Design & Consultancy for natural and built assets

Revitalizing Auto Communities Environmental Response (RACER) Trust

APPROVAL REQUEST: LOWER 1,4-DIOXANE BIOREACTOR PILOT TEST

Plants 2 and 3, Industrial Land
Lansing, Michigan

May 20, 2016

,

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Plants 2 and 3

Lansing, Michigan

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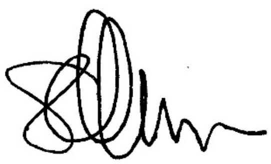
Principal Engineer



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ACRONYMS AND ABBREVIATIONS

AOP	advanced oxidation process
bgs	below ground surface
CSIA	compound-specific isotope anlaysis
DGR	directed groundwater recirculation
DO	dissolved oxygen
gpm	gallons per minute
ISCO	in-situ chemical oxidation
LEL	lower explosive limit
µg/L	micrograms per liter
MBBR	moving bed bioreactor
MDEQ	Michigan Department of Environmental Quality
O&M	operation and maintenance
ORP	oxidation-reduction potential
PFM	passive flux meter
PVC	polyvinyl chloride
qPCR	quantitative polymerase chain reaction
RACER	Revitalizing Auto Communities Environmental Repsonse
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation

1. INTRODUCTION

Arcadis has been retained by the Revitalizing Auto Communities Environmental Response (RACER) Trust to perform groundwater and soil remediation at the Lansing Plants 2, 3, and 6 (the Site) located in Lansing, Michigan (see Figures 1 and 2). The purpose of this work plan is to provide information required to obtain Michigan Department of Environmental Quality (MDEQ) approval to perform a moving bed bioreactor (MBBR) field pilot test at the Site.

The objective of the field pilot test is to evaluate the effectiveness of a directed groundwater recirculation (DGR) system using an MBBR to treat 1,4-dioxane present in the weathered bedrock at Plants 2 and 3 (lower 1,4-dioxane plume). The results of the pilot test will be used to verify the effectiveness of the MBBR system compared to traditional ex-situ treatment technologies such as an advanced oxidation process (AOP). If deemed the most technically appropriate and cost-effective remedial alternative, the data collected during the field pilot test will be used as the basis for the full-scale design of a MBBR system. The pilot test will occur in the northwest portion of Plant 2 (Figure 2). Due to the daily volume of water necessary for culturing biomass for testing, a field pilot test is recommended over a bench test.

1.1 Lower 1,4-Dioxane Plume Overview

The lower 1,4-dioxane plume is present in the deep overburden and weathered bedrock at depths generally ranging from 70 to 90 feet below grade. The lower 1,4-dioxane plume, extending from the Plant 3 “coliseum” area to the south-central portion of Plant 2, has been delineated with numerous vertical aquifer profiling borings and monitoring wells.

At the 1,4-dioxane source area (south of the coliseum), the plume is present in the saturated deep overburden and weathered bedrock zones. South of the source area, the lower 1,4-dioxane plume coalesces and migrates primarily within the weathered bedrock zone. The transition from weathered bedrock to consolidated rock is gradational and, in the vicinity of the bioreactor pilot test, the weathered bedrock zone is estimated to be approximately 10 feet thick. The bedrock consists of the Grand River Formation to the north and Saginaw Formation to the south. The contact between these units is in the vicinity of the bioreactor field pilot test wells (Figure 2). The Grand River Formation is fine- to medium-grained sandstone that occupies erosional valleys within the Saginaw Formation (United States Geological Survey and National Park Service 2000). The Saginaw Formation consists of finer-grained sandstone with thin layers of shale that vary in thickness.

Groundwater elevation measurements collected from the monitoring wells installed along the lower 1,4-dioxane plume reflect a complex heterogeneous aquifer structure. Due to large vertical gradients observed at certain areas of the Site, the observed groundwater elevation varies depending on the specific depth of a well. Based on the evaluation presented in the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Phase 2 Supplemental Report (Arcadis 2014b), the analyses completed in March and April 2014 using passive flux meters (PFMs; EnviroFlux, Inc.), and the In-Situ Chemical Oxidation (ISCO) Tracer Study Report (Arcadis 2016 [Draft]), the groundwater flow along the lower 1,4-dioxane plume appears to be southerly, consistent with the plume morphology. The Passive Flux Meter and Transducer Study Memorandum (Arcadis 2015, as revised) presents a summary of the study and results.

Data from monitoring wells installed within the deep overburden and weathered bedrock in the area beneath the perched zone near the south wall of the coliseum indicate concentrations of 1,4-dioxane up to 1,400 micrograms per liter (µg/L) in groundwater.

1.2 Bioremediation Overview

Enhanced co-metabolic biodegradation has been successfully applied to remediate groundwater for decades, most commonly for chlorinated volatile organic compounds. More recently, research and field demonstrations have shown that enhanced co-metabolic biodegradation of 1,4-dioxane to be a viable mechanism for treating 1,4-dioxane in groundwater. This biological process is understood to involve propane oxidizing bacteria (propanotrophs) that fortuitously degrade 1,4-dioxane while growing on propane as a primary source of food and energy (Vainberg et al. 2006). Propane and oxygen are used to proliferate propanotrophs, but to optimize treatment, propane is limited such that 1,4-dioxane is consumed as a secondary carbon source. Oxygen is provided in excess to ensure sufficient electron acceptors. Enhanced co-metabolic degradation of 1,4-dioxane can be implemented ex situ or in situ.

Ex-situ co-metabolic biodegradation using a bioreactor is one of the technologies under consideration to treat 1,4-dioxane as part of a groundwater recirculation system. Groundwater recirculation is a reliable and proven technology for the removal and treatment of chemicals of concern in groundwater. Compared to groundwater extraction alone, recirculation increases pore flushing, thereby reducing remediation timeframes. Selection of the optimal ex-situ treatment process for a recirculation system depends on a number of variables including the type and concentration of contaminant present, effluent criteria, and flow rates. Bioreactors have been used for 1,4-dioxane treatment where propanotrophs are used to seed the bioreactor. A constant feed of 1,4-dioxane impacted groundwater (extracted from the plume) in combination with essential nutrients (nitrogen, phosphorous), oxygen, and propane are delivered to the bioreactor. Over time, the microbial community developed within the bioreactor acclimates and optimizes to treat site-specific groundwater impacts. Bioreactors for 1,4-dioxane have proven to be technically and cost-effective relative to other ex-situ treatment approaches, such as AOP systems.

Arcadis has therefore prepared this work plan to perform a bioreactor pilot test at the Site to determine whether it can be implemented effectively as a remedy for the lower 1,4-dioxane plume at the Site.

2. BIOREACTOR PILOT TEST

2.1 Test Objectives

The primary objective of the bioreactor pilot test is to determine whether DGR with ex-situ treatment using a bioreactor will be cost-effective for removing and treating 1,4-dioxane impacts in the weathered bedrock at Plants 2 and 3. Specific test objectives include determining:

- Achievable long-term flow rates for extraction and injection
- Optimal propane, oxygen, and nutrient feed rates for the MBBR
- The most effective bacterial culture for 1,4-dioxane degradation
- System robustness with respect to process upsets.

2.2 Pilot Test Setup and Equipment

The pilot test will be conducted in the northwestern portion of the fenced-in area of Plant 2 (Figure 2 presents a site plan). Groundwater will be pumped from an extraction well to a primary treatment building, where it will pass through an iron oxidation tank, primary clarifier, one of three bioreactors, and a secondary clarifier (Figure 3 is a simplified process flow diagram). Clean effluent water and excess flow from the iron oxidation tank will flow by gravity to the injection well. Precipitated iron and biosolids from the clarifiers will be pumped to a sludge storage tank. Due to potential for explosive conditions, the main treatment building will meet Class I Division II requirements and contain the bioreactors, propane, floor level switch, lower explosive limit (LEL) meter, ventilation fan, and heater. A separate, smaller, unclassified shed will contain the pumps, compressor, nutrients, and ventilation fan. Both buildings will be winterized.

The treatment system components will be shipped to the Site and assembled on site. The system will be staffed with local personnel as needed for operations, and the equipment will be enclosed in a security fence. Field activities will be conducted in accordance with the site-specific health and safety plan.

The following sections describe the pilot test system equipment.

2.2.1 Extraction Equipment

Groundwater will be pumped from existing extraction well PW-14-02, located approximately 20 feet southeast of the proposed treatment buildings (Figure 2). Extraction well PW-14-02 is an 80-foot-deep, 6-inch-diameter polyvinyl chloride (PVC) well with a 10-slot stainless steel screen from 75 to 80 feet below ground surface (bgs). Groundwater will be pumped at various flow rates, with an average expected flow rate range of 0.4 to 1.7 gallons per minute (gpm) based on the 2014 hydraulic study (Arcadis 2014a). Water will be pumped with a QED AP3 bottom-loading pneumatic bladder pump (or equivalent) through a flexible hose to the treatment building. An air compressor located in the second treatment building will provide compressed air.

2.2.2 Treatment Equipment

Three MBBRs will be utilized for the pilot study. MBBRs are an attached growth system consisting of a tank with submerged, neutral buoyant plastic media that offer a large surface area for abundant bacterial growth. Mixers in the tank ensure contact between the applied nutrients, gases, and the biomass growing on the media. Attached growth systems are best suited for this application over other types of bioreactors, such as traditional suspended growth systems. Traditional suspended growth systems use a free floating biomass that requires gravity settling in a clarifier and pumped return to the bioreactor for continued treatment. However, the low organic concentration of the groundwater (primarily consisting of 1,4-dioxane) would cause a low concentration, dispersed biomass. Dispersed biomass settles poorly and much of the biomass would be lost to the effluent, which would lead failure of the bioreactor.

Attached growth systems like MBBRs and fluidized bed reactors (FBRs) (another common attached growth technology using granulated activated carbon as the growth media) are more appropriate for this application. Attached growth systems do not require biomass recycle from a clarifier to maintain a healthy biomass. Instead, the biomass grows on the media and retained by screens or other means. The MBBRs require less energy for mixing than FBRs, as maintaining the FBR requires significant mixing energy compared to the slow speed propeller agitator required to mix an MBBR.

Each bioreactor will be designed for an initial 60-minute hydraulic residence time. High specific surface area media will be used to maximize binding sites for bacteria to grow. Approximately 50% of the bioreactor volume will be filled with media. Two different bacterial cultures and three different bioreactors will be used in parallel to test different hydraulic retention times and upset conditions. Operating the three bioreactors in parallel will maximize data collection while minimizing field time for the pilot test. Bioreactors #1 and #2 will be seeded with ENV425, a propane co-metabolizer of 1,4-dioxane. Bioreactor #3 will be seeded with CB1190, a direct 1,4-dioxane metabolizer.

Essential nutrients (in the form of diammonium phosphate) from a storage tank will be delivered to each bioreactor with a dosing pump. Oxygen (for all three bioreactors) and propane (for Bioreactors #1 and #2) will be added via pressurized storage containers. Guarded mixers that will not damage the MBBR media will mix the bioreactors.

Other components of the treatment system will include:

- An iron oxidation tank, which uses a blower to provide oxygen to the groundwater and oxidize and precipitate dissolved iron
- Flow meters and pressure gauges
- Aerated sludge storage tank to store solids from the oxidized iron clarifier and MBBR secondary clarifier.

2.2.3 Injection Equipment

Existing monitoring well TW-14-03, located approximately 15 feet north of the proposed treatment buildings, will be used as the injection well for the pilot test (Figure 2). Treated water from the bioreactor system effluent will be injected into this well. A small amount of overflow water from the oxidized iron clarifier tank may also be injected into this well, as the iron clarifier will be continuously overflowing. The purpose of the overflow is to ensure a constant supply of feed water for the reactors with a minimum of controls. Constantly overflowing the iron clarifier tank eliminates the need for level or flow controls on the feed wells; instead, they can operate at a constant speed. Monitoring well TW-14-03 is a 2-inch-diameter PVC well with a 10-slot stainless steel screen from 75 to 80 feet bgs. The injection rate will vary depending on the extraction rate. The maximum achievable injection rate is expected to be approximately 6.5 gpm based on injection tests performed on TW-14-03 and two nearby wells (Arcadis 2014a). Flow rates throughout the bioreactor system will be monitored to understand total extraction rate, flows through each bioreactor, and total injection rate.

The injection well will be fitted with a bleed valve open to the atmosphere that will remain open to ensure that the well is not pressurized during the injection. Pressurization of the well could fracture the formation and create preferential pathways for the treated water. The injection well will also be equipped with a level sensor designed to shut down the bioreactor system if the well becomes fouled (e.g., from metal scaling or excessive biological growth) and the water level in the injection well becomes too high. If this occurs, the well will be rehabilitated prior to re-starting the bioreactor.

2.2.4 Monitoring Equipment

Monitoring activities are described in Section 3. Monitoring equipment is summarized below.

- An electronic oil/water interface probe to measure groundwater levels
- Hand-held water quality meter to measure pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP)
- Hach test strips to measure ammonia and orthophosphate
- Flow meters to measure water, nutrient, and propane/oxygen flow rates
- Sample ports to collect water quality samples
- Pressure gauges
- LEL sensor to monitor explosive vapor concentrations in the treatment building
- Level sensor to monitor water level in the injection well
- Liquid presence detector to for bioreactor overflow protection.

2.3 Bioreactor Test Operation and Data Collection

The bioreactor pilot test will consist of the following four phases: acclimation, adjustment to design parameters, steady-state testing, and challenge (upset) testing.

2.3.1 Phase 1: Acclimation

During the acclimation phase, groundwater will be recirculated at a low 1,4-dioxane loading rate with propane and oxygen addition to allow the seeded propanotrophs to grow in Bioreactors #1 and #2. Groundwater will also be recirculated at a low 1,4-dioxane loading rate to Bioreactor #3 with only oxygen addition. The acclimation phase will continue until a sufficient biological community is established. Arcadis will collect water samples for laboratory analyses to establish baseline conditions (see Section 3 for the analytical program). The acclimation phase is expected to last approximately 4 weeks.

2.3.2 Phase 2: Adjustment to Design Parameters

Following acclimation, the 1,4-dioxane, oxygen, propane, and nutrient feed rates will be slowly increased to the pilot test design initial operating conditions. This phase is expected to last approximately 2 weeks.

2.3.3 Phase 3: Testing

The system will be operated at several design operating conditions (10- to 60-minute hydraulic residence time) for an extended duration for 1,4-dioxane removal. Regular laboratory testing will monitor treatment effectiveness, increase the statistical significance of trends observed, and determine when steady state is reached. If the process effectiveness declines, troubleshooting will determine the problem and make appropriate corrections. Arcadis will periodically increase loading rates to test several operating conditions, returning to steady-state conditions after each change. The testing phase is expected to last approximately 12 weeks.

2.3.4 Phase 4: Challenge (Upset) Testing

When sufficient data have been obtained for the design conditions, Arcadis will change loading rates to simulate upsets and evaluate process robustness. Possible upsets include increased 1,4-dioxane loading rates, decreasing propane, decreasing oxygen, and electrical shutdown or restart. Effluent water samples will be analyzed to determine how well the treatment process recovers during and after each adverse condition. This phase is expected to last approximately 5 weeks.

3. MONITORING, OPERATIONS, AND MAINTENANCE

3.1 Field Monitoring

An Arcadis field technician will monitor field parameters throughout the pilot testing operations phase to assess system operation and effectiveness. Parameters to be monitored include:

- System feed flow rate
- Propane, oxygen, and nutrient addition rates
- Water chemistry field parameters including pH, temperature, ORP, and DO concentrations of the feed and recycle streams
- Total suspended solids and media solids (approximate amount of biosolids attached to the media) within each bioreactor
- Ammonia and orthophosphate
- Water level readings from injection and extraction wells.

Table 1 presents the sampling frequencies for the field parameters for each phase of the pilot test.

3.2 Laboratory Analyses

Water samples for laboratory analysis will be collected at the system influent and effluent. Samples will be analyzed for the following parameters:

- Microbial quantitative polymerase chain reaction (qPCR; propane mono-oxygenase enzyme)
- Compound-specific isotope analysis (CSIA)
- 1,4-dioxane
- Nitrate as nitrogen
- Nitrite as nitrogen
- Total phosphorous
- Propane.

Table 1 presents the sampling frequencies for the analytical parameters for each phase of the pilot test.

3.3 Operations and Maintenance

Routine operations and maintenance (O&M) activities to be conducted during these phases include:

- Performing the required checklists of the key mechanical parameters
- Changing out the propane and oxygen cylinders as needed
- Filling the nutrient tanks as needed

- Calibrating the propane/oxygen and nutrient delivery systems weekly
- Calibrating the pH, DO, and LEL sensors weekly
- Attending to the motors, pumps, and valves to ensure continuous operation.

Residuals generated are expected to be minimal, will not be classified as hazardous, and will be disposed of off site as needed.

4. DATA EVALUATION AND REPORTING

The data collected during the bioreactor pilot test will be evaluated against the pilot test objectives to assess the following:

- Treatment effectiveness for reducing 1,4-dioxane concentrations to below the remedial objective
- Achievable long-term flow rates for extraction and injection
- Optimal propane, oxygen, and nutrient feed rates for the MBBR
- The most effective bacterial culture for 1,4-dioxane degradation
- System robustness with respect to process upsets.

Evaluation of these data will determine if the MBBR can meet the overall goal of treating groundwater extracted from the weathered bedrock beneath Plants 2 and 3 that contains dissolved-phased 1,4-dioxane. Following data evaluation, Arcadis will prepare a final report to document the test activities, data evaluation, and make a final recommendation for a full-scale treatment process.

5. CONTINGENCY PLAN

As discussed, treated groundwater will be injected in well TW-14-03. Samples will be collected from the bioreactor effluent streams for analysis of field parameters; ammonia; orthophosphate; and laboratory 1,4-dioxane, nitrate/nitrite, phosphorous, and propane. Although unlikely, if concentrations above background levels or applicable MDEQ criteria (whichever is higher) are observed in effluent water, an exposure pathway evaluation will be completed to assess the associated risk and determine the need for groundwater monitoring or adjustments to the treatment system.

There is the potential for fouling of the injection well screen due to iron precipitation, other metal oxide scaling, or biological growth. The injection well will be rehabilitated (cleaned and redeveloped) if significant fouling is observed.

6. SCHEDULE

Planning and coordination of this work will begin immediately after approval from MDEQ. Implementation of this work is estimated to begin in the summer of 2016. The total expected duration of the activities described in this work plan is approximately 36 weeks, inclusive of the final report, and is subject to change based on field conditions and test results.

7. REFERENCES

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TABLES

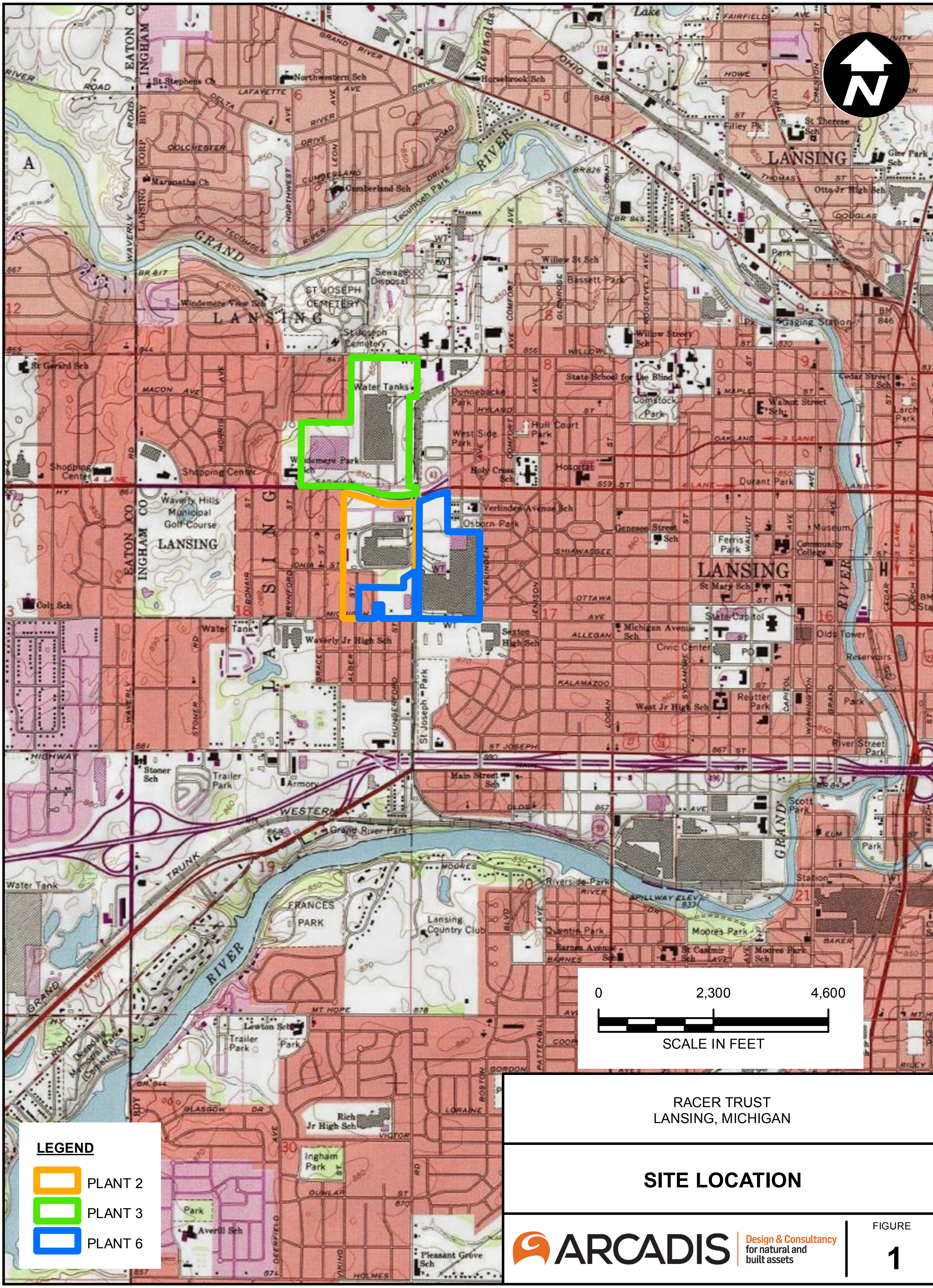
Table 1
Pilot Sampling Plan
RACER Trust Plants 2 and 3
Lansing, Michigan

Parameter	Number of Samples/Reactor				Method	Field Measurement or Lab Analysis
	1. Acclimation	2. Adjustment	3. Steady State	4. Upset		
Temperature	3/week	3/week	3/week	3/week	Multi-probe	Field Measurement
pH	3/week	3/week	3/week	3/week	Multi-probe	Field Measurement
ORP	3/week	3/week	3/week	3/week	Multi-probe	Field Measurement
DO	3/week	3/week	3/week	3/week	Multi-probe	Field Measurement
1,4-Dioxane	1/week	2/week	3/week	3/upset	8260B-SIM	Lab Analysis
Ammonia	1/week	1/week	1/week	1/week	Hach test	Lab Analysis
Nitrate	1/week	1/week	1/week	1/week	E300	Lab Analysis
Nitrite	1/week	1/week	1/week	1/week	E300	Lab Analysis
Propane	0	0	1/SSC	0	AM20GAX	Lab Analysis
Microbial PPO	0	0	8/SSC	0	DNA (qPCR)	Lab Analysis
CSIA	0	0	8/SSC	0	CSIA	Lab Analysis
Total Phosphorous	1/week	1/week	1/week	1/week	SM 4500-PE	Lab Analysis
Orthophosphate	1/week	1/week	1/week	1/week	Hach test	Field Measurement
Media Solids	1/week	1/week	2/week	1/week	Field Method	Field Measurement

Note:
1. Temperature/pH/DO/ORP to be measured via hand-held multi-probe

Acronyms:
DO = Dissolved oxygen
CSIA = Compound-specific isotope analysis
ORP = Oxidation-reduction potential
PPO = Propane mono-oxygenase
SSC = Steady-state condition/hydraulic residence time tested

FIGURES



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SITE LOCATION

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FIGURE 1

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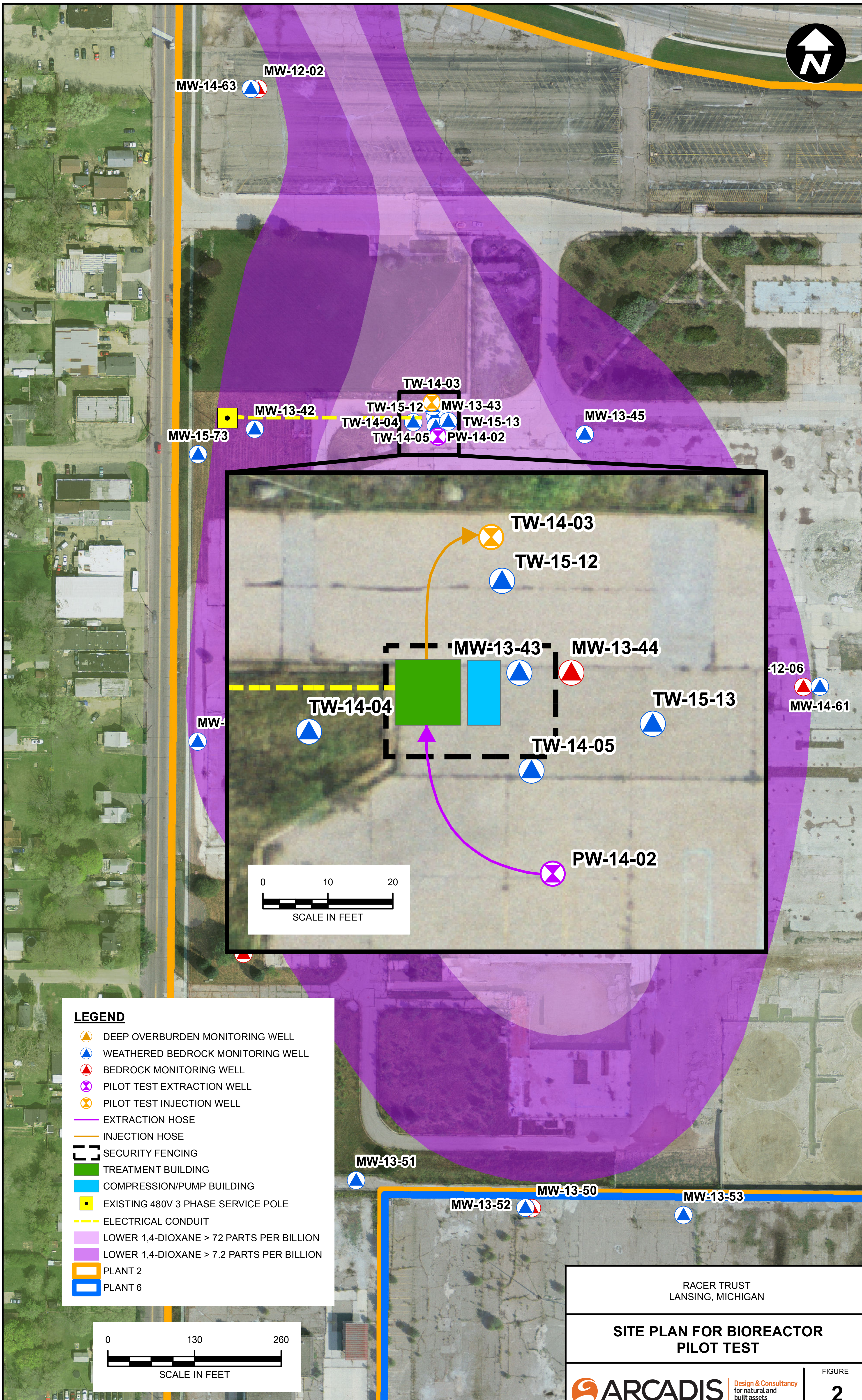

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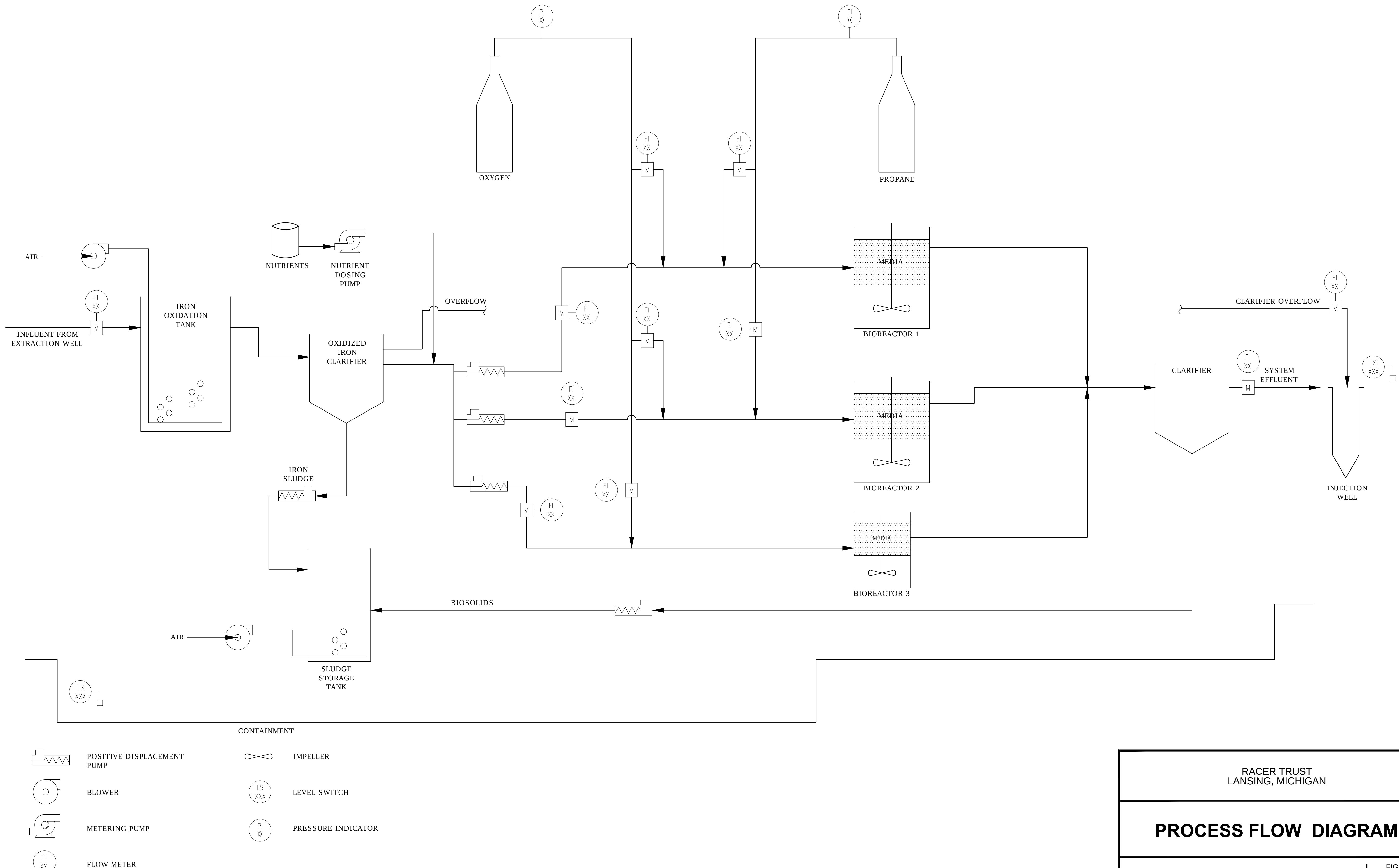

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PROCESS FLOW DIAGRAM

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FIGURE
3

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