradual meanders throughout the river segment. The meanders are within a relatively narrow corridor, therefore, the channel sinuosity, or ratio of channel length to valley length, is relatively low and representative of a stable river. The channel width is relatively uniform and ranges from about 200 ft to 400 ft.

The geomorphic features include floodplain, wetland, tributaries, natural levee, historic natural levee, low terrace, intermediate terrace, high terrace, and upper high terrace, and upland. Throughout most of the river segment, overbank flow is not contained within a relatively narrow corridor by embankments and upland, as compared to the previously discussed river segments. The most significant land uses include a surface water impoundment in the upper river segment, woodland, and agricultural fields. Prominent anthropogenic modifications adjacent to or near the river include: a large MCV surface water impoundment (greater than 40 acres in size) and associated drainage channels, extending from Reach I through upper Reach K; the Gordonville Road Bridge in lower Reach K; the Smiths Crossing Bridge (abandoned) in Reaches L/M; and several constructed drainage tributaries that discharge into the Tittabawassee River within the river reaches from lower Reach K through Reach O.

#### *5.5.3.2 Contaminant Distribution - Summary*

<u>Reaches I through K</u>

Reaches I though K are located between UTR stations 163+50 and 233+50. This section includes the first large inside bend of the river downstream of the Midland Plant. At its widest point, Reach K extends 425 feet from the river toward Saginaw Road, with the narrowest sections at each end. A large wetland bounds the area along most of its northeastern side, with Saginaw Road further to the northeast beyond the wetland. The Caldwell boat launch bounds the downstream end of Reach K.

From geomorphological and anthropogenic perspectives areas included in Reach I through K have a rich history. As discussed in the RIWP (ATS, 2006a), the deforestation, fires and flooding of the logging era, followed by the installation of the series of upriver hydroelectric and flood control dams in 1925, likely combined to create the double series of levees ("pre-industrial" and "post-industrial") that remain along much of the UTR, especially along inside bends. In Reach K, as in many downstream areas of the UTR, the post-industrial (natural levees) levees closest to the river have relatively low concentrations near the ground surface, with concentrations of furan and dioxins increasing to a maximum level in the 3 to 8 foot depth range (reflecting post-industrial levee building with highly contaminated sediments in the past). The pre-industrial (historic natural levee) levee, along with the intermediate terraces adjacent to river and wetlands, generally have the opposite concentration profile, with higher concentrations closest to the ground surface and the lowest concentrations below 2 to 3 ft bgs. This pattern of concentrations is exhibited throughout Reaches K though O. See Attachment L, and Attachment N, for Maximum TEQ concentration maps and cross-sections that graphically present the concentration profiles for the Reach I through O transects, respectively.

Based on a comparison of 1937 to 2004 aerial photographs, Reaches I through K portions of the river have been expanding to the northeast with erosion occurring on the inside of the meander bend and limited accretion on the outside of the meander bend which is an unusual pattern of channel movement. This lateral movement to the northeast into the inside bend is most likely due to: the hydrodynamic effects of the progressive channeling and berm construction along the river just upstream of Reach K through the Midland Plant and MCV areas just upstream of Reach K; the installation of the Dow dam in 1945; and the narrowing of the river channel by 100 feet at the beginning of Reach K. The plant construction and the embankment of Saginaw Road just upstream of Reach K constrain flood flows to a very narrow, essentially manmade, channelized floodway until river station RJ-190+00, at which point the floodway immediately widens out into the low terrace area On the northeast side of the river

Hydrodynamic modeling to date of 3-year, 8-year and 100-year floods (the 1986 flood is assumed to approximate a 100-year flood) indicate that high shear stresses exist all along the inside river bend of Reach K during the 8-year and 100-year floods. This modeling also shows that the post-industrial levees in the downstream portion of Reach K, from approximately RK-218+00 to RK-228+00, are subject to high shear stresses even during relatively moderate 3-year storm events.

The highest TEQ concentrations in Reach K are found in buried deposits adjacent to the river's edge. At the southeastern end of Reach K, just upstream of the Caldwell boat launch, a soil core from the post-industrial levee at RK-224+50-NE30 identified a TEQ concentration of 26,000 ppt TEQ in a buried deposit at 7.5–8.5 ft bgs. See Attachment N for a cross-section of transect RK-224+50. The highest TEQ concentrations in the northwestern end of Reach K tend to have concentrations over 1,000 ppt at the surface and extend to depths ranging from 1.7 to 5.5 feet bgs. The highest concentration in Reach K was found at RK 201+00-NE-25, where a TEQ concentration of 84,000 ppt TEQ occurs in a buried deposit at a depth of 2.2-3.3 ft bgs. At this location, the concentrations in the two stratigraphic horizons above this deposit (0.0-0.7 ft bgs, and 0.7-2.2 ft bgs) are 1,300 and 40,000 ppt TEQ respectively. This suggests a pre-industrial terrace that has been buried by contaminated flood deposits. The TEQ concentrations in the flood deposits have decreased over time, which is reflected in the soil profiles in this area where concentrations increase with depth to the highest concentration then decrease below the highest concentration. See Attachment N for a cross-section of transect RK-201+00.

Further inland, the low terrace adjacent to the large wetland that occupies the upstream portion of Reach K has relatively high concentrations at the ground surface. TEQ concentrations in the upper 0.5 feet of the soil profile measured at 30,000 ppt TEQ at RK-206+00-NE170, and 18,000 ppt TEQ at RK-201+00-NE425 (see Attachment N for a cross-section of transect RK-201+00). These elevated TEQ concentrations indicate the low terrace in Reach K has acted as a sediment trap during flooding conditions over time. This sediment trap exists because the large wetland complex in Reach K is inundated during a storm event prior to the beginning of overbank flooding of the river. This "ponding" in the wetland causes a decrease in the flood water velocity and sediment-carrying capacity. This situation has contributed to the surface contamination away from the river in the upstream portion of Reach K.

The highest TEQ concentration in the large wetland adjacent to Reach K is 3,100 ppt TEQ at RK 201+00-NE440 at the extreme northwestern end of the wetland (see Attachment N for a cross-section of transect RK-201+00). TEQ Concentrations in the wetland decline toward the southeast. Only three other locations in the northwestern end of the wetland show TEQ concentrations >1,000 ppt TEQ. Soil samples collected from the remaining portion of the wetland to the southeast show TEQ concentrations <1,000 ppt TEQ.

Reach L

Reach L is located between downstream from the Gordonville Road Bridge and the abandoned Smith's Crossing Bridge. Site characterization information is only available for the river channel and the southwestern overbank area. To date, the owner of the property on the northeast side of the river has denied access for site characterization activities.

The bridges and their approaches at either end of Reach L have a marked influence on the hydrodynamics and fluvial geomorphology of the river and floodplain in this Reach, particularly during flood events. The contraction of river flows at the Gordonville Rd. Bridge followed by the broad floodway downstream of the bridge result in elevated peak shear stresses on both banks for approximately 1,500 feet downstream based on the hydrodynamic modeling to date. The abandoned Smith's Crossing Bridge, with its narrower bridge opening orifice and lower approaches causes a spreading of flooding stream lines as the river approaches the bridge resulting in increased peak shear stresses on both banks of the river for approximately 500 feet upstream of Smith's Crossing during major flooding conditions based on the hydrodynamic modeling outputs.

Based on a comparison of aerial photographs from 1937 and 2004 for Reach L there has been a significant migration of the entire river channel toward the northeast over time, which is consistent with the slight outside meander bend of the river on the northeastern bank. This channel migration information along with the peak shear stress information from the hydrodynamic modeling indicates that the post-industrial levees on the northeast bank of the river are at risk of continued erosion from this long term movement of the river channel and stresses during flooding conditions.

The southwestern inside bend of the river along Reach L, along with the geomorphology and soil concentration profiles indicates that the southwestern bank of the river is generally accretive, although the banks are subject to erosion likely due to day-to-day fluctuations of the water levels resulting from the Sanford Dam releases. Erosion scars above the water line, mapped in the Spring 2006, are evident along virtually all of the southwestern inside bend river bank and also along a portion of the northeastern outside bend river bank. Follow-up erosion scar mapping conducted in Fall 2006 indicates considerably less erosion in Reach L due to vegetative growth stabilizing the banks during the growing season.

The southwestern bank of the river through Reach L is moving toward the northeast with time, consistent with the general pattern of inside bends, and appears to be generally accretive in the overbank. In the natural levees, the same depositional pattern is present, with the highest concentrations buried in the middle of the soil profile. These post-industrial levees in Reach L appear to extend in a relatively narrow strip from approximately RL-239+00-SW10 to RL-258+50-SW15. The maximum TEQ concentrations in the post-industrial levees along the southwestern river bank range from: 5,800 ppt TEQ in a buried deposit from 3.4 to 4.1 ft bgs at RL-239+00-SW10; to 35,000 ppt TEQ in a buried deposit from 5 to 6 ft bgs at RL-246+00-SW20; to 12,000 ppt TEQ in a buried deposit from 2.9 to 3.4 feet at RL-258+50-SW15 at the southeastern end of Reach L. The RL-246+00 location is the apex of the inside meander bend (see Attachment N for a cross-section of transect RK-201+00; Attachment M for Surface TEQ concentration maps; and Attachment L for Maximum TEQ concentration maps).

Reaches M, N, and O

Reaches M, N, and O are located downstream of Smith's Crossing Bridge. The major geomorphological and anthropogenic features within Reaches M, N, and O are: the Smith's Crossing Bridge and it's approaches; major natural upland area that rise above the surrounding floodway in the northeastern overbank of Reaches N and O; the proximity of the southwest upland scarp to the river; numerous wetlands; and several manmade tributaries that bisect the uplands and wetlands throughout this area. Reach M is the beginning of the more sinuous reaches of the UTR and includes three significant bends in the river.

Reaches M, N, and O are the most complex portions of the UTR study area, with both pre- and post-industrial levees evident throughout these reaches. The levees are most evident topographically at the ground surface on inside bends and in relatively stable transition zones between the bends, as would be expected from a fluvial geomorphological perspective. The natural levees are not present downstream of Smith's Crossing Bridge, likely as a result of the high shear stress during large storm events as the storm flows quickly emerge laterally over the banks after passing through the orifice formed by the bridge abutments. The flood water velocities during high flows downstream of the bridge have limited the development of natural levees within 500 feet of the bridge.

A comparison of 1937 and 2004 river channel positions generally indicate substantial channel movement over time toward the outside bends at each of the three meander bends, with relatively stable channel positions in the transition sections between the bends, as would be expected. Water line erosion undercutting is evident along both sides of the river throughout Reaches M though O. Hydrodynamic modeling indicates that high shear stresses exist along the most of the banks in Reaches M, N, and O during the 8-year and 100 year storms. High shear stress occurs principally along the outside bends during a 3-year storm event and generally along the southwestern side of the river downstream of Smith's Crossing Bridge.

The preliminary hydrodynamic modeling also indicates that during the 100-year storm, Smith's Crossing Bridge and its approaches tend to redistribute flood streamlines along the upland floodplain areas as a result of floodwaters rising to a level where they can cross virtually all of the road approaches to the bridge on both sides of the river. This effect, along with the rapid lateral expansion of the streamlines downstream of the Smith Crossing Bridge abutments creates a streamline movement to the north of the upland located in the center of the floodway on the northeast side of Reach N. The 100-year event reverses the flow in the man-made tributary through the wetlands at river station RM-280+00. This same flow reversal occurs at the man-made tributary at river station RN-320+00, further contributing to the proportion of flow leaving the river channel and flowing along the northeast side of the upland feature in the middle of the floodway in Reaches N and O during large storm events.

As a result of these hydrodynamic diversions during high flow conditions a significant portion of the floodwaters in Reach N bypass the low-flow channel and move along the north of the upland high grounds into Reach P. To a lesser extent this same expansion into the floodplain occurs along the southwestern overbank as a result of flooding across the southwestern approach to Smith's Crossing Bridge and rapid streamline expansion into the southwestern uplands after passing through the bridge abutments.

#### *5.5.3.3 Chemistry Data – Summary*

*In-Channel Samples*

Preliminary in-channel characterization involved collection of 275 samples from 84 in-channel sample locations in Reaches I through O. Furan and dioxin levels in all these samples were less <1,000 ppt TEQ except for eight sampling locations. Four locations had sample intervals containing 1,000 to 5,000 ppt TEQ, all in buried deposits. Four additional locations had sample intervals containing >5,000 ppt TEQ, again all in buried deposits. See Attachment L for Maximum TEQ maps. A summary of the soil profiles and analytical results is presented in Attachment R.

*In-Channel Deposition areas with TEQ Concentrations >15,000 ppt TEQ*

A sample from a buried deposit at RO-322+50-IC-C (0.5-1.1 ft) exhibited a concentration of 87,000 ppt TEQ. MDEQ requested laboratory replication of this result. Additional subsamples from the same container resulted in laboratory duplicates of 24,000 and 100,000 ppt TEQ. This yields a geometric mean of 59,300 for this sample. This deposit is located near the apex of an inside meander bend, approximately 350 ft downstream of a perennial tributary which enters the Tittabawassee River from the northeast side of the river. The surficial sediment (0.0-0.5 ft bss) at this location is 240 ppt TEQ, and the concentration at the bottom of the sediment profile (1.1-1.3 ft bss) is 120 ppt TEQ. An additional 14 locations were sampled in the vicinity of RO-322+50-IC-C, and only two additional intervals contained concentrations higher than 500 ppt TEQ, both of them in buried deposits: RO-323+00-IC-SW75 (0.6-0.9 ft bss) at 4,000 ppt TEQ, and RO-327+50-IC-C (0.4-1.0 ft bss) at 6,300 ppt TEQ. In addition, the highest concentration in the transect immediately upstream was 120 ppt TEQ in surface deposit (0.0-0.4 ft bss) at RN-316+00-IC-NE. The highest concentration in the transect immediately downstream from these locations was 19 ppt TEQ in a buried deposit (0.9-1.1 ft bss) at RO-333+00-IC. A summary of the soil profiles and analytical results is presented in Attachment R.

The sediment profile at the RO-322+50-IC-C location discussed above shows mixed sand in the upper part of the profile, underlain by elevated concentrations in a layer containing burnt wood and other organic matter. The perennial tributary immediately upstream, and the influence of the point bar to the northeast and the river Thalweg to the southwest are likely to be factors in the location of this organic deposit in the center of the channel. The RO-322+50 cross-section in included in Attachment N.

The other channel sediment sample containing >15,000 ppt TEQ was collected from a core at RL-258+50-IC-SW, located 300 ft upstream of the abandoned Smith's Crossing Bridge on the southwest side of the river. Analysis of the sample collected at RL-258+50-IC-SW at a depth of 1.9-2.4 ft bss identifies a buried deposit containing 23,000 ppt TEQ. Both the surface sample concentration and the bottom sediment sample at this location contain <100 ppt TEQ. All other in-channel sediment samples in Reach L have TEQ concentrations <200 ppt TEQ, with the majority of in-channel sediment TEQ concentrations <100 ppt TEQ.

At RL-258+50-IC-C, in the center of the channel approximately 100 feet away from the southwest channel location described above, the maximum TEQ concentration is 140 ppt TEQ at 1.9 ft to 2.3 ft bss. The TEQ concentration is <100 ppt TEQ at the sediment surface for this location. The TEQ concentration in the upstream transect, RL-252+00-IC, is 160 ppt TEQ in the center location at a depth of 1.0 ft to 1.6 ft bss. The TEQ surface concentration is <100 ppt TEQ.

*In-Channel TEQ Concentrations >5,000 ppt TEQ*

Two in-channel sample locations indicated concentrations >5,000 ppt TEQ in buried deposits: RM-262+00-IC-C (0.7-1.2 ft) with a concentration of 8,300 ppt TEQ and RO-327+50-IC-C (0.4-1.0 ft) with a concentration of 6,300 ppt TEQ.

The RM- 262+00 transect located immediately downstream of the Smith Crossing Bridge has a maximum TEQ concentration of 8,300 ppt TEQ in the center of the channel at a depth of 0.7 ft to 1.2 ft bss. The sediment profile at this location reveals a well sorted sand in the upper part of the profile. The elevated concentration layer includes a mixture of sand and fine material with organic material in the center of the profile. The hydrodynamic shadow of the center pier of Smith's Crossing Bridge, the inside bank of the meander bend, the overlying clean sand armoring, and the relatively low storm shear stresses in the area of 262+00-IC-C have likely combined to protect the historically deposited organic rich layer buried at this location from erosion.

The TEQ surface concentration at the RM-262+00-IC location is <100 ppt TEQ and the bottom sediment layer TEQ concentration is 2,800 ppt TEQ at a depth of 1.2 ft to 1.8 ft bss. Approximately 40 feet northeast, the maximum TEQ concentration at RM-262+00-IC-NE is <100 ppt. Approximately 40 feet southwest the maximum concentration is 780 ppt TEQ at RM-262+00-IC-SW 2.9-3.3 ft). Surface samples at both locations are <100 ppt TEQ.

RO-327+50-IC-C is located at the apex of a meander bend. The three sample locations in this transect are located from the center of the channel to the northeast toward the inside of the meander bend. This location has an elevated TEQ concentration of 6,300 ppt TEQ in a buried deposit from 0.4 ft to 1.0 ft bss. The surface and bottom sediment layer TEQ concentration is <100 ppt TEQ. The maximum TEQ concentrations approximately 60 feet to the northeast and southwest at RO-327+50-IC-NE and RO-327-50-IC-SW are <100 ppt TEQ. The maximum TEQ concentration in the upstream transect, RO-322+50-IC, is >15,000 ppt TEQ and is discussed above. The highest concentration downstream is <100 ppt TEQ at RO-333+00-IC (0.9 -1.1 ft). The sediment profile at RO-327+50-IC-C shows mixed sand in the upper part of the profile with elevated TEQ concentrations appearing in layers consisting predominately of burnt wood and organic matter. The inside meander bend and reduced stream velocity have contributed to this in-channel deposit.

*In-Channel TEQ Concentrations >1,000 ppt TEQ*

Samples at depth from four locations show concentrations between 1,000 ppt TEQ and 5,000 ppt TEQ: RI-184+00-IC-SW (2.3-2.7 ft), RK-206+00-IC-SW (0.5-0.9 ft), RM- 268+00-IC-C (0.6-1.0 ft) and RO-323+00-IC-SW75 (0.6-0.9 ft).

The RM-268+00-IC (0.6-1.0 ft) location has a buried concentration of 1,500 ppt TEQ. This location is approximately 650 feet downstream of the Smith's Crossing Bridge center pier and is on the next transect downstream of the RM-262+00-IC sample location discussed just above. Sediment layers above and below this interval were both <100 ppt TEQ, at 61 and 23 ppt TEQ respectively. The sediment profile at RM-268+00-IC-SW shows a well sorted sand in the upper layers. The buried deposits with elevated concentrations consist of poorly sorted sand with the presence of burnt wood and organic matter. Approximately 40 feet northeast at RM-268+00-IC-NE the maximum concentration is <100 ppt TEQ. Approximately 80 feet southwest at RM-268+00-IC-SW (0.5-1.0 ft) the maximum concentration is 130 ppt TEQ.  Once again, the hydrodynamic shadow of the center pier of Smith's Crossing Bridge, the overlying clean sand armoring, and the relatively low storm shear stresses in this area have likely combined to protect this historically deposited layer from erosion.

RI-184+00-IC-SW is located in the upstream portion of the Natural River Setting reaches on the downstream portion of the inside meander bend on the southwest side of the river.  This location has an elevated TEQ concentration of 2,100 ppt TEQ in a buried deposit from 2.3 ft to 2.7 ft bss.  The surface TEQ concentration is <100 ppt TEQ and the bottom sediment layer TEQ concentration is <100 ppt TEQ at a depth of 3.3 ft to 3.6 ft bss.  Approximately 40 feet away is RI-184+00-IC-C (0.0-0.5 ft) with a maximum TEQ concentration <100 ppt TEQ.  The highest TEQ concentration upstream is 180 ppt TEQ at RI-177+50-IC (1.6-2.0 ft).  The surface TEQ concentration at this location is <100 ppt TEQ and the bottom sediment layer has a TEQ concentration of <100 ppt TEQ.  The highest concentration downstream is <100 ppt TEQ at RJ-187+50-IC-NE (0.8-1.3 ft) in the northeast portion of the channel.  The sediment profile at RI-184+00-IC-SW shows well sorted sand in the upper layers.  The buried deposit with the elevated TEQ concentration layer consists of mixed sand.  The deposition at this location is related to the inside meander bend and the reduction in stream velocity on the southwest side of the river.

RK-206+00-IC-SW is located on the apex of the inside meander bend on the northeast side of the river.  The three samples in this transect are located on the northeast half of the river channel.  The lack of soft sediment prevented sampling on the southwest half of the river.  This location has an elevated TEQ concentration of 1,400 ppt TEQ at a depth of 0.5 ft to 0.9 ft bss.  The surface TEQ concentration is <100 ppt TEQ and the bottom sediment layer TEQ concentration is <100 ppt TEQ at a depth of 0.9 ft to 1.5 ft bss.  Approximately 20 feet away at RK-206+00-IC-C (1.0-1.9 ft) the maximum TEQ concentration is <100 ppt TEQ.  The sediment profile at RK-206+00-IC-SW shows a well sorted sand in the upper layers.  The buried deposits with elevated concentrations consists of poorly sorted sand with the presence of burnt wood and organic matter.  The deposition at this location is related to the inside meander bend and the reduction in stream velocity on the northeast side of the river.

RO-323+00-IC-SW75 is a "step out" sampling location to the southwest of the RO-322+50-IC location discussed above.  A sample from this location contains an elevated TEQ concentration of 4,000 ppt TEQ in a buried deposit from 0.6 ft to 0.9 ft bss.  The surface TEQ concentration is <100 ppt TEQ.  The bottom sediment layer TEQ concentration is 140 ppt TEQ at a depth of 0.9 ft to 1.0 ft bss.  Approximately 50 feet upstream and downstream, the maximum TEQ concentrations are <100 ppt TEQ.  The sediment profile at RO-323+00-IC-SW75 shows a poorly sorted sand in the upper part of the profile.  The buried deposits with elevated concentrations consist of decomposing wood fragments and organic matter. The bottom of the sediment profile is poorly sorted sand.

To provide a better understanding of the river conditions needed to mobilize the in-channel buried deposits with elevated TEQ concentrations, the hydrodynamic model was used to simulate flood and normal flow hydrodynamics for Reaches J though O. Initially the model evaluated areas at and immediately adjacent to sample location RO-322+50-IC-C. The hydrodynamic model indicates the shear stresses experienced at sample location RO-322+50-IC-C and the area immediately northwest are high enough to armor these areas over time under most high flow and flood flow conditions. The RO-322+50-IC-C deposit area is on an inside bend, which usually is a net depositional area where an in-river point bar has formed. During higher flows, Shields Law states that shear stresses can increase enough to remove fine grained material, while leaving coarse sands and gravels. Over time these higher flow sorting processes will armor the bed, making these areas more resistant to erosional processes that occur during future high flow events. Sampling done at location RO-322+50-IC-C and other in-channel locations in the Natural River Setting Area of the UTR with elevated TEQ concentrations show that coarse sands and gravels with low TEQ concentrations have uniformly been deposited on top of the buried in-channel deposits containing elevated TEQ concentrations. These sands and gravels appear to have created a protective cap over the higher TEQ concentration, find grained, more organic sediments. These grain size types reconcile well with the hydrodynamic model predictions of lower shear stress values at these buried deposits with elevated TEQ concentrations, net depositional, and unlikely to be eroded away under normal or flood flow conditions in the near future.

The hydrodynamic model was expanded to evaluate Reaches J though O results for both normal flows and flood flows up to the 1986 storm (estimated 100-year storm). These Reaches were also analyzed to see if the elevated TEQ concentrations in buried deposits would be disturbed under high flow conditions. Modeling results indicate that the areas at in-channel sample points: RO-322+50-IC-C (0.5-1.1 ft), RO-327+50-IC (0.4-1.0 ft), RL-258+50-IC-SW (1.9-2.4 ft), RM-262+00-IC (0.7-1.2 ft), RM- 262+00-IC-C (0.7-1.2 ft), RO-327+50-IC-C (0.4-1.0 ft), RM-262+00-IC-C (1.2-1.8 ft), and RM-268+00-IC (0.6-1.0 ft) are not affected by excessively high shear stresses for long periods of time during flooding events. While, as expected, these areas do show elevated velocities during the flood simulation, these areas are outside of the main high in-channel velocity areas and are deeply submerged by the flood wave, which lessens the shear stresses that could potentially erode the bed. Peak model calculated flood flow shear stresses are below the shear stress values described by Shields law that are needed to mobilize the Overbank Samples

The overbank depositional pattern in the Natural River segment of UTR is concentrated in two geomorphic settings: natural levees adjacent to the river and the low and intermediate terraces associated with the wetlands located approximately 200 feet from the river. Samples were collected from 373 overbank locations and six erosion scar locations. The highest concentration in an overbank sample is 84,000 ppt TEQ at RK-201+00-NE25 at a depth of 2.2-3.3 ft bgs. The highest concentration identified in an erosion scar is 50,000 ppt TEQ at RM-284+00-NE-ES at a depth of 2.0-3.0 ft measured horizontally into the face of the bank. A discussion of the nature and extent organized by geomorphic feature is presented below.

Additional samples beyond those collected for UTR *GeoMorph*® site characterization were also collected in Reach L along a fixed interval transect at sample locations selected by the MDEQ. Samples were collected at 47 sample locations on the MDEQ defined fixed interval locations. Following the sample design, only 0 – 1 ft surface samples were collected at most of these locations. At four locations, an additional depth interval was collected near the surface. The majority of the samples contain less than 100 ppt TEQ with one sample at RL-246+00-SW220 (0.0-1.0) showing a concentration of 1,300 ppt TEQ. The fixed interval samples are discussed further in Section 5.5 Statistical Calibration and Verification of *GeoMorph*® Sample Design. Attachment O contains the maps of the fixed-interval and random-on-grid sampling locations.

*Natural Levees*

Twenty-seven locations have concentrations >15,000 ppt TEQ. Thirteen locations with concentrations >15,000 ppt TEQ are associated with natural levees. Two natural levee locations are present in straight portions of the river, RK-224+50-NE35 and RN-297+00-NE25. Eleven of the natural levee locations are associated with the five inside meander bends present in Reaches K through O. The inside meander bends are listed from upstream to downstream; along the northeast side of Reach K, the southwest side of Reaches L through M, the northeast side of Reach M, the southwest side of Reach N, and the northeast side of Reach O northeast. The Reach N inside meander is the only one with sample locations that do not exceed TEQ concentrations of 15,000 ppt TEQ. The thirteen natural levee locations are within 55 feet of the river bank. The locations include: RJ-192+50-NE50, RK-224+50-NE35, RL-246+00-SW20, RL-249+00-SW10, RM-268+00-SW20, RM-276+00-NE20, RM-284+00-NE20, RM-284+00-NE55, RN-293+00-NE10, RN-297+00-NE25, RN-316+00-NE30, RO-323+00-NE40, and RO-333+00-NE10. See Attachment N for cross-sections of select transects and sampling locations discussed above. A summary of the soil profiles and analytical results is presented in Attachment R. A summary of the erosion scar sampling results is presented in Attachment S.

The maximum TEQ concentrations for natural levee locations are within the middle of the soil profile at depths typically ranging from 0.7 to 8.5 ft, with lower TEQ concentrations both above and below. The typical natural levee soil profile consists of weak A horizon and B horizon development at the surface due to the consistent deposition of new flood deposits. The middle portion of the soil profile, which includes the maximum TEQ concentrations, consists of a C horizon of well sorted sand, varying in thickness from one to several feet. The bottom portion of the soil profile consists of distinct C horizons that include more fine material than the thick C horizon above and contain layers of burnt wood. The underlying glacial lacustrine deposit is silty clay loam or clay loam.

Forty-eight locations have concentrations >5,000 ppt TEQ but <15,000 ppt TEQ. Thirteen of the 48 locations are associated with the natural levees. Of these 13 natural levee locations, eight are associated with the five inside meander bends present in Reaches K through O. The five locations not found on inside meander bends in the natural levees are present adjacent to the river on outside meander bends or straight portions of the river. The thirteen natural levee locations are present within 30 feet of the river bank.

*Terraces Adjacent to River*

Nine locations with sample concentrations >15,000 ppt TEQ are located adjacent to the river on terraces. Four locations are along the northeast side of Reach K on the inside meander bend, one in Reach K in a straight portion of the river, two along the northeast side of Reach M, one along the northeast side of Reach N, and one along the northeast side of Reach O. These low, intermediate, and high terrace locations are within 70 feet of the river bank. The maximum TEQ concentrations are in the near surface horizons ranging from the 0.0 ft to 6.0 ft bgs. The locations include RK-197+00-NE25, RK-197+00-NE70, RK-201+00-NE25, RK-201+00-NE60, RK-224+50-NE30, RM-284+00-NE55, RM-290+50-NE15, RN-316+00-NE30N, and RO-321+50-NE50. The typical vertical profile shows an A horizon underlain by C horizons. The A horizon in the terraces is typically more developed (thicker) than at the natural levee locations. See Attachment N for cross-sections of select transects and sampling locations discussed above. A summary of the soil profiles and analytical results is presented in Attachment R.

Nineteen sample locations with TEQ concentrations >5,000 ppt TEQ are on terraces adjacent to the river and not on natural levees. These low, intermediate, and high terrace locations are within 70 feet of the river bank. Most of these locations are present on terraces found adjacent to the natural levees or are adjacent to the river where natural levees do not exist. The maximum TEQ concentrations are typically found in the surface and near surface horizons.

<u>*Terraces Away from River*</u>

Five sampling locations with horizons exhibiting concentrations >15,000 ppt TEQ are found on terraces away from the river. Three locations are found in Reach K, one in Reach M, and one in Reach N. The locations in Reach K, RK-201+00-NE425, RK-203+50-NE 420, and RK-206+00-NE170, are located 170 ft to 425 ft from the river bank on a low terrace that receives deposition from the river after an adjacent wetland is inundated from flood water. The surface water velocities in the inundated wetland are typically diminished as compared to the channel surface water velocities. Therefore, sedimentation and any sediment bound contamination likely occurs in the low terrace adjacent to the wetland. Elevated TEQ concentrations typically occur at these locations within the upper 1.3 feet from the surface. See Attachment N for TEQ concentration profiles for transect RK-201+00. The maximum concentration of 30,000 ppt TEQ is found at RK-206+00-NE170 (0.0-0.6 ft). A summary of the soil profiles and analytical results is presented in Attachment R.

The Reach M location, RM-268+00-NE190, with a maximum concentration of 22,000 ppt TEQ at a depth of 1.1-2.2 ft bgs, is also on a low terrace adjacent to the wetland. See Attachment N for TEQ concentration profiles for transect RM-268+00

The Reach N location, RN-310+00-NE150, is located 150 ft from the river bank in an area where the floodway widens, following an upland scarp constriction, and is influenced by backwater during flooding within the upstream perennial tributary in Reach N that discharges from the northeast bank.

Sixteen terrace locations with concentrations >5,000 ppt TEQ are located away from the river on the low and intermediate terraces that border the wetlands. Large wetland complexes are present on both sides of the river but are commonly associated with inside meander bends. The deposits >5,000 ppt TEQ on the terraces adjacent to the wetland are likely due to sedimentation from diminished surface water velocities as the flood streamlines encounter wetlands that have already filled with water prior to the river flooding

Two of the sixteen sample locations that have high TEQ concentrations on the intermediate and high terraces, are located upstream from a perennial tributary. Flooding of the tributary channel by runoff from the uplands occurs prior to the river flooding, therefore ponding within the tributary diminishes river streamline velocities on the terrace surfaces. The TEQ concentrations >5,000 ppt TEQ on the terraces are likely due to sedimentation from the diminished surface water velocities in the vicinity of these tributaries.

Eighty locations have concentrations >1,000 ppt TEQ but <5,000 ppt TEQ. Seventeen of the eighty locations are located in the wetlands. The remaining >1,000 ppt TEQ are in locations within 600 feet of the river bank. The TEQ maximum concentrations are in surface or near surface soil horizons.

*Tributary Samples*

A series of small tributaries feed into the Tittabawassee River in reaches I through O. Ten locations were sampled along these tributaries. The highest concentrations are at RO-322+00-T-SW205 (0.0-0.8 ft) with a concentration of 1,100 ppt TEQ and at RM-280+00-T-NE80 (0.3-1.4 ft), also with a concentration of 1,100 ppt TEQ. A summary of the soil profiles and analytical results is presented in Attachment R.

*Secondary PCOI*

Six samples from the natural river setting area were analyzed for Appendix IX constituents – one in-channel location and five overbank samples. The six samples contained a limited set of VOCs that were present at concentrations below 0.7 mg/kg. The detected compounds are benzene, chloroform, tetrachloroethene, toluene, and xylenes. A summary of the Appendix IX analytical results is presented in Attachment T.

All of the samples contained some PNAs, and naturally occurring metals. The concentrations of the naturally occurring metals detected in these five samples are within the concentration range typically found in Michigan soils (MDEQ, 2005; Page 3, Table 1; column {c}).

Three of the six samples contained detectable concentrations of 4-4'-DDD, with a maximum detected concentration of 0.014 mg/kg at RO-325+50-NE45 (0.0-0.3 ft). Two of these samples also contain 4-4'-DDE and/or 4-4'-DDT.

Chlorinated semi-volatile organic compounds were present in some of the samples at low concentrations. Five of six samples contained hexachlorobutadiene (maximum of 0.073 mg/kg) and hexachlorobenzene (maximum of 0.13 mg/kg). Hexachloroethane was detected in four of the six samples (maximum of 0.025 mg/kg). Chlorobenzene was detected in two of six samples (maximum of 0.03 mg/kg) and 1,3-dichlorobenzene was detected in one of six samples (at 0.0081 mg/kg). Trichlorinated or tetrachlorinated phenols were detected in three of the six samples all below 0.05 mg/kg.

### 5.5.4 Statistical Calibration and Verification of *GeoMorph*® Sample Design

Statistical procedures document that the *GeoMorph*® sampling design generated a dataset where a significant portion of the variation can be explained by the geomorphic features mapped in the field. In addition, the *GeoMorph*® sampling design generated a dataset that focused more samples in areas where the highest concentration of furans and dioxins were identified than a random sampling design. The following section reports on a statistical analysis of furan and dioxin data collected in Reaches L and N/O. The objective of the statistical analysis was to evaluate the biased *GeoMorph*® sampling design against more traditional sampling designs, including a random-on-grid and a fixed interval approach. Statistical methods specified in the SAP (ATS, 2006b) were used. Results from this analysis were used to evaluate the efficiency of biased sampling designs in fluvial settings, where levels of furan and dioxin contamination are closely associated with geomorphic features. Details of the evaluation are provided in Attachment O figures depicting the fixed interval transect and random-on-grid sampling locations. Attachment P provides details of the statistical evaluation.

Data used in the analysis included samples from: 1) *GeoMorph*® features from Reach L and Reach N/O; 2) fixed interval transect data from Reach L; and 3) random-on-grid data from Reach N/O. A toxicity equivalency (TEQ) value was assigned to each data point, based on furan and dioxin concentrations reported for that sample. To enhance comparability between the three datasets, only surface concentrations were used. Where sample duplicates occurred, the maximum detected concentration was used to represent the concentration at that location.

#### *5.5.4.1 Screening for Outliers in Geomorphic Features*

All of the TEQ data were lognormally transformed, and the validity of the lognormal assumption was evaluated using probability plots and the Shapiro-Francia Goodness of Fit test. The lognormality assumption was accepted for datasets defined by 11 of 13 *GeoMorph*® floodplain features and 2 of 4 fixed-interval transects, as well as for the full random-on-grid dataset. The lognormal (ln) transformation was deemed appropriate on the basis of the overall weight of these graphical comparisons and test results, facilitating a fair statistical comparison of the three sampling approaches.

TEQ concentrations from each geomorphic feature within Reach L and Reach N/O were graphically screened for potential outliers by using "box and whisker" plots of each population. For each geomorphic feature, as well as for the random-on-grid dataset and each fixed interval transect, quartiles of the distribution of ln(TEQ) were identified. Potential outliers were defined as values outside the following bounds, where the largest and smallest members of each dataset within these bounds are shown as "whiskers" in Figures A and B in Attachment P:

- 25th quartile – 1.5* interquartile range ; and
- 75th quartile + 1.5* interquartile range.

Based on these criteria there were no outliers in the *GeoMorph*®, random-on-grid, or fixed transect datasets, and none of the data were excluded.

#### *5.5.4.2 Evaluate* **GeoMorph**® *Stratification*

Analysis of Variance (ANOVA) was used to test the null hypothesis of "no effect" of the *GeoMorph*® characterization of samples. ANOVA analyzes the variation in a variable of interest (in this case TEQ concentrations) and assigns portions of the variation to each member of a set of explanatory variables (in this case *GeoMorph*® features), leaving a residual that is associated with a random or unexplained component. The hypothesis of no effect is tested by constructing an F statistic from the explained and unexplained portions of variation in concentration.

As provided in Tables A and B below, ANOVA results show that for both Reach N/O and Reach L, the null hypothesis of "no-effect" is rejected at the $p = 0.0001$ confidence level. This means that the *GeoMorph*® features help to explain the variability we see in mean ln(TEQ) concentrations, with a high level of confidence.

Tables 1 and 2 also estimate the mean ln(TEQ) values associated with each *GeoMorph*® feature and upper and lower 95% confidence limits for those estimated means. Tables 1 and 2 show that the mean ln(TEQ)s associated with *GeoMorph*® features tend to be divided into two groups. In Reach N/O, the levees, low and intermediate terraces, and wetlands tend to have higher floodplain concentrations, whereas upland and high terrace areas have lower concentrations. Results are similar for Reach L, except that the mean concentration in high terrace areas are greater than all geomorphic features, except the natural levee.

**Table A: Means for ANOVA for Reach N/O Floodway *GeoMorph*® Samples**

| Feature | Number | Mean | Geomean (ppt TEQ) | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|---|
| high terrace | 24 | 5.37681 | 216.331 | 0.32788 | 4.7290 | 6.0247 |
| historic natural levee | 7 | 7.23732 | 1390.362 | 0.60711 | 6.0377 | 8.4369 |
| intermediate terrace | 20 | 6.82433 | 919.959 | 0.35917 | 6.1146 | 7.5340 |
| low terrace | 41 | 6.60682 | 740.125 | 0.25086 | 6.1111 | 7.1025 |
| natural levee | 16 | 7.10852 | 1222.337 | 0.40157 | 6.3151 | 7.9020 |
| upland | 8 | 4.94528 | 140.51 | 0.56790 | 3.8232 | 6.0674 |
| wetland | 10 | 6.60454 | 738.440 | 0.50795 | 5.6009 | 7.6082 |

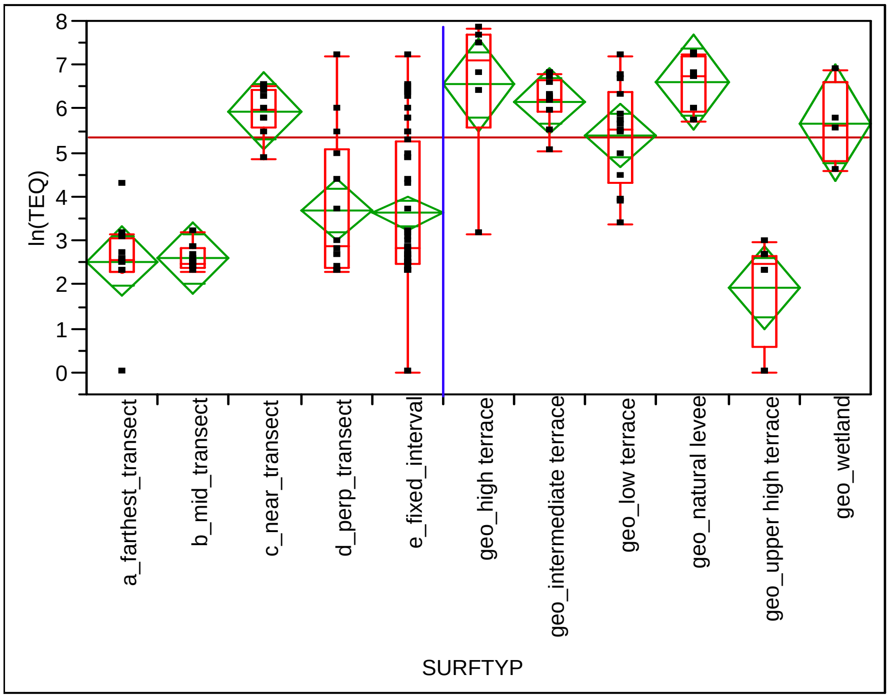
**Table B: Means for ANOVA for Reach L Floodway *GeoMorph*® Samples**

| Feature | Number | Mean | Geomean (ppt TEQ) | Std Error | Lower 95% | Upper 95% |
|---|---|---|---|---|---|---|
| high terrace | 6 | 6.53929 | 691.795 | 0.50726 | 5.5250 | 7.5536 |
| intermediate terrace | 13 | 6.17412 | 480.1602 | 0.34462 | 5.4850 | 6.8632 |
| low terrace | 14 | 5.39051 | 219.315 | 0.33208 | 4.7265 | 6.0546 |
| natural levee | 6 | 6.59980 | 734.948 | 0.50726 | 5.5855 | 7.6141 |
| upper high terrace | 8 | 1.93335 | 6.9126 | 0.43930 | 1.0549 | 2.8118 |
| wetland | 4 | 5.67748 | 292.2121 | 0.62127 | 4.4352 | 6.9198 |

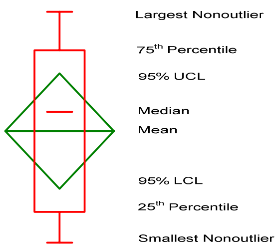
#### *5.5.4.3 Comparison to Random-on-Grid Sampling Design Method*

The statistical analysis documents that the *GeoMorph*® sampling design does a superior job over the random-on-grid sample design in at least two areas: First, the *GeoMorph*® sampling design segregates the variation of TEQ into meaningful geomorphic features and second, the *GeoMorph*® sampling design focuses the sample locations in areas with higher dioxin and furan concentrations. The mean ln(TEQ) value was 6.4 (geomean = 616 ppt) for Reach N/O *GeoMorph*® samples. The mean value was much lower (4.7, geomean = 106 ppt) for the Reach N/O random-on-grid sampling design. The difference reflects *GeoMorph*®'s intentional bias toward identifying and oversampling areas of higher concentration. As mentioned above, the *GeoMorph*® results are grouped by geomorphologic features into datasets with higher and lower concentrations. In contrast, the random-on-grid sampling method produced an overall mean that is intermediate in magnitude, as seen in Figure A below. This reflects the fact that the random-on-grid approach combines data from multiple geomorphologic regimes.

Figure A: Comparison of means from *GeoMorph*® features and random-on-grid sampling methods for Reach N/O.




**Key:**

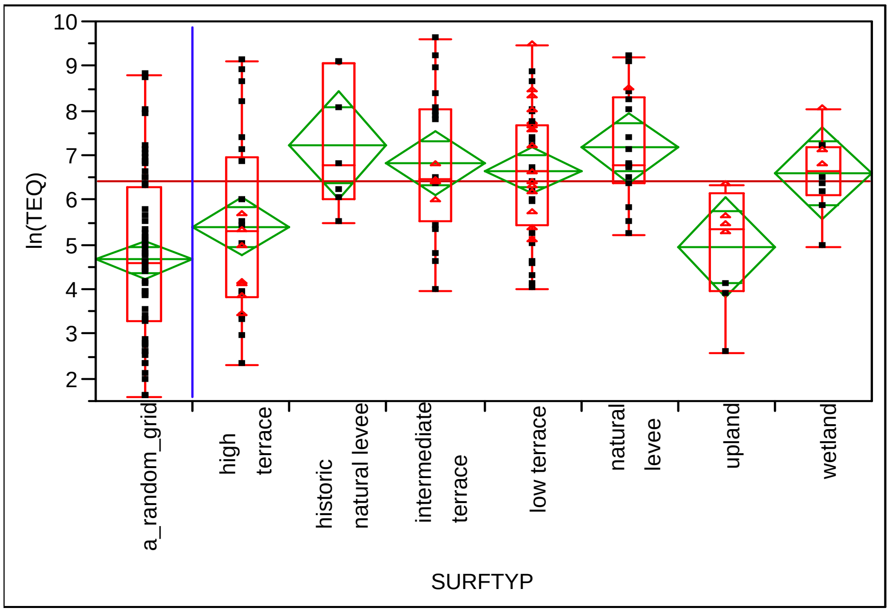



### *5.5.4.4 Comparison to Fixed Interval Transect Sampling Design Method*

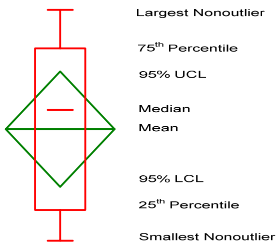
The statistical analysis documents that the *GeoMorph*® sampling design does a superior job over the fixed interval transect sample design in at least two areas: First, the *GeoMorph*® sampling design segregates the variation of TEQ into meaningful geomorphic features and second, the *GeoMorph*® sampling design focuses the sample locations in areas with higher dioxin and furan concentrations. The mean ln(TEQ) value was 5.3 (geomean = 210 ppt) for Reach L *GeoMorph*® samples. The mean value was much lower (3.6, geomean = 37 ppt) for Reach L fixed interval sampling design. As mentioned above, the *GeoMorph*® results tend to be grouped by features into an above-average and a below-average set. In contrast, to the *GeoMorph*® approach, which distinguished features with above- and below-average concentrations, the fixed transect approach produced an overall mean that is intermediate in magnitude, as seen in Figure B below. This reflects the fact that computing a mean using either of the traditional sampling approaches combines data from multiple geomorphologic regimes. The data distributions for the three transects, each at a specific distance from the river, and oriented parallel to the river show a decrease in mean concentrations with increasing distance from the river. The *GeoMorph*® approach provides a more detailed explanation for trends in the data, based on the geomorphologic features shown in Table B and Figure B.

On the basis of the demonstrated ability of *GeoMorph*® sampling to identify and focus on areas of higher concentration, it is concluded that geomorphologic information can make sampling strategies more efficient, reducing the number of samples needed to characterize the spatial distribution of contamination and targeting samples in areas with higher concentrations.

Figure B: Comparison of means from *GeoMorph*® features and fixed interval transects from Reach L.




**Key:**




### 5.5.5 Surface Weighted Average Concentration Analysis

The geomorphic-based surface weighted average concentration (SWAC) analysis will be provided in a future Technical Memorandum after methodology has been agreed upon with MDEQ.

# 6. CONCLUSIONS AND SUPPLEMENTAL SITE CHARACTERIZATION WORK

## 6.1 CONCLUSIONS

1. The geomorphology and hydrology of the Upper Tittabawassee River have been established through geomorphic mapping and hydrodynamic modeling. This information has been used to update the Conceptual Site Model for assessing contaminant distribution and transport.

2. Numerous anthropogenic influences exist along the Tittabawassee River, including dams, bridges, bank armoring, man-made tributaries and outfall structures. These influences complicate the hydrology and geomorphology of the river, both within the UTR study area as well as downstream.

3. A master database of potential constituents of interest has been developed for the Tittabawassee River and Upper Saginaw River site investigations. This database includes references to more than 1,000 chemical and elemental substances, and has been cross-referenced with CAS numbers, physical and chemical properties, and production history at the Midland site if applicable.

4. Seventeen chlorinated dibenzofurans and dibenzodioxins used to calculate TEQ are the primary constituents of interest (COI) for the UTR site characterization. Six of these compounds, including five characteristic furans and, to a lesser degree, one dioxin, are consistently present in contaminant residues. As a result, they are useful as site indicators for sediment and soil contamination, where it occurs and where it does not. The five furans are attributed to residues formed through direct chlorination of coal tar binders in graphitic electrodes used in historic brine electrolysis production. The single dioxin is attributed to residuals of chlorophenol production.

5. USEPA Appendix IX was used as the default target analyte list for secondary COI in the 2006 *GeoMorph*® site characterization. A number of secondary COI were found to co-occur in deposits containing elevated furans and dioxins. These secondary COI included polynuclear aromatic hydrocarbons (PNAs), phthalates, chlorinated hydrocarbons, chlorinated phenols, and certain metals including arsenic, chromium, copper, lead and zinc.

6. Bank and overbank areas of the UTR have been sufficiently characterized to establish that the majority of contamination occurs in deposits buried in levees which have accreted as bank materials along much of the natural, riverine sections of the river, including Reaches L through O. Some additional contamination occurs as flood-borne deposits in surficial soils on intermediate

terraces and upper terraces adjacent to these levees or other sections of river bank. As predicted by the Conceptual Site Model, elevated concentrations are found in certain geomorphological features that occur in proximity to the river within specific deposition settings.

7. Preliminary in-channel characterization indicates the bulk of the in-channel soft sediment deposits typically contains furans and dioxins at less than 1,000 ppt TEQ. However, this characterization also reveals the presence of isolated and buried deposits containing furans and dioxins at elevated concentrations necessitating detailed mapping of the UTR in-channel sediments. Based on the contaminant fingerprint and other factors, these materials appear to have been deposited 75 or more years ago.

8. The fate and transport-based *GeoMorph*® site characterization process has been validated against classic investigation methods (fixed-transect and random-on-grid sampling schemes) using standard statistical tools.

## 6.2 SUPPLEMENTAL UTR SITE CHARACTERIZATION WORK

### 6.2.1 Detailed Survey of In-Channel Sediments

Preliminary in-channel characterization indicates the bulk of the in-channel soft sediment deposits in the UTR typically contain furans and dioxins at less than 1,000 ppt TEQ. They are also relatively clean with respect to secondary COI substances, as indicated by Appendix IX analysis. However, this characterization also reveals the presence of isolated and buried deposits containing furans and dioxins at elevated concentrations. Based on the contaminant fingerprint and other factors, these materials appear to have been deposited 75 or more years ago.

The contaminated deposits are, in all cases observed to date, buried under a layer of well sorted medium sand. This sand serves as an armoring layer preventing the re-suspension and mobilization of this material under the current river conditions. However, detailed mapping of the soft sediments in the UTR will be needed to complete the site characterization. The scope of work for this mapping is being developed at this time, and involves spatially-continuous survey using non-intrusive, geophysical instruments (e.g. multi-beam side-scan sonar and "sub-bottom profiling"). Core samples will be collected and analyzed at specific locations to calibrate and validate the geophysical survey results. This work for the UTR is scheduled to be completed in spring 2007, based on when the river can safely be accessed.

### 6.2.2 Analysis of Secondary COI

The USEPA Appendix IX target analyte list was used as the default list of secondary COI for UTR site characterization work in 2006, until site-specific COIs and TALs could be developed for the Tittabawassee River, Upper Saginaw River and Midland Soils projects. A comprehensive PCOI evaluation was undertaken in the summer of 2006, and these COI and TAL were developed in a collaborative effort with MDEQ and USEPA. The evaluation process and results were documented in a technical memorandum entitled “PCOI/COI/TAL Evaluation – Target Analyte List Development” (ATS, December 1, 2006).

The PCOI/COI/TAL tech memo identified a series of USEPA methods that would be used to analyze primary and secondary COI including a broad range of chemical and elemental substances, and falling into four analyte classes: standard target analytes, extended target analytes, site-specific TICs, and other TICs. The UTR SAP (ATS, 2006b) and QAPP (ATS, 2006c) specify that samples from selected locations will be analyzed for these site-specific COI. The list of the specific samples for this extensive analysis will be developed collaboratively with MDEQ, and these analyses will be conducted in the first and second quarter of 2007, such that the results can be factored into the development of the Middle Tittabawassee River Sampling and Analysis Plan.

### 6.2.3 SWAC Analysis

The surface weighted average concentration analysis will be provided in a future Technical Memorandum after methodology has been agreed upon with MDEQ.

## 6.3 PILOT CORRECTIVE ACTION PLAN

Based on early findings from the UTR site characterization elevated concentrations of chlorinated furans and dioxins in levees and isolated in-channel deposits have been identified within certain reaches of the UTR study area. Pursuant to a request by MDEQ, a memorandum was submitted on December 18, 2006, outlining the objectives, approach and schedule for development of focused Pilot Corrective Action Plans (PCAP) to address these areas.

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# 8. GLOSSARY

| | |
|---|---|
| **Accretion** | The gradual addition of new land to old by the deposition of sediment carried by the water. |
| **Aquifer** | A subsurface strata or zone that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs. |
| **Bedload** | The part of a river's load that is moved on or immediately above the stream bed, such as the larger or heavier particles (boulders, pebbles, gravel) rolled along the bottom; the part of the load that is not continuously in suspension or solution. |
| **Constituents of Interest (COI)** | The lists of COI for this project are derived from the PCOI, and reflect those substances that are likely to have been released to the environment during the period of interest for the study. Because of the large number of PCOI, the COI lists have been organized by chemical class to facilitate evaluation of physical/chemical properties and selection of analytical methods. COI may or may not have suitable analytical methods, and therefore may or may not be included on the Target Analyte List.(TAL) |
| **Cut bank** | The steep or overhanging slope on the outside of a meander curve. It is produced by lateral erosion of the river. |
| **Flashy** | River flow regime characterized by a rapid rate of change. |
| **Floodplain** | That portion of a river valley, adjacent to the channel, which is built of sediments deposited during the present regimen of the river and is covered with water when the river overflows its banks at flood stages. The estimated 8-year and 100-year Floodplains represent the extent of the floodplain inundated during floods with recurrence intervals of 8 years and 100 years, respectively. |
| **Fluvial** | Of or pertaining to rivers. |
| **Geochronology** | Study of time in relationship to the history of the earth. |
| **Geomorphic feature** | An identifiable landform such as a levee or a terrace. |
| **Geomorphology** | The science that treats the general configuration of the earth's surface; specifically, the study of the classification, description, nature, origin, and development of landforms and their relationships to underlying structures and the history of geologic changes as recorded by these surface features. |
| **Hazardous substance** | Any substance that the Michigan Department of Environmental Quality demonstrates, on a case-by-case basis, poses an unacceptable risk to public health, safety, or welfare, or the environment, considering the state of the material, dose-response, toxicity, or adverse impact on natural resources**.** |
| **Hydrophobic** | Lacking strong affinity for water. |
| **Midland Plant** | The Dow Chemical Company Midland Plant in Midland, Michigan |
| **Morphology** | The observation of the form of lands. |
| **Natural levee** | A ridge or embankment of sand and silt, built by a river on its floodplain along both banks of its channel, especially in times of flood when water overflowing the normal banks is forced to deposit the coarsest part of its load. |
| **Overbank deposit** | Silt and clay deposited from suspension on floodplain by floodwaters that cannot |

| | |
|---|---|
| | be contained within the river channel. |
| **Pedogenic** | The natural process of soil formation and development, including erosion and leaching. |
| **Photolysis** | Chemical decomposition induced by light or other radiant energy. |
| **Point bar** | One or a series of low, crescent-shaped ridges of sand and gravel developed on the inside of a growing meander of a river or stream by the slow addition of individual accretions accompanying migration of the channel toward the outer bank. |
| **Potential Constituent of Interest (PCOI)** | The PCOI for this project consist of those substances on the master list of chemicals submitted by The Dow Chemical Company to MDEQ on June 1, 2006, plus those substances found in biomonitoring of the Tittabawassee and Saginaw Rivers. It is recognized that not all substances on the Dow master list will have significance as environmental contaminants, nor that the substances found in biomonitoring of the two rivers are necessarily related to Dow operations in Midland. |
| **Scoping Study** | *Tittabawassee River Floodplain Scoping Study*: CH2M Hill 2005a |
| **Sediment** | Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, or ice, and has come to rest on the earth's surface either above or below sea level. |
| **Shear stress** | Force produced at the sediment bed as a result of friction between the flowing water and the solid bottom. |
| **Soil** | A natural body consisting of layers or horizons of mineral and/or organic constituents of variable thicknesses, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics; at least some of these properties are pedogenic. |
| **Splay** | Deposit typically composed of sandy or silty material found in floodplain areas where floodwaters breach levees or banks formed by reduction in velocity as floodwaters spread out. |
| **Streamline** | Predicted flow path of a particle under different flow conditions. |
| **Study Area** | The Study Area for this RIWP is the river channels and 100 year floodplains for the 22 miles of the Tittabawassee River between the Chippewa and Saginaw Rivers, and the upper 6 miles of the Saginaw River from its confluence with the Tittabawassee River down to the 6$^{th}$ Street turning basin. |
| **Target Analyte (TA)** | An analyte include on the Target Analyte Lists (see below). |
| **Target Analyte Lists (TALs)** | The Target Analyte Lists are compilations of those substances (elements or chemicals) that will be analyzed in samples from the Study Area. TALs are method specific, and are integral components of the project QAPP and method SOPs. Because of the large number of COI and project samples, not all samples will be analyzed for all TAs. |
| **Thalweg** | The line drawn to join the lowest points along the entire length of a river bed or valley. |

# 9. ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| **°C** | Degrees Celsius |
| **ANOVA** | Analysis of Variance |
| **ATS** | Ann Arbor Technical Services, Inc. |
| **bgs** | Below ground surface |
| **bss** | Below sediment surface |
| **CDD** | Chlorinated dibenzodioxins |
| **CDF** | Chlorinated dibenzofurans |
| **cfs** | Cubic feet per second |
| **COC** | Chain of Custody |
| **COI** | Constituent of Interest: The lists of COI for this project are derived from the PCOI, and reflect those substances that are likely to have been released to the environment during the period of interest for the study. Because of the large number of PCOI, the COI lists have been organized by chemical class to facilitate evaluation of physical/chemical properties and selection of analytical methods. COI may or may not have suitable analytical methods, and therefore may or may not be included on the Target Analyte List.(TAL) |
| **CoPC** | Contaminant of Potential Concern**:** A Target Analyte List (TAL) chemical present in soil or sediment at a concentration that is greater than background concentrations and relevant risk-based screening values for human health derived either by MDEQ or EPA. |
| **CSM** | Conceptual Site Model |
| **CWS** | Clear Water Sewer |
| **DDD** | Dichloro-diphenyl-dichloroethane |
| **DDT** | 4,4'-(2,2,2-Trichloroethane-1,1-diyl)bis(chlorobenzene) |
| **DGPS** | Digital Global Positioning System |
| **dioxin** | Polychlorinated dibenzo-p-dioxin |
| **Dow** | The Dow Chemical Company |
| **EDD** | Electronic Data Deliverable |
| **EF** | Erosion Factor |
| **EFDC** | Environmental Fluid Dynamics Code |
| **EPA** | Environmental Protection Agency |
| **ERA** | Ecological Risk Assessment |
| **ETEQ** | Estimated Toxic Equivalent Quotient |
| **FEMA** | Federal Emergency Management Agency |
| **FTP** | File Transfer Protocol |
| **furan** | Polychlorinated dibenzo-p-furan |
| **GIS** | Geographic Information System |
| **GPS** | Global Positioning System |
| **HHRA** | Human Health Risk Assessment |

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|---|---|
| **LCS** | Laboratory Control Sample |
| **License** | Hazardous waste management facility operating license |
| **LiDAR** | Light Detection and Ranging |
| **ln** | Natural Logarithm |
| **LTI** | Limno-Tech, Inc. |
| **MCV** | Midland Cogeneration Venture |
| **MDEQ** | Michigan Department of Environmental Quality |
| **MDNR** | Michigan Department of Natural Resources |
| **mg/L** | Milligrams per liter |
| **MNFI** | Michigan natural features inventory |
| **msl** | Mean sea level |
| **MSU** | Michigan State University |
| **NOD** | Notice of Deficiency |
| **NPDES** | Nation Pollutant Discharge Elimination System |
| **NRCS** | Natural Resources conservation Service |
| **NRT** | Near-Real-Time |
| **PAH** | Polynuclear Aromatic Hydrocarbons |
| **PCB** | Polychlorinated Biphenyls |
| **PCOI** | Potential Constituent of Interest: The PCOI for this project consist of those substances on the master list of chemicals submitted by The Dow Chemical Company to MDEQ on June 1, 2006, plus those substances found in biomonitoring of the Tittabawassee and Saginaw Rivers. It is recognized that not all substances on the Dow master list will have significance as environmental contaminants, nor that the substances found in biomonitoring of the two rivers are necessarily related to Dow operations in Midland. |
| **PNA** | Polynuclear Aromatic Hydrocarbons |
| **ppt** | Parts per trillion or picograms per gram |
| **QA/QC** | Quality Assurance/Quality Control |
| **QAPP** | Quality Assurance Project Plan |
| **R 299.5528** | Michigan Administrative Code, Rule 299.5528 |
| **RGIS** | Revetment Groundwater Interception System |
| **RI** | Remedial Investigation |
| **RIWP** | Remedial Investigation Work Plan |
| **S3TM** | *Sampling Strategies and Statistics Training Materials for Part 201 Cleanup Criteria*: MDEQ 2003b |
| **SAP** | Sampling and Analysis Plan |
| **SCR** | Site Characterization Report |
| **SCS** | Soil Classification System |
| **SOP** | Standard Operating Procedure |
| **SOW** | Scope of Work |
| **SRF** | Sample Receipt Form |
| **SVOC** | Semivolatile Organic Compound |

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|---|---|
| **SWAC** | Surface Weighted Average Concentration |
| **TAL** | Target Analyte List: The Target Analyte Lists are compilations of those substances (elements or chemicals) that will be analyzed in samples from the Study Area. TALs are method specific, and are integral components of the project QAPP and method SOPs. Because of the large number of COI and project samples, not all samples will be analyzed for all TAs. |
| **TCDD** | 2,3,7,8-Tetrachloro-dibenzo-p-dioxin |
| **TEF** | Toxic Equivalency Factor |
| **TIC** | Tentatively Identified Compounds |
| **TEQ** | Toxic Equivalent Quotient |
| **TOC** | Total Organic Carbon |
| **TR** | Tittabawassee River |
| **USCS** | Unified Soil Classification System |
| **USDA-SCS** | United States Department of Agriculture - Soil Classification System |
| **USEPA** | United States Environmental Protection Agency |
| **USGS** | United States Geological Survey |
| **USR** | Upper Saginaw River |
| **UTR** | Upper Tittabawassee River |
| **VOC** | Volatile organic compound |
| **WHO** | World Health Organization |
| **WSS** | Water Settling Sewer (?) |
| **WWTP** | Wastewater Treatment Plant |