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# Advisory

Date: June 21, 2011

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**Subject: Treatment Train Advisory**
**Torrance Groundwater Remedial System**
**Los Angeles, California**

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## 1. INTRODUCTION

This Treatment Train Advisory provides an update on the application and sequence of treatment technologies to be used for the Torrance Groundwater Remedial System ("TGRS") for the Dual Site Groundwater Operable Unit in Torrance, California (the "Site") and also provides a response to a CH2M Hill/USEPA memorandum addressing the same topics. Additionally, it provides a summary of the results of a study of macro porous polymer extraction ("MPPE") treatment technology that was pilot-tested as part of the development of the TGRS treatment train and an overall evaluation of treatment technologies considered for use for the TGRS. This advisory was prepared on behalf of Montrose Chemical Corporation of California ("Montrose") by Geosyntec Consultants ("Geosyntec").

More specifically, this Advisory presents the following information:

- Results of the recent pilot-scale test of the MPPE treatment technology, which was evaluated as a potential option for treating volatile organic compounds (VOCs) and

other organic contaminants present in groundwater at the Site. The pilot-scale test was conducted in accordance with the Revised Macro Porous Polymer Extraction Pilot-Scale Work Plan dated August 13, 2010 ("Advisory and Work Plan"). These results and the viability of the technology and vendor were evaluated according to several factors as part of this exercise.

- An additional review of the VOC treatment technologies that have been considered for use in the TGRS has been conducted.

- A plan for the TGRS treatment train as revised based on the findings of the re-evaluation of VOC treatment technologies is then presented. As described herein, the treatment train now includes APTwater, Inc.'s HiPOx™, air stripping with off-gas treatment through vapor-phase granular activated carbon ("VGAC"), and liquid-phase GAC ("LGAC").

This Advisory concludes the re-evaluation of VOC treatment technologies and presents a plan for the TGRS. The re-evaluation has built upon the information initially described in the technical memorandum submitted to USEPA on March 5, 2010,[1] the analysis that has been conducted in the interim, and the technical memorandum prepared by USEPA/CH2M HILL.[2] Tables, figures, and attachments follow the Advisory text.

## 2. MPPE PILOT-SCALE TEST AND TGRS APPLICATION SUMMARY

### 2.1 MPPE Pilot-Scale Test

As described in the August 13, 2010 Advisory and Work Plan, MPPE bench-scale tests concluded that MPPE is capable of removing each of the VOCs projected to be present in the TGRS influent groundwater and appeared to be a viable option.

The MPPE pilot-scale test was conducted by Geosyntec in coordination with Veolia Water Solutions and Technologies, the owner of the MPPE technology. Whittier Filtration of Brea, California (a division of Veolia Water Solutions and Technologies), a licensed vendor of MPPE, provided the MPPE pilot-scale equipment and provided support for the pilot-scale testing that was conducted at the Site.

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[1] Geosyntec Consultants; Re-evaluation of Volatile Organic Compound Treatment, Dual Site Groundwater Operable Unit, Torrance, California. March 5, 2010.

[2] CH2M HILL, Preliminary Evaluation of Alternative Treatment Technologies, Dual Site Groundwater Operable Unit Remedial Design, Montrose Chemical and Del Amo Superfund Site; January 24, 2011.

A description of the MPPE process, contained in Attachment 1, describes the normal operation of the MPPE units in both pilot-scale and full-scale modes. In addition to the information contained in Attachment 1, more detail on the methodology of the full pilot-scale test is presented in Attachment 2. The analytical results of the test are presented in Attachment 1 and Attachment 2.

Based on the analytical data and observations made during the pilot-scale test, findings related to MPPE treatment of the organic chemicals listed in Table 2 include the following:

- MPPE is capable of removing VOCs that are expected to be present in the TGRS influent to concentrations that meet the in-situ groundwater standard ("ISGS")[3] for each VOC, which include the following compounds: 1,2-dichloroethane, 1,4-dichlorobenzene, benzene, chlorobenzene, chloroform, methylene chloride, tetrachloroethylene, trichloroethylene, alpha-BHC, beta-BHC, gamma-BHC, and pCBSA. Carbon tetrachloride is also expected to be in the TGRS influent in excess of the ISGS but was not detected in the influent stream of the MPPE pilot-scale test. Thus MPPE removal of this compound was not demonstrated. However, Whittier Filtration advised that carbon tetrachloride removal to its (ISGS) would be expected based on previous MPPE treatment data.

- Although the MPPE treatment system was not designed to remove para-chlorobenzenesulfonic acid ("pCBSA"), removal of pCBSA occurred. The data set regarding pCBSA removal, however, is limited to three samples. These data show that the amount of pCBSA removal is proportional to the residence time in the MPPE units.

- In general, the data set from samples collected during each flow step indicated relatively low variability in the removal efficiency for a given constituent.

- The MPPE media did not appear to accumulate contaminants over the short-term pilot-scale test, based on the fact that the removal efficiency results did not diminish as the test progressed.

- Numerous operational parameters were monitored to prepare a more accurate estimate of the maintenance demands and costs of a full-scale MPPE system. For example, the steam usage rate was higher than expected, and the MPPE media re-generates more frequently than anticipated.

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[3] Table 9-1, In Situ Groundwater Standards, Record of Decision for Dual Site Groundwater Operable Unit, Montrose Chemical and Del Amo Superfund site, March 1999.

## 2.2 TGRS Applicability of MPPE

The MPPE pilot test was successful from a technical perspective. Montrose considered the issues associated with incorporating MPPE into the treatment train for TGRS. This consideration included an assessment of several factors in addition to the pilot-scale technical results. The factors considered, and Montrose's assessment of them, follows:

- Whittier Filtration, a division of Veolia Water Solutions and Technologies, is the owner of the MPPE technology. While Montrose will consider working with sole-source vendors for provision of treatment equipment, Montrose has a decided preference for equipment that can be competitively bid. Without a clear cost preference for a sole-source technology over a technology that is equally effective and has multiple vendors, Montrose generally will choose the more commercially-available technology. In the final analysis, MPPE does not have a clear cost advantage compared with other equally effective technologies.

- At the heart of the MPPE technology is a resin that is manufactured in Europe and supplied from Europe. There is no evidence that Veolia has been unable to supply its US customers with resin from Europe in the quantity and time frame required, but the distant source of replacement resin over a lengthy expected operation and maintenance period is an added issue for Montrose.

- The MPPE resin requires regular on-site regeneration, which is not a concern. On a periodic basis, however (perhaps every two years), the resin must be refreshed by replacing within the resin bead the extractant that very slowly bleeds out of the resin during normal operation. Contrary to the on-site regeneration operation, the refreshment operation is conducted in Europe, which raises for Montrose the same issues as mentioned above for resin replacement.

- Although the technology has a number of US applications, none of those applications is a full-scale groundwater remediation project. Montrose perceives a disadvantage with being the first such US application.

- Montrose has assessed that the labor requirements associated with MPPE are higher and would require more skilled operators than for other competitive technologies.

Montrose therefore has concluded that while the MPPE technology is technically feasible, practical long-term operational considerations prevent it from being considered for use in the TGRS.

## 3. VOC TREATMENT TECHNOLOGY REVIEW AND TREATMENT TRAIN DEVELOPMENT

Geosyntec evaluated the following five treatment technologies for VOC treatment in the TGRS:

- LGAC;
- Air stripping;
- MPPE;
- Advanced Oxidation Processes (AOP); and
- Biologically-active granular activated carbon (BioGAC).

The evaluation began with a review focusing on whether each technology is capable of meeting the threshold criteria of treating the nine VOCs that are expected to be present in the TGRS influent (Table 1). The review resulted in the first three technologies being considered as viable technologies for potential treatment of the VOCs: 1) LGAC; 2) Air Stripping; and 3) MPPE. AOP and BioGAC were ruled out as described in Attachment 3. The three viable technologies were then evaluated in terms of several factors, including: effectiveness, performance and reliability, waste disposal, community impacts, sustainability, and life-cycle costs. A summary of the comparison of the technologies is presented in Attachment 3.

Although each technology has drawbacks given the mix of constituents requiring treatment, Geosyntec concluded that air stripping is the most appropriate technology for treatment of VOCs because it is effective, well-understood, cost-competitive, and readily implementable. A key consideration for air stripping is the need for treatment of the off-gas before atmospheric emission. Thermal treatment and VGAC treatment were both evaluated, with VGAC treatment being the preferred technology for this site. Additionally, APTwater, Inc.'s HiPOx™ technology will be required for pCBSA treatment, as will an LGAC polishing step for redundancy and treatment of pesticides.

During the review that was being conducted by Geosyntec, USEPA contractor CH2M HILL also conducted a review of technologies that is described in their technical memorandum dated January 24, 2011.[4] CH2M HILL's review also concluded that the same treatment technologies were viable options. The next section of this Advisory provides additional details about the treatment train now being designed for the TGRS as well as a discussion of the recommendations made by CH2M HILL in its technical memorandum.

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[4] Ibid.

## 4. VOC TREATMENT TECHNOLOGY SELECTION

The final selected treatment train includes HiPOx™, followed by air stripping, and then an LGAC polishing step. The off-gas from the air stripper will be treated by VGAC prior to emission. A conceptual diagram of the selected treatment train is included as Figure 1. Montrose will continue design of the TGRS based on this treatment train. The treatment sequence has been developed to treat the groundwater in a reliable and cost-effective manner. A description of the sequence of treatment processes is as follows:

- **HiPOx™** – the HiPOx™ system will treat the pCBSA to achieve the Record of Decision ("ROD") required injection standard of 25,000 micrograms per liter (µg/L). As an additional benefit, a fraction of VOCs will be destroyed thereby decreasing the VOC mass loading to the air stripper and carbon adsorption units. For design purposes it is assumed there will be a 35% reduction in the concentration of the alkenes through the HiPOx™ system, though actual reduction will vary by compound and field conditions. Placing the HiPOx™ first in the sequence of treatment steps also assists with controlling biofouling in the downstream air stripper and LGAC due to residual peroxide from the HiPOx™. The HiPOx™ is expected to be in service for approximately two years at the outset of system operation, at which time the ROD injection standard is expected to be achieved.

- **Air Stripper** – the air stripper will treat the remaining VOCs by transferring them into the vapor phase which will flow through VGAC adsorption vessels prior to emission to the atmosphere. Placing the air stripper after the HiPOx™ will decrease the amount of carbon needed to treat the vapor stream. VGAC treatment will readily remove most VOCs from the air stripper off-gas. Although VOCs such as methylene chloride, 1,2-dichloroethane, and chloroform will be removed to a lesser degree, modeling calculations indicate that emission of these constituents will be at levels that would meet requirements established by the South Coast Air Quality Management District ("SCAQMD"). The VGAC usage is expected to be a manageable amount of approximately 1,000 pounds per day at start-up.

- **LGAC** – the LGAC "polishing" vessels will remove the pesticides from the groundwater and also be a contingency treatment if residual VOCs were to pass through the HiPOx™ and air stripper.

Montrose's planned treatment train is consistent with the treatment train described in Section 4.5 of the January 24, 2011 memorandum from CH2M HILL/USEPA, with the exception that the off-gas from the air stripper will be treated by VGAC instead of CH2M HILL/USEPA's proposal to use a thermal oxidizer. VGAC was chosen as a cost-effective option given the allowable

emissions under SCAQMD Rule 1401. VGAC also is likely to be more acceptable to the surrounding community than a thermal oxidizer would be. In their memorandum, CH2M HILL/USEPA made additional recommendations which had been considered by Geosyntec and resolved as follows:

- CH2M HILL/USEPA Recommendation: "We recommend further discussion with the HiPOx$^{TM}$ supplier regarding the possibility of adjusting the AOP treatment parameters to effectively treat methylene chloride."

    - *Montrose Response: As mentioned in the CH2M HILL/USEPA memorandum, historical HiPOx$^{TM}$ tests at the site are inconclusive regarding methylene chloride treatment due to elevated detection limits. Geosyntec consulted with APTwater, Inc. which acknowledges difficulty treating methylene chloride, chloroform, and 1,2-DCA. Successful treatment of these VOCs by HiPOx$^{TM}$ would require a large reactor capable of delivering a very high dosage of ozone and peroxide oxidants to destroy the other organic chemicals and overcome the resistance to treatment posed by these three VOCs. In addition, relying on HiPOx$^{TM}$ to treat these chemicals would require that the HiPOx$^{TM}$ continue operating for five or more years. The combination of the increased oxidant dosage, the significant high chemical handling requirements, large reactor size, and the prolonged HiPOx$^{TM}$ treatment period cause this option to be impractical and infeasible.*

- CH2M HILL/USEPA Recommendation: "The effectiveness of the Trojan [Ultraviolet] UV AOP placement at the end of the overall treatment train for methylene chloride should also be evaluated."

    - *Montrose Response: As mentioned in the CH2M Hill/USEPA memorandum, the groundwater became light brown in color and more opaque during UV AOP bench-scale testing, thereby decreasing the UV transmittance. The low UV transmittance drives up treatment costs because the UV lamp would need to be large and the UV reactor would need to be larger to increase the treatment time. The water later cleared and the UV transmittance improved after a high dose of peroxide and UV light was applied and the pCBSA was destroyed. It is suspected that the groundwater discoloration and low UV transmittance were caused by an unidentified intermediate breakdown product. Thus, the UV AOP would likely still be affected by the presence of up to 25,000 µg/L of pCBSA in the groundwater at the end of the treatment process. Further, the system would be more complex, the cost would increase, and the project schedule would be delayed further for additional bench-scale and pilot-scale testing of the UV AOP.*

- CH2M HILL/USEPA Recommendation: "Air stripping with off-gas treatment should be considered in place of the MPPE process if it is determined that HiPOx and Trojan UV AOPs do not remove methylene chloride cost-effectively."

  - *Montrose Response: As noted above, Geosyntec analyzed various VOC treatment options and agrees with the CH2M HILL/USEPA memorandum recommending that air stripping is the most reliable and cost-effective primary treatment technology for the TGRS. Air stripping is an attractive option because it is a well-understood process for removing VOCs from groundwater, it can be readily integrated into the TGRS treatment train and, in combination with a carbon adsorption polishing stage, it is effective at treating the VOCs that will be present in the TGRS influent groundwater. Air stripping followed by LGAC adsorption and VGAC for off-gas treatment also is the primary recommendation contained in the ROD for the chlorobenzene plume.*

As described in this Treatment Train Advisory, the treatment train will consist of a reliable and cost-effective treatment train that is consistent with CH2M HILL/USEPA recommendations, with the exception that VGAC instead of thermal oxidation will be used to treat the air stripper off-gas. This treatment train can be designed without further testing and does not entail costly AOP operation for an extended period of time. The VGAC will treat the stripped VOCs prior to emission to the atmosphere. In conclusion, the planned treatment train that will proceed in the design process consists of: HiPOx$^{TM}$, followed by air stripping with VGAC off-gas treatment, and then an LGAC polishing step.

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# TABLES

**TABLE 1**
**INFLUENT COMPILATION SUMMARY**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

| Chemical Class | Analyte | Anticipated Full-Scale TGRS Flow Weighted Influent Concentration at Start-Up (1) (µg/L) | In-Situ Groundwater Standards (ISGS)(2) (µg/L) | Regulatory Standard | Exceeds Regulatory Standard at Start-Up? |
|---|---|---|---|---|---|
| VOC | 1,2-Dichloroethane | 9 | 0.5 | ISGS | YES |
| VOC | 1,4-Dichlorobenzene | 17 | 5 | ISGS | YES |
| VOC | Benzene | 250 | 1 | ISGS | YES |
| VOC | Carbon Tetrachloride | 1.5 | 0.5 | ISGS | YES |
| VOC | Chlorobenzene | 13,900 | 70 | ISGS | YES |
| VOC | Chloroform | 340 | 100 | ISGS | YES |
| VOC | Methylene Chloride | 16.0 | 5 | MCL | YES |
| VOC | Tetrachloroethylene | 170 | 5 | ISGS | YES |
| VOC | Trichloroethylene | 38.0 | 5 | ISGS | YES |
| pCBSA | Para-Chlorobenzene Sulfonic Acid | 39,600 | 25,000 | ISGS | YES |
| Pesticide | BHC, alpha- | 0.42 | 0.011 | ISGS | YES |
| Pesticide | BHC, beta- | 0.31 | 0.037 | ISGS | YES |
| Pesticide | BHC, gamma- | 0.59 | 0.2 | ISGS | YES |

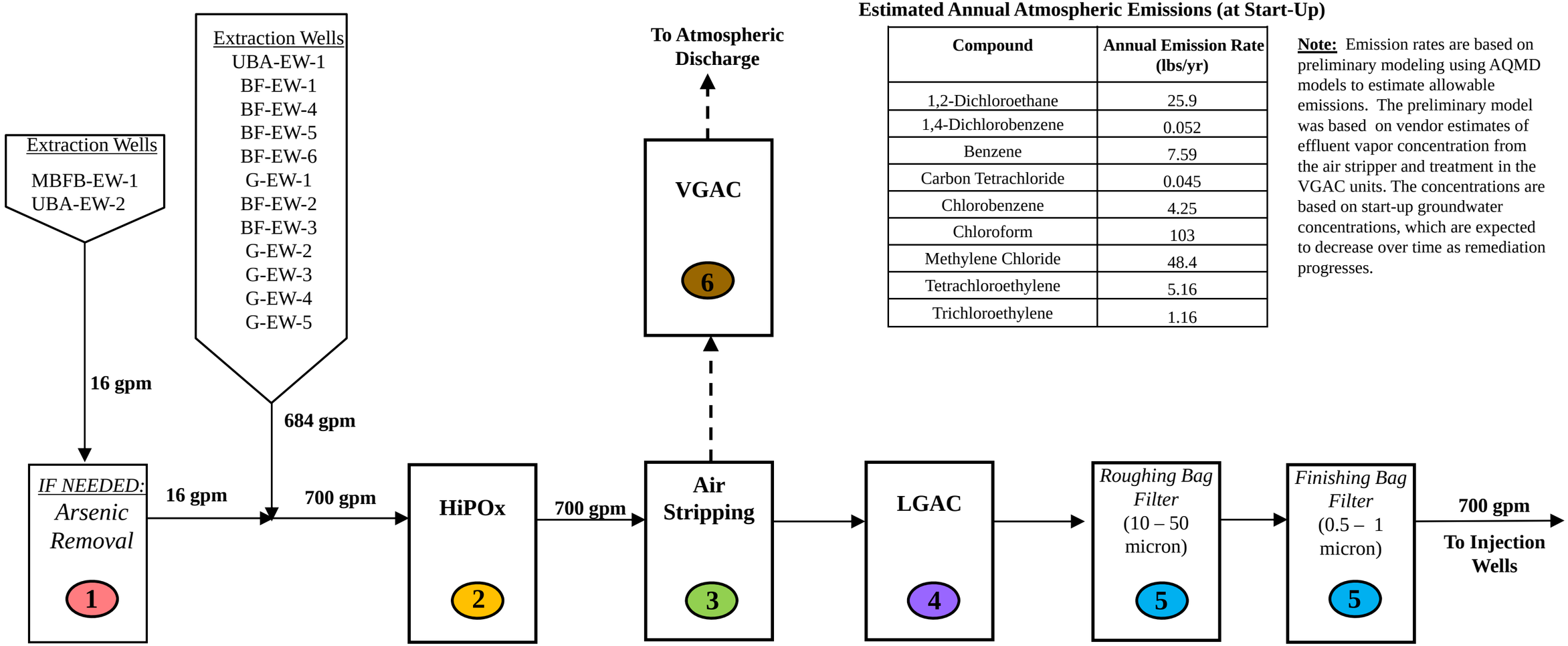
NOTES:
(1) Based on calculations completed with the April 2009 groundwater monitoring results
(2) ISGS - In Situ Groundwater Standard as outlined in the Record of Decision

**TABLE 2**
**RESULTS SUMMARY**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

| Chemical Class | Analyte | Anticipated Full-Scale TGRS Flow Weighted Influent Concentration at Start-Up (1) (µg/L) | In-Situ Groundwater Standards (ISGS) (2) (µg/L) | Regulatory Standard | Anticipated MPPE Pilot Test Influent Concentration(3) (µg/L) | Actual Pilot-Scale Test Influent Concentration Range (µg/L) | MPPE Able to Treat to Regulatory Standard? | Maximum Flow Rate to Achieve Effluent Below Regulatory Criteria During MPPE Pilot-Scale Test (gpm) |
|---|---|---|---|---|---|---|---|---|
| VOC | 1,2-Dichloroethane | 9 | 0.5 | ISGS | 23 | 17 - 59 | Yes | 30 |
| VOC | 1,4-Dichlorobenzene | 17 | 5 | ISGS | 39 | 24 - 76 | Yes | 40 |
| VOC | Benzene | 250 | 1 | ISGS | 1030 | 320 - 2000 | Yes | 20 |
| VOC | Carbon Tetrachloride | 1.5 | 0.5 | ISGS | ND | ND (5) | ND (5) | |
| VOC | Chlorobenzene | 13,900 | 70 | ISGS | 35,200 | 16,000 - 37,000 | Yes | 40 |
| VOC | Chloroform | 340 | 100 | ISGS | 1710 | 260 - 880 | Yes | 40 |
| VOC | Methylene Chloride | 16.0 | 5 | MCL | 35 | 6.7 - 110 | Yes | 12 |
| VOC | Tetrachloroethylene | 170 | 5 | ISGS | 60 | 13 -23 | Yes | 40 |
| VOC | Trichloroethylene | 38.0 | 5 | ISGS | 53 | 21 - 98 | Yes | 40 |
| pCBSA | Para-Chlorobenzene Sulfonic Acid | 39,600 | 25,000 | ROD | 53,800 | 94,000 - 130,000 | Yes | 3 |
| Pesticide | BHC, alpha- | 0.42 | 0.011 | ISGS | 0.181 | 0.099 -0.18 | Yes(4) | 40 |
| Pesticide | BHC, beta- | 0.31 | 0.037 | ISGS | 0.608 | 0.29 - 0.64 | Yes | 40 |
| Pesticide | BHC, gamma- | 0.59 | 0.2 | ISGS | 0.352 | 0.15 - 0.33 | Yes | 40 |

NOTES:
(1) Based on calculations completed with the April 2009 groundwater monitoring results
(2) ISGS as outlined in ROD
(3) Based on influent stream of 95 percent by volume from BF-EW-1 and 5 percent by volume from MBFB-EW-1
(4) ISGS is below the method detection limit; alpha -BHC was not detected in the effluent
(5) Carbon Tetrachloride was not detected in the influent or effluent during the pilot-scale test

# FIGURE




**Estimated Annual Atmospheric Emissions (at Start-Up)**

| Compound | Annual Emission Rate (lbs/yr) |
|---|---|
| 1,2-Dichloroethane | 25.9 |
| 1,4-Dichlorobenzene | 0.052 |
| Benzene | 7.59 |
| Carbon Tetrachloride | 0.045 |
| Chlorobenzene | 4.25 |
| Chloroform | 103 |
| Methylene Chloride | 48.4 |
| Tetrachloroethylene | 5.16 |
| Trichloroethylene | 1.16 |

**Note:** Emission rates are based on preliminary modeling using AQMD models to estimate allowable emissions. The preliminary model was based on vendor estimates of effluent vapor concentration from the air stripper and treatment in the VGAC units. The concentrations are based on start-up groundwater concentrations, which are expected to decrease over time as remediation progresses.

| Treatment Step | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Groundwater Flow (gpm) | 16 | 700 | 700 | 700 | 700 | - |
| Design Constituent | Arsenic | pCBSA | VOCs | Pesticides | Solids | VOCs |
| Additional Treatment | - | VOCs | - | VOCs | - | - |
| Phase | Aqueous | Aqueous | Aqueous | Aqueous | Aqueous | Vapor |

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**UPDATED TREATMENT TRAIN**
**TREATMENT TRAIN ADVISORY**
**DUAL SITE GROUNDWATER OPERABLE UNIT**
**TORRANCE, CALIFORNIA**

**Figure 1**
**HM0508**
**June 2011**

# Attachment 1

# Whittier Filtration Pilot Testing Report

WHITTIER FILTRATION

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# Macro Porous Polymer Extraction Pilot Study

## Analytical & Operational Report

Presented to: Geosyntec Consultants, Inc.
Date: October 13, 2010

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# 1 Introduction

A field demonstration pilot study has been completed at the Montrose Chemical – Torrance site testing the efficiency of Whittier Filtration's proprietary macro-porous polymer extraction (MPPE) organic contaminant extraction technology for removal of a range of target volatile organic compounds (VOCs) from the site's ground water. The process utilized MPPE media to successfully remove non-polar solvents, chlorinated solvents and chlorinated pesticide residues down to EPA ground water regulatory limits.

MPPE is a patented macro-porous polymer impregnated with a stabilized non-toxic solvent which is being used for the continuous treatment of industrial effluent, contaminated ground water and produced water from oil and gas fields. The media absorbs organic contaminants from water during the extraction process and is regenerated *in-situ*, collecting the recovered contaminants for later disposal or reuse. The process has proven to be particularly effective for removal of common non-polar solvents. The media typically lasts for two years in continuous use and is then re-activated off-site for later reuse. Reactivation entails several proprietary techniques which bring the media back to original specification. While rarely necessary, if it is deemed appropriate, the media is disposed of by means consistent with its waste profile.

Whittier Filtration is the licensed provider of MPPE technology in North and South America, providing consulting, engineering, system supply and integration, startup services and operations support.

## *1.1 Background*

In May, 2010, Whittier Filtration performed bench tests on samples of ground water to determine the feasibility of MPPE to reduce several key contaminants expected at the Montrose site. The bench tests, performed as 24-hour shaker tests, were run on 3500 ml samples of ground water with various doses of MPPE media added to each. MPPE was quite effective at reducing the concentration of the full range of constituents. Whittier Filtration produced a report on the bench tests dated June 10, 2010. With encouraging results from the bench tests, Montrose decided to perform a pilot-scale test ("pilot study") on ground water at the Torrance, CA, site.

## *1.2 Pilot Test Objectives*

The objectives of the pilot study included:

1. Verify proof of concept for use of MPPE on contaminated ground water associated with the Torrance Groundwater Remedial System (TGRS)

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2. Evaluate MPPE under actual field conditions
3. Evaluate MPPE at a variety of operating conditions
4. Generate data which will be used to decide whether to incorporate MPPE into the project's treatment plant

## *1.3 Test Protocol*

The pilot study was performed under two test protocols. The first test protocol involved operating the pilot study test unit at selected feed rates for short periods of time to determine the test unit's ability to remove target constituents and the overall capacity for the mix of components. During this stage of the test, ground water was fed to the test unit as rates from 3 – 40 gpm in a step-wise fashion. At each new flow rate the process was allowed to stabilize for one cycle (see description below) after which samples of the feed water and treated effluent water were taken. The test unit was allowed to operate for at least three cycles between process changes. Just prior to each scheduled change another set of samples was taken.

The second test-protocol involved operating the test unit at a continuous flow rate of 15 gpm for an extended run to look for any short-term degradation of performance. During this test protocol it was decided to spike the feed with methylene chloride which was not detectable in the feed water, to determine the system's ability to remove and separate this key constituent. Throughout the continuous test protocol, samples were taken at routine times, roughly once every four to eight hours.

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# 2 Equipment

## *2.1 MPPE media*

This pilot study utilized MPPE media for removal of organic and chlorinated constituents. The media is engineered for highly effective removal and easy recovery of absorbed contaminants.

MPPE is a proprietary macroporous polymer extrusion impregnated with a stabilized, non-toxic extraction oil with a high affinity for general hydrocarbons, including aliphatic, aromatic, polyaromatic and chlorinated compounds. In process, the media preferentially absorbs organic constituents from wastewater, accumulating the compounds within the matrix. The media has a finite absorption capacity varying by compound, and must be regenerated prior to saturation to maintain system performance. During regeneration, low-pressure steam efficiently strips the contaminants from the media, leaving the extraction oil behind.

MPPE has a unique ability to be custom engineered to optimize recovery of target constituents. In the case of Montrose – Torrance, the bench-scale shaker study identified methylene chloride as a pacing compound, likely to drive design of the full facility. Due to its high solubility in water, methylene chloride is often a problematic constituent. In response to this result, the MPPE media for the pilot study was modified to improve its removal efficiency on methylene chloride, while maintaining its affinity for moderate to slightly soluble entities.

While the operational life of the media is typically measured in years, over time the media can become contaminated with scale, inorganic compounds (such as iron and calcium) and low-volatility hydrocarbons, degrading system performance. Based on known water composition, the degradation is generally slow and predictable, allowing for scheduled or proactive change-out of the media for re-activation. The average lifetime is 2 years after which the used MPPE media is replaced with fresh media and the used media is sent offsite for re-activation.

## *2.2 MPPE process description*

In the MPPE process, contaminated water is passed through a column packed with MPPE media. The immobilized extraction oil within the MPPE resin removes the contaminants from the water. Only the organic contaminants, which have a high affinity for the extraction oil, are removed. The treated water can either be reused or discharged. MPPE media has a finite absorption capacity. In practice, the saturation of MPPE is kept within a target range to prevent breakthrough and to allow for variability in feed concentrations. The key to MPPE removal performance is its periodic regeneration, *in situ*, which restores its absorption capacity. Regeneration of the extraction oil is accomplished by stripping the hydrocarbons with low-pressure steam. The stripped hydrocarbons are condensed and then separated from the water phase by gravity. The organic liquids are recovered, removed from the system and are ready

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for use, reuse or disposal. The organic phase has very little retained water, keeping disposal costs to a minimum. The condensed aqueous phase is recycled within the system. The application of two columns allows continuous operation with simultaneous extraction and regeneration. A typical cycle is one hour of extraction and one hour of regeneration.

The MPPE process is a cyclic process, which consists of 6 repeating steps. In Table 1 the various process steps are given together with the step advance criteria. The process steps and following description refer to equipment shown on the Process Flow Diagram contained in Sec. 2.3 of this report.

**Table 1 Overview MPPE process steps and step advance criteria.**

| Step | Column C-01 | Column C-02 | Step advance criterion |
|---|---|---|---|
| 1 | Regeneration | Extraction | Regeneration timer elapsed |
| 2 | Filling | Condensate injection | Low level LBS-002 |
| 3 | Extraction | Heating-up | TIS-002 > set point |
| 4 | Extraction | Regeneration | Regeneration timer elapsed |
| 5 | Condensate injection | Filling | Low level LBS-002 |
| 6 | Heating-up | Extraction | TIS-001 > set point |

**Step 1: Regeneration of column C-01/extraction in column C-02**
Influent groundwater runs via filter F-01A/B to column C-02. In column C-02 the groundwater is purified, and leaves the column for post-treatment through carbon beds at the site. Simultaneously column C-01 is regenerated with low pressure steam. Steam from steam generator G-01 entered column C-01 at the top and strips the organic contaminants from the MPPE material. Steam and vaporized organic contaminants exit column C-01 at the bottom. Steam and vaporized organics enter the condenser H-01 and are condensed. Condensed steam and organics enter separator S-01. The light organic phase overflows to separator S-02. For the pilot test, the condensed steam and heavy organic phase were retained in separator S-1 and drained as needed to a 55-gallon drum. Water from return water tank T-01 is continuously added to the influent via pump P-01 until the pump stop level has been reached.

Step 1 is ended after a set regeneration time has elapsed.

**Step 2: Filling of column C-01 and condensate injection column C-02**
Influent groundwater runs via filter F-01A/B to the bottom of column C-01. While filling column C-01 the water is heated up due to the transfer of heat from the MPPE material. Residual steam and organic vapor exits column C-01 at the top and enters column C-02 at the top. The residual steam and vapor entering column C-02 condenses, preheating the column. After filling column C-01 the treated groundwater exits the top of the column and enters column C-02 at the top. The water runs through column C-02 and releases its heat to the MPPE material. Water exits column C-02 at the bottom and runs via XSV-016 to return water tank T-01. The water flowing to return water tank T-01 is not fully treated and may contain hydrocarbons. Water from

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return water tank T-01 is continuously added to the influent via pump P-01 until the pump stop level has been reached.

Step 2 ends after all heat is transferred from C-01 to C-02 which is indicated by temperature reading TISZA-003 < set point.

**Step 3: Extraction column C-01/heating up column C-02**
Influent groundwater runs via filters F-01A/B to column C-01. In column C-01 the groundwater is purified and leaves the column for post-treatment through carbon beds at the site. Simultaneously column C-02 is heated up with low pressure steam. Steam from steam generator G-01 enters column C-02 at the top and heats up the MPPE material. The steam condensate exits column C-02 at the bottom and runs via XSV-016 to return water tank T-01. Water from return water tank T-01 is continuously added to the influent via pump P-01.

Step 3 ends after temperature reading TIS-002 > set point.

**Step 4: Extraction in column C-01/regeneration of column C-02**
Influent groundwater runs via filters F-01A/B to column C-01. In column C-01 the water is purified, the purified groundwater is discharged for post-treatment through carbon beds at the site. Simultaneously column C-02 is regenerated with low pressure steam. Steam from steam generator G-01 enters column C-02 at the top and strips the organic contaminants from the MPPE material. Steam and vaporized organic contaminants exit column C-02 at the bottom. Steam and vaporized organics enter the condenser H-01 and are condensed. Condensed steam and hydrocarbons enter separator S-01. The light organic phase overflows to S-02 and drained manually as necessary to a 55 gallon drum. Water from return water tank T-01 is continuously added to the influent via pump P-01 until the pump stop level has been reached.

Step 4 is the mirror image of step 1. Step 4 ends after a set regeneration time has elapsed.

**Step 5: Filling of column C-02 and condensate injection column C-01**
Influent groundwater runs via filter F-01A/B to the bottom of column C-02. While filling column C-02 the water is heated up due to the transfer of heat from the MPPE material. Residual steam and organic vapor exits column C-02 at the top and enters column C-01 at the top. The residual steam and vapor entering column C-01 condenses, preheating the column. After filling column C-02 the treated groundwater exits the top of the column and enters column C-01 at the top. The water runs through column C-01 and releases its heat to the MPPE material. Water exits column C-01 at the bottom and runs via XSV-016 to return water tank T-01. The water flowing to return water tank T-01 is not fully treated and may contain hydrocarbons. Water from return water tank T-01 is continuously added to the influent via pump P-01 until the pump stop level has been reached.

Step 5 ends after all heat is transferred from C-02 to C-01 which is indicated by temperature reading TISZA-003 < set point.

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**Step 6: Heating up column C-01/extraction column C-02**
Influent runs via filters F-01A/B to column C-02. In column C-02 the water is purified, the purified water is returned to the customer. Simultaneously column C-01 is heated up with low pressure steam. Steam from external or steam generator G-01 enters column C-01 at the top and heats up the MPPE material. The steam condensate exits column C-01 at the bottom and runs via XSV-016 to return water tank T-01. Water from return water tank T-01 is continuously added to the influent via pump P-01 until the pump stop level has been reached.

Step 6 ends after TIS-002 > set point.

## *2.3 Process Flow Diagram*

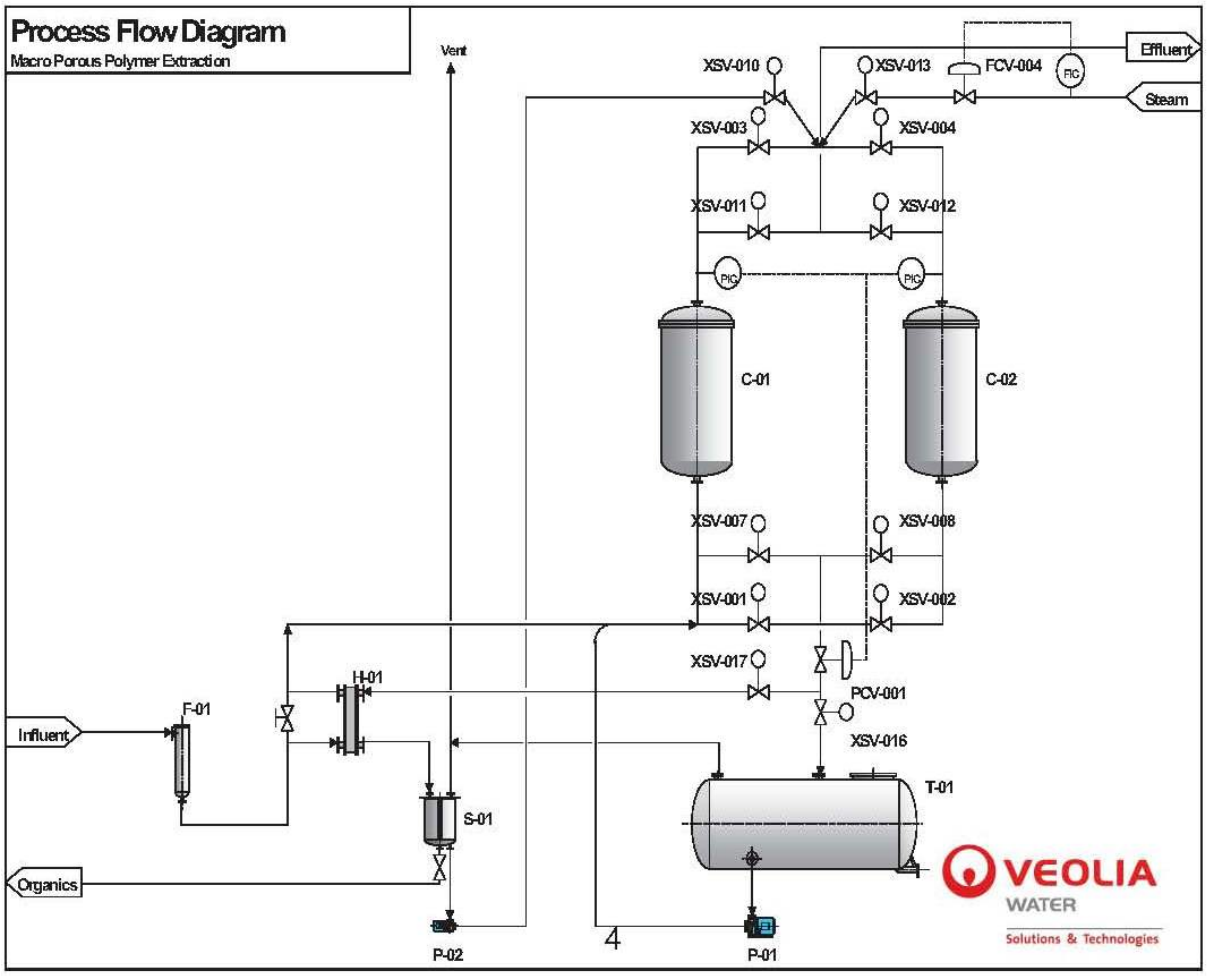


Figure 1 Simplified schematic of MPPE pilot unit.

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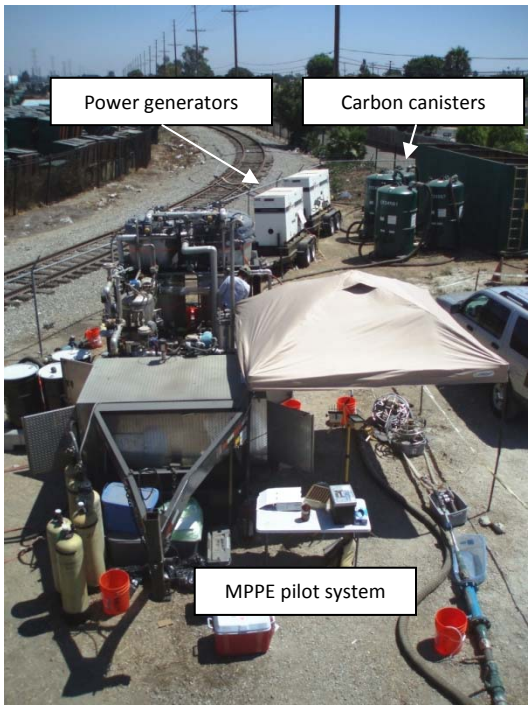
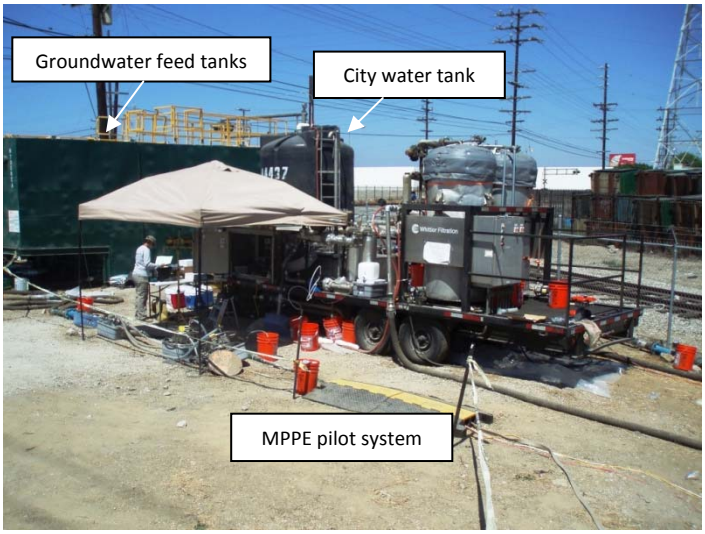
The piping and instrumentation diagram (P&ID) of the test unit is presented in Appendix 1 followed by the system screen and the set points. The system and PID set point screens in Appendices 2 and 3 show all settings used for the test unit.

During the operation, all measured data of the different installed instruments are saved on the hard disk of the PC. A sample of these historical data is visually displayed in Appendices 3 – 7.

## *2.4 Pilot Set-up*

The influent ground water was pumped from two groundwater wells and combined in a large storage tank on-site. After equalization and mixing the water was then fed to the test unit using a centrifugal pump. The treated ground water leaving the test unit was discharged to a set of carbon adsorbers to remove residual organic content, if any, and then discharged.




The photos above show the treatment train set up. The test unit is in the middle of the photo (just left of the generator sets). The carbon adsorbers are to the right and two Baker temporary storage tanks are located just to the left of the test unit.

The MPPE pilot study was conducted over a three (3) week period at a variety of flow conditions to check the overall performance of MPPE and verify its ability to treat fluctuations in influent water characteristics. During the pilot study, the test unit was periodically sampled by Geosyntec Consultants (Geosyntec). Roughly twice a day the flow to the test unit was adjusted to measure the system response over a range of flow rates. Samples of both the influent (after pre-filter) and the effluent were taken mid-cycle approximately one hour after the new flow rate was introduced and periodically after that.

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At the end of the step flow protocol it was decided to operate the test unit in an extended continuous flow protocol. From the prior results a flow rate of 15 gpm (column residence time of 6 minutes) was selected for this protocol. Twice a day samples of feed and effluent were taken for analysis. As was mentioned in Sec. 1.3 and shown in Table 2, the feed water did not contain detectable concentrations of methylene chloride, expected to be a pacing compound for potential full-scale design. For the final two days of the continuous flow protocol, therefore, the feed was spiked with methylene chloride to gain a better understanding of how methylene chloride was being removed through the test unit. A metering pump was used to pump a concentrated source of methylene chloride into the feed stream at the inlet to deliver a concentration of approximately 100 μg/L to the test unit. Full-scale system concentrations of methylene chloride are expected to be 16 μg/l in the full production (700 gpm) stream configuration, and 28 μg/l in a side stream (380 gpm) configuration.

Samples collected during the pilot test were sent to an independent certified laboratory, (TestAmerica Denver or Calscience Environmental Laboratory, Inc.) for the analysis of VOCs and pesticides.

## *2.5 MPPE Pilot Test Unit Specifications*

| | |
|---|---|
| Type of installation | Trailer Mounted Unit |
| Trailer Footprint | 8’ w X 28’ l X 11’ ht |
| Construction | Stainless Steel |
| Interface | Intellution *i*Fix HMI on Notebook Computer |
| Panel Construction | Weather Proof |
| Pre-Filters | Bag Type, Inline Solids Filtration |
| Max. influent flow | 40 gpm |
| Min. influent flow | 3 gpm |
| Column Dimensions | |
| Diameter | 32 inches |
| Height | 80 inches (packed bed height = 64”) |
| Total weight | 7 tons |
| | |
| Treatment and utility connections | |
| Influent water flow | 3-40 gpm |
| Effluent discharge | 3-40 gpm |
| Organics discharge and disposal | manual |
| Cooling water supply | 2 - 5 gpm |
| Cooling water return | 2 - 5 gpm |
| Plant steam (P < 15 psig, T < 230oF) | max. 105 lb/hr |
| Or water for steam generator (> 25 psig) | 1-2 gpm |

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| | |
|---|---|
| Condensate/drain from boiler (atmospheric) | 1-2 gpm |
| Power requirements | 480 v, 3 phase, 60 Hz, 60 Amp |
| Compressed DRY air | 2 scfm @ 80 psig |

The test unit is PLC controlled, with a PC–based human-machine interface (HMI). In addition, the test unit can be fully operated remotely via wireless connection.

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# 3 Results

The analytical results obtained for the influent and effluent samples taken from the test unit are listed in the following tables.

## *3.1 Step Flow Protocol*

Results indicated that MPPE is highly effective at removal of the target constituents at the Montrose site. As shown in Table 2, below, at column residence times of greater than 5 minutes the EPA criteria for ground water discharge are met for the nine target VOCs listed and the three pesticides. Additionally, p-chlorobenzene sulfonic acid (pCBSA) was also removed to regulatory limits by MPPE at long column residence times (Figure 2).

It may be noted in Table 2 that at shorter column residence times, effluent concentrations of some constituents did not meet EPA criteria. This resulted from saturation of the column media with these compounds during the extraction phase. Although substantial removal was accomplished, the moderate water solubility of these compounds combined with less-than-adequate contact time allowed for some column breakthrough. Results for these short residence times are in general agreement with better than 95% reduction of benzene, chloroform and chlorobenzene. A return to longer retention times re-established the MPPE media's ability to remove the VOCs to below detectable limits. This result is as expected and is useful in establishing full-scale design criteria.

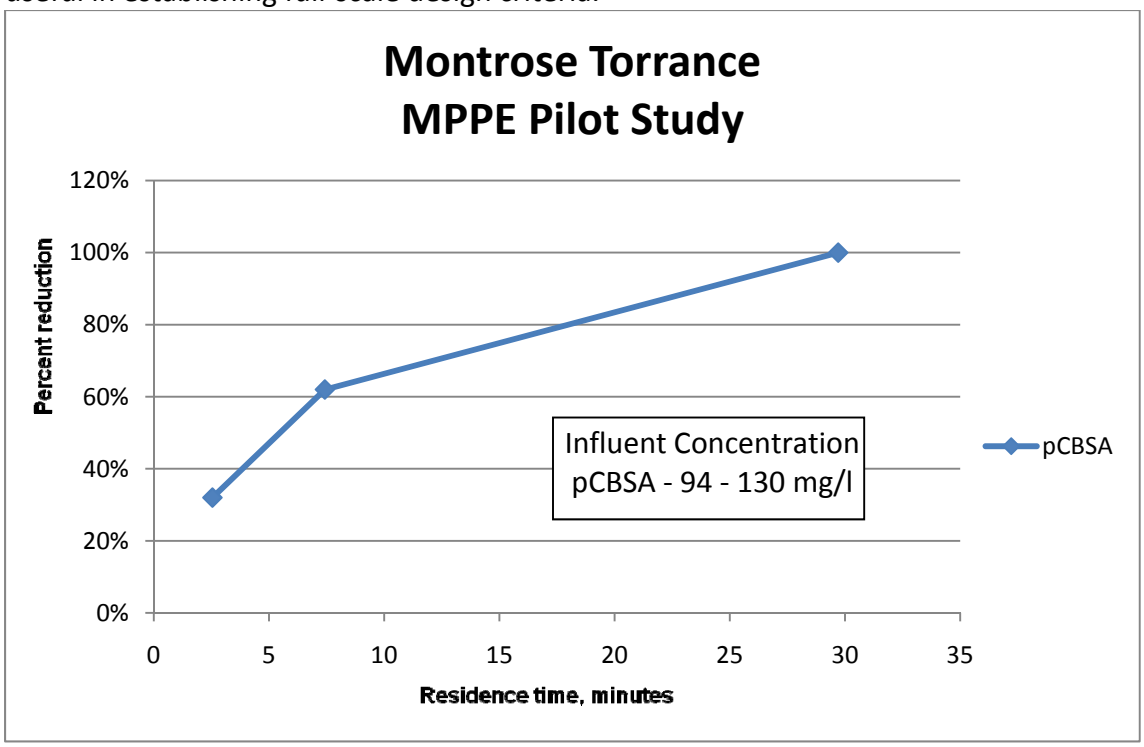


Figure 2 Removal of pCBSA from Montrose ground water

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**Table 2 Consolidated performance of MPPE pilot test unit at various residence times on target constituents.**

| Flow rate, gpm | | 40 | 35 | 25 | 20 | 15 | 12 | 10 | 9 | 6 | 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Residence time, min | | 2.23 | 2.55 | 3.56 | 4.46 | 5.94 | 7.43 | 8.91 | 9.9 | 14.85 | 29.71 | | | |
| | | | | | | | | | | | | | | |
| Constituent | Inlet (ave), μg/l | Effluent concentration (ave), μg/l | | | | | | | | | | ISGS, μg/l | Sol. in water, mg/l | Density, g/cm$^3$ |
| Benzene | 778 | 29.4 | 24.3 | 32.0 | 0.8 | ND | ND | ND | ND | ND | ND | 1.0 | 1,750 | 0.879 |
| Chlorobenzene | 22,929 | 5.2 | 3.3 | 6.5 | ND | ND | ND | ND | ND | ND | ND | 70 | 50 | 1.106 |
| Chloroform | 465 | 22.0 | 18.6 | 18.4 | 1.4 | 0.4 | 0.3 | ND | ND | ND | ND | 100 | 8,150 | 1.483 |
| 1,2-Dichloroethane | 2 | 1.9 | 2.2 | ND | ND | ND | ND | ND | ND | ND | ND | 0.5 | 870 | 1.235 |
| Methylene chloride | 0 | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 5.0 | 13,000 | 1.327 |
| 1,1,2-Trichloroethene | 22 | ND | ND | 0.9 | ND | ND | ND | ND | ND | ND | ND | 5.0 | 1,280 | 1.464 |
| 1,4-Dichlorobenzene | 20 | ND | ND | ND | ND | ND | ND | | ND | ND | | 5.0 | 105 | 1.248 |
| Carbon Tetrachloride | 20 | ND | ND | ND | ND | ND | ND | | ND | ND | | 1.0 | 785 | 1.594 |
| Tetrachloroethene | 27 | ND | ND | ND | ND | ND | ND | | ND | ND | | 5.0 | 150 | 1.623 |
| | | | | | | | | | | | | | | |
| Constituent | Inlet (ave), mg/l | Effluent concentration (ave), mg/l | | | | | | | | | | ISGS, mg/l | Sol. in water, mg/l | Density, g/cm$^3$ |
| pCBSA | 108 | | 73 | | | | 41 | | | | 0.150 | 25 | NA | NA |
| | | | | | | | | | | | | | | |
| Constituent | Inlet (ave), ng/l | Effluent concentration (ave), ng/l | | | | | | | | | | ISGS, ng/l | Sol. in water, mg/l | Density, g/cm$^3$ |
| α-BHC | 150 | ND | | ND | ND | ND | ND | | ND | ND | | 11 | NA | 1.87 |
| β-BHC | 4,936 | ND | | ND | ND | ND | ND | | ND | ND | | 37 | NA | 1.89 |
| γ-BHC (Lindane) | 248 | ND | | ND | ND | ND | ND | | ND | ND | | 200 | NA | NA |

(α,β,γ-BHC = isomers of 1,2,3,4,5,6-hexachlorocyclohexane)

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## 3.2 Continuous Flow Protocol

The continuous flow protocol was conducted at a column residence time of 6 minutes. With the exception of chloroform on a few occasions, the constituents listed in Table 2 were removed to below detection limits. Several samples indicated very low levels of chloroform in the effluent at concentrations of 0.38 to 0.49 µg/L, well below EPA discharge limit of 100 µg/L.

One sample taken during the middle of the protocol had benzene concentrations in excess of EPA limits, and performance results for other constituents, while all within EPA limits, were below those of adjacent samples. It is unclear what the cause of this result was.

## 3.3 Methylene Chloride Spike Study

The methylene chloride spike study during the continuous flow protocol was operated over a range of flow rates with equivalent column residence times from 7 to 29 minutes. During the study, feed concentrations of methylene chloride averaged 91 µg/L, and effluent concentrations were non-detect (less than 2.6 µg/L) for all flow rates.

## 3.4 Operation at Short Residence Times

MPPE is highly effective at removal of organic compounds when properly applied. Operation at very short residence times – less than 5 minutes – will not allow sufficient mass transfer time for the compounds to be completely absorbed. Additionally, operation at high flow rates will bring substantial organic compounds to the media, perhaps beyond its saturation point. In both cases this leads to breakthrough at the exit of the extraction columns. Sufficient contact time is necessary for the organic compounds to absorb into the extraction oil.

## 3.5 Three Phase Separation

The test unit is designed for the clean separation of the organic and aqueous phases. Generally this is limited to two phases – a low density organic phase and a higher density water phase. During operation, the condensed vapor is collected in the separator, building volume over time and allowing the two phases to separate. Due the small volume of water required to steam the beds, the organic phase builds faster than the aqueous phase, ultimately overflowing into an organic collection tank. The top portion of the organic layer is normally very clean and dry. Eventually water collects up to the level of a probe in the separator and a valve is opened to drain a small portion of the water into the holding tank.

At the Montrose site, the majority of VOCs have a density greater than water, although some are lighter than water and perhaps somewhat less soluble in the dense organic phase. Over time three phases were present in the separator. Since the test unit is not designed for three phase separation, it was not possible to operate the separator in automatic mode and therefore the separator was drained manually as necessary.

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### *3.6 Remote Access System Analysis and Reporting*

The MPPE process is fully capable of remote access and performance reporting. PLC controlled, with a PC-based SCADA system, the process collects and stores data for historical trending and analysis in excess of 6 months. The historical data is accessed on an agreed-to periodic basis to review system health and stable operation. The data can be used to assess media bed health as well, to allow proactive scheduling of repairs and media replacement. In addition, when selected data are transmitted automatically to a central monitoring station, information on operational parameters, system upsets, up-time, down-time and a host of other consolidated data can be easily formatted for routine reporting.

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# 4 Major Observations and Conclusions

From the MPPE pilot study at Montrose Chemical - Torrance, the following can be concluded:

***Separation performance***

- The MPPE technology is able to remove all target compounds to well below required *in-situ* groundwater standards (ISGS) and routinely below detectable limits at contact times above 5 minutes
- During the 1 week continuous flow protocol, the concentration of target compounds in the treated water was consistently non-detectable at contact times above 5 minutes
- During the methylene chloride spike study, the influent was dosed with methylene chloride at ~100 μg/L. At no time was methylene chloride detected in the effluent at contact times above 7 minutes
- MPPE successfully removed isomers of BHC to below detectable limits
- Depending upon the column residence time, pCBSA is removed to ISGS requirements

***Operational performance***

- The test unit was operated 24 hours a day, 7 days a week, fully automated
- During running hours uptime was approximately 90%
- Some minor difficulties with the steam and air pressure at the test unit were resolved quickly and the test unit was brought back on-line without impact to the performance
- The inlet bag filters had to be changed several times due to high solids loading. Another filter technology may need to be considered for final implementation.
- The test unit was successfully observed remotely without the necessity of changing parameters
- The test unit was not capable of clean separation of organic and aqueous phases due to limitations of the two-phase separator. Design for a three-phase separator would need to be considered for full-scale implementation.

***Overall conclusion:***

- **The MPPE technology proved to be capable of lowering the concentration of benzene, chlorobenzene, chloroform, 1,2-dichloroethane, methylene chloride, 1,1,2-trichloroethene, 1,4-dichlorobenzene, carbon tetrachloride, tetrachloroethylene, as well as α, β, and γ-BHC to EPA discharge criteria**

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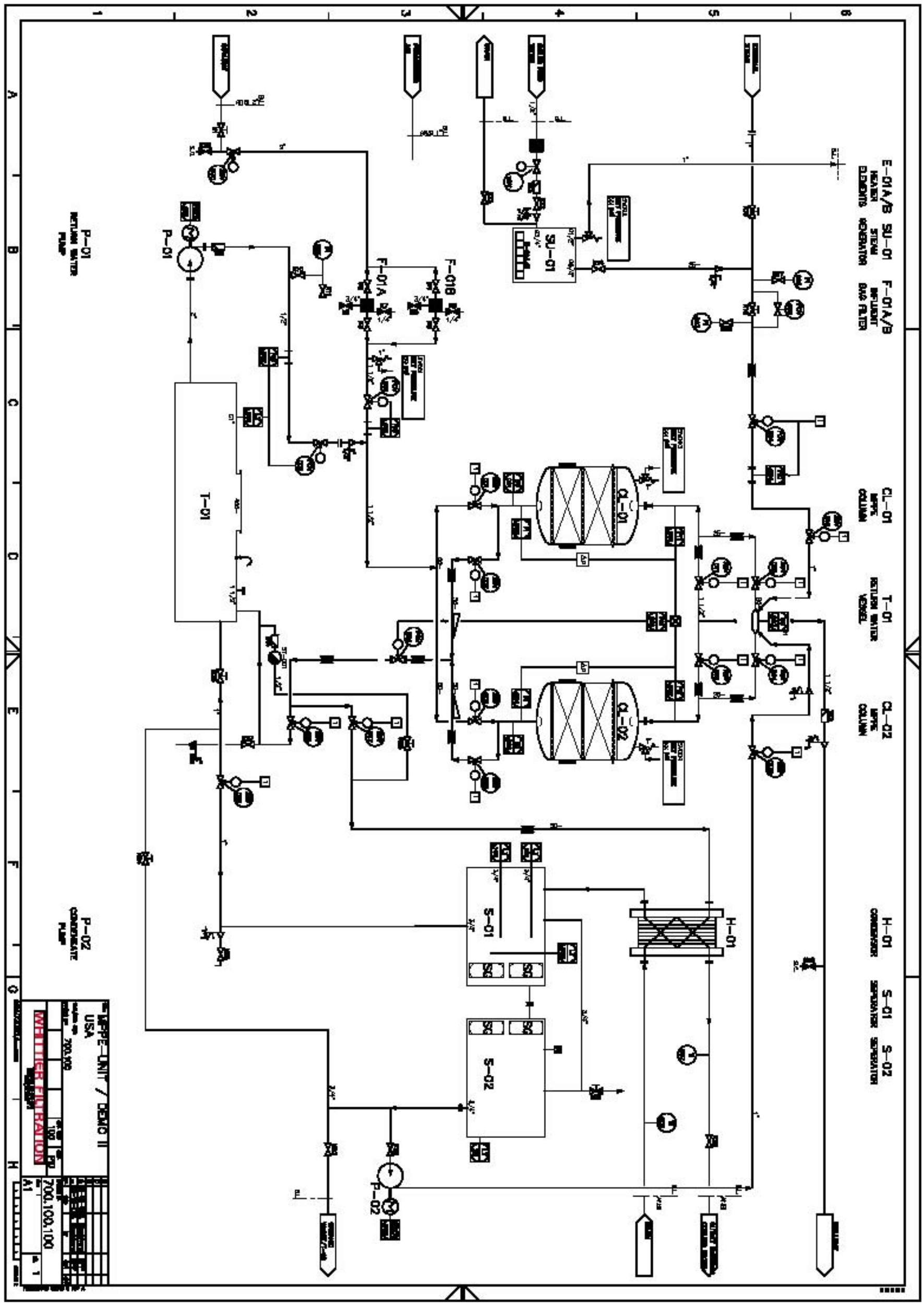
# Appendix 1: Piping & Instrumentation Diagram



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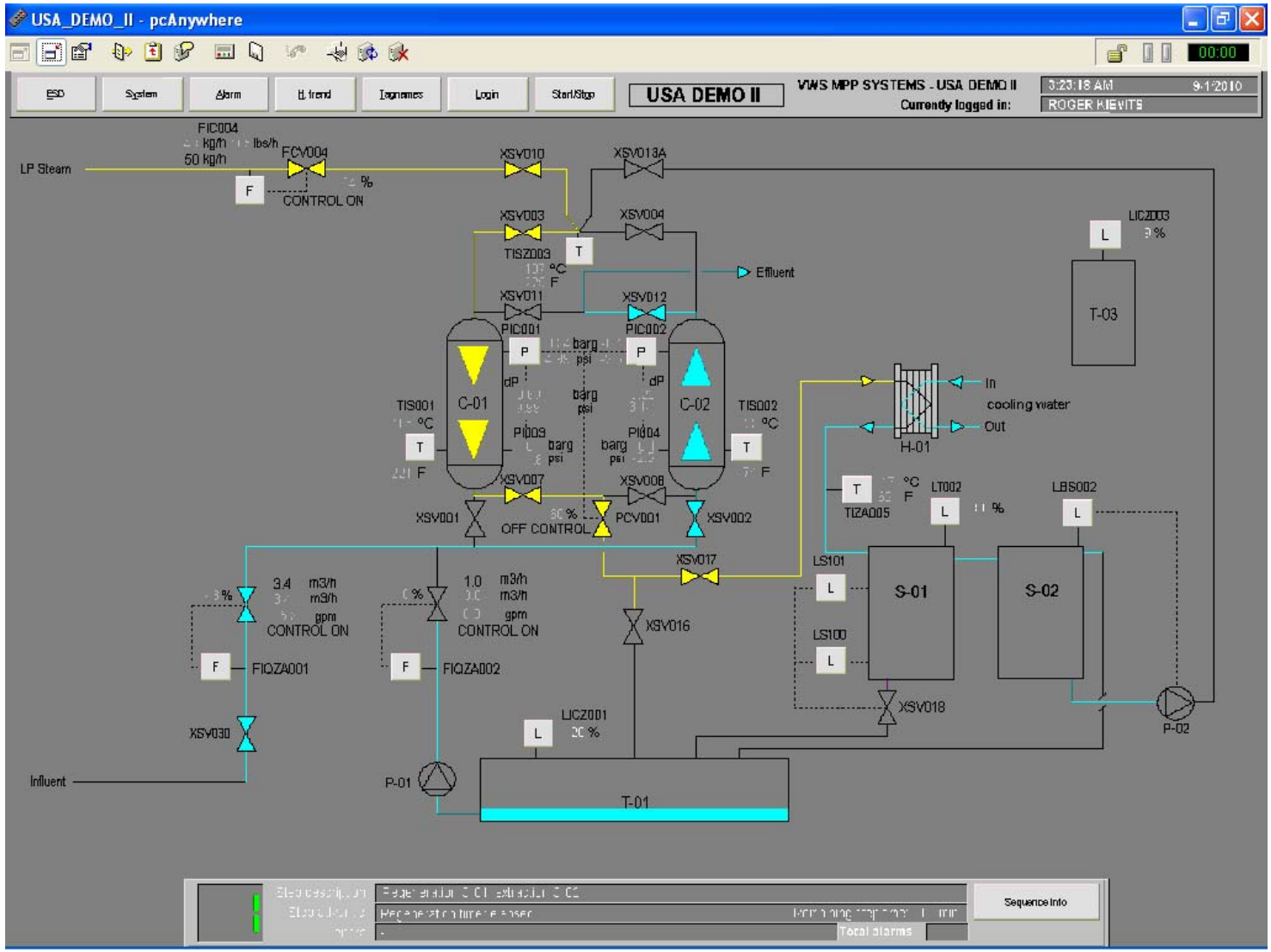
# Appendix 2: System Screen



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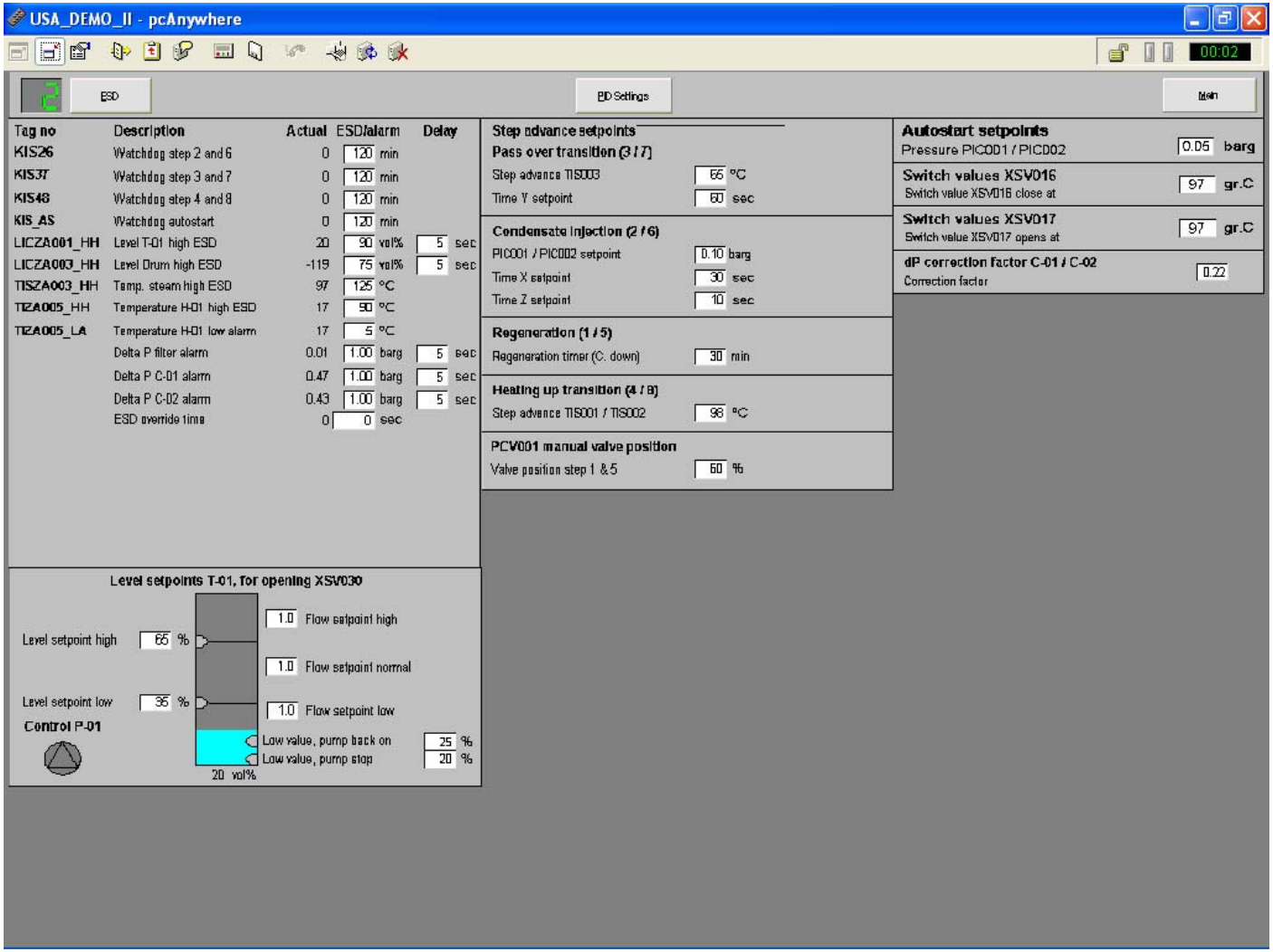
# Appendix 3: Set Points and PID Settings Screen



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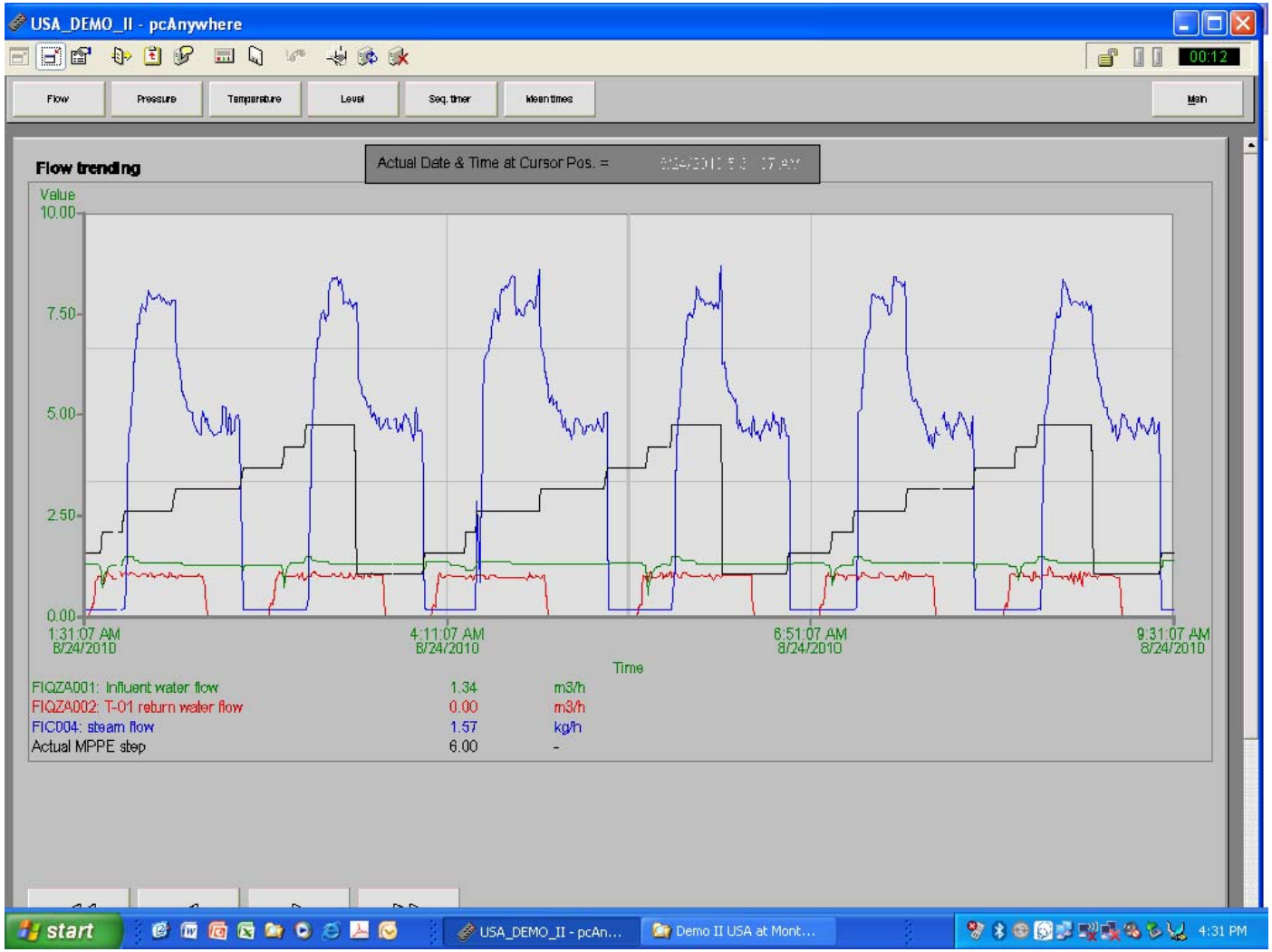
# Appendix 4: Typical Trending Data; Flow



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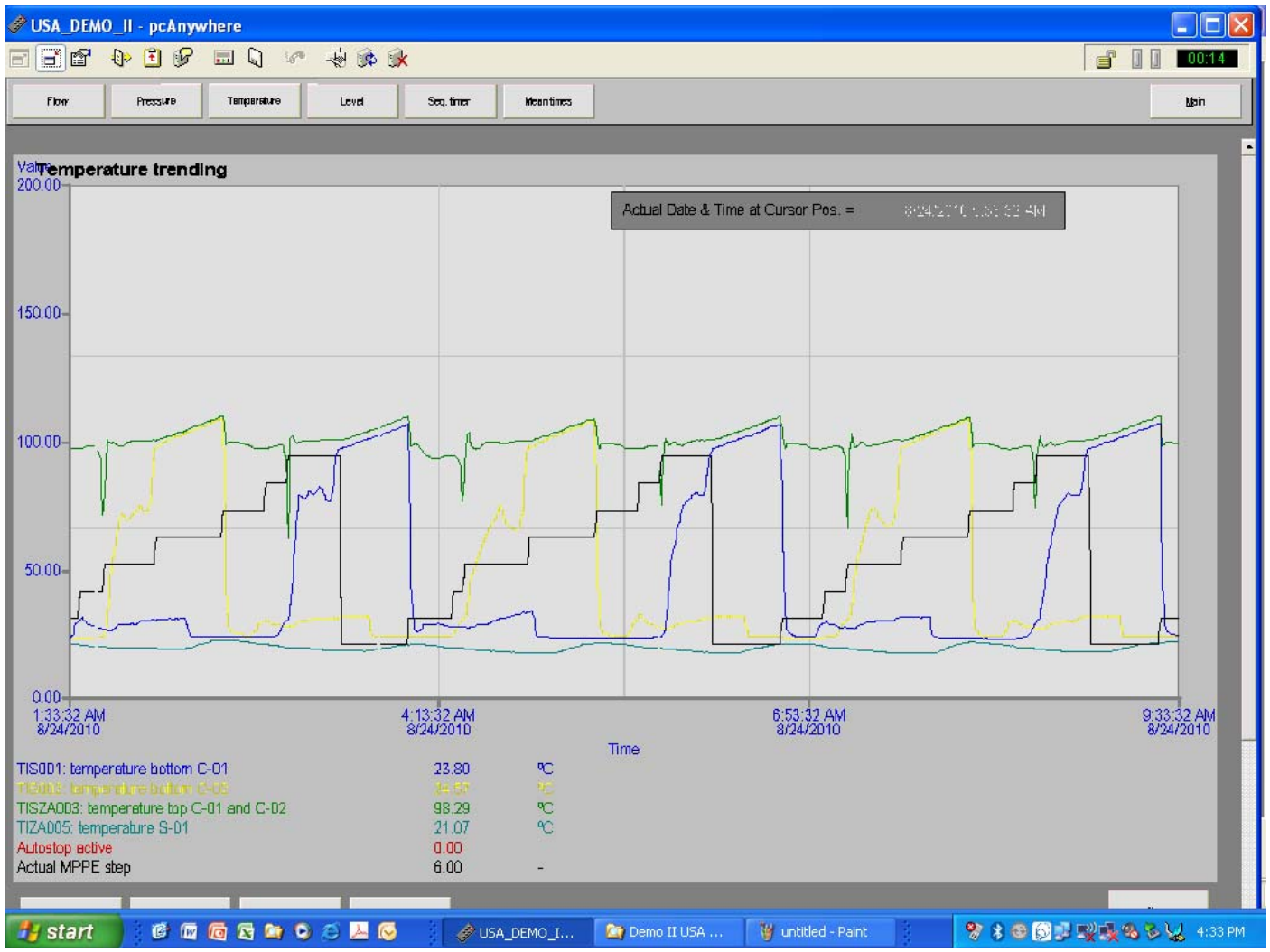
# Appendix 5: Typical Trending Data; Temperature



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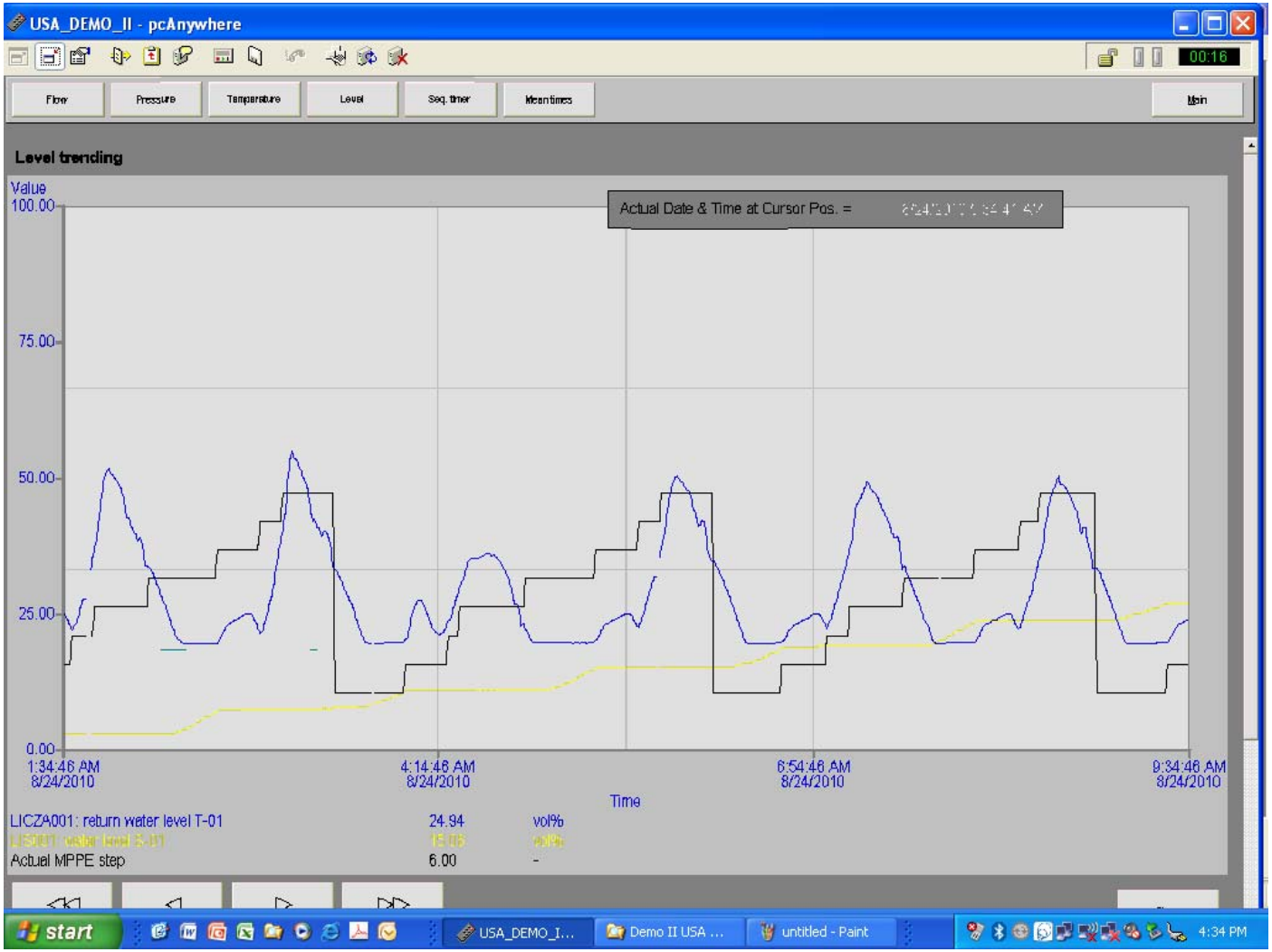
# Appendix 6: Typical Trending Data; Level



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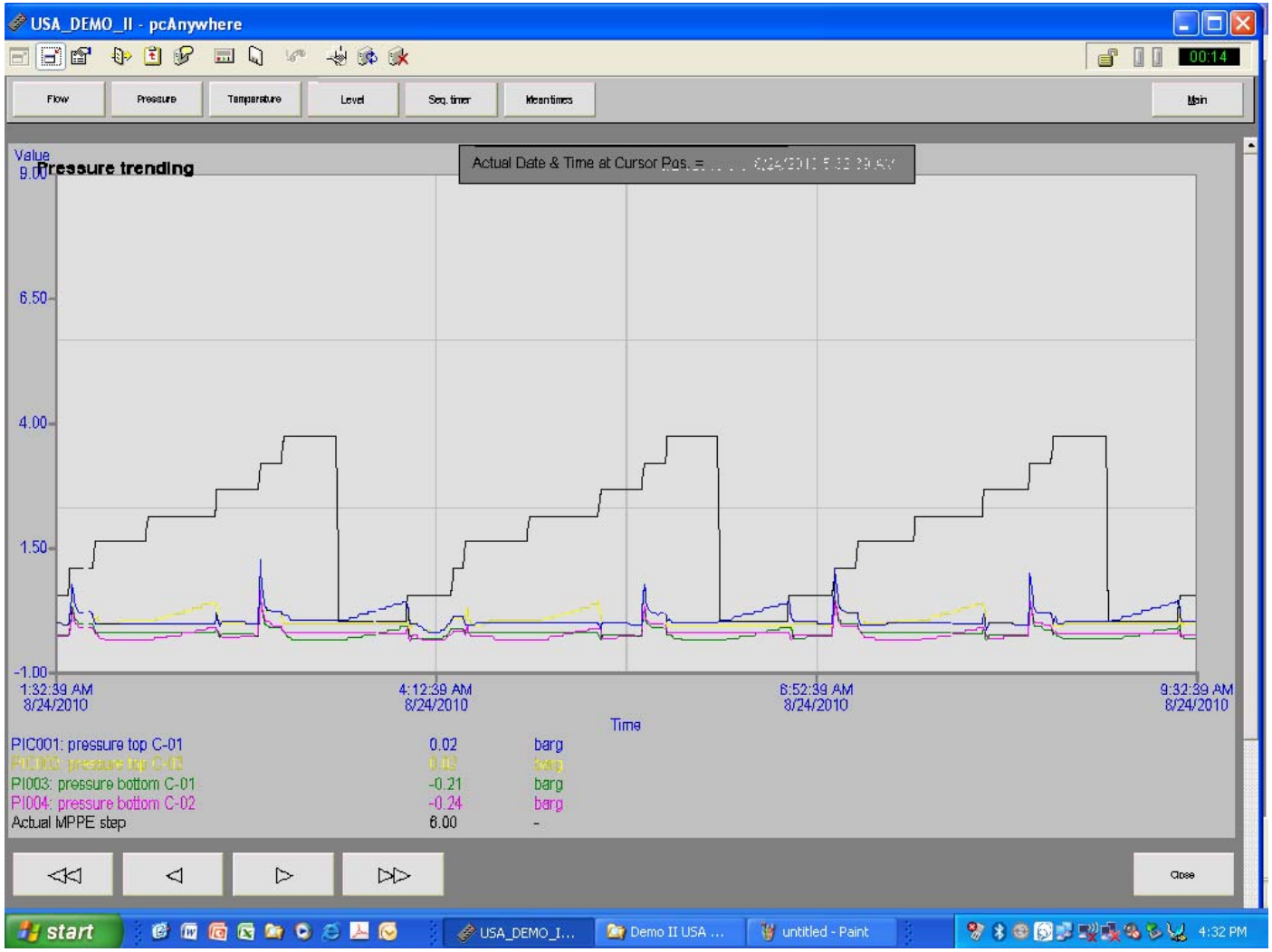
# Appendix 7: Typical Trending Data; Pressure



# Attachment 2

# Macro Porous Polymer Extraction
# Pilot-Scale Test Procedures

**ATTACHMENT 2**

**Macro Porous Polymer Extraction Pilot-Scale Test Procedures**
**Torrance Groundwater Remedial System**
**Torrance, California**

## 1. INTRODUCTION

This document describes the methodology and procedures used to test the Macro Porous Polymer Extraction ("MPPE") water treatment technology in pilot-scale for potential use in the full-scale Torrance Groundwater Remedial System ("TGRS"). This document includes a detailed description of the MPPE pilot-scale test, an analysis of the testing data, and a summary of the operational observations made during the test.

## 2. GROUNDWATER PUMPING AND INFLUENT MIXING

The MPPE pilot-scale equipment was staged near extraction wells MBFB-EW-1 and BF-EW-1 (Figure 1). Figure 2 shows the approximate layout of the pilot-scale test equipment and immediate surroundings. During the pilot-scale test, water was extracted from extraction wells BF-EW-1 and MBFB-EW-1. Approximately 95 percent of the groundwater used in the test was extracted from BF-EW-1 and 5 percent from MBFB-EW-1. The pump in MBFB-EW-1 was set at approximately 70 feet below ground surface ("ft-bgs") and had an average flow rate of 6 gallons per minute ("gpm"). The pump in BF-EW-1 was set at approximately 80 ft-bgs and had an average flow rate of 17 gpm. During the first week of the test, BF-EW-1 was pumped for approximately 20 hours at a time and then MBFW-EW-1 was pumped for approximately 3 hours at a time to achieve the desired mixture in the influent holding tank. However, during the second week of the test, MBFB-EW-1 could not sustain this duration of pumping. The pumping intervals were shortened while still achieving the desired mixture.

The extracted groundwater was pumped into one of two closed influent holding and mixing tanks. The tanks held approximately 21,000 gallons each and contained a submersible recirculation pump that was capable of pumping at approximately 450 gpm. Before the influent water from the tank was fed to the MPPE system, it was mixed by using the submersible pump. At least one tank volume of water was passed through the pump for mixing before the water was pumped through the pilot-scale MPPE unit.

## 3. MPPE TESTING PROTOCOLS

The MPPE pilot-scale equipment consisted of five main components including the MPPE columns, MPPE media, boiler, condenser, and separator. Associated process equipment used with the MPPE pilot-scale equipment included influent tanks, boiler feed pump, liquid-phase granular activated carbon (LGAC) unit, hydrant water holding tank, chemical feed pump, static mixer, ground water pumps, reinforced hoses and flexible hose.

The MPPE pilot-scale process flow diagram is shown in Figure 3. The MPPE pilot-scale test unit was operated at the Site for approximately 13 days from August 23, 2010, to September 4, 2010. Additionally, start-up testing was conducted on August 12, 2010, when the test unit was run for approximately 8 hours to test the performance prior to continuous operation. The test unit was stopped periodically for maintenance, but it was operated approximately 90% of the time. Maintenance steps included removing liquid from the separators or tank, changing bag filters, repairing the condenser, and performing generator maintenance.

The influent flow rate and duration of each flow rate step was varied throughout the pilot-scale test to evaluate the MPPE removal capacity in a variety of situations. The test unit operated in three protocol modes over the duration of the test; step test protocol, continuous flow protocol, and spike test protocol. The modes are described as follows:

- Step Test Protocol: The purpose of the step test protocol was to evaluate the removal efficiency of the MPPE test unit at various flow rates. The step test mode was run at the following flow rates: 3 gpm, 6 gpm, 9 gpm, 10 gpm, 12 gpm, 15 gpm, 20 gpm, 25 gpm, 35 gpm, and 40 gpm. Each step was operated at least 4 hours in duration and at least two or more samples were collected during each step. Step test mode was operated from August 23, 2010 to August 27, 2010.

- Continuous Flow Protocol: The purpose of the continuous flow protocol was to evaluate the MPPE test unit at a constant flow rate of 15 gpm. This flow rate was chosen based on input from Whittier and the production rate of the extraction pumps in BF-EW-1 and MBFB-EW-1. During the continuous flow test, samples were collected approximately every six hours. The continuous flow mode was operated from August 28, 2010 to September 3, 2010 (approximately 7 days).

- Methylene Chloride Spike Study: During the step test protocol and continuous flow protocol, the high concentrations of VOCs (primarily chlorobenzene) relative to the

methylene chloride caused methylene chloride to be non-detectable in the influent samples. Because the predicted MPPE pilot-scale test influent concentration range of methylene chloride was below the test detection limit of 52 micrograms per liter ("µg/L"), the influent was spiked with methylene chloride to achieve a target influent concentration of approximately 100 µg/L. During the spike test a chemical dosing pump was used to feed a 200 milligrams per liter ("mg/L") solution of methylene chloride into the influent groundwater stream. A static inline mixer was installed in the influent line to achieve a well-mixed influent prior to the influent sampling port (see Figure 3). The spike step test mode was operated as the last step of the pilot-scale test on September 3, 2010 and September 4, 2010. Similar to the step test, several flow rates were operated during this step for approximately 4 hours each. Two samples were collected during each step.

Samples collected from the MPPE test unit during the pilot-scale test were collected from the influent and effluent during each sampling event to provide a comparable influent stream sample for each effluent sample collected. Samples were analyzed for VOCs by USEPA Method 8260B, and a subset were analyzed for organochlorine pesticides by EPA Method 8081A and pCBSA by USEPA Method 314.0M.

The work described herein was completed in general accordance with the Revised Macro Porous Polymer Extraction Pilot-Scale Work Plan that was submitted to USEPA on August 13, 2010 ("Advisory and Work Plan").[1] The few notable exceptions include:

- The filtration test described in the Advisory and Work Plan was not conducted. The MPPE test unit was equipped with 25 micrometer (micron) filters that were cleaned out twice. Additional filtration would have required more head pressure, which was decided against to maintain focus on the flowrate and pressure needs of the MPPE system.

- The spike step test as described above was conducted based on the high method detection limits relative to the concentration of methylene chloride in the water.

[1] Geosyntec Consultants; Results of Macro Porous Polymer Extraction Bench-Scale Testing and Revised Pilot-Scale Workplan; Dual Site Groundwater Operable Unit; Torrance, California. August 13, 2010.

- Samples were collected for three flow rates during the step test to evaluate the ability of the MPPE media used in the pilot-test to remove pCBSA.

- The two-phase separator configuration of the MPPE pilot-scale test equipment did not allow the collection of data that could be used to prepare a mass balance across the pilot-scale system. The separator, which was not configured to handle the three liquid phases produced at the Site, accumulated a significant amount of water into the organic liquid waste. Thus, the amount of liquid waste generated was not solely due to the removed VOCs. As was learned during the test, pCBSA was also removed by the MPPE. However, pCBSA data were not collected from each of the flow steps, thereby making for an uncertain calculation of the amount of mass of pCBSA removed. Finally, based on the proprietary nature of the resin (an added concern to Montrose) Whittier Filtration would not provide samples of the MPPE media for chemical testing before or after the test.

## 4. SUMMARY OF ANALYTICAL RESULTS

Analytical data collected during the MPPE pilot-scale test are summarized in the following accompanying tables:

- *Table 1:* Step Test Data Summary (includes VOC and pesticide data);

- *Table 2:* Continuous Flow Data Summary (includes VOC and pesticide data);

- *Table 3:* Spike Step Test Data Summary (includes VOC data from methylene chloride spike tests); and

- *Table 4:* pCBSA Results Summary (includes pCBSA data collected during the step test)

Tables 1 through 3 include calculations of the removal efficiency for each chemical and the coefficient of variation of each flowrate data set. The removal efficiency provides insight into the effectiveness of the MPPE system and the coefficient of variation provides information on the precision of data collected during each flowrate. Data plots for key constituents are included in Figures 4 through 7.

## 5. SUMMARY OF OPERATIONAL OBSERVATIONS

The pilot-scale test was also used to gather information related to the operation of the MPPE system. Major observations of the MPPE operation include:

- During the continuous flow test mode the MPPE system was operated for approximately 7 days and generated reliable data for 23 sample sets collected during that time.

- During the testing period a light-phase organic liquid accumulated in the onboard condensed steam holding tank. This occurred because the separators were equipped to remove only the heavy organic liquid from the condensed steam. Since the water was drawn from the bottom of this tank, the pilot-scale test was successful despite the presence of floating organic liquid in the onboard holding tank. However, this pilot-scale configuration would be modified in full-scale design by designing a separation system for the three separate liquid phases.

- The organic liquid that was removed from the groundwater was treated as hazardous waste and was not recyclable because of the presence of pesticides. In addition, the quantity of organic liquid was greater than anticipated because of the unexpected removal of pCBSA by the MPPE media.

- The MPPE system was operated with no major operational issues; although the system is fairly complex with numerous mechanical parts, the system was fully automated and required relatively little oversight during the short-term pilot-scale test.

- Numerous mechanical connections exist that need to be monitored for leaks.

## 6. PERMITTING

During the pilot-scale testing, several permits were secured to comply with applicable regulations. A brief description of each is included below.

- National Pollutant Discharge Elimination System Permit ("NPDES permit"); Los Angeles Regional Water Quality Control Board – Montrose has an existing NPDES permit for discharge to the storm drain system (NDPES Permit Number CAG994004, CI-8819). The permit specifies numeric limits for water quality parameters and flow. Treated water samples were collected to confirm that the treated water was in

compliance prior to discharge. During the pilot-scale test the effluent was discharged continuously in accordance with this permit.

- Industrial Waste Discharge Permit ("IDW permit"); Los Angeles County Department of Public Works, Environmental Programs Division – An IDW permit was obtained for discharge to the LA County storm drain system. The IDW permit provided additional numeric water quality limitations.

- Flood Control District Permit ("flood permit"); Los Angeles County Department of Public Works – The flood permit was obtained because the discharge locations include water conveyance pathways that are under the jurisdiction of the Flood Control District.

- Bureau of Street Services ("BSS permit"); City of Los Angeles – A permit was secured with the BSS for the hose that ran from the hydrant to the pilot-scale testing location (approximately 400 feet).

- Right of Entry Agreement ("UPRR permit"); Union Pacific Rail Road – The UPRR permit allowed access to the inactive railroad track to the north of the pilot-scale test location to access Outfall 1.

## 7. WASTE DISPOSAL

The wastes associated with the pilot-scale test include: the MPPE media, LGAC, personal protective equipment ("PPE"), and extracted organic liquids. The PPE and extracted organic product were disposed as hazardous waste. The extracted organic liquid was disposed at a thermal treatment facility to destroy the trace pesticides that are present in the liquid. The LGAC was disposed as non-hazardous waste.

## 8. QUALITY CONTROL DATA

During the pilot-scale test duplicates and field blanks were collected. Approximately 10% duplicates were collected and field blanks were collected for 10 of 14 days the system was operated. The quality control samples are summarized as follows:

- Table 5: Duplicates – Samples collected from the influent in which both compounds were reported above the detection limit in general were reported to have a relative percent difference (RPD) of less than 25 percent, except for the trichloroethene at the 3 gpm step. In the effluent, the RPD was higher in several cases due to the fact that

detections were lower and close to the detection limit. The magnitudes of the differences were relatively small.

- Table 6: Field Blanks - Field blanks collected during the bench-scale test were reported to contain trace amounts of 2-butanone, chlorobenzene, chloroform, and chloromethane. The concentrations in the field blanks are relatively low and do not warrant qualification of MPPE pilot-scale test data for TGRS constituents

Data from the field duplicates and field blanks indicate that the MPPE pilot-scale test data are reliable.

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Figure 4: Step Test Data Plot
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Geosyntec consultants

# TABLE 1
# STEP TEST DATA SUMMARY
# MPPE PILOT-SCALE TREATMENT TEST
# DUAL SITE GROUNDWATER OPERABLE UNIT

| | EPA 8260B | | | | | | | | EPA 8081A | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Name** | **1,2-Dichloroethane** | **1,4-Dichlorobenzene** | **Benzene** | **Chlorobenzene** | **Chloroform** | **Methylene Chloride** | **Tetrachloroethene** | **Trichloroethene** | **Alpha-BHC** | **Beta-BHC** | **Gamma-BHC** |
| Units | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| ***Anticipated Full Scale TGRS Influent Concentration - Full Stream*** (1) | 9 | 17 | 248 | 13,900 | 336 | 16 | 168 | 38 | 0.42 | 0.31 | 0.59 |
| ***Anticipated Full Scale TGRS Influent Concentration - Side Stream*** (2) | 8 | 19 | 444 | 19,159 | 322 | 28 | 293 | 69 | 0.65 | 648.00 | 1.01 |
| ***Regulatory Criteria*** (3) | 0.5 | 5 | 1 | 70 | 100 | 5 | 5 | 5 | 0.011 | 0.037 | 0.2 |
| ***Anticipated MPPE Pilot Test Influent Concentration*** (4) | 23 | 39 | 1031 | 35,200 | 1710 | 35 | 60 | 53 | 0.18 | 0.608 | 0.35 |
| **Flow Step: 3 gpm** | | | | | | | | | | | |
| MPPE-IN-3A | <8.7 | 35 | 350 | 19000 | 370 | <21 | <13 | 30 | 0.17 | 0.6 | 0.32 |
| MPPE-EFF-3A | <0.13 | <0.16 | <0.16 | <0.17 | <0.16 | <0.32 | <0.2 | <0.16 | <0.005 | <0.0083 | <0.0066 |
| Removal Efficiency(5) (%) | - | 99.54% | 99.95% | 99.999% | 99.96% | - | - | 99.47% | 97.06% | 98.62% | 97.94% |
| MPPE-IN-3B | <8.7 | 36 | 340 | 18000 | 340 | <21 | <13 | 34 | 0.17 | 0.61 | 0.31 |
| MPPE-EFF-3B | <0.13 | <0.16 | <0.16 | <0.17 | <0.16 | <0.32 | <0.2 | <0.16 | <0.0051 | <0.0084 | <0.0066 |
| Removal Efficiency(5) (%) | < | 99.56% | 99.95% | 99.999% | 99.95% | - | - | 99.53% | 97.00% | 98.62% | 97.87% |
| MPPE-IN-3C | <8.7 | 24 | 340 | 19000 | 350 | <21 | <13 | 21 | 0.18 | 0.63 | 0.33 |
| MPPE-EFF-3C | <0.13 | <0.16 | <0.16 | <0.17 | <0.16 | <0.32 | <0.2 | <0.16 | <0.005 | <0.0083 | <0.0066 |
| Removal Efficiency(5) (%) | - | 99.33% | 99.95% | 99.999% | 99.95% | - | - | 99.24% | 97.22% | 98.68% | 98.00% |
| **Average Removal Efficiency (%)** | **-** | **99.48%** | **99.95%** | **99.999%** | **99.95%** | **-** | **-** | **99.41%** | **97.09%** | **98.64%** | **97.94%** |
| Coefficient of Variation, (%) | - | 0.13% | 0.00% | 0.00% | 0.00% | - | - | 0.15% | 0.12% | 0.04% | 0.07% |
| **Flow Step: 6 gpm** | | | | | | | | | | | |
| MPPE-Inf-6A | 17 | 25 | 320 | 30000 | 280 | <52 | <10 | 27 | 0.15 | 0.53 | 0.29 |
| MPPE-Eff-6A | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | 98.18% | 99.16% | 99.91% | 99.999% | 99.88% | - | - | 98.89% | 91.33% | 98.45% | 93.10% |
| MPPE-In-6B | 18 | 25 | 320 | 26000 | 260 | <52 | <10 | 29 | 0.15 | 0.53 | 0.28 |
| MPPE-Eff-6B | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | 98.28% | 99.16% | 99.91% | 99.999% | 99.87% | - | - | 98.97% | 91.33% | 98.45% | 92.86% |
| **Average Removal Efficiency (%)** | **98.23%** | **99.16%** | **99.91%** | **99.999%** | **99.88%** | **-** | **-** | **98.93%** | **91.33%** | **98.45%** | **92.98%** |
| Coefficient of Variation, (%) | 0.073% | 0.00% | 0.00% | 0.00% | 0.01% | - | - | 0.05% | 0.00% | 0.00% | 0.19% |
| **Flow Step: 9 gpm** | | | | | | | | | | | |
| MPPE-In-9A | <78 | 62 | 900 | 24000 | 530 | <650 | <130 | <76 | 0.16 | 0.5 | 0.26 |
| MPPE-Eff-9A | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.66% | 99.97% | 99.999% | 99.94% | - | - | | 91.88% | 98.36% | 92.31% |
| MPPE-In-9B | <78 | 69 | 1300 | 32000 | 700 | <650 | <130 | <76 | 0.14 | 0.44 | 0.23 |
| MPPE-Eff-9B | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.70% | 99.98% | 99.999% | 99.95% | - | - | - | 90.71% | 98.14% | 91.30% |
| **Average Removal Efficiency (%)** | **-** | **99.68%** | **99.97%** | **99.999%** | **99.95%** | **-** | **-** | **-** | **91.29%** | **98.25%** | **91.81%** |
| Coefficient of Variation, (%) | - | 0.02% | 0.01% | 0.00% | 0.01% | - | - | - | 0.90% | 0.16% | 0.77% |

# TABLE 1
## STEP TEST DATA SUMMARY
## MPPE PILOT-SCALE TREATMENT TEST
## DUAL SITE GROUNDWATER OPERABLE UNIT

| | EPA 8260B | | | | | | | | EPA 8081A | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Name** | **1,2-Dichloroethane** | **1,4-Dichlorobenzene** | **Benzene** | **Chlorobenzene** | **Chloroform** | **Methylene Chloride** | **Tetrachloroethene** | **Trichloroethene** | **Alpha-BHC** | **Beta-BHC** | **Gamma-BHC** |
| Units | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| ***Anticipated Full Scale TGRS Influent Concentration - Full Stream*** (1) | 9 | 17 | 248 | 13,900 | 336 | 16 | 168 | 38 | 0.42 | 0.31 | 0.59 |
| ***Anticipated Full Scale TGRS Influent Concentration - Side Stream*** (2) | 8 | 19 | 444 | 19,159 | 322 | 28 | 293 | 69 | 0.65 | 648.00 | 1.01 |
| ***Regulatory Criteria*** (3) | 0.5 | 5 | 1 | 70 | 100 | 5 | 5 | 5 | 0.011 | 0.037 | 0.2 |
| ***Anticipated MPPE Pilot Test Influent Concentration*** (4) | 23 | 39 | 1031 | 35,200 | 1710 | 35 | 60 | 53 | 0.18 | 0.608 | 0.35 |
| **Flow Step: 10 gpm** | | | | | | | | | | | |
| MPPE-IN-10A | <8.7 | 35 | 320 | 18000 | 340 | <21 | <13 | 31 | - | - | - |
| MPPE-EFF-10A | <0.13 | <0.16 | <0.16 | <0.17 | <0.16 | <0.32 | <0.2 | <0.16 | - | - | - |
| Removal Efficiency(5) (%) | - | 99.54% | 99.95% | 99.999% | 99.95% | - | - | 99.48% | - | - | - |
| MPPE-IN-10B | <8.7 | 35 | 340 | 19000 | 340 | <21 | <13 | 30 | - | - | - |
| MPPE-EFF-10B | <0.13 | <0.16 | <0.16 | <0.17 | <0.16 | <0.32 | <0.2 | <0.16 | - | - | - |
| Removal Efficiency(5) (%) | - | 99.54% | 99.95% | 99.999% | 99.95% | - | - | 99.47% | - | - | - |
| **Average Removal Efficiency (%)** | **-** | **99.54%** | **99.95%** | **99.999%** | **99.95%** | **-** | **-** | **99.48%** | **-** | **-** | **-** |
| Coefficient of Variation, (%) | - | 0.00% | 0.00% | 0.00% | 0.00% | - | - | 0.012% | - | - | - |
| **Flow Step: 12 gpm** | | | | | | | | | | | |
| MPPE-In-12A | <63 | <42 | 630 | 18000 | 430 | <520 | <100 | <61 | 0.13 | 0.39 | 0.23 |
| MPPE-Eff-12A | <0.31 | <0.21 | <0.28 | <0.22 | 0.49 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | - | 99.96% | 99.999% | 99.89% | - | - | - | 90.00% | 97.90% | 91.30% |
| MPPE-Inf-12A | <63 | <42 | 620 | 18000 | 450 | <520 | <100 | <61 | 0.17 | 0.63 | 0.3 |
| MPPE-Eff-12A | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | - | 99.95% | 99.999% | 99.93% | - | - | - | 92.35% | 98.70% | 93.33% |
| MPPE-IN-12B | <63 | <42 | 590 | 17000 | 430 | <520 | <100 | <61 | 0.14 | 0.54 | 0.25 |
| MPPE-Eff-12B | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | - | 99.95% | 99.999% | 99.92% | - | - | - | 90.71% | 98.48% | 92.00% |
| **Average Removal Efficiency (%)** | **-** | **-** | **99.95%** | **99.999%** | **99.91%** | **-** | **-** | **-** | **91.02%** | **98.36%** | **92.21%** |
| Coefficient of Variation, (%) | - | - | 0.00% | 0.00% | 0.02% | - | - | - | 1.33% | 0.42% | 1.12% |
| **Flow Step: 15 gpm** | | | | | | | | | | | |
| MPPE-In-15A | <63 | <42 | 1100 | 22000 | 510 | <520 | <100 | <61 | 0.16 | 0.48 | 0.24 |
| MPPE-Eff-15A | <0.31 | <0.21 | <0.28 | <0.22 | 0.42 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | < | 99.97% | 99.999% | 99.92% | - | - | - | 91.88% | 98.29% | 91.67% |
| MPPE-In-15B | <63 | 46 | 1100 | 25000 | 620 | <520 | <100 | <61 | 0.14 | 0.45 | 0.23 |
| MPPE-Eff-15B | <0.31 | <0.21 | <0.28 | <0.22 | 0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.54% | 99.97% | 99.999% | 99.95% | - | - | - | 90.71% | 98.18% | 91.30% |
| MPPE-In-15C | <0.31 | 36 | 710 | 18000 | 330 | 7.4 | 13 | 39 | 0.14 | 0.47 | 0.24 |
| MPPE-Eff-15C | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.42% | 99.96% | 99.999% | 99.90% | 64.86% | 96.08% | 99.23% | 90.71% | 98.26% | 91.67% |
| **Average Removal Efficiency (%)** | **-** | **99.48%** | **99.97%** | **99.999%** | **99.92%** | **-** | **-** | **99.23%** | **91.10%** | **98.24%** | **91.55%** |
| Coefficient of Variation, (%) | - | 0.09% | 0.01% | 0.00% | 0.03% | - | - | - | 0.00% | 0.06% | 0.28% |

# TABLE 1
## STEP TEST DATA SUMMARY
## MPPE PILOT-SCALE TREATMENT TEST
## DUAL SITE GROUNDWATER OPERABLE UNIT

| | EPA 8260B | | | | | | | | EPA 8081A | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Name** | **1,2-Dichloroethane** | **1,4-Dichlorobenzene** | **Benzene** | **Chlorobenzene** | **Chloroform** | **Methylene Chloride** | **Tetrachloroethene** | **Trichloroethene** | **Alpha-BHC** | **Beta-BHC** | **Gamma-BHC** |
| Units | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| ***Anticipated Full Scale TGRS Influent Concentration - Full Stream*** (1) | 9 | 17 | 248 | 13,900 | 336 | 16 | 168 | 38 | 0.42 | 0.31 | 0.59 |
| ***Anticipated Full Scale TGRS Influent Concentration - Side Stream*** (2) | 8 | 19 | 444 | 19,159 | 322 | 28 | 293 | 69 | 0.65 | 648.00 | 1.01 |
| ***Regulatory Criteria*** (3) | 0.5 | 5 | 1 | 70 | 100 | 5 | 5 | 5 | 0.011 | 0.037 | 0.2 |
| ***Anticipated MPPE Pilot Test Influent Concentration*** (4) | 23 | 39 | 1031 | 35,200 | 1710 | 35 | 60 | 53 | 0.18 | 0.608 | 0.35 |
| **Flow Step: 20 gpm** | | | | | | | | | | | |
| MPPE-In-20A | <7.8 | 41 | 810 | 23000 | 430 | <65 | <13 | 52 | 0.15 | 0.47 | 0.24 |
| MPPE-Eff-20A | <0.31 | <0.21 | <0.28 | <0.22 | 0.4 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.49% | 99.97% | 99.999% | 99.91% | - | - | 99.42% | 91.33% | 98.26% | 91.67% |
| MPPE-In-20B | <63 | 50 | 910 | 22000 | 440 | - | <100 | <61 | 0.17 | 0.57 | 0.25 |
| MPPE-Eff-20B | <0.31 | <0.21 | 0.77 | <0.22 | 1.4 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.58% | 99.92% | 99.999% | 99.68% | - | - | < | 92.35% | 98.56% | 92.00% |
| **Average Removal Efficiency (%)** | **-** | **99.53%** | **99.94%** | **99.999%** | **99.79%** | **-** | **-** | **99.42%** | **91.84%** | **98.41%** | **91.83%** |
| Coefficient of Variation, (%) | - | 0.07% | 0.04% | 0.00% | 0.16% | - | - | - | 0.79% | 0.22% | 0.26% |
| **Flow Step: 25 gpm** | | | | | | | | | | | |
| MPPE-In-25A | <63 | <42 | 670 | 16000 | 340 | <520 | <100 | <61 | 0.14 | 0.46 | 0.23 |
| MPPE-Eff-25A | <0.31 | <0.21 | 62 | 13 | 33 | <2.6 | <0.51 | 1.8 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | - | 90.75% | 99.919% | 90.29% | - | - | - | 90.71% | 98.22% | 91.30% |
| MPPE-In-25B | <63 | 47 | 820 | 21000 | 460 | <520 | <100 | 61 | 0.17 | 0.64 | 0.28 |
| MPPE-Eff-25B | <0.31 | <0.21 | 2 | <0.22 | 3.7 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.55% | 99.76% | 99.999% | 99.20% | - | - | 99.51% | 92.35% | 98.72% | 92.86% |
| **Average Removal Efficiency (%)** | **-** | **99.55%** | **95.25%** | **99.959%** | **94.74%** | **-** | **-** | **99.51%** | **91.53%** | **98.47%** | **92.08%** |
| Coefficient of Variation, (%) | - | - | 6.69% | 0.06% | 6.64% | - | - | - | 1.27% | 0.36% | 1.19% |
| **Flow Step: 30 gpm** | | | | | | | | | | | |
| MPPE-In-30A | <0.31 | 38 | 730 | 18000 | 340 | 7.2 | 14 | 43 | 0.14 | 0.47 | 0.24 |
| MPPE-Eff-30A | <0.31 | <0.21 | 20 | 1.5 | 13 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.45% | 97.26% | 99.992% | 96.18% | 63.89% | 96.36% | 99.30% | 90.71% | 98.26% | 91.67% |
| MPPE-In-30B | <0.31 | 35 | 710 | 18000 | 350 | 6.7 | 13 | 40 | 0.13 | 0.43 | 0.24 |
| MPPE-Eff-30B | <0.31 | <0.21 | 0.59 | <0.22 | 1.4 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.40% | 99.92% | 99.999% | 99.60% | 61.19% | 96.08% | 99.25% | 90.00% | 98.09% | 91.67% |
| MPPE-In-30C | <63 | <42 | 600 | 21000 | 500 | <520 | <100 | 68 | - | - | - |
| MPPE-Eff-30C | <0.31 | <0.21 | <0.28 | 0.6 | 0.76 | <2.6 | <0.51 | <0.3 | - | - | - |
| Removal Efficiency(5) (%) | - | - | 99.95% | 99.997% | 99.85% | - | - | 99.56% | - | - | - |
| MPPE-In-30D | <63 | <42 | 600 | 22000 | 510 | <520 | <100 | 64 | - | - | - |
| MPPE-Eff-30D | <0.31 | <0.21 | 0.74 | 9.8 | 2 | <2.6 | <0.51 | <0.3 | - | - | - |
| Removal Efficiency(5) (%) | - | - | 99.88% | 99.955% | 99.61% | - | - | 99.53% | - | - | - |
| **Average Removal Efficiency (%)** | **-** | **99.42%** | **99.92%** | **99.984%** | **99.69%** | **62.54%** | **96.22%** | **99.41%** | **90.36%** | **98.17%** | **91.67%** |
| Coefficient of Variation, (%) | - | 0.03% | 1.34% | 0.02% | 1.78% | 3.05% | 0.21% | 0.16% | 0.56% | 0.12% | 0.00% |

# TABLE 1
## STEP TEST DATA SUMMARY
## MPPE PILOT-SCALE TREATMENT TEST
## DUAL SITE GROUNDWATER OPERABLE UNIT

| Sample Name | EPA 8260B | | | | | | | | EPA 8081A | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1,2-Dichloroethane | 1,4-Dichlorobenzene | Benzene | Chlorobenzene | Chloroform | Methylene Chloride | Tetrachloroethene | Trichloroethene | Alpha-BHC | Beta-BHC | Gamma-BHC |
| Units | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| ***Anticipated Full Scale TGRS Influent Concentration - Full Stream*** (1) | 9 | 17 | 248 | 13,900 | 336 | 16 | 168 | 38 | 0.42 | 0.31 | 0.59 |
| ***Anticipated Full Scale TGRS Influent Concentration - Side Stream*** (2) | 8 | 19 | 444 | 19,159 | 322 | 28 | 293 | 69 | 0.65 | 648.00 | 1.01 |
| ***Regulatory Criteria*** (3) | 0.5 | 5 | 1 | 70 | 100 | 5 | 5 | 5 | 0.011 | 0.037 | 0.2 |
| ***Anticipated MPPE Pilot Test Influent Concentration*** (4) | 23 | 39 | 1031 | 35,200 | 1710 | 35 | 60 | 53 | 0.18 | 0.608 | 0.35 |
| **Flow Step: 35 gpm** | | | | | | | | | | | |
| MPPE-In-35A | <63 | <42 | 1100 | 21000 | 490 | <520 | <100 | <61 | 0.17 | 0.47 | 0.25 |
| MPPE-Eff-35A | 3.8 | <0.21 | 42 | 6.1 | 31 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | - | 96.18% | 99.971% | 93.67% | - | - | - | 92.35% | 98.26% | 92.00% |
| MPPE-In-35B | <63 | 64 | 2000 | 37000 | 880 | <520 | <100 | 98 | 0.099 | 0.29 | 0.15 |
| MPPE-Eff-35B | 0.61 | <0.21 | 6.5 | 0.54 | 6.2 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.67% | 99.68% | 99.999% | 99.30% | - | - | 99.69% | 86.87% | 97.17% | 86.67% |
| **Average Removal Efficiency (%)** | **-** | **99.67%** | **97.93%** | **99.985%** | **96.48%** | **-** | **-** | **99.69%** | **89.61%** | **97.71%** | **89.33%** |
| Coefficient of Variation, (%) | - | - | 2.52% | 0.02% | 4.12% | - | - | - | 4.33% | 0.78% | 4.22% |
| **Flow Step: 40 gpm** | | | | | | | | | | | |
| MPPE-In-40A | <6.3 | 76 | 1400 | 36000 | 790 | <52 | 22 | 87 | 0.14 | 0.45 | 0.22 |
| MPPE-Eff-40A | 0.78 | <0.21 | 8.7 | 0.67 | 10 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.72% | 99.38% | 99.998% | 98.73% | - | 97.68% | 99.66% | 90.71% | 98.18% | 90.91% |
| MPPE-In-40B | <6.3 | 50 | 920 | 24000 | 510 | <52 | 23 | 61 | 0.17 | 0.52 | 0.27 |
| MPPE-Eff-40B | 3 | <0.21 | 50 | 9.7 | 34 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(5) (%) | - | 99.58% | 94.57% | 99.960% | 93.33% | - | 97.78% | 99.51% | 92.35% | 98.42% | 92.59% |
| **Average Removal Efficiency (%)** | **-** | **99.65%** | **96.97%** | **99.979%** | **96.03%** | **-** | **97.73%** | **99.58%** | **91.53%** | **98.30%** | **91.75%** |
| Coefficient of Variation, (%) | - | 0.10% | 3.51% | 0.03% | 3.98% | - | 0.073% | 0.10% | 1.27% | 0.18% | 1.30% |

NOTES:
(1) Based on modeling conducted after April 2009 groundwater monitoring results; assumes flow rate of 700 gpm
(1) Based on modeling conducted after April 2009 groundwater monitoring results; assumes side stream flow rate of 380 gpm
(3) Regulatory Requirements as outlined in ROD
(4) Based on influent stream on 95 percent by volume form BF-EW-1 and 5 percent by volume from MBFB-EW-1
(5) Where concentration was reported to be non detectable, method detection limit was used to calculate removal efficiency

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**TABLE 2**
**CONTINUOUS FLOW DATA SUMMARY**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

| | | EPA 8260B | | | | | | | | EPA 8081A | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Name** | **Sample Date** | **1,2-Dichloroethane** | **1,4-Dichlorobenzene** | **Benzene** | **Chlorobenzene** | **Chloroform** | **Methylene Chloride** | **Tetrachloroethene** | **Trichloroethene** | **Alpha-BHC** | **Beta-BHC** | **Gamma-BHC** |
| Units | | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| ***Anticipated Full Scale TGRS Influent Concentration*** (1) | | 9 | 17 | 248 | 13,900 | 336 | 16 | 168 | 38 | 0.42 | 0.31 | 0.59 |
| ***Regulatory Criteria*** (2) | | 0.5 | 5 | 1 | 70 | 100 | 5 | 5 | 5 | 0.011 | 0.037 | 0.2 |
| ***Anticipated MPPE Pilot Test Influent Concentration*** (3) | | 23 | 39 | 1031 | 35,200 | 1710 | 35 | 60 | 53 | 0.18 | 0.608 | 0.35 |
| MPPE-In-15C | 08/28/10 | <63 | 46 | 770 | 19000 | 410 | <520 | <100 | 39 | 0.16 | 0.63 | 0.26 |
| MPPE-Eff-15C | 08/26/10 | <0.31 | <0.21 | <0.28 | <0.22 | 0.45 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(4) (%) | | - | 99.54% | 99.96% | 99.999% | 99.89% | - | - | 99.23% | 91.88% | 98.70% | 92.31% |
| MPPE-In-15D | 08/28/10 | <63 | 46 | 760 | 20000 | 430 | <520 | <100 | <61 | 0.17 | 0.62 | 0.28 |
| MPPE-Eff-15D | 08/28/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(4) (%) | | - | 99.54% | 99.96% | 99.999% | 99.92% | - | - | - | 92.35% | 98.68% | 92.86% |
| MPPE-In-15E | 08/28/10 | <63 | 45 | 880 | 23000 | 500 | <520 | <100 | <61 | 0.15 | 0.5 | 0.23 |
| MPPE-Eff-15E | 08/28/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | <0.013 | <0.0082 | <0.02 |
| Removal Efficiency(4) (%) | | - | 99.53% | 99.97% | 99.999% | 99.93% | - | - | - | 91.33% | 98.36% | 91.30% |
| MPPE-In-15F | 08/28/10 | <63 | 52 | 910 | 24000 | 470 | <520 | <100 | <61 | | | |
| MPPE-Eff-15F | 08/28/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | 99.60% | 99.97% | 99.999% | 99.93% | - | - | - | | | |
| MPPE-In-15G | 08/29/10 | <63 | <42 | 750 | 19000 | 390 | <520 | <100 | <61 | | | |
| MPPE-Eff-15G | 08/29/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | - | 99.96% | 99.999% | 99.92% | - | - | - | | | |
| MPPE-In-15H | 08/29/10 | <63 | <42 | 800 | 20000 | 400 | <520 | <100 | <61 | | | |
| MPPE-Eff-15H | 08/29/10 | <0.31 | <0.21 | <0.28 | <0.22 | 0.37 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | - | 99.97% | 99.999% | 99.91% | - | - | - | | | |
| MPPE-In-15I | 08/29/10 | <63 | <42 | 730 | 18000 | 410 | <520 | <100 | <61 | | | |
| MPPE-Eff-15I | 08/29/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | - | 99.96% | 99.999% | 99.92% | - | - | - | | | |
| MPPE-IN-15J | 08/29/10 | <63 | <42 | 920 | 23000 | 450 | <520 | <100 | <61 | | | |
| MPPE-EFF-15J | 08/29/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | - | 99.97% | 99.999% | 99.93% | - | - | - | | | |
| MPPE-IN-15K | 08/30/10 | <31 | 39 | 870 | 23000 | 490 | <260 | <51 | 53 | | | |
| MPPE-EFF-15K | 08/30/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | < | 99.46% | 99.97% | 99.999% | 99.93% | < | < | 99.43% | | | |
| MPPE-In-14A | 08/30/10 | 59 | 36 | 790 | 18000 | 410 | <260 | <51 | 48 | | | |
| MPPE-Eff-14A | 08/30/10 | 6.2 | <0.21 | 15 | 0.77 | 25 | <2.6 | <0.51 | 0.98 | | | |
| Removal Efficiency(4) (%) | | 89.49% | 99.42% | 98.10% | 99.996% | 93.90% | < | < | 97.96% | | | |
| MPPE-In-15L | 08/30/10 | <31 | 36 | 790 | 19000 | 420 | <260 | <51 | 46 | | | |
| MPPE-Eff-15L | 08/30/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | 99.42% | 99.96% | 99.999% | 99.92% | - | - | 99.35% | | | |
| MPPE-In-15M | 08/31/10 | <31 | 35 | 730 | 17000 | 380 | <260 | <51 | 52 | | | |
| MPPE-Eff-15M | 08/31/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | 99.40% | 99.96% | 99.999% | 99.91% | - | - | 99.42% | | | |
| MPPE-In-15N | 08/31/10 | <63 | <42 | 820 | 24000 | 490 | <520 | <100 | 66 | | | |
| MPPE-Eff-15N | 08/31/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | - | 99.97% | 99.999% | 99.93% | - | - | 99.55% | | | |

**TABLE 2**
**CONTINUOUS FLOW DATA SUMMARY**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

| | | EPA 8260B | | | | | | | | EPA 8081A | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Name** | **Sample Date** | **1,2-Dichloroethane** | **1,4-Dichlorobenzene** | **Benzene** | **Chlorobenzene** | **Chloroform** | **Methylene Chloride** | **Tetrachloroethene** | **Trichloroethene** | **Alpha-BHC** | **Beta-BHC** | **Gamma-BHC** |
| Units | | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| ***Anticipated Full Scale TGRS Influent Concentration*** (1) | | 9 | 17 | 248 | 13,900 | 336 | 16 | 168 | 38 | 0.42 | 0.31 | 0.59 |
| ***Regulatory Criteria*** (2) | | 0.5 | 5 | 1 | 70 | 100 | 5 | 5 | 5 | 0.011 | 0.037 | 0.2 |
| ***Anticipated MPPE Pilot Test Influent Concentration*** (3) | | 23 | 39 | 1031 | 35,200 | 1710 | 35 | 60 | 53 | 0.18 | 0.608 | 0.35 |
| MPPE-In-15O | 08/31/10 | <63 | 54 | 780 | 23000 | 460 | <520 | <100 | <61 | | | |
| MPPE-Eff-15O | 08/31/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | 99.61% | 99.96% | 99.999% | 99.93% | - | - | - | | | |
| MPPE-In-15P | 09/01/10 | 41 | 38 | 620 | 17000 | 380 | <260 | <51 | 50 | | | |
| MPPE-Eff-15P | 09/01/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | 99.24% | 99.45% | 99.95% | 99.999% | 99.91% | - | - | 99.40% | | | |
| MPPE-In-15Q | 09/01/10 | 42 | 43 | 660 | 18000 | 400 | <260 | <51 | 49 | | | |
| MPPE-Eff-15Q | 09/01/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | 99.26% | 99.51% | 99.96% | 99.999% | 99.92% | - | - | 99.39% | | | |
| MPPE-In-15R | 09/01/10 | <63 | <42 | 760 | 22000 | 490 | <520 | <100 | 70 | | | |
| MPPE-Eff-15R | 09/01/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | - | 99.96% | 99.999% | 99.93% | - | - | 99.57% | | | |
| MPPE-In-15S | 09/01/10 | <63 | 42 | 730 | 22000 | 440 | <520 | <100 | <61 | | | |
| MPPE-Eff-15S | 09/01/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | 99.50% | 99.96% | 99.999% | 99.93% | - | - | - | - | | |
| MPPE-In-15T | 09/02/10 | <63 | 44 | 500 | 21000 | 500 | <520 | <100 | <61 | | | |
| MPPE-Eff-15T | 09/02/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | 99.52% | 99.94% | 99.999% | 99.93% | - | - | - | | | |
| MPPE-In-15U | 09/02/10 | <63 | <42 | 600 | 22000 | 490 | <520 | <100 | <61 | | | |
| MPPE-Eff-15U | 09/02/10 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | - | 99.95% | 99.999% | 99.93% | - | - | - | | | |
| MPPE-In-15V | 09/02/10 | <63 | 51 | 620 | 22000 | 510 | <520 | <100 | 61 | | | |
| MPPE-Eff-15V | 09/02/10 | <0.31 | <0.21 | 0.44 | 5.7 | 0.49 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | 99.59% | 99.93% | 99.974% | 99.90% | - | - | 99.51% | | | |
| MPPE-In-15W | 09/02/10 | <63 | 52 | 600 | 22000 | 510 | <520 | <100 | <61 | | | |
| MPPE-Eff-15W | 09/02/10 | <0.31 | <0.21 | 0.34 | 4.9 | 0.38 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | 99.60% | 99.94% | 99.978% | 99.93% | - | - | - | | | |
| MPPE-In-15X | 09/03/10 | <63 | <42 | 370 | 20000 | 440 | <520 | <100 | <61 | | | |
| MPPE-Eff-15X | 09/03/10 | <0.31 | <0.21 | <0.28 | <0.22 | 0.42 | <2.6 | <0.51 | <0.3 | | | |
| Removal Efficiency(4) (%) | | - | - | 99.92% | 99.999% | 99.90% | - | - | - | | | |
| **Average Removal Efficiency (%)** | | **96.00%** | **99.51%** | **99.88%** | **99.997%** | **99.66%** | **-** | **-** | **99.28%** | **91.85%** | **98.58%** | **92.16%** |
| Coefficient of Variation, (%) | | 5.871% | 0.07% | 0.39% | 0.01% | 1.26% | - | - | 0.48% | 0.56% | 0.19% | 0.85% |

NOTES:
(1) Based on modeling conducted after April 2009 groundwater monitoring results
(2) Regulatory Requirements as outlined in ROD
(3) Based on influent stream on 95 percent by volume form BF-EW-1 and 5 percent by volume from MBFB-EW-1
(4) Where concentration was reported to be non detectable, method detection limit was used to calculate removal efficiency

# TABLE 3
# SPIKE STEP TEST DATA SUMMARY
# MPPE PILOT-SCALE TREATMENT TEST
# DUAL SITE GROUNDWATER OPERABLE UNIT

| Sample Name | EPA 8260B | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1,2-Dichloroethane | 1,4-Dichlorobenzene | Benzene | Chlorobenzene | Chloroform | Methylene Chloride | Tetrachloroethene | Trichloroethene |
| Units | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| ***Anticipated Full Scale TGRS Influent Concentration*** (1) | 9 | 17 | 248 | 13,900 | 336 | 16 | 168 | 38 |
| ***Regulatory Criteria*** (2) | 0.5 | 5 | 1 | 70 | 100 | 5 | 5 | 5 |
| ***Anticipated MPPE Pilot Test Influent Concentration*** (3) | 23 | 39 | 1031 | 35,200 | 1710 | 35 | 60 | 53 |
| **Spike Flow Step: 3 gpm** | | | | | | | | |
| MPPE-In-3S1 | 24 | 39 | 380 | 19000 | 430 | 64 | <10 | 54 |
| MPPE-Eff-3S1 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 |
| Removal Efficiency(4) (%) | 98.71% | 99.46% | 99.93% | 99.999% | 99.92% | 95.94% | < | 99.44% |
| MPPE-In-3S2 | 23 | 40 | 390 | 19000 | 430 | 92 | <10 | 52 |
| MPPE-Eff-3S2 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 |
| Removal Efficiency(4) (%) | 98.65% | 99.48% | 99.93% | 99.999% | 99.92% | 97.17% | - | 99.42% |
| **Average Removal Efficiency (%)** | **98.68%** | **99.47%** | **99.93%** | **99.999%** | **99.92%** | **96.56%** | **-** | **99.43%** |
| Coefficient of Variation, (%) | 0.04% | 0.01% | 0.00% | 0.00% | 0.00% | 0.91% | - | 0.02% |
| **Spike Flow Step: 6 gpm** | | | | | | | | |
| MPPE-In-6S3 | 25 | 40 | 390 | 20000 | 430 | 81 | <10 | 51 |
| MPPE-Eff-6S3 | 0.44 | <0.21 | 3 | 0.58 | 5.8 | <2.6 | <0.51 | <0.3 |
| Removal Efficiency(4) (%) | 98.24% | 99.48% | 99.23% | 99.997% | 98.65% | 96.79% | - | 99.41% |
| MPPE-In-6S4 | 23 | 39 | 380 | 18000 | 430 | 93 | <10 | 50 |
| MPPE-Eff-6S4 | <0.31 | <0.21 | <0.28 | <0.22 | 0.52 | <2.6 | <0.51 | <0.3 |
| Removal Efficiency(4) (%) | 98.65% | 99.46% | 99.93% | 99.999% | 99.88% | 97.20% | - | 99.40% |
| **Average Removal Efficiency (%)** | **98.45%** | **99.47%** | **99.58%** | **99.998%** | **99.27%** | **97.00%** | **-** | **99.41%** |
| Coefficient of Variation, (%) | 0.30% | 0.01% | 0.49% | 0.00% | 0.87% | 0.30% | - | 0.01% |
| **Spike Flow Step: 9 gpm** | | | | | | | | |
| MPPE-In-9S5 | 25 | 38 | 380 | 18000 | 430 | 91 | <10 | 49 |
| MPPE-Eff-9S5 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 |
| Removal Efficiency(4) (%) | 98.76% | 99.45% | 99.93% | 99.999% | 99.92% | 97.14% | - | 99.39% |
| MPPE-In-9S6 | 23 | 39 | 390 | 17000 | 430 | 96 | <10 | 49 |
| MPPE-Eff-9S6 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 |
| Removal Efficiency(4) (%) | 98.65% | 99.46% | 99.93% | 99.999% | 99.92% | 97.29% | - | 99.39% |
| **Average Removal Efficiency (%)** | **98.71%** | **99.45%** | **99.93%** | **99.999%** | **99.92%** | **97.22%** | **-** | **99.39%** |
| Coefficient of Variation, (%) | 0.08% | 0.01% | 0.00% | 0.00% | 0.00% | 0.11% | - | 0.00% |
| **Spike Flow Step: 12 gpm** | | | | | | | | |
| MPPE-In-12S1 | 24 | 35 | 370 | 18000 | 400 | 110 | <10 | 48 |
| MPPE-Eff-12S1 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 |
| Removal Efficiency(4) (%) | 98.71% | 99.40% | 99.92% | 99.999% | 99.92% | 97.64% | - | 99.38% |
| MPPE-In-12S2 | 25 | 33 | 360 | 17000 | 410 | 110 | <10 | 43 |
| MPPE-Eff-12S2 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 |
| Removal Efficiency(4) (%) | 98.76% | 99.36% | 99.92% | 99.999% | 99.92% | 97.64% | - | 99.30% |
| **Average Removal Efficiency (%)** | **98.73%** | **99.38%** | **99.92%** | **99.999%** | **99.92%** | **97.64%** | **-** | **99.34%** |
| Coefficient of Variation, (%) | 0.04% | 0.03% | 0.00% | 0.00% | 0.00% | 0.00% | - | 0.05% |

NOTES:

(1) Based on modeling conducted after April 2009 groundwater monitoring results

(2) Regulatory Requirements as outlined in ROD

(3) Based on influent stream on 95 percent by volume form BF-EW-1 and 5 percent by volume from MBFB-EW-1

(4) Where concentration was reported to be non detectable, method detection limit was used to calculate removal efficiency

**TABLE 4**
**pCBSA RESULTS SUMMARY**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

| Flow Rate (gpm) | Influent pCBSA Concentration (µg/L) | Effluent pCBSA Concentration (µg/L) | Removal Efficiency |
|---|---|---|---|
| 3 | 130 | 0.15 | 99.9% |
| 12 | 100 | 41 | 59.0% |
| 35 | 94 | 73 | 22.3% |

**TABLE 5**
**QUALITY CONTROL SAMPLES - DUPLICATES**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

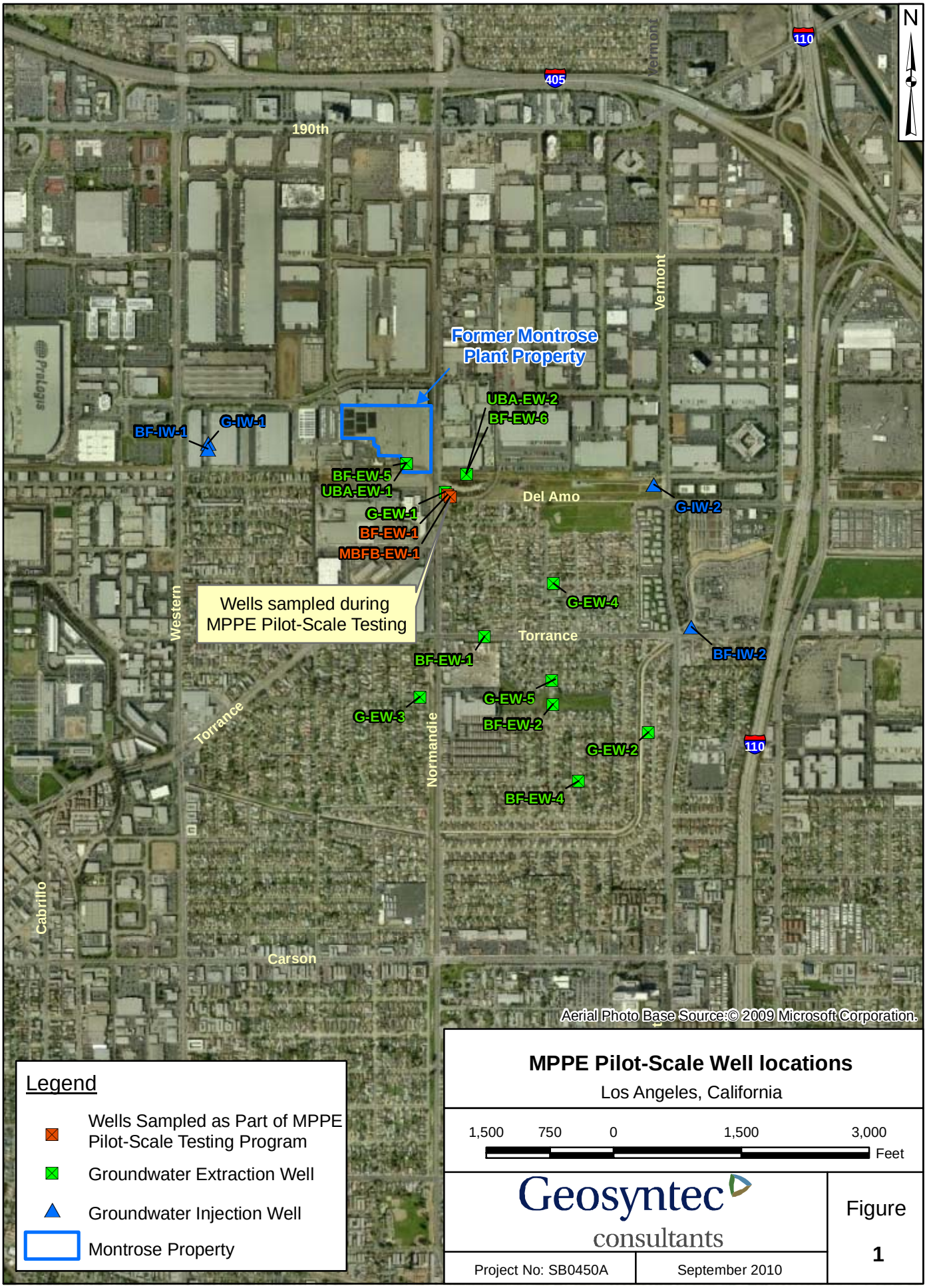
| Sample Name | EPA 8260B (2) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **1,2-Dichloroethane** | **1,4-Dichlorobenzene** | **Benzene** | **Chlorobenzene** | **Chloroform** | **Methylene Chloride** | **Tetrachloroethene** | **Trichloroethene** |
| Units | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L |
| MPPE-Eff-12A-DUP | <0.31 | <0.21 | <0.28 | <0.22 | 0.37 | <2.6 | <0.51 | <0.3 |
| MPPE-Eff-12A | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 |
| **Relative Percent Difference(1) (%)** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** |
| MPPE-Eff-15V-Dup | <0.31 | <0.21 | <0.28 | 4.6 | 0.36 | <2.6 | <0.51 | <0.3 |
| MPPE-Eff-15V | <0.31 | <0.21 | 0.44 | 5.7 | 0.49 | <2.6 | <0.51 | <0.3 |
| **Relative Percent Difference(1) (%)** | **n/a** | **n/a** | **n/a** | **21%** | **31%** | **n/a** | **n/a** | **n/a** |
| MPPE-Eff-30C-Dup | <0.31 | <0.21 | <0.28 | 1.3 | 0.78 | <2.6 | <0.51 | <0.3 |
| MPPE-Eff-30C | <0.31 | <0.21 | <0.28 | 0.6 | 0.76 | <2.6 | <0.51 | <0.3 |
| **Relative Percent Difference(1) (%)** | **n/a** | **n/a** | **n/a** | **74%** | **3%** | **n/a** | **n/a** | **n/a** |
| MPPE-Eff-3S1-Dup | <0.31 | <0.21 | <0.28 | <0.22 | 1.6 | <2.6 | <0.51 | <0.3 |
| MPPE-Eff-3S1 | <0.31 | <0.21 | <0.28 | <0.22 | <0.33 | <2.6 | <0.51 | <0.3 |
| **Relative Percent Difference(1) (%)** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** |
| MPPE-IN-3C_DUP | <8.7 | 34 | 340 | 18000 | 340 | <21 | <13 | 32 |
| MPPE-IN-3C | <8.7 | 24 | 340 | 19000 | 350 | <21 | <13 | 21 |
| **Relative Percent Difference(1) (%)** | **n/a** | **n/a** | 0% | **5%** | **3%** | **n/a** | **n/a** | **42%** |
| MPPE-In-15C-DUP | <63 | 56 | 800 | 20000 | 430 | <520 | <100 | <61 |
| MPPE-In-15C | <63 | 46 | 770 | 19000 | 410 | <520 | 13 | 39 |
| **Relative Percent Difference(1) (%)** | **n/a** | **20%** | **4%** | **5%** | **5%** | **n/a** | **n/a** | **n/a** |
| MPPE-In-15H-DUP | <63 | <42 | 730 | 18000 | 380 | <520 | <100 | <61 |
| MPPE-In-15H | <63 | <42 | 800 | 20000 | 400 | <520 | <100 | <61 |
| **Relative Percent Difference(1) (%)** | **n/a** | **n/a** | **9%** | **11%** | **5%** | **n/a** | **n/a** | **n/a** |
| MPPE-In-15V-Dup | <63 | <42 | 590 | 22000 | 510 | <520 | <100 | <61 |
| MPPE-In-15V | <63 | 51 | 620 | 22000 | 510 | <520 | <100 | 61 |
| **Relative Percent Difference(1) (%)** | **n/a** | **19%** | **5%** | 0% | 0% | **n/a** | **n/a** | **n/a** |
| MPPE-In-30C-Dup | <63 | 61 | 630 | 24000 | 510 | <520 | <100 | 65 |
| MPPE-In-30C | <63 | <42 | 600 | 21000 | 500 | <520 | <100 | 68 |
| **Relative Percent Difference(1) (%)** | **n/a** | **n/a** | **5%** | **13%** | **2%** | **n/a** | **n/a** | **5%** |
| MPPE-In-3S1-Dup | 30 | 39 | 430 | 18000 | 470 | 53 | <10 | 57 |
| MPPE-In-3S1 | 24 | 39 | 380 | 19000 | 430 | 64 | <10 | 54 |
| **Relative Percent Difference(1) (%)** | **22%** | 0% | **12%** | **5%** | **9%** | **19%** | **n/a** | **5%** |
| MPPE-In-9S6-Dup | <63 | <42 | 330 | 17000 | 450 | <520 | <100 | <61 |
| MPPE-In-9S6 | 23 | 39 | 390 | 17000 | 430 | 96 | <10 | 49 |
| **Relative Percent Difference (%)** | **n/a** | **n/a** | **17%** | 0% | **5%** | **n/a** | **n/a** | **22%** |

**Notes:**
(1) - In the case were one or more value was not detected, relative percent difference was not calculated.
(2) - Values provided for VOCs that are expected to be in excess of the regulatory criteria in the full-scale TGRS influent, except for carbon tetrachloride which was not detected in a sample collected during the pilot-scale.

**TABLE 6**
**QUALITY CONTROL SAMPLES - FIELD BLANKS**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

| Sample Name | Sample Date | EPA 8260B (1) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1,2-Dichloroethane | 1,4-Dichlorobenzene | 2-Butanone | Benzene | Carbon Tetrachloride | Chlorobenzene | Chloroform | Chloromethane | Methylene Chloride | Tetrachloroethene | Trichloroethene |
| FB | 8/12/2010 | <0.13 | <0.16 | **2.5** | <0.16 | <0.19 | <0.17 | <0.16 | <0.3 | <0.32 | <0.2 | <0.16 |
| FB | 08/24/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | <0.33 | **0.67** | <2.6 | <0.51 | <0.3 |
| FB082510 | 08/25/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | **0.54** | <0.49 | <2.6 | <0.51 | <0.3 |
| FB082610 | 08/26/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | <0.33 | <0.49 | <2.6 | <0.51 | <0.3 |
| FB20100827 | 08/27/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | **0.38** | <0.49 | <2.6 | <0.51 | <0.3 |
| FB20100828 | 08/28/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | <0.33 | **0.52** | <2.6 | <0.51 | <0.3 |
| FB08292010 | 08/29/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | <0.33 | **0.58** | <2.6 | <0.51 | <0.3 |
| FB 083010 | 08/30/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | <0.33 | <0.49 | <2.6 | <0.51 | <0.3 |
| FB 090210 | 09/02/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | <0.33 | <0.49 | <2.6 | <0.51 | <0.3 |
| FB090310 | 09/03/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | **4.4** | <0.33 | <0.49 | <2.6 | <0.51 | <0.3 |
| FB090310 | 09/03/10 | <0.31 | <0.21 | <6.9 | <0.28 | <0.43 | <0.22 | <0.33 | <0.49 | <2.6 | <0.51 | <0.3 |

**Notes:**
(1) - Values provided for VOCs that are expected to be in excess of the regulatory criteria in the full-scale TGRS influent and constituents that were detected in the a field blank.




**MPPE Pilot-Scale Well locations**

Los Angeles, California

1,500 750 0 1,500 3,000 Feet

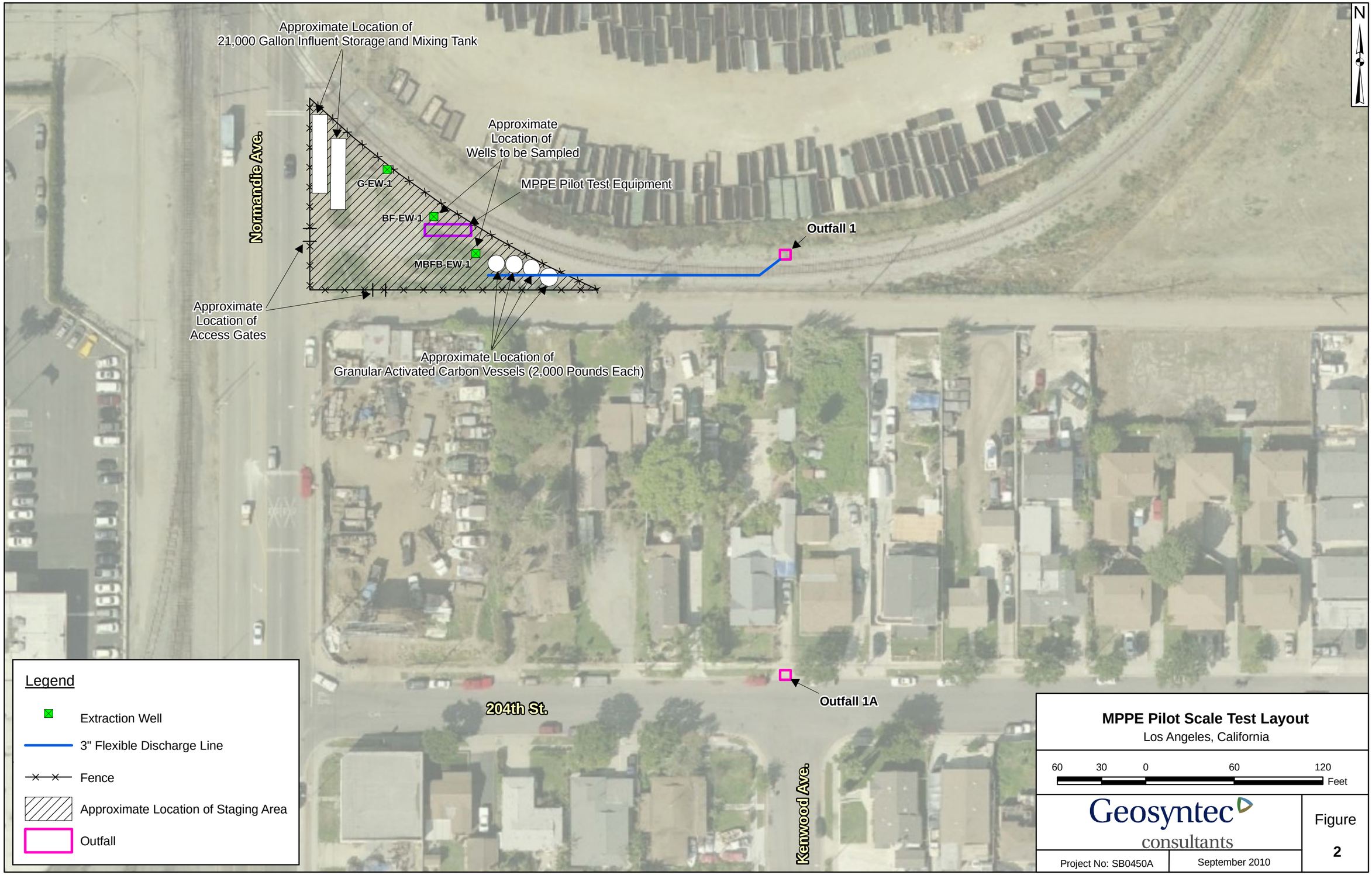
Geosyntec consultants

Figure 1

Project No: SB0450A

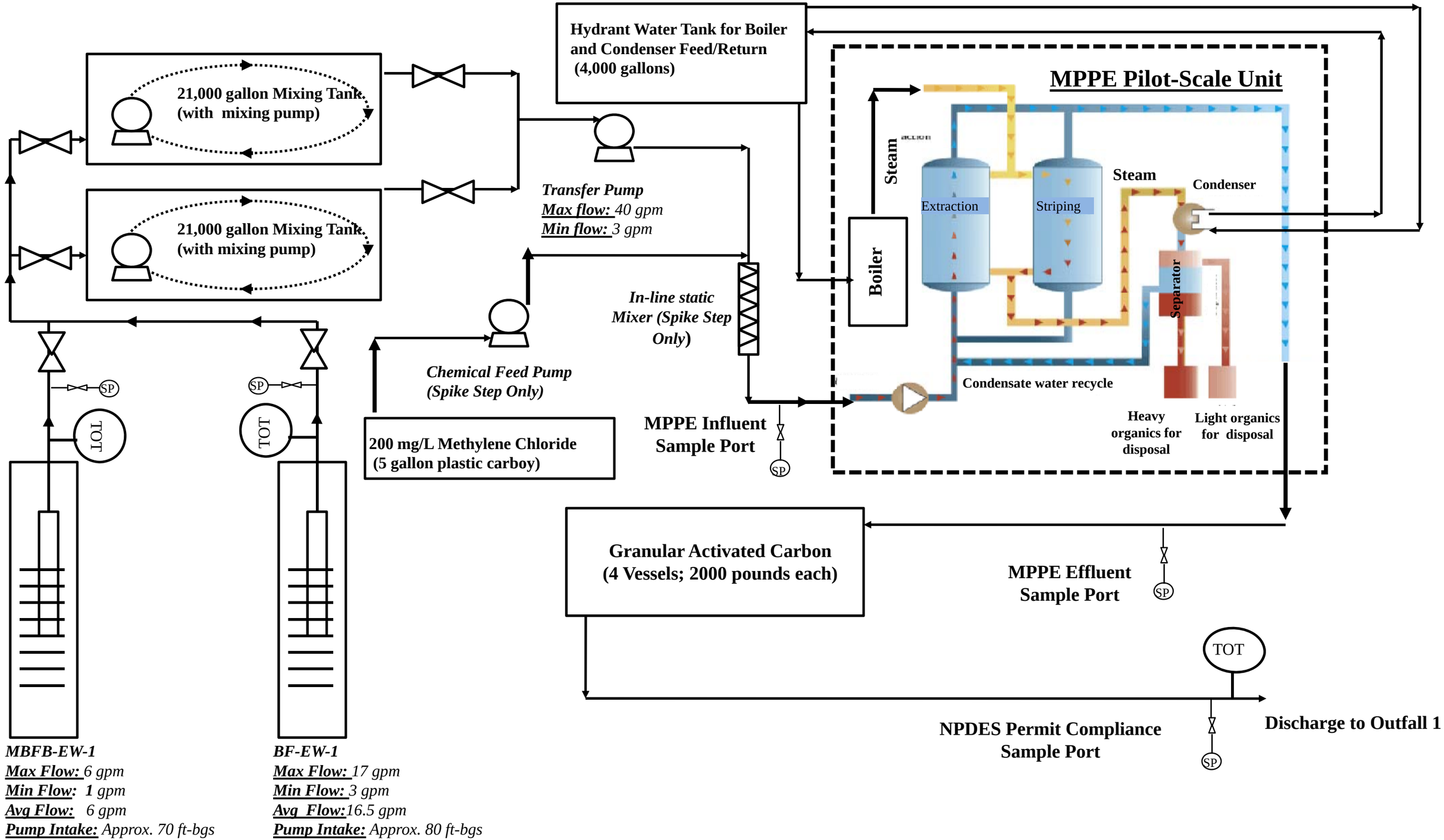
September 2010

S:\GIS\SB0450A\Project\NPDES_OutFall_20100708.mxd sn 20100929




**MPPE Pilot Scale Test Layout**
Los Angeles, California

S:\GIS\SB0450A\Projects\MPPE_PilotTest.mxd sn 20100929



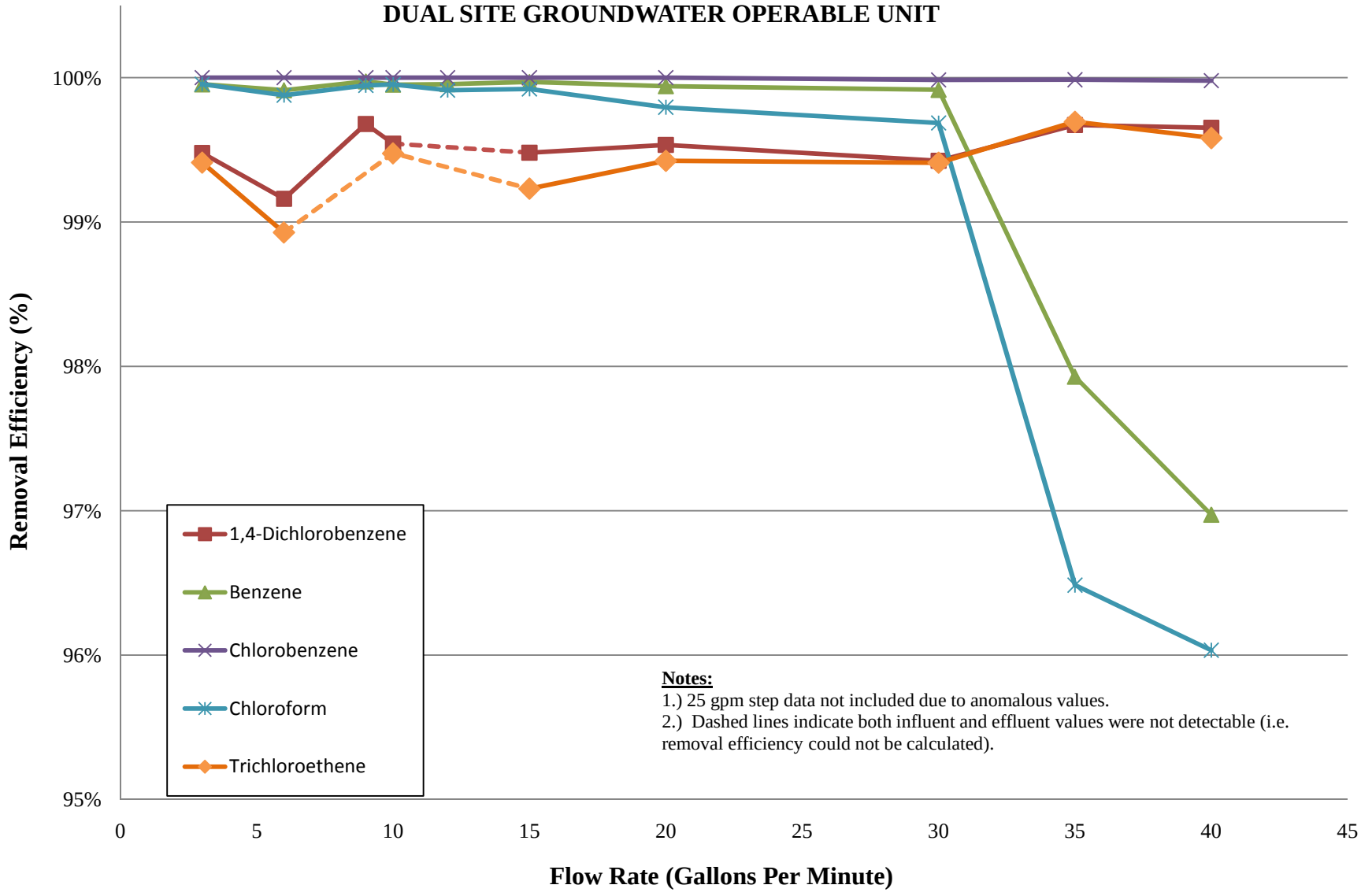

## Legend

- TOT — Analog Flow Meter and Toatlizer
- Electrical Line
- Process Water pipe with Flow Direction Indicated
- Pump
- Manual Valve
- SP — Sample Port

**PROCESS FLOW DIAGRAM**
**MPPE PILOT-SCALE**
**TORRANCE GROUNDWATER REMEDIAL SYSTEM**
**TORRANCE, CALIFORNIA**

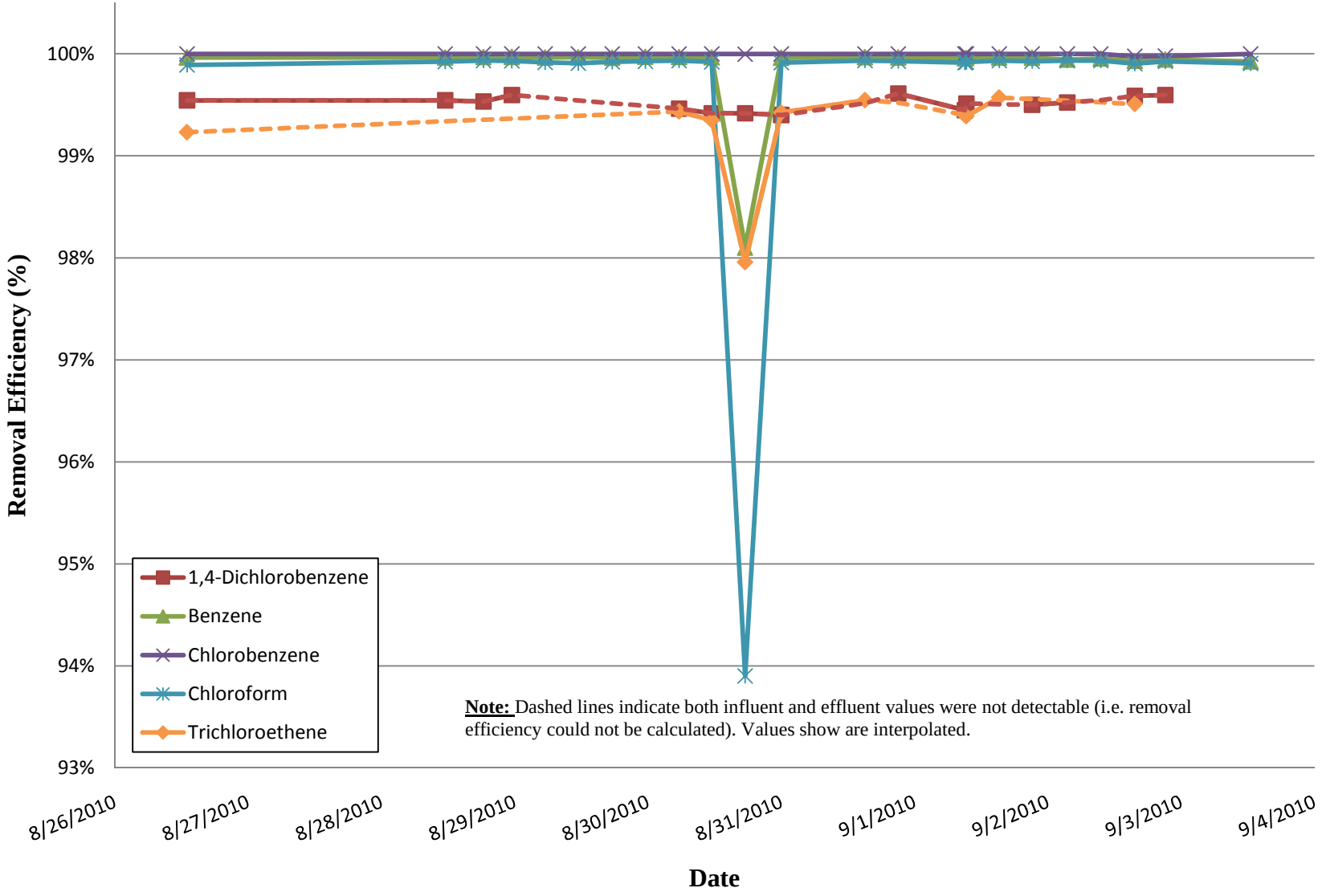
| | |
|---|---|
| Figure 3 | |
| SB0508 | |
| October 2010 | |

**FIGURE 4**
**STEP TEST DATA PLOT**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**




**Notes:**
1.) 25 gpm step data not included due to anomalous values.
2.) Dashed lines indicate both influent and effluent values were not detectable (i.e. removal efficiency could not be calculated).

**FIGURE 5**
**CONTINUOUS FLOW DATA PLOT**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**




**Note:** Dashed lines indicate both influent and effluent values were not detectable (i.e. removal efficiency could not be calculated). Values show are interpolated.

**FIGURE 6**
**SPIKE STEP TEST DATA SUMMARY**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

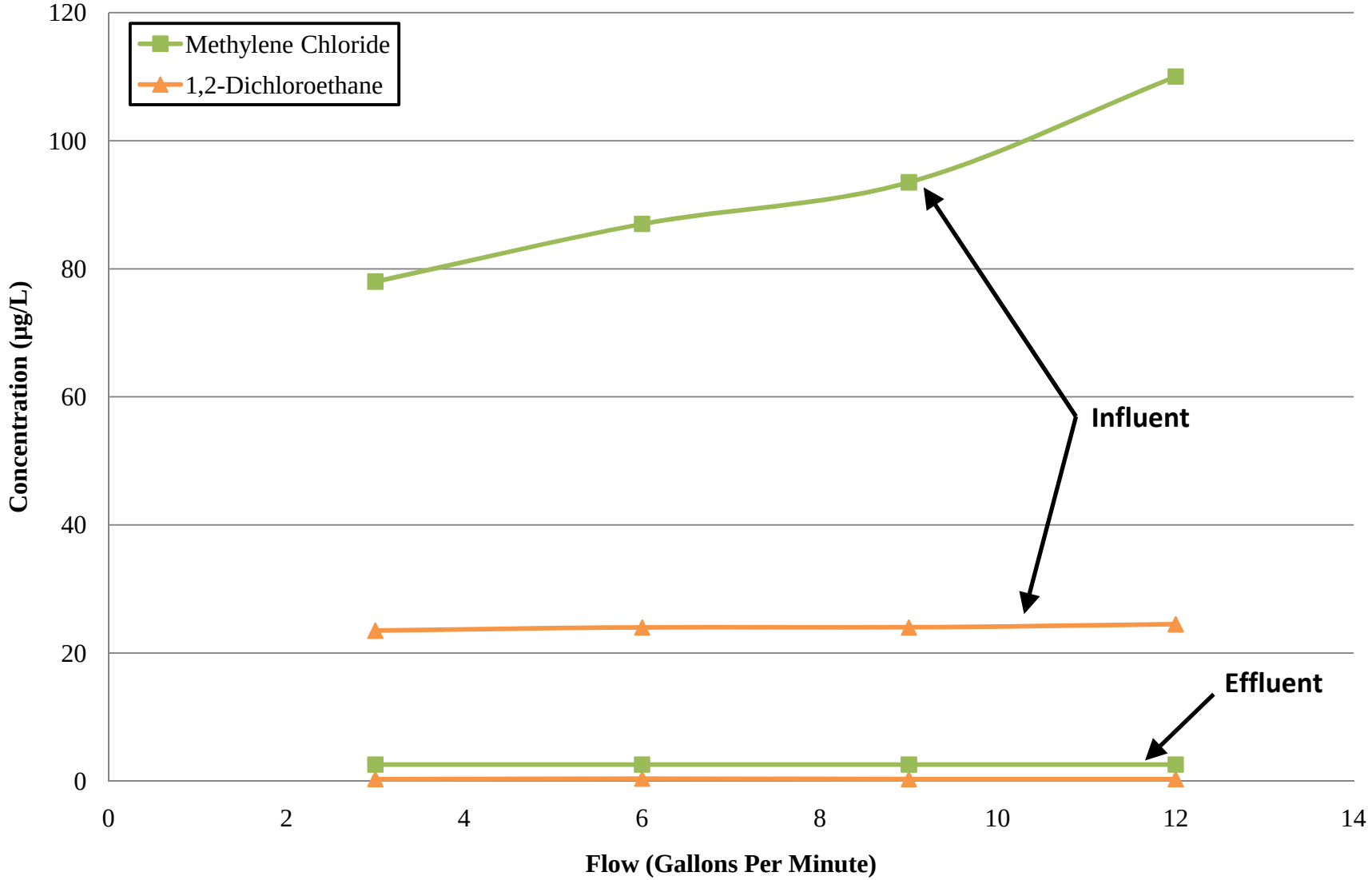
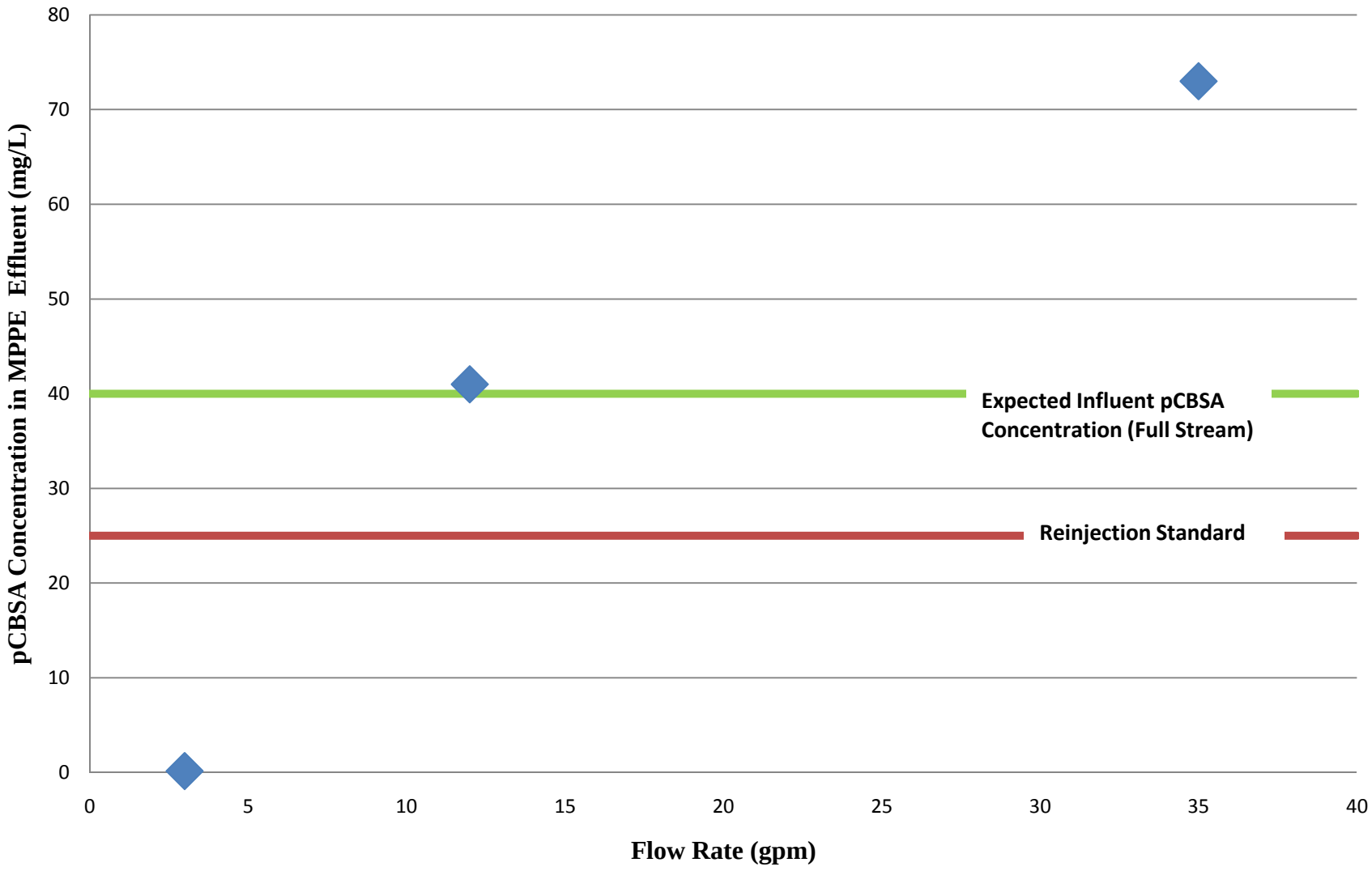


**FIGURE 7**
**pCBSA DATA SUMMARY**
**MPPE PILOT-SCALE TREATMENT TEST**
**DUAL SITE GROUNDWATER OPERABLE UNIT**



# Attachment 3

# VOC Treatment Technology Review

**ATTACHMENT 3**

**VOC Treatment Technology Review**
**Torrance Groundwater Remedial System**
**Torrance, California**

## 1. INTRODUCTION

This VOC Treatment Technology Review document provides a review of potential treatment technologies that have been considered for use in the full-scale Torrance Groundwater Remedial System ("TGRS"). As determined by extensive site groundwater sampling and as summarized in Table 1, nine volatile organic compounds ("VOCs") are expected to require treatment. Groundwater data updated as of 2009 caused the design team to re-assess the initially planned treatment train, which consisted of a sequential combination of an advanced oxidation process ("AOP") and liquid-phase granular activated carbon ("LGAC") treatment. The technologies reviewed as potential remedial options for treatment of VOCs included:

- LGAC;
- Air stripping;
- Macro porous polymer extraction ("MPPE");
- AOP; and
- Biologically-active granular activated carbon ("BioGAC").

The VOCs will need to be treated to meet the in-situ groundwater standards ("ISGS") shown in Table 1. Each of the five technologies can treat VOCs, albeit with varying efficiencies. Additionally, the technologies exhibit varying effectiveness in treating other compounds (i.e., pCBSA, pesticides, and arsenic) that are expected to be in the TGRS influent stream.

### 1.1 Liquid-Phase Granular Activated Carbon

LGAC is a demonstrated and proven technology for removing VOCs, although removal efficiencies are dependent on the specific VOC and concentration. Previous technical evaluations[6] determined that an LGAC system would be effective at removing the majority of

[6] Liquid- Phase Granular Activated Carbon Bench-Scale Testing Report and Cost Projection, Montrose Superfund Site, 20201 South Normandie Avenue, Torrance, California, 11 November 2008

VOCs from the groundwater at the Site. However, methylene chloride in particular, and chloroform and 1,2-dichloroethane ("1,2 – DCA") to a lesser degree, would not be as amenable to removal based on their chemical characteristics, requiring excessive quantities of activated carbon (approximately 7,500 pounds of carbon per day during initial operation) to achieve the necessary treatment.

### 1.2 Macro Porous Polymer Extraction

MPPE is a liquid-liquid extraction process that uses inert porous polymer beads (MPPE particles), measuring approximately 0.5 - 1 millimeters in diameter, that contain a proprietary extraction liquid. Initially the effectiveness of MPPE at treating the TGRS groundwater was uncertain, which resulted in both bench and pilot-scale treatability tests. The MPPE bench and pilot-scale tests demonstrated that MPPE is a viable alternative for treating VOCs and pesticides. Although not a focus on the tests, limited data indicated the technology may have some applicability for treating pCBSA.

### 1.3 Air Stripping

Air stripping is a demonstrated and proven technology for the removal of VOCs from extracted groundwater. Air stripping disperses contaminated water throughout cascading trays, promoting removal of compounds with high vapor pressure and/or low aqueous solubility into the air that flows through the tower. Air vapor containing the stripped contaminants requires treatment prior to atmospheric emission.

Air stripping is a viable technology for treating the majority of the VOCs anticipated to be present in the influent to the TRGS. Treating 1,2-DCA to a concentration less than the 0.5 micrograms per liter (µg/L) ISGS may be challenging with air stripping and will likely require an additional treatment technology (such as LGAC) used as a downstream polishing step. In addition, an air stripper would include handling a vapor stream that would require treatment.

### 1.4 Advanced Oxidation Processes

AOP rely upon the formation of oxidative radicals that react non-specifically with contaminants, generally forming inorganic compounds such as water, carbon dioxide and salts. Three specific AOP technologies were considered:

1. APTwater, Inc. HiPOx™ – this technology produces hydroxyl radicals via injection of ozone and hydrogen peroxide into extracted groundwater.

2. TrojanUVPhox™ – this technology includes a pressurized reactor that utilizes ultraviolet light to generate hydroxyl radicals from hydrogen peroxide.

3. Purifics Photo-Cat™ – this technology utilizes a titanium dioxide ($TiO_2$) slurry catalyst, in conjunction with UV light, to generate four different oxidative pathways.

AOP systems are generally effective at treating some VOCs. However, they generally are not as effective at treating methylene chloride, chloroform, and 1,2-DCA. Each of the three evaluated AOP systems appears capable of treating pCBSA, with the Purifics Photo-Cat™ reportedly also capable of removing pesticides and arsenic.

### 1.5 Biologically-Active Granular Activated Carbon

BioGAC treatment utilizes microorganism growth on the surface and in pore spaces of LGAC treatment systems to enhance the removal of compounds. Fixed biofilms biodegrade compounds when supplied with either a supplemental carbon source or through the use of organic carbon present in influent waters. BioGAC is a demonstrated technology for the removal of petroleum hydrocarbons and oxygenates; however, limited performance data are available for use of this technology for the removal of the nine VOCs expected in the TGRS influent. Biodegradation of pCBSA and pesticides, and sequestration of arsenic has been documented in biological systems, although not specifically in conjunction with a BioGAC system.

## 2. TECHNOLOGY COMPARISON AND EVALUATION

### 2.1 Introduction

The following section provides an overview of the technical effectiveness and associated costs of the remedial technologies described above. The evaluation of technical effectiveness was based primarily on the ability of the technology to treat each of the nine VOCs listed in Table 1 to its ISGS. Those technologies believed to meet the threshold requirement of being capable of meeting the ISGS were further qualitatively assessed using the following criteria:

- Performance and Reliability;
- Waste Disposal;
- Community Impacts; and
- Life-cycle costs.

Table 2 provides a summary of the effectiveness, relative costs, and other considerations of each of the treatment technologies while a detailed discussion is provided below.

## 2.2 Liquid Phase Granular Activated Carbon

An LGAC system would generally be effective at treating most VOCs expected in the TGRS influent stream, except for methylene chloride which requires large amounts of carbon. Although methylene chloride is the most problematic VOC for LGAC treatment, chloroform and 1,2-DCA are also not easily treated by LGAC. An LGAC system would also provide effective treatment of pesticides present in the groundwater. The anticipated capital costs for a LGAC system capable of treating VOCs is relatively low, though the high long-term costs associated with the cost of replacing the carbon would offset the benefit of the relatively low capital cost.

The overall system performance and operational reliability of LGAC is high, as it is a well known and highly-used technology. The system effectiveness would be highly influenced by changes in influent concentrations of methylene chloride and to a lesser extent chloroform and 1,2-DCA. Wastes generated by a LGAC system would include the spent carbon. The frequent carbon replacement would also result in elevated truck traffic and additional noise impacts.

*In summary, LGAC meets the threshold criteria and is considered a viable technology for treating VOCs in the TGRS.*

## 2.3 Macro Porous Polymer Extraction

### 2.3.1 Threshold Performance

As stated previously, MPPE is effective at treating each of the nine VOCs, pCBSA, and three pesticides that are expected to be present in the TGRS influent down to ISGS. The anticipated MPPE capital cost is relatively high but the operation and maintenance costs are reasonable and predictable over time. Given the fact that MPPE is a technology based on liquid-liquid partitioning (rather than mixing of reagents), the ability of MPPE to treat each VOC over time is not expected to diminish as concentrations decline.

### 2.3.2 MPPE Process Waste Streams

***MPPE Media***

MPPE media is an inert, porous polymer that is impregnated with the extractant. Although the MPPE media is not consumed during the treatment process, it requires occasional replacement (i.e., approximately once every two to three years) for re-activation. The re-activation process allows the MPPE media to be re-impregnated with extractant before it is used again. The MPPE media has a lifetime of several re-activation periods and some MPPE media is still in use after more than a decade.

During normal TGRS operation, the MPPE media would be returned to Europe for re-activation. Prior to shipment to Europe for re-activation, the media would be stripped of its extractant, including accumulated constituents from TGRS, if any.

***Extractant Contained Within MPPE Media***

According to Whittier Filtration, the extractant is a non-hazardous liquid. The extractant preferentially removes organic constituents from the TGRS groundwater, followed by steam stripping to remove the organic constituents from the extractant. The removed organic constituents are separated into an organic liquid phase for off-site disposal. During steam stripping a small fraction of the extractant may be removed and disposed with the organic liquid. Although not observed during the pilot-scale test, it is also possible that the efficiency of the extractant may diminish over time if it accumulates organic constituents. To address these potential issues, every two to three years Whittier Filtration subjects the media to an extended steam stripping and cleaning process to remove the extractant prior to re-activation, which was described previously.

***Organic Liquid***

The organic liquid is removed from the MPPE media during the steam stripping process. It would be stored on site up to 90 days until it is disposed off-site. The organic liquid contains pesticides, and consequently it was disposed by incineration during the pilot-scale test. Future options for disposing of the liquid may include:

- Recycling/re-use – this option does not seem viable at this point due to concentrations of pesticides in the organic liquid. However, this option could be re-assessed periodically as groundwater conditions change.

- Thermal Destruction – this disposal method destroys the organic constituents and seems to be relatively cost-effective based on proximity to local thermal destruction facilities.

- Solidification/stabilization and disposal in a permitted facility – this disposal method involves mixing the liquid with solidification agents to demobilize the liquid. Disposal in a landfill will include a larger hauling distance and will not reduce the volume of toxic substances in the environment.

### 2.3.3 MPPE Summary

The overall system performance and operational reliability is expected to be moderately high, with MPPE less sensitive than LGAC to changes over time in influent concentrations of VOCs such as methylene chloride and chloroform. However, there are major concerns regarding the continued availability of the MPPE media, reliability of vendor support, and lack of use in other groundwater treatment systems. MPPE also is more expensive than other reliable technologies. However, a MPPE system would be expected to require little downtime and generate significantly less waste when compared with a LGAC system. The quantity of waste and frequency of waste extraction is expected to be significantly less than a LGAC system, resulting in less community impact with respect to traffic and the associated noise and air-pollution. Additionally, the inert MPPE media is not a waste stream as it is regenerated over time by removing and replacing the extractant liquid. Further, the organic liquid waste stream containing the VOCs, pesticides, and pCBSA will be collected for off-site disposal in volumes that are significantly less than the spent LGAC.

*MPPE meets the threshold criteria and is considered a viable technology for treating VOCs in the TGRS*

## 2.4 <u>Air Stripping</u>

An air stripping system would be effective at treating VOCs. Since the treatment requirements for 1,2-DCA, chloroform, and methylene chloride increase the system size and complexity, it is advisable to include a secondary LGAC system to provide redundancy and treat residual VOCs

and pesticides. Even with the LGAC system as a polishing step, the anticipated capital costs are relatively low for the air stripper. Long-term operation and maintenance costs are anticipated to be moderate, but could be significantly higher depending on vapor treatment requirements. Additionally, air emissions would require permitting and testing, further increasing costs. As discussed in previous technical memorandums, air stripping is a attractive remedial option.

*Air stripping meets the threshold criteria and is considered a viable and attractive technology for treating VOCs in the TGRS.*

## 2.5 Advanced Oxidation

The HiPOx™ and TrojanUVPhox™ treatment technologies will be of moderate or limited ability to remove many of the VOCs present in groundwater down to the ISGS. In particular, the systems will provide little treatment of 1,2-DCA, chloroform, and methylene chloride. Although it is possible to design systems that can treat these VOCs, the oxidant dosages and reactor sizes to destroy these chemicals would not be cost-effective. In addition, the systems would be required for five or more years until influent methylene chloride concentrations are below the ISGS.

Based on results observed from other sites and vendor correspondence, the Photo-Cat™ treatment technology appears capable of removing VOCs down to ISGS. However, 1,2-DCA appears generally resistant to Photo-Cat™ treatment and performance issues remain unresolved for treating this compound. Additionally, no similar case studies exist for the Photo-Cat™ to demonstrate that it is capable of treating groundwater containing the mix of chemicals present in the TGRS influent.

*AOP does not meet the threshold criteria and is not considered a viable technology for treating VOCs in the TGRS.*

## 2.6 Biologically-Activated GAC

A BioGAC system would typically be expected to have approximately the same anticipated capital costs as the LGAC system. However, significant performance unknowns exist for this technology, particularly for removal of compounds such as 1,2-DCA, methylene chloride and chloroform. BioGAC systems are typically developed over the course of several months as a pre-treatment to a fully operational LGAC system. This allows an appropriate microbial population to develop, while also meeting discharge requirements. Given the need for frequent

carbon change outs during this time period, and as a result of technical and performance unknowns, this technology appears to be infeasible.

*BioGAC does not meet the threshold criteria and is not considered a viable technology for treating VOCs in the TGRS.*

## 3. CONCLUSIONS

The analysis presented an evaluation of five potential VOC treatment technologies, based on the threshold criteria (treat influent VOCs); the following technologies are considered to be viable treatment technologies for VOC treatment at the TGRS:

1. LGAC
2. Air Stripping
3. MPPE

Based on a comprehensive evaluation of the technologies, air stripping was determined to be the most appropriate primary treatment technology for VOCs. Please refer to the main Advisory text for a description of the entire treatment train and sequential configuration now being planned for the TGRS, which involves the use of HiPOx$^{TM}$ followed by air stripping and then an LGAC polish.

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Table 1: Influent Compilation Summary
Table 2: Remedial Technology Comparisons

**TABLE 1**
**INFLUENT COMPILATION SUMMARY**
**VOC TREATMENT TECHNOLOGY REVIEW**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

| Chemical Class | Analyte | Anticipated Full-Scale TGRS Flow Weighted Influent Concentration at Start-Up (1) (µg/L) | In-Situ Groundwater Standards (ISGS)(2) (µg/L) | Regulatory Standard | Exceeds Regulatory Standard at Start-Up? |
|---|---|---|---|---|---|
| VOC | 1,2-Dichloroethane | 9 | 0.5 | ISGS | YES |
| VOC | 1,4-Dichlorobenzene | 17 | 5 | ISGS | YES |
| VOC | Benzene | 250 | 1 | ISGS | YES |
| VOC | Carbon Tetrachloride | 1.5 | 0.5 | ISGS | YES |
| VOC | Chlorobenzene | 13,900 | 70 | ISGS | YES |
| VOC | Chloroform | 340 | 100 | ISGS | YES |
| VOC | Methylene Chloride | 16.0 | 5 | MCL | YES |
| VOC | Tetrachloroethylene | 170 | 5 | ISGS | YES |
| VOC | Trichloroethylene | 38.0 | 5 | ISGS | YES |
| pCBSA | Para-Chlorobenzene Sulfonic Acid | 39,600 | 25,000 | ISGS | YES |
| Pesticide | BHC, alpha- | 0.42 | 0.011 | ISGS | YES |
| Pesticide | BHC, beta- | 0.31 | 0.037 | ISGS | YES |
| Pesticide | BHC, gamma- | 0.59 | 0.2 | ISGS | YES |

NOTES:
(1) Based on calculations completed with the April 2009 groundwater monitoring results
(2) ISGS - In Situ Groundwater Standard as outlined in the Record of Decision

Geosyntec consultants

**TABLE 2**
**REMEDIAL TECHNOLOGY COMPARISONS**
**VOC TREATMENT TECHNOLOGY REVIEW**
**DUAL SITE GROUNDWATER OPERABLE UNIT**

| TECHNOLOGY | EFFECTIVENESS | | | | | OPERABLITY | COST | | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|
| | *Primary VOCs* (1) | *Secondary VOCs* (2) | *pCBSA* | *Pesticides* | *Arsenic* | *Concern* | *Capital Cost* | *O&M* | |
| LGAC | High | Low | Low | High | Very Low | Carbon usage infeasible due to high consumption rate | Low | Very High | • Relatively low capital cost<br>• Effective, reliable, well-known treatment technology<br>• Large waste generation due to spent carbon<br>• Additional traffic and noise associated with high frequency change outs |
| MPPE | High | High | Moderate | Moderate | No | Reliability of pCBSA removal uncertain; many process involved with regeneration of media (i.e. boiler, separator, and condenser); organic liquid handling and onsite storage required. | High | Moderate | • Highly effective<br>• High capital cost<br>• No full-scale treatment systems in the US.<br>• Reduced waste generation relative to LGAC<br>• VOC treatment costs will be locked-in with performance guarantee<br>• Organic liquid not amendable to recycling and will require thermal disposal or landfilling with stabilization |
| Air Stripping | High | Moderate | No | No | No | Potential for scaling could require use of sequestering agent or frequent shutdowns. Vapor treatment need for air emission | Moderate | Moderate | • Requires polishing step (LGAC)<br>• Effective, reliable, well-known treatment technology<br>• Requires air emissions controls/treatmeant<br>• Scaling could cause frequent shutdowns for cleaning<br>• Thermal treatment of vapor phase not feasible due to lack of community and regulatory acceptance |
| AOP | | | | | | | | | |
| *HiPOx* ™ | Moderate | no | High | Moderate | No | Only needed for 1-2 years | Moderate | Low | • HiPOx and TrojanUVPhox™ ineffective at treating the nine VOCs expected to be present in the TGRS influent<br>• Photo-Cat™ untested on Site-specific groundwater.<br>• Relatively low waste generation.<br>• Chemicals stored on-site |
| *TrojanUVPhox* ™ | Limited | no | Limited | Moderate | No | Pilot test showed limited success | High | High | |
| *Photo-Cat* ™ | Yes | Moderate | Low | Low | Moderate | Untested, No 1,2-DCA treatment | High | Moderate | |
| BioGAC | Unknown | Unknown | Unknown | Unknown | Unknown | Untested, No site treatability data | *Not determined.* | | • Undemonstrated technology for site contaminants |

**Notes:**

(1) Primary VOCs include benzene, chlorobenzene, tetrachloroethylene, trichloroethylene, 1,4-dichlorobenzene, carbon tetrachloride, 1,2,4-trimethyl benzene and naphthalene.

(2) Secondary VOCs include 1,2-dichloroethane, chloroform and methylene chloride.

**Abbreviations**

VOCs - volatile organic compounds
O&M - operation-and-maintenance
LGAC - liquid-phase granular activated carbon
MPPE - macro porous polymer exchange
AOP - advanced oxidation processes
BioGAC - biologically-activated granular activated carbon