December 5, 2014

Kevin Sullivan
Pacific Gas and Electric Company
3401 Crow Canyon Road
San Ramon, CA 94583

**NOTICE OF APPLICABILITY TO CONDUCT BIOREACTOR PILOT TEST, PG&E COMPRESSOR STATION, HINKLEY, SAN BERNARDINO COUNTY (BOARD ORDER R6V-2008-0014, WDID NO. 6B360912003)**

The California Regional Water Quality Control Board, Lahontan Region (Water Board) is approving Pacific Gas and Electric Company's (PG&E) proposal to conduct a two-stage bioreactor pilot test (Project). We received information that completes the June 19, 2014, Notice of Intent/Work Plan for the Project. Additional Project information was provided in a September 17, 2014, Memorandum by Geosyntec, the pilot test proponent, and PG&E's response letter dated October 7, 2014, that included an attached October 3 , 2014, Memorandum by Geosyntec. All documents are enclosed.

Based on the submitted information, it is our determination that this Project meets the required conditions under our General Waste Discharge Requirements for the General Site-wide Groundwater Remediation Project (General Permit), Board Order R6V-2008-0014.

## DISCHARGER

The Pacific Gas and Electric Company (PG&E) is the Discharger for this Project.

## PROJECT DESCRIPTION

The Project will consist of an above-ground two-stage bioreactor for converting hexavalent chromium [Cr(VI)] in groundwater to solid trivalent chromium [Cr(III)]. The process begins by diverting extracted groundwater from Central Area In-situ Reactive Zone (IRZ) operations and sending it to the first bioreactor, a 10,500-gal vessel. Up to 585 gallons acetic acid (vinegar) and up to 46 gallons phosphoric acid, both at 20% concentration by weight, will be added to the influent to promote Cr(VI) conversion to Cr(III). As Cr(III) precipitates out, it is removed by attaching to biofilms. Treated water then moves to the second bioreactor (an 8,400-gal vessel) to undergo aerobic treatment using rock and sand filters and finally to a bag filter for removal of biomass, Cr(III), and byproducts, such as iron and manganese.

The effluent leaving the second stage vessel is expected to be depleted of chromium, nitrate, acids, biomass, and byproduct metals. Final treated effluent will be dosed with ethanol and re-Injected south of the Central IRZ, in the SCRIA (South Central Reinjection Area). No impact to groundwater quality is expected since total dissolved solids (TDS) and pH are expected to be the same as the influent.

The two-stage bioreactor system is planned to initially operate at 5 gallons per minute (gpm) for six months. If Cr(VI) reduction is consistently achieved, the flow rate may be increased to 20 gpm and operate for up to two more months. Sampling is proposed for influent, mid-stage, and effluent locations. The overall duration of the project is approximately 12 months, from final system design and installation to system shut down and final sampling. No change in groundwater levels are expected since all Project water will be returned to the aquifer and the added volumes of acids will be negligible in comparison.

The Project will be limited to fourteen months from the date of this NOA. The Discharger may propose to extend the Project either during, at the end of, or any time following completion of the one year of operation. All phases of this Project are proposed on land owned by PG&E or land with access agreements with PG&E.

The treatment effectiveness of the Project will be evaluated during and after the operational period. The re-injection of effluent dosed with acids and ethanol south of Frontier Road in the SCRIA during the Project operational period is not expected to result in lateral migration of the 3.1 micrograms per liter (µg/L) Cr(VI) plume boundaries. Should migration occur, it must not extend to areas of existing groundwater use, such as domestic and agricultural wells, or outside the Project boundaries as defined in the General Permit, Finding No. 2 Facility. An increase in chromium concentration from below the maximum background concentration of 3.1 µg/L Cr(VI) to above the maximum background concentration in groundwater samples collected at monitoring wells and domestic wells outside the Project boundaries will be considered plume migration. If the 3.1 µg/L Cr(VI) iso-contour lateral spreading occurs, PG&E will be in violation of this NOA and CAO No. R6V-2008-0002A2. PG&E will then be required to take all necessary actions to reduce chromium concentrations in groundwater such that the 3.1 µg/L Cr(VI) iso-contour is returned to the pre-pilot study conditions, and PG&E may be subject to other enforcement actions.

## PROJECT LOCATION

The Project will take place on the south side of Frontier Road and east of the Central Area IRZ compound, as shown in Figure 1 (Enclosure 4). The Project is located within the central area of the southern-most chromium plume, as shown in Figure 2 (Enclosure 5), which is also the northern portion of the combined IRZ area.

## RECEIVING WATER LIMITATIONS

PG&E shall implement the Project under provisions of Board Order No. R6V-2008-0014 and shall not violate any water quality standards. Specification I.C of the General Permit provides that waste discharges shall not cause a violation of water quality objectives inside the Project boundaries at locations that adversely affect a receptor, such as a drinking water well or agricultural well. In addition, waste discharged shall not cause the groundwater to contain concentrations of constituents in amounts that adversely affect any beneficial use outside the Project boundaries or in amounts significantly exceeding baseline conditions specific for the area of the Project.

For the purpose of this Project, any degradation must be limited to no more than 25 percent above current or baseline concentrations prior to initial discharge for constituents not assigned a primary Maximum Contaminant Level, such as TDS, orthophosphate, sulfate, etc. Baseline concentration will be based upon the average of each well's maximum value during the two years. Numeric criteria for these constituents reflect the lower of either (1) the most restrictive beneficial use standard or existing water quality if presently higher than the most restrictive beneficial use standard; or, (2) a 25 percent increase above the baseline conditions if existing water quality is presently below the most restrictive beneficial use standard. If limits are exceeded, an Evaluation Monitoring Program (EMP) is required (see General Requirements).

**CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA)**

The Discharger shall take all reasonable steps to minimize or prevent any discharge in violation of the General Permit which has a reasonable likelihood of adversely affecting human health or the environment.

The Mitigated Negative Declaration (State Clearinghouse No. 2008011097) adopted by the Water Board on April 9, 2008 states the effects on the environment from projects allowed under the General Permit are not significant as mitigated. Therefore, PG&E must implement the Mitigation Monitoring and Reporting Plan to satisfy CEQA throughout all phases of the Project.

**PUBLIC PARTICIPATION**

On August 22, 2014, the Water Board issued a letter to PG&E requesting additional information concerning the proposed Project. The letter was forwarded to interested parties informing them that the Water Board was considering PG&E's request to conduct a bioreactor pilot test. Public comments were requested during a 21-day review period.

The Water Board received a comment letter, dated September 4, 2014, from Project Navigator, the Independent Review Panel (IRP) Manager for the Hinkley community. Overall, the IRP Manager requested clarification for the selection of the two-stage bioreactor over other ex-situ technologies that were recommended in the 2013 EIR. In addition, the comments requested specific information about the details of the bioreactor and its operation.

Information requested in the Water Board's August 22, 2014, letter was provided in a September 17, 2014, response by Geosyntec.

PG&E's October 7, 2014, response stated its experience with pilot testing of various other technologies to treat Cr(VI), along with the completion of studies by others, prevent the need to repeat such studies. The reasons why the two-stage bioreactor was selected for pilot testing is the expectation it will create significantly less waste when implemented and require significantly less operation and maintenance than other Cr(VI) treatment technologies. If effective, this technology is expected to provide a lower cost and potentially be a more sustainable alternative for above ground treatment of Cr(VI). Geosyntec's October 3, 2014 Memorandum provided the specific information requested about the details of the bioreactor and its operation.

**MONITORING AND REPORTING**

Compliance with the Monitoring and Reporting Program shall be as follows:

1. Monitoring shall be according to the June 19, 2014, Notice of Intent/ Work Plan and Table 1, the September 17 and October 3, 2014, response letters, and this Notice of Applicability.

    a. Bioreactor samples will be collected from influent and effluent ports of each reactor, as well as from two sampling locations along the flow path within the first stage bioreactor (a total of six internal sampling locations. The sampling and analysis frequency, by operational phase, shall be according to Table 1 in Geosyntec's June 19, 2014, Work Plan.

    b. Potential impacts to water quality shall be monitored and evaluated through the existing IRZ quarterly monitoring and reporting program, pursuant to the Water Board's April 7, 2009, and July 7, 2010, NOAs.

2. The monitoring parameter "Arsenic" shall be added to the monitoring program for the same locations and frequency as iron and manganese.

3. Prior to any discharge under this NOA, the Discharger must sample all wells within 500 feet in the downgradient and cross gradient flow directions of all effluent re-injection points, within 90 days of the scheduled discharge.

4. Quarterly monitoring status reports are required within 45 days following the end of the quarter from the date of this NOA. Reports must describe the type, volume, and concentration of discharge(s). The manner and methodology of discharge and monitoring must be described. Reports must contain laboratory data sheets, a description of laboratory results, and a map of discharge and monitoring locations. Provide maps showing the location of all extraction wells, injection wells, monitoring wells, project compound, the chromium plume boundaries, and any other item referenced in the text portion in reports. Furthermore, reports must contain a statement as to whether any constituents criteria were exceeded and, if so, what mitigation measure(s) to restore water quality, if any, were taken. Finally, the reports must describe all mitigation measures taken pursuant to CEQA.

5. IRZ quarterly monitoring reports must include a pilot test section describing injection well locations receiving pilot-test treated effluent. The section must also describe water quality results in potentially affected wells located in the downgradient and cross gradient flow directions of the injection wells. All impacts to water quality shall be described and the extent shown on a site map. If no impacts are indicated, provide an explanation stating whether effluent injections have had time to migrate to monitoring wells locations or not and provide basis for reasoning.

6. Monitoring requirements are in addition to and do not supersede or eliminate monitoring requirements of the same well locations specified in other monitoring programs.

7. Notify the Water Board of any additional operation time needed to complete the pilot test before the expiration date.

8. Within 60 days upon completion of the Project, submit a final results report to the Water Board. In addition to the items required in quarterly monitoring status reports, the final report shall describe:

    - Fate and disposal of all wastes generated during the Project: include the type, amount, and facility name and location.
    - Whether tracers were used in the Project and the results of sampling in groundwater.
    - An evaluation of the feasibility of the bioreactor as a contingency for existing ex-situ remediation technologies (agricultural treatment units), including implementability, costs, and cleanup times.

**GENERAL REQUIREMENTS**

1. The Project shall be constructed and implemented in accordance with the requirements contained in the General Permit and in accordance with the information submitted in the Notice of Intent, work and response letters. Project activities must be completed within the Project boundaries, as described in the General Permit.

2. Storage, handling, transportation, and disposal of chemicals shall be in accordance with requirements and permits issued by San Bernardino County.

3. Other than re-injection of treated effluent back to injection wells in the SCRIA, there shall no disposal to ground of treated or untreated groundwater, waste streams, sludge, metals, biofilm, or filter materials.

4. All wastes generated during and upon completion of the pilot test, such as chemical containers, sludge, metals, filters, waste water, etc., must be disposed of at a licensed facility.

5. Water Board staff shall be notified at least 24 hours prior to the start of discharges to groundwater.

6. Notify the Water Board within five (5) working days of receipt of validated laboratory results indicating a violation of this NOA.

7. In the event that a receiving water limitation listed in the General Permit is exceeded during a monitoring event for the pilot test, the Discharger shall implement within 21 days an EMP for the purposes of determining whether the exceedance is the result of the Project. Under the EMP process, wells may be re-sampled to verify monitoring results. Groundwater data will undergo a statistical evaluation to determine if increases in concentrations are valid. If verified data indicate that exceedances are valid, remediation conditions will be evaluated to determine the factors responsible for the change. If exceedances cannot logically be explained by conditions outside the Project, corrective actions will be developed.

8. The EMP report must be submitted to the Water Board within 30 days following the receipt of laboratory reports of wells that were re-sampled. In addition, the Discharger must include a mitigation plan in the EMP report if increases in constituent concentrations are likely the result of the Project. The mitigation plan shall clearly describe those measures that will be taken by the Discharger and an implementation schedule to achieve compliance with receiving water criteria.

9. The required annual fee (as specified in the annual billing you will receive from the State Water Resources Control Board) shall be submitted until this Notice of Applicability is officially revoked.

10. Failure to abide by the conditions of the General Permit, this Notice of Applicability and Cleanup and Abatement Order No. R6V-2008-0002 and amendments may result in an enforcement action as authorized by provisions of the Water Code.

11. This Notice of Applicability will expire within 14 months from the date listed on the cover page.

If you have any questions concerning this matter, please contact Lisa Dernbach at (530) 542-5424 or ldernbach@waterboards.ca.gov.

PATTY Z. KOUYOUMDJIAN
EXECUTIVE OFFICER

cc: Iain Baker, PG&E
PG&E Technical Mailing List

Enclosures:
1. June 19, 2014 Notice of Intent/Work Plan
2. September 17, 2014 Memorandum by Geosyntec
3. October 7, 2014, PG&E response to Water Board and IRP comments
4. Map of Project Location
5. Project location within chromium plume

LSD/dk/T: PG&E bioreactor pilot test NOA 11-14
File: WDID No. 6B369107001 (VVL)

Pacific Gas and
Electric Company

**Kevin M. Sullivan**
Director of Chromium
Remediation Program

77 Beale Street, B28P
San Francisco, CA 94105
(925) 818-8069 (cell)
kmsu@pge.com

June 19, 2014

Laurie Kemper
Lisa Dernbach
California Regional Water Quality Control Board
Lahontan Region
2501 Lake Tahoe Blvd
South Lake Tahoe, CA 96150

**Re: Notice of Intent (NOI) for Request for Coverage under the General Permit for Site-Wide Groundwater Remediation: In Situ Remediation Projects**
**Board Order No. R6V-2008-0014**
**PG&E Groundwater Remediation Project**
**Hinkley, San Bernardino County**

Dear Ms. Kemper and Ms. Dernbach:

PG&E is currently operating an In Situ Reactive Zone (IRZ) and multiple Agricultural treatment units (ATUs) for treatment of the hexavalent chromium (Cr(VI)) groundwater plume in Hinkley, California. The IRZ project is covered under the General Waste Discharge Requirements (WDR) [Board Order Number R6V-2008-0014] for the Hinkley plume. This Notice of Intent (NOI) is being submitted in order to perform a pilot test of an above ground biological treatment technology for potential future use at the site. The proposed remedial pilot test described below can be implemented under the existing General WDR for the IRZ upon receipt of a Notice of Applicability (NOA), and would not interrupt or alter operation of the IRZs or ATUs. The proposed pilot study is based upon the collective technical lessons learned from the various successful remediation strategies already implemented at the Site, as well as proven technical approaches for treating Cr(VI) and may subsequently serve as an ATU contingency if proven to be successful.

This NOI provides a general description of the proposed treatment technology, project objectives, proposed treatment process, and proposed changes to the existing operations at the Central Area IRZ (CA IRZ). A detailed Work Plan describing the specific pilot study that will be conducted along with the monitoring and reporting program and project schedule is submitted concurrently with this NOI [Geosyntec, 2014].

Through this NOI PG&E is requesting an NOA to move forward with this pilot test under the General WDR. PG&E plans to move forward with implementing the pilot within 3 months of receiving the NOA. If the treatment technology proves effective, this treatment method may be considered as a contingency aboveground treatment alternative for the ATUs.

**Current Site Operations under the General WDR**

Current operation of the IRZ includes extraction of plume groundwater, amendment with organic carbon substrate (ethanol), and reinjection into the subsurface. The organic carbon substrate (electron donor) stimulates microbial activity in the subsurface, that leads to reducing geochemical conditions conducive for reduction of Cr(VI) to Cr(III).

**Proposed Pilot Test Technology Overview**

The proposed treatment consists of a two-step microbial treatment process: an above-ground anaerobic bioreactor designed to reduce and immobilize Cr(VI) to Cr(III) within the vessel under precisely controlled redox conditions (as occurs in situ in the IRZ), and a second-stage aeration cascade and sand bio-filtration to facilitate aerobic biological removal of residual electron donor (if any) and reduced species, such as dissolved iron and manganese. Bioreactors are a technically sound, commonly-used means of treating a variety of groundwater contaminants, including Cr(VI). The team selected for construction and operation of the proposed bioreactor, Geosyntec Consultants, has extensive experience designing and operating bioreactors. Geosyntec has designed and operated numerous bioreactors for the treatment of Cr(VI), with concentrations ranging from tens of parts per billion to tens of parts per million.

In order to minimize impacts on current ATU and IRZ operations, as well as reduce potential impact to sensitive habitat, the bioreactor is proposed to be constructed adjacent to the CA IRZ mixing compound and have a limited footprint (approximately 1,000 $ft^2$). A "slip-stream" from the CA IRZ groundwater extraction system of approximately 5 gallons per minute ("gpm") would be diverted to the bioreactor for treatment. The 5 gpm slip-stream will be amended with acetic acid (concentrated vinegar) and phosphoric acid (nutrient) prior to the first stage bioreactor where Cr(VI) treatment occurs, and then further treated in the aerobic second stage bioreactor designed to minimize residual electron donor exiting the bioreactor (and for trace iron and manganese removal, if present). Treated water on the outlet end of the second stage bioreactor would then be returned to the CA IRZ reinjection system upstream of the ethanol dosing system (South Central Reinjection Area [SCRIA] metering vault). This design configuration mitigates the potential for adverse effects if Cr(VI) is not completely treated (during start-up for example) and maintains the current IRZ groundwater extraction and reinjection rates. After fully testing system performance at 5 gpm, the slipstream flow rate may be increased to 20 gpm to assess treatment effectiveness under different hydraulic conditions.

Ex-situ biological treatment technology provides the following potential benefits:

- The bioreactor, once stabilized operation has been achieved, can be operated continuously year-round, with minimal maintenance;

- The bioreactor will allow for immobilization of Cr(VI) from groundwater ex situ, within the reactor – the immobilized chromium may later be physically removed from the bioreactor followed by off-site disposal;
- Due to the use of an inert media bed, iron and manganese production is minimized;
- Bioactive filtration in the second stage bioreactor reduces the biomass content in the effluent and removes particles greater than 100 microns – minimizing potential deleterious impacts to reinjection wells; and
- The design is expected to have low evaporative losses if implemented full scale and is therefore not likely to result in significant increases in TDS in receiving groundwater.

**Treatment Objectives**

The primary objectives of the pilot testing are:

- To evaluate the minimum hydraulic residence time ("HRT") within the first stage of the bioreactor for Cr(VI) treatment;
- To evaluate the removal of iron, manganese and total dissolved solids by the second stage of the bioreactor system
- To quantify electron donor and nutrient requirements, as well as utilization rates;
- To evaluate system performance under varying seasonal conditions; and
- To evaluate effluent quality including the residual electron donor in the effluent and the biomass yield.

**Description of Proposed Pilot Test Technology**

The proposed treatment will be comprised of a two-step bioreactor process (see Figure 1 for preliminary design drawings). The first stage of the bioreactor, presented in detail in the Work Plan [Geosyntec, 2014], is designed to consistently target reduction of oxygen, nitrate, Cr(VI) and incremental reduction of sulfate (if necessary) by maintaining bioreactor oxidation-redox potential (ORP) at desired levels. The ORP will be controlled by real-time monitoring of influent parameters (nitrate and flow rate) coupled to automated electron donor (acetic acid) dosing based on the influent flow rate and chemical profile. Phosphoric acid, a nutrient amendment, is also proposed to be dosed within the first stage bioreactor. Detailed design and operational information is included in the Work Plan [Geosyntec, 2014].

The function of the aerobic cascade and biofiltration second stage of the bioreactor is to biologically remove residual electron donor that is not used in the first stage, as well as reduced species, such as dissolved iron and manganese (if any). Sand filtration will remove particles to 100 microns and a bag filter with 25 micron pores will result in a high-quality effluent being reintroduced to the IRZ system. Detailed design and operational information is included in the Work Plan [Geosyntec, 2014].

**Bioreactor Monitoring**

The frequency of monitoring will vary as a function of operational status during start-up and stabilization. A detailed description of the proposed sampling and analysis program can be found in Table 1 of the Work Plan [Geosyntec, 2014]. The overall effluent water returned to the injection system, prior to ethanol dosing, is expected be of better quality, and in the worst case scenario (no treatment occurs in the bioreactor), of the same quality as the extracted groundwater. PG&E is proposing to monitor potential impacts through the existing IRZ WDR Monitoring and Reporting Plan (M&RP), and an additional M&RP is not warranted based on the scope of the project. A contingency plan in case of bioreactor failure is not considered at this time, given that the effluent of the bioreactor is being returned to the same combined water from which it came, and will still be dosed with ethanol per IRZ requirements, before reinjection.

**Proposed Changes to Existing IRZ Operations for Pilot Testing**

The following table details the minor potential changes to existing operations as a result of implementing the treatment test.

**Table 1: Proposed Changes to Existing Operations for Treatment Pilot Testing**

| Operations | Proposed under NOI for the IRZ Area under R6V-2008-0014 (General WDR) | Considerations Pertaining to the General WDR |
|---|---|---|
| **Extraction and Reinjection** | Splitting off 5-20 gpm of CA IRZ extracted groundwater to send through the bioreactor, and reintroduction into the same flow path, upstream of IRZ ethanol dosing. | No change in net extraction or reinjection volumes for the CA IRZ. No change or an overall improvement in groundwater quality for reinjection via IRZ due to potential removal of Cr(VI), iron and manganese (if any) in the bioreactor and filtration of the effluent. The effluent from the bioreactor will be reintroduced "upstream" of the IRZ ethanol dosing, such that if the bioreactor operation fails completely, the IRZ injections will continue unaffected. |
| **Bioreactor** | A bioreactor is proposed to be constructed on the eastern side of the current CA IRZ treatment compound. The bioreactor is expected to have a footprint of no more than 1,000 $ft^2$, including vessels, tanks, equipment storage and security fencing. Acetic acid is proposed as the electron donor and phosphoric acid is proposed as a nutrient amendment. | The use of acetic acid as an electron donor for the bioreactors is proposed. Phosphoric acid is proposed as an amendment for microbial growth. Acetic acid and phosphoric acid are included in the General WDR (see Sections I.B.2 and I.B.5) The proposed area for construction of the bioreactor is in a previously disturbed area adjacent to the current CA IRZ treatment compound, and is not designated as sensitive habitat. See Figure 2 of the Work Plan [Geosyntec, 2014] for proposed configuration. |
| **Tracer Compounds** | Inert tracer compounds may be introduced to the effluent of the bioreactor to monitor flow rates, breakthrough rates, and other key operational items. Bromide will be used if tracer testing is conducted. | Allows injection of tracers into the influent of the bioreactor, as has been previously approved (see NOA dated 7/7/2010). No new tracers are proposed. |

The overall duration of the pilot test project is expected to be approximately twelve months. Final system design, material specifications and construction of the pilot system is estimated to take four months. The testing phase will last approximately six months to assess different operational rates and assess alternate electron donors, changing dose rates, and "stress" testing. The final two months will be directed at documenting and reporting system performance.

We look forward to proceeding with the pilot testing upon receipt of a Notice of Applicability (NOA) from the LRWQCB. If you have questions or need any further information, please contact Iain Baker at (415) 265-5196.

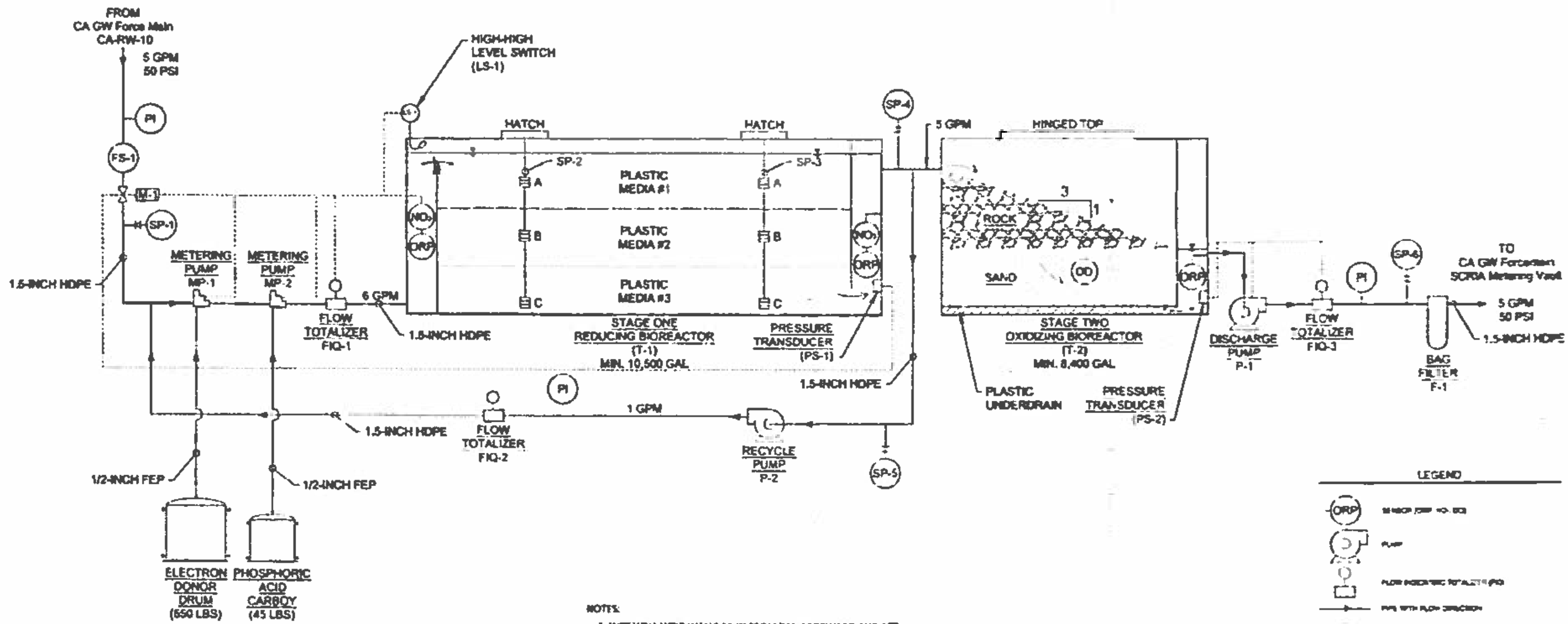
Best Regards,

Iain Baker For

Kevin Sullivan

References: Geosyntec (2014), Pilot Test Work Plan – Two Stage Bioreactor, Hinkley CA

Figure 1: Draft Bioreactor Process Flow Diagram



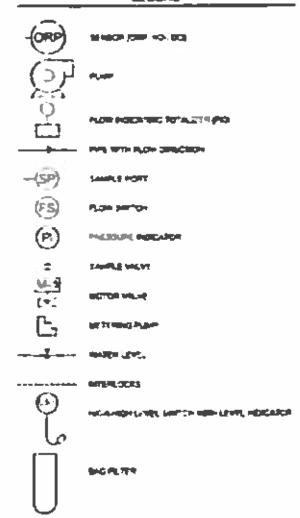

NOTES:

1. WET WELL WEIR WALLS 36-IN FROM TANK FORWARD AND AFT
2. FILTER (F-1) 25-MICRON ELEMENT

INTERLOCKS:

1. IF BIOREACTOR (T-1) WATER ELEVATION HIGH-HIGH (LS-1) HIGH, CLOSE MOTOR VALVE (M-1) AND STOP PUMP (P-1); ACTIVATE SYSTEM LEVEL ALARM 1.
2. IF FLOW SWITCH (FS-1) READS NO FLOW FOR 60 SECONDS, THEN STOP PUMP (P-1).
3. CONTROL MOTOR VALVE (M-1) TO MAINTAIN WATER ELEVATION 96-IN ABOVE PRESSURE SENSOR (PS-1).
4. CONTROL PUMP (P-1) TO MAINTAIN WATER ELEVATION 36-IN ABOVE PRESSURE SENSOR (PS-2).
5. IF FLOW INDICATOR (FIQ-3) IS >25% DIFFERENT THAN FLOW INDICATOR (FIQ-1), THEN STOP PUMP (P-1) AND CLOSE MOTOR VALVE (M-1); ACTIVATE FLOW ALARM 2.

LEGEND



ASSUMED INFLUENT PROFILE

| PARAMETER | CONCENTRATION (MG/L) |
|---|---|
| DISSOLVED OXYGEN (DO) | 3 |
| NITRATE ($NO_3$) | 10 |
| HEXAVALENT CHROMIUM | 0.100 |
| SULFATE ($SO_4$) | 200 |

REVISIONS

CLIENT:
PACIFIC GAS AND ELECTRIC COMPANY (PG&E)
NATIONWIDE ENVIRONMENTAL SERVICES, INC.
ADDRESS

ENGINEER
Geosyntec consultants

PROCESS FLOW DIAGRAM

TWO-STAGE BIOREACTOR PILOT TEST
PG&E COMPRESSOR STATION
PG&E GROUNDWATER REMEDIATION PROJECT
HINKLEY, SAN BERNARDINO COUNTY, CALIFORNIA

DRAFT CONSTRUCTION DRAWING

FIGURE NO.
1

*Prepared for*

**Pacific Gas & Electric Company**
77 Beale Street
San Francisco, California, 94105

# PILOT TEST WORK PLAN

# TWO-STAGE BIOREACTOR

## HINKLEY, CALIFORNIA

*Prepared by*

Geosyntec consultants

engineers | scientists | innovators

199 South Hudson Avenue, Suite 110
Pasadena, California 91101

HA 1419

19 June 2014

# Pilot Test Work Plan
## Two-Stage Bioreactor
## Hinkley, CA

*Prepared by*

**Geosyntec Consultants, Inc.**

199 South Hudson Avenue, Suite 110
Pasadena, California 91101

Mark Davidson, Ph.D.
Project Microbiologist

Bruce Marvin, P.E.
Associate Engineer

Project Number: HA 1419
19 June, 2014

# TABLE OF CONTENTS

Geosyntec
consultants

## LIST OF TABLES



## LIST OF FIGURES

# 1. INTRODUCTION

On behalf of Pacific Gas & Electric (PG&E), Geosyntec Consultants (Geosyntec) has prepared this Two-stage Bioreactor Pilot Study Work Plan (Work Plan) for testing of a potential alternate technology for treatment of hexavalent chromium (Cr(VI)) impacted groundwater from the Hinkley, CA site (Site). The two-stage bioreactor system consists of an ex-situ submerged bed fixed film bioreactor followed by an aeration cascade and biofiltration stage.

PG&E is currently operating an In Situ Reactive Zone (IRZ) and multiple agricultural treatment units (ATUs) for treatment of the Cr(VI) groundwater plume in Hinkley. The IRZ project is covered by Notice of Applicability dated July 7, 2010 under the General Waste Discharge Requirement (WDR) [Board Order Number R6V-2008-0014]. As the proposed pilot test would be completed as a slip stream within the Central Area IRZ recirculation line the project will be completed under the General WDR.

The remainder of this Work Plan is organized into the following sections:

- Section 2, "Current Remediation Activities," describes the ongoing remediation at the Site.
- Section 3, "Pilot Study Objectives" describes the rationale for selecting a bioreactor.
- Section 4, "Bioreactor Design" presents key criteria considered in the design of the bioreactor, and how these criteria are to be evaluated during the pilot study.
- Section 5, "Bioreactor Operation" presents the proposed pilot study operational phases, including variations in operation upon successful demonstration of Cr(VI) treatment under initial conditions.
- Section 6, "Sampling and Reporting" describes the sampling and analysis program through the various stages of operation and proposes a reporting schedule.
- Section 7, "Schedule" presents the estimated project schedule

Tables and figures are presented at the end of this Work Plan.

# 2. CURRENT REMEDIATION ACTIVITIES

The Hinkley groundwater remediation program has three primary treatment elements: groundwater extraction and application to ATUs for (Cr(VI)) treatment and hydraulic control, freshwater injection for hydraulic control, and the IRZs for in situ treatment of Cr(VI) within the aquifer. A total of six ATUs are operated currently, treating groundwater produced from an extensive network of groundwater extraction wells. The freshwater injection system consists of three freshwater supply wells located south of the Cr(VI) plume and seven injection wells located to the northwest of the Cr(VI) plume core. The IRZ system is operated in three areas, each with groups of groundwater extraction wells and injection wells. Extracted groundwater within the IRZ program is periodically amended with ethanol to serve as an electron donor for microbial growth that stimulates the reduction of Cr(VI) to trivalent chromium (Cr(III)).

### 2.1 Agricultural Treatment Units

Current operation of the ATUs entails extraction of plume groundwater and land application via subsurface or drag-drip irrigation for agricultural use. As the extracted groundwater passes through the soil and root zone, Cr(VI) is converted to relatively insoluble Cr(III) form and immobilized. The DVD ATU is the longest operating element of the Hinkley site groundwater remediation program and performance monitoring has demonstrated that ATUs are effective for treatment of Cr(VI) in extracted groundwater.

### 2.2 In-Situ Reactive Zone

Current operation of the IRZ includes extraction of plume groundwater, amendment with organic carbon substrate (ethanol), and reinjection into the upper aquifer. The organic carbon substrate (electron donor) stimulates microbial activity in the subsurface, which leads to reducing geochemical conditions conducive for reduction of Cr(VI) to Cr(III).

## 3. PILOT STUDY RATIONALE AND OBJECTIVES

PG&E is evaluating the use of a bioreactor as a potential alternative aboveground treatment technology for site remediation. The proposed pilot study described herein is based upon the collective technical lessons learned from the various successful remediation strategies already implemented at the Site, as well as proven technical approaches for treating Cr(VI) and may subsequently serve as an ATU contingency if proven to be successful.

Biological treatment of Cr(VI) has been demonstrated in the IRZ program described above and has been shown to be effective at significantly reducing concentrations of

Cr(VI) in groundwater. Therefore ex-situ biological treatment of groundwater provides a potential treatment technology for above ground treatment that is based on processes similar to those already demonstrated to be effective at the site. Prior analysis of other water treatment alternatives, such as adsorption or chemical treatment and precipitation, has been conducted and is not described herein.

A two-stage anaerobic/aerobic bioreactor configuration was selected for pilot testing for a number of reasons. The first stage is a reducing microbial bioreactor that offers similar benefits of the IRZ treatment in a compact, above-ground footprint. Additional benefits of the reducing bioreactor include physical accumulation of removed Cr(III) within the bioreactor and the ability to tailor electron donor dosing according to the influent geochemistry profile. The second stage of the bioreactor system has the ability to minimize the residual electron donor in the effluent and remove trace iron and manganese from groundwater. The second stage of the bioreactor is comprised of an aeration cascade followed by bio-active sand filtration. Aeration of the effluent from the reducing bioreactor will de-activate denitrifying microbes, oxidize dissolved iron that may be present in the influent and stimulate growth of manganese oxidizing microbes in the second stage sand filter. Bioactive filtration will minimize the biomass content in the effluent and remove larger particles, and an inline bag filter (25 micron) will provide final "polishing" prior to reintroduction to the IRZ line.

Geosyntec has successfully designed, built, and operated submerged bed fixed-film bioreactors for treating elevated concentrations (~10 ppm range) of Cr(VI). Geosyntec has also operated two-stage bioreactor systems that consistently meet applicable surface water discharge criteria. As such, the two-stage bioreactor system is a proven and reliable technology.

The primary objectives of the treatment testing are:

- Evaluate the required hydraulic residence time ("HRT") within the first stage of the bioreactor for Cr(VI) treatment;
- Evaluate the removal of unutilized electron donor (if any) in effluent from the first stage effluent by the second stage bioreactor system
- Evaluate the removal of trace iron, manganese and total dissolved solids (if any) by the second stage of the bioreactor system
- Quantify electron donor and nutrient requirements, as well as utilization rates;
- Evaluate system performance under varying seasonal conditions

- Evaluate effluent quality including the residual electron donor in the effluent and the biomass yield
- Establish design and operational criteria that would apply to a full-scale application

# 4. BIOREACTOR DESIGN

The function of a submerged bed fixed-film bioreactor system is to biologically reduce Cr(VI) to Cr(III) by altering the redox chemistry of the groundwater through stimulation of microbial respiration processes, in particular nitrate reduction, and physically remove Cr(III) within the first stage of the bioreactor system. In order for a bioreactor to perform consistently, stabile redox potential (ORP) is critical. From experience on other projects, the ORP can be controlled through real-time monitoring of influent parameters such as nitrate; flow rate can then be coupled to automatic electron donor dosing based on the influent profile. The reduction of Cr(VI) to Cr(III) generally occurs in the nitrate-reducing or lower range, therefore the bioreactor presented in this Work Plan is designed to consistently target appropriate reduction of oxygen, nitrate, Cr(VI) and incremental reduction of sulfate (if necessary).

The function of the aerobic cascade and biofiltration second stage of the bioreactor is to remove reduced species, such as dissolved iron and manganese, and residual electron donor that is not used in the first stage. Aeration of the influent will stimulate aerobic microbial activity, chemically oxidize ferrous iron and remove sulfides. Manganese oxidizing bacterial growth will be stimulated on the sand filtration media. Sand filtration will remove particles to 100 microns and a bag filter with 25 micron pores will result in a high-quality effluent being reintroduced to the IRZ system.

## 4.1 Hydraulic Retention Time (HRT)

The time required to microbially reduce Cr(VI) to Cr(III) can be estimated from other Cr(VI) bioreactor results, using a standard first order kinetic degradation equation:

$$C = C_0 e^{-kt}$$

Where C is the concentration of Cr(VI) at a given time, $C_0$ is the initial concentration of Cr(VI) prior to reduction, $k$ is the kinetic degradation constant ($t^{-1}$), and t is the time.

Based on previous experience with Cr(VI) bioreactors and comparison of literature values for estimates of *k*, a value of 13.8 $d^{-1}$ is considered to be appropriate and conservative. An average influent concentration of 100 ug/L Cr(VI) is assumed based on average concentrations in Central Area In Situ Reactive Zone (CA IRZ) groundwater, and a target effluent concentration goal of 0.1 ug/L was used for design (99.9 percent Cr(VI) removal) that results in a calculated HRT of 12 hrs. The pilot study will assess Cr(VI) treatment at lower HRTs to further evaluate this design criterion.

## 4.2 Bioreactor Sizing and Materials

The calculated HRT (12 hrs) was used to size the pilot study bioreactor. HRT is a measure of the average length of time that a representative volume of water remains within a bioreactor on average and was calculated as the working volume of the reactor divided by the influent flow rate:

$$HRT = \frac{V}{Q}$$

where HRT is the hydraulic retention time (min), V is the bioreactor volume (gal) and Q is the influent flow rate (gpm). HRT in this use is consistent with the empty bed contact time within the first stage of the bioreactor.

The petroleum industry commonly uses corrosion resistant, epoxy coated and mobile "frac" tanks for storing and mixing large volumes of process water. Given the wide-scale use of these mobile "frac" tanks, a wide-range of sizes and configurations are available that with minor modification, can be effectively used as bioreactor vessels for pilot studies. These mobile tanks are approximately 8 feet in width and 7 feet for the height, with variable lengths. Assuming a tank with internal dimensions (L x W x H) of 20' x 8' x 7', the calculated internal volume is approximately 8,400 gal. Assuming a working headspace of 1ft depth (a volumetric loss of approximately 1,200 gal), the working volume is 7,200 gallons. At a flow rate of 5 gpm, the maximum empty bed contact time in this working volume is approximately 24 hrs.

In the case of a fixed-film bioreactor, a term relating to the porosity of the bed material is added to the HRT expression presented above and the volume of headspace in the vessel is subtracted to estimate the pilot study HRT within the packed bed:

$$HRT = \frac{(V - Hs) * ø}{Q}$$

where Hs is the headspace volume (gal) and ø is the porosity (unitless).

Using the working volume of ~7,200 gal and a nominal operating flow rate of 5 gpm, 75% for ø (based on vendor information for the recommended bed materials), results in a calculated HRT of approximately 18 hrs, or 150% of the calculated required HRT from the kinetic degradation calculation (12 hrs), above. In other words, a safety factor of 1.5 is included in the pilot study tank sizing as compared to the HRT after accounting for the void ratio and packing efficiency of the bioreactor media.

Based on experience on other projects, inert plastic media with a high void-space ratio serves as an excellent substrate on which biomass may attach.

In order to facilitate effective mixing of electron donor and influent groundwater prior to introduction to the submerged bed, a "wet well" will be installed on the influent end of the bioreactor, 3 ft from the front wall (see Fig 1). Flow through the media bed will be top-downward with an entrance over-flow weir near the front of the tank and an underdrain system at the opposite end of the tank.

## 4.3 First Stage Bioreactor Effluent Recycle

The first stage (reducing) bioreactor will be constructed with a recycle line from the effluent to the influent (Figure 1). This hybrid activated-sludge-like feature of the submerged bed fixed-film design increases system stability by increasing the residence time of groundwater within the bioreactor. This design feature is especially valuable during system start-up and growth of the biofilm, as well as during system upsets such as loss of electron donor or phosphoric acid feed(s). At times, such as during start-up or system maintenance, the first stage bioreactor will be run in 100% recycle mode. The effluent ORP from the first stage is a primary indicator of the reducing bioreactor condition, and upon completion of the pilot study a threshold ORP value will be established that is indicative of effective Cr(VI) treatment and can be used for long-term system monitoring and process control.

Up to 20% of flow is typically redirected to the influent of bioreactors during steady-state operations in order to increase the overall HRT. The effluent recycle will be set at 20% unless adjustment is warranted.

### 4.4 Electron Donor Feed System

A 20% by weight solution of acetic acid is proposed to be used as the electron donor for the bioreactor system. The feed rate will be automatically adjusted based on the flow rate, influent profile and real-time nitrate concentration in the influent. Based upon average concentrations for groundwater in the CA IRZ area, an assumed influent chemistry profile was obtained. The assumed bioreactor influent chemistry profile is 3 mg/L dissolved oxygen (D.O.), 40 mg/L nitrate (as $NO_3$), 200 mg/L sulfate, and 100 ug/L Cr(VI). The acetic acid dosage, or use rate, will be dependent on the influent flow rate (approx. 5 gpm), the real-time nitrate concentration (assumed 40 mg/L), and removal of D.O. (3 mg/L), Cr(VI) (100 ug/L) and 5% of the sulfate (10mg/L) resulting in an estimated volume of acetic acid (~2,820 gal) needed for a single year of pilot testing.

Ethanol is a common intermediate in the anaerobic microbial food chain, where labile organic matter is step-wise degraded to intermediate products - such as acetate, carbon dioxide ($CO_2$), methane ($CH_4$), and hydrogen gas ($H_2$) - by the combined action of several different types of bacteria for both energy and cell synthesis. For example, acetogenic bacteria are capable of oxidizing ethanol to acetate, hydrogen gas, and carbon dioxide under anaerobic conditions. Ethanol is currently used as the electron donor in the CA IRZ and will be tested in comparison to acetic acid, as described in more detail below.

### 4.5 Phosphoric Acid Feed System

The function of the phosphoric acid feed system is to provide macronutrients to sustain biological growth in the bioreactor. Phosphoric acid will be delivered via a metering pump to maintain a relatively steady concentration (3 mg/L) of phosphate in the bioreactor influent water. The metering pump pulse rate will be manually set based on the nominal flow rate (5 gpm) and acetic acid use rate (~2,820 gal/yr). Approximately 150 gallons per year of a 20% phosphoric acid solution are calculated to be needed for a single year of operation, assuming a 20:5:1 (C:N:P) ratio.

### 4.6 Aeration Cascade (Aerobic Bioreactor)

The first stage bioreactor will result in moderately anaerobic effluent and may contain trace amounts of unutilized electron donor and trace dissolved iron and manganese that may be present in the system influent. Dissolved iron and manganese production are not expected in the first stage reducing bioreactor because plastic media was selected.

An aeration cascade comprised of rock and gravel over a sand bed will be used as an aeration system and support matrix for the formation of aerobic biofilms. The second stage bioreactor will be installed in a "mud tank" (~200 barrels) of similar dimensions as the first stage (reducing) bioreactor described above, completed with hinged covers. As effluent water from the first vessel cascades over the irregular surface of the rocks and gravel, the water becomes aerated, allowing for abiotic and aerobic microbial sequestration of the iron and manganese. The aerated groundwater will be filtered through a bio-active sand bed prior to collection in an effluent wet well. A dissolved oxygen (D.O.) sensor will be installed at the base of the aeration cascade to monitor real-time D.O. concentrations and effectiveness of the cascade.

The aeration cascade will be followed by a bio-active sand filtration to allow for removal of residual electron donor (2 - 5 mg/L based on Geosyntec experience) to mitigate the potential for bio-fouling of the IRZ reinjection system (instrumentation and wells) upon reintroduction of the effluent into the IRZ injection system. In addition, a bag filter with 25 micron pores will result in a high-quality effluent being reintroduced to the IRZ system. This additional second stage aerobic bioreactor step is considered a "polishing" step to produce a high-quality effluent from the two-stage bioreactor system.

## 4.7 Control System

A control system will be used to monitor the bioreactor system and provide off-site monitoring of system status and key performance indicators. The control system is designed to provide real-time monitoring of the redox conditions within each of the two bioreactors, while providing some capacity to alter operational conditions.

Instrumentation will include:

- Process monitoring including monitoring of system flows
- Process monitoring of bioreactor chemistry
  - Stage one influent nitrate
  - Stage one influent ORP
  - Stage one effluent nitrate

  - Stage one effluent ORP
  - Stage two influent DO
  - Stage two effluent ORP
  - High-high stage one water elevation stop condition
  - Water elevations and pump control in stage two
- Automated balancing of flows into and out of the bioreactor system;
- Remote monitoring of flow rates, water elevations and ORP/DO; and
- Shutdown and remote notification of alarm conditions to protect process equipment and prevent releases.

The control system will be constructed using a programmable logic controller (PLC) that provides real-time 24-hour monitoring of the system.

The control system will have the capacity to remotely modify the electron donor dosage settings. The PLC will be housed in a control panel designed to NEC® requirements with appropriate connections to the instruments described above and shut-down control over the effluent pump. The PLC will be programmed to operate the system in a fully automatic mode with a locally- or remotely-enabled manual override (local priority). The program includes adjustable operational set points and shut-down conditions to protect the system equipment. The SCADA system includes data-logging capability such as:

- Treatment system influent, discharge and recycle flow rates; and
- Treatment system ORP, DO and liquid levels.

Field and treatment plant motors will be wired to a motor control center (MCC) per NEC® requirements, including overload protection and disconnects. The control system and MCC will be housed in a weather-proof enclosure and be powered by a power drop from the nearby CA IRZ vault.

# 5. BIOREACTOR OPERATION

## 5.1 <u>Installation and Construction</u>

The pilot study bioreactor system is proposed to be constructed on the eastern side of the current CAIRZ treatment compound (see Fig 2). A power drop will be installed from the CAIRZ system to the bioreactor control system and MCC. The influent to the bioreactor system will be from a tie-in to the Central Area Manifold Vault and the bioreactor system effluent will be tied into the SCR1A Bypass piping at the SCR1A metering vault. The tie-in laterals will be buried HDPE piping installed by Arcadis/ETIC and day-light at the bioreactor system pump and control/MCC enclosure at locations shown on Figure 2.

The customized mobile tanks (one 250 bbl and one 200 bbl) used as bioreactors will be placed on a gravel pad installed by Arcadis/ETIC adjacent to the CA IRZ system compound after the surface has been leveled by blading the surface, as needed. The equipment enclosure will be will placed adjacent to the second stage bioreactor and provide weather protection for pumps (2), flow meters (3), electron donor stock tanks and the control/MCC panel(s).

Media placement within the bioreactors will be dependent on the media type. Plastic media will be manually placed in lifts, as described in section 4.2. Sand, gravel and rock will be placed from super-sacks suspended from a crane or below the tines fork-lift sequence. Sand and gravel will be leveled after placement by raking from the top of the tank surface. Appropriate lift plans, confined space entry, and fall protection work plans shall be developed and adhered to.

## 5.2 Start-up and Stabilization

After completion of construction, and leak testing using potable water, of the first stage bioreactor system, the vessel will be drained and filled with CA IRZ-extracted groundwater and operated in 100% recycle mode with electron donor dosing in order to lower ORP and "seed" the bioreactor with inoculum obtained from IRZ injection wells during rehabilitation. Upon stabilization of the redox chemistry at or below nitrate reduction, as evidence by ORP and comparison of influent and effluent nitrate and Cr(VI) concentrations, the effluent recycle percentage will incrementally be reduced to 20% for normal operations, with a total flow rate of 5 gpm.

Once the first stage bioreactor has reached sufficiently low ORP and is being primed for normal operations, approximately 30 gallons of groundwater will be collected from an IRZ extraction/injection well that has significant biofouling and will be recirculated in the second stage bioreactor, in order to "seed" the aeration cascade with the appropriate microorganisms.

## 5.3 Initial Operation

The two stage bioreactor system is planned to operate at a nominal flow rate of 5 gpm for a period of six months, to evaluate Cr(VI) reduction with a 1.5 safety factor of the HRT, and to establish a mature biofilm. A six month period will provide temperature variability with which to assess the impact of temperature extremes on the operation of the bioreactors.

The target electron donor concentration will be calculated based on the facts discussed in Section 4.4 that include real-time measurement of the influent flow rate and influent nitrate concentration. Secondary inputs to the actual electron donor concentration are D.O., Cr(VI), and other electron acceptor concentrations (i.e., sulfate) that will be modified by the operator in the control system. A stoichiometric multiplier is applied as a safety factor (typical range of 1.1 to 1.8) to account for additional electron donor demand(s) and/or non-ideal utilization of donor, resulting in a higher than stoichiometric estimate donor dosage requirement. A mass flow sensor will monitor the electron donor feed rate and provide feedback to a PID control which will automatically adjust the electron donor feed metering pump. The stoichiometric multiplier will be higher during start-up and then decreased based on effluent ORP values and process monitoring of the effluent (e.g. residual electron donor exiting stage one).

### 5.3.1 HRT Evaluation

After it has been demonstrated that Cr(VI) reduction is consistently achieved under varying temperatures (~6 months), the influent flow rate will be incrementally increased, in order to reduce HRT while monitoring the effect on effluent ORP and Cr(VI) concentrations. This period of operations is intended to further assess the attainable HRT that maintains Cr(VI) treatment.

The influent flow rate will be increased by increments of at least 50%, up to a maximum of 20 gpm (equivalent HRT of ~5hrs). The bioreactor system will be operated at a given flow rate for approximately two weeks, this duration may be decreased if the ORP stabilizes within 15 percent after three days under the new flow regime. If little or no loss of Cr(VI) reduction capability is observed at 20 gpm, the influent flow rate may be increased in 10 gpm increments up to the maximum flow rate practicable based on the CA IRZ system available flow rates and pressures.

### 5.3.2 Alternate Electron Donor Assessment

Upon completing the HRT evaluation phase of the pilot study, as described above, the electron donor will be changed from acetic acid to ethanol (which is currently used for the IRZ program). Diluted ethanol will be obtained from the ethanol dosing infrastructure from Central Area Manifold Vault. The initial influent flow rate may be reduced in order to allow for the microbial population in the bioreactor to adjust to ethanol as the electron donor. A comparison of nitrate and Cr(VI) reduction for ethanol vs. acetic acid for the same flow rate will be performed for at least two flow rate/HRT combinations.

### 5.3.3 System Recovery Performance

Upon completion of the alternate electron donor assessment, electron donor feed will be switched off completely, and the time taken for stage one effluent ORP to return to near baseline and nitrate breakthrough will be monitored. Upon ORP recovery to within 100 mV of baseline, the electron donor feed will be restarted and the time taken to re-establish reducing conditions and target ORP will be assessed.

## 6. SAMPLING AND REPORTING

Continuous monitoring of nitrate and ORP in the influent and effluent of the first stage bioreactor, as well as DO after the aeration cascade in the second stage bioreactor will be conducted. Samples will be also collected to monitor system performance and will be analyzed at an off-site laboratory for the following compounds, at a minimum:

- Field measurements: pH and temperature;
- Hexavalent chromium by EPA 218.6 (Low Level);
- Total dissolved chromium by EPA Method 6010B;
- Dissolved metals (iron and manganese) by EPA Method 6020;
- Nitrate, nitrite, and sulfate by EPA Method 300.0;
- Total dissolved solids (TDS) by EPA Method SM 2540C;
- Orthophosphate by EPA Method SM4500;
- Total organic carbon by EPA Method SM 5310D;
- Dissolved organic carbon (DOC) by EPA Method SM 5310D; and
- Volatile fatty acids by HPLC/UV.

Samples will be collected from influent and effluent ports of each reactor, as well as from two sampling locations along the flow path within the first stage bioreactor (a total of six internal sampling locations – see Fig 1). The frequency of monitoring will vary as a function of operational status during start-up and stabilization. The proposed sampling and analysis frequency, by operational phase, is provided in Table 1.

In addition, periodic video inspection of the bioreactor media may be conducted to verify biofilm condition and the relative fractions of dispersed growth versus attached growth within the bioreactors.

Reporting will be performed on a quarterly basis, and will consist of a summary of the previous quarter's activities and analytical result updates.

## 7. SCHEDULE

Following approval of this Work Plan procurement will commence and is expected to take approximately two months, given prefabrication requirements of the bioreactor vessels. Assembly and final construction of the bioreactor system is anticipated to take approximately one month, upon delivery of materials to the Site.

The initial stabilization phase (100% recycle mode) is anticipated to take approximately two months.

After this, nominal operation (5 gpm) will commence for a six month period, capturing seasonal temperature variability.

The final phases of "stress testing" (HRT reduction, electron donor changes and system recovery performance) are anticipated to last for approximately twelve weeks in total.

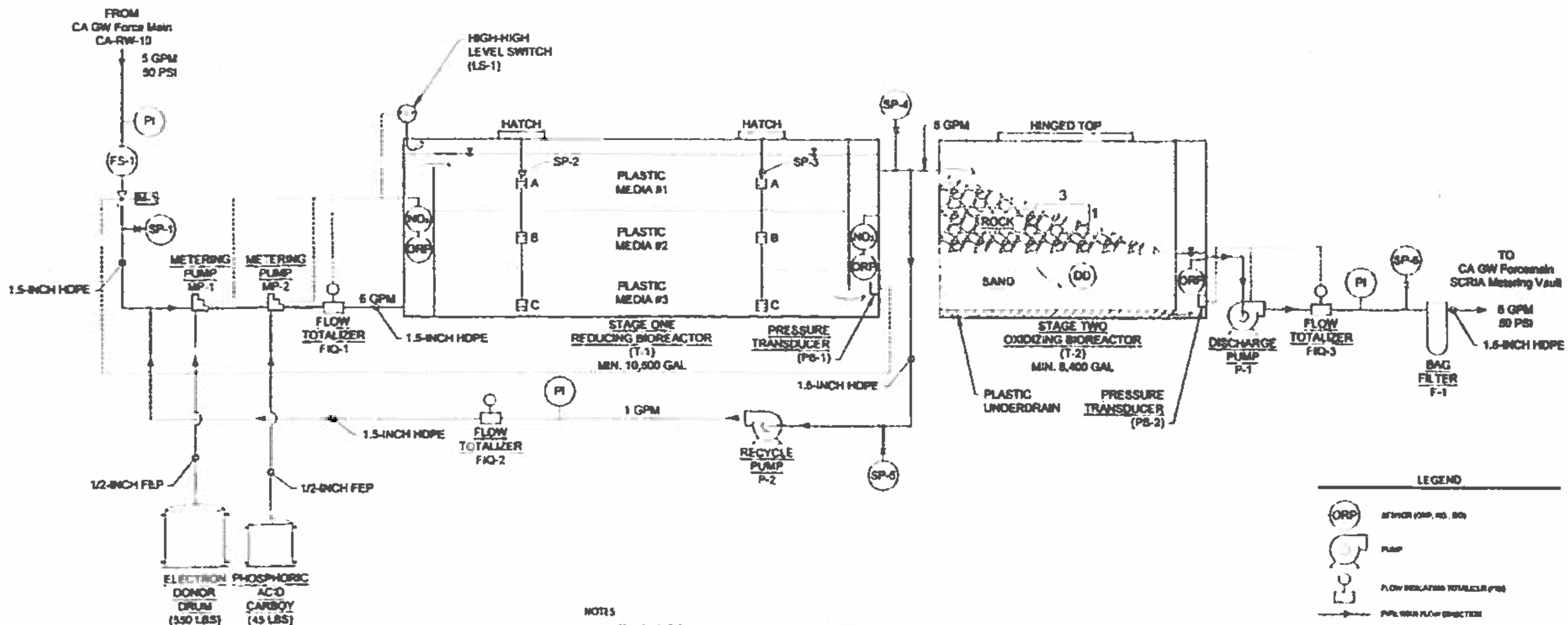
# TABLES

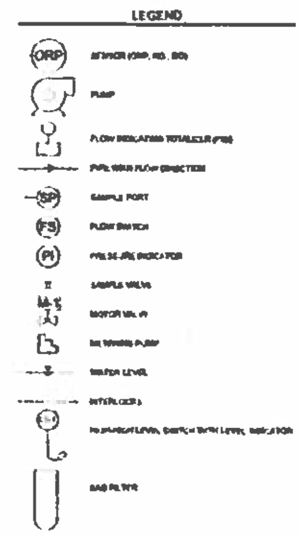
**Table 1: Proposed Sampling and Analysis Frequency by Operational Phase**

| Phase of Operation | Sample Location | Sampling Location Shown on Figure 1 | ORP (inline analyzer) | Dissolved Oxygen (inline analyzer) | Nitrate (inline analyzer) | Nitrate as $NO_3$ (EPA 300.0) | Nitrite (EPA 300.0) | Hexavalent Chromium (EPA 218.6) | Total Dissolved Chromium (EPA 6010B) | Orthophosphate (SM4500) | Iron and Manganese (EPA 6010B) | Sulfate (EPA 300.0) | TDS (SM 2540C) | Total Organic Carbon (SM 5310B) | Dissolved Organic Carbon (SM 5310D) | Volatile Fatty Acids (by HPLC/UV) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stabilization (~2 months) | 1° Stage Influent | SP-1 | C | | C | W | W | W | W | W | W | W | W | W | W | M |
| | 1° Stage Internal (6 ports) | SP-2/-3 | | | | M | M | M | M | M | M | M | M | M | M | M |
| | 1° Stage Effluent | SP-4 | C | | C | W | W | W | W | W | W | W | W | W | W | M |
| | 2° Stage Internal | DO | | C | | | | | | | | | | | | |
| | 2° Stage Effluent | SP-6 | C | | | W | W | W | W | W | W | W | W | W | W | M |
| Operation (~6 months) | 1° Stage Influent | SP-1 | C | | C | T | T | T | T | T | T | T | T | T | T | T |
| | 1° Stage Internal (6 ports) | SP-2/-3 | | | | M | M | M | M | M | M | M | M | M | M | M |
| | 1° Stage Effluent | SP-4 | C | | C | T | T | T | T | T | T | T | T | T | T | T |
| | 2° Stage Internal | DO | | C | | | | | | | | | | | | |
| | 2° Stage Effluent | SP-6 | C | | | T | T | T | T | T | T | T | T | T | T | T |
| Stress Test: HRT Adjustment (~4 weeks) | 1° Stage Influent | SP-1 | C | | C | W | W | W | W | W | W | W | W | W | W | |
| | 1° Stage Internal (6 ports) | SP-2/-3 | | | | O | O | O | O | O | O | O | O | O | O | |
| | 1° Stage Effluent | SP-4 | C | | C | W | W | W | W | W | W | W | W | W | W | O |
| | 2° Stage Internal | DO | | C | | | | | | | | | | | | |
| | 2° Stage Effluent | SP-6 | C | | | W | W | W | W | W | W | W | W | W | W | O |
| Stress Test: Electron Donor (~6 weeks) | 1° Stage Influent | SP-1 | C | | C | W | W | W | W | W | W | W | W | W | W | |
| | 1° Stage Internal (6 ports) | SP-2/-3 | | | | O | O | O | O | O | O | O | O | O | O | |
| | 1° Stage Effluent | SP-4 | C | | C | W | W | W | W | W | W | W | W | W | W | O |
| | 2° Stage Internal | DO | | C | | | | | | | | | | | | |
| | 2° Stage Effluent | SP-6 | C | | | W | W | W | W | W | W | W | W | W | W | O |
| Stress Test: System Recovery (~2 weeks) | 1° Stage Influent | SP-1 | C | | C | W | W | W | W | W | W | W | W | W | W | |
| | 1° Stage Internal (6 ports) | SP-2/-3 | | | | O | O | O | O | O | O | O | O | O | O | |
| | 1° Stage Effluent | SP-4 | C | | C | W | W | W | W | W | W | W | W | W | W | O |
| | 2° Stage Internal | DO | | C | | | | | | | | | | | | |
| | 2° Stage Effluent | SP-6 | C | | | W | W | W | W | W | W | W | W | W | W | O |

C = Continuous monitoring via inline analyzer
W = Weekly sampling
M = Monthly sampling
T = Twice per month
O = Once during test period

# FIGURES




NOTES

1. WET WELL WEIR WALLS 36-IN FROM TANK FORWARD AND AFT
2. FILTER (F-1) 25-MICRON ELEMENT

INTERLOCKS:

1. IF BIOREACTOR (T-1) WATER ELEVATION HIGH-HIGH (LS-1) HIGH, CLOSE MOTOR VALVE (DA-1) AND STOP PUMP (P-1); ACTIVATE SYSTEM LEVEL ALARM 1.
2. IF FLOW SWITCH (FS-1) READS NO FLOW FOR 60 SECONDS, THEN STOP PUMP (P-1).
3. CONTROL MOTOR VALVE (DA-1) TO MAINTAIN WATER ELEVATION 96-IN ABOVE PRESSURE SENSOR (PS-1).
4. CONTROL PUMP (P-1) TO MAINTAIN WATER ELEVATION 36-IN ABOVE PRESSURE SENSOR (PS-2).
5. IF FLOW INDICATOR (FIQ-3) IS >25% DIFFERENT THAN FLOW INDICATOR (FIQ-1), THEN STOP PUMP (P-1) AND CLOSE MOTOR VALVE (M-1); ACTIVATE FLOW ALARM 2.

ASSUMED INFLUENT PROFILE

| PARAMETER | CONCENTRATION (MG/L) |
|---|---|
| DISSOLVED OXYGEN (DO) | 3 |
| NITRATE ($NO_3$) | 10 |
| HEXAVALENT CHROMIUM | 0.100 |
| SULFATE ($SO_4$) | 200 |

CLIENT:
PACIFIC GAS AND ELECTRIC COMPANY (PG&E)
NATIONWIDE ENVIRONMENTAL SERVICES, INC.

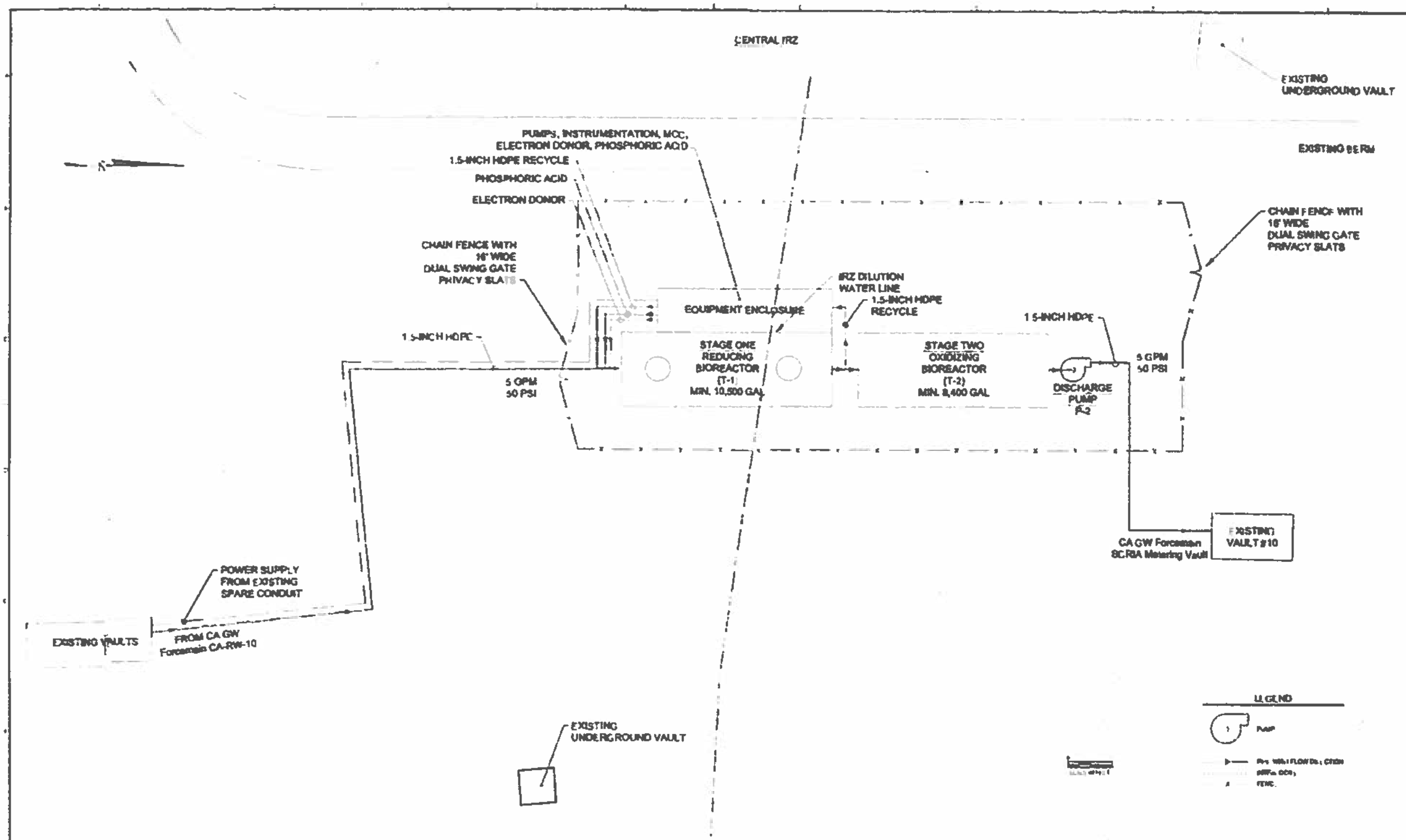
ENGINEER:
Geosyntec consultants

PROCESS FLOW DIAGRAM

TWO-STAGE BIOREACTOR PILOT TEST
PG&E COMPRESSOR STATION
PG&E GROUNDWATER REMEDIATION PROJECT
HINKLEY, SAN BERNARDINO COUNTY, CALIFORNIA 92347

DRAFT CONSTRUCTION DRAWING

FIGURE NO.
1




| | | | | | |
|---|---|---|---|---|---|
| REVISIONS | CLIENT: PACIFIC GAS AND ELECTRIC COMPANY (PG&E) NATIONWIDE ENVIRONMENTAL SERVICES, INC. ADDRESS | ENGINEER Geosyntec consultants | | BIOREACTOR LAYOUT AND PLAN<br>TWO-STAGE BIOREACTOR PILOT TEST<br>PG&E COMPRESSOR STATION<br>PG&E GROUNDWATER REMEDIATION PROJECT<br>HINKLEY, SAN BERNARDINO COUNTY, CALIFORNIA 92347 | DRAFT CONSTRUCTION DRAWING | FIGURE NO. 2 |

199 S Hudson Ave, Suite 110
Pasadena, California 91101
PH 626.449.0664 x203
www.geosyntec.com

# Memorandum

Date: 17 September 2014

To: Laurie Kemper and Lisa Dernbach
Lahontan Regional Water Quality Control Board

Copies to: Kevin Sullivan, Pacific Gas and Electric Company

Iain Baker, Pacific Gas and Electric Company

From: Mark Davidson, Geosyntec Consultants

Bruce Marvin, Geosyntec Consultants

Subject: Response to Request for Additional Information: Bioreactor Pilot Test Work Plan, PG&E Compressor Station, Hinkley, San Bernardino County
Geosyntec Project Number: HA1419

---

Geosyntec Consultants, Inc. ("Geosyntec") has reviewed the 22 August 2014 letter from the Lahontan Regional Water Quality Control Board ("LWRQCB") entitled "Request for Additional Information, Bioreactor Pilot Test Work Plan, PG&E Compressor Station, Hinkley, San Bernardino County." This memorandum addresses the specific comments raised by the LWRQCB.

In the responses below, original comments from the Water Board are numbered per the 22 August letter and presented in *italics*, and Geosyntec responses are presented in standard typeface, indented beneath the respective comment.

*1. After Cr(VI) is reduced to solid Cr(III), describe how it will be removed from the effluent and what medium will be involved.*

> Cr(III) will be removed by incorporation into microbial biofilms and/or by interception and adsorption onto surfaces within the first-stage bioreactor. The second-stage bioreactor also provides bio-active sand filtration that is expected to remove particles greater than 100 microns in size. An effluent bag filter will provide tertiary filtration removing particles greater than 25 microns.

*2. Describe more details about the use of acetic acid and phosphoric acid; what will be the on-site volumes and how will they be stored and handled. Will chemical storage require permitting by San Bernardino County?*

The total estimated volume of acetic acid (20% concentration by weight) required is 585 gal and the total estimated volume of phosphoric acid (20% concentration by weight) required is 46 gal. Acetic acid will be procured in 2,140 pound (250 gallon) containers while phosphoric acid will be procured in 48 pound (5 gallon) containers. These volumes are calculated based on an assumed influent nitrate profile and while the total volume might vary during the course of pilot testing, at any given time there would be no more than 500 gallons of acetic acid and 10 gallons of phosphoric acid (in use container plus back up) on-site for use in this test. The Hazardous Materials Division of the San Bernardino County Fire Department will be provided with an updated version of PG&E's Hazardous Materials Business Plan which includes the volumes of these chemicals proposed to be stored on-site and the storage locations.

These materials will be stored within secondary containment systems inside the locked "equipment enclosure" and inside the locked chain-link fence shown on Figure 2 of the Pilot Test Work Plan while in use. Replacement containers will also be stored within secondary containment systems, either within the fenced enclosure for the pilot test or in the Central Area compound. Phosphoric acid and acetic acid will be delivered and stored in manufacturer sealed DOT-approved containers until a container is connected to the amendment delivery system to minimize handling of acids. When exchanging containers of either acid, workers shall wear goggles, face shield, protective outer and inner gloves, an acid-resistant apron, and acid-resistant footwear.

*3. Further describe the hydraulic residence time and how it affects operations; will the influent feed to the first bioreactor be continuous or intermittent?*

The influent feed of both groundwater and amendments will be continuous. The hydraulic residence time (HRT) is dependent on the flow rate of groundwater through the bioreactors. Pilot testing will begin with a high HRT (low influent flow rate and high recycle percentage) to maximize microbial growth and development of a biofilm on the media. As the microbial biofilm develops, the oxidation-reduction potential (ORP) within the first-stage bioreactor will decline. Higher HRT typically leads to lower ORP, higher utilization of acetic and phosphoric acid, and greater Cr(VI) treatment. In addition to the HRT, the dosage of acetic and phosphoric acid and recycle ratio also affects the ORP within the first-stage bioreactor. When the HRT decreases (due to increases in influent flow rate or a reduction in the recycle ratio) two conditions may occur. First, the efficiency of acetic and phosphoric acid utilization may decrease. Secondly, the ORP within the first-stage bioreactor may increase. The "stress testing" portions of the pilot test are intended to evaluate the minimum HRT under a variety of influent flow rates and acid dosage rates.

*4. Describe all wastes expected from the pilot test. Also describe storage and disposal of wastes during and upon completion of the pilot test.*

Based on the assumed influent profile of 100 ug/L of Cr(VI) and the proposed flow rates and durations, a maximum of 2.5 pounds of Cr(III) will accumulate and be retained within the first-stage bioreactor during pilot testing. Upon completion of pilot testing the bioreactors will be drained and the media will be washed to remove sludge from the media. The bioreactors will be ventilated to dry the media and sludge. Sludge and plastic media will be segregated and removed from the bioreactors. Both waste streams will be sampled for constituents of concern, profiled, and disposed of at an appropriately permitted facility.

Other waste streams from the pilot test include spent bag filters and acetic acid and phosphoric acid containers. Bag filters are designed to remove biomass, if any is present, from effluent after sand filtration. Spent bag filters will be accumulated on-site, sampled and profiled prior to disposal. Empty acetic and phosphoric acid containers will be disposed of according to Title 22, California Code of Regulations, section 66261.7. All waste streams will be profiled and then disposed of at appropriately permitted facilities.

*5. Describe in more detail the expected chemical make-up of final effluent following two-stage treatment.*

Once stable flow conditions and a biofilm are established, the effluent from the two-stage bioreactor system is expected to be depleted in nitrate, chromium, iron and manganese (if present in the influent to the first stage). The sampling and analysis program proposed in the Work Plan contains sample collections from influent, effluent and mid-stage sampling ports in addition to the real-time nitrate and ORP monitoring, allowing for confirmation that complete denitrification is occurring. Complete consumption of electron donor (acetic acid or ethanol) and phosphoric acid is expected. Biomass exiting the first-stage reactor (if any) is expected to be removed by the second-stage that is a bioactive gravel/sand filter. The bag filter on the effluent of the second-stage bioreactor is included to remove all particles greater than 25 microns. Denitrification in the first-stage bioreactor will increase the pH slightly and carbon dioxide production within the first-stage bioreactor will buffer the pH to near neutral conditions. The quantity of acids added to the influent will not alter the effluent pH. The total dissolved solids concentration is not expected to measurably change due to the offsetting effects of acid addition and denitrification.

*6. Describe the expected impacts to groundwater quality from discharge of final effluent.*

No impact to groundwater quality is expected. The effluent will contain less chromium and nitrate than the influent. The effluent pH will be circumneutral. The effluent flow rate is a small fraction of the total reinjection volume and supplemental IRZ treatment will occur (the effluent will be amended with ethanol prior to injection into groundwater).

*7. Provide a larger scale map showing the location of the pilot test, Central IRZ, and geographic identifiers, such as street names.*

Please see attached map (Figure 1). The IRZ Area boundary was obtained from http://www.waterboards.ca.gov/lahontan/water_issues/projects/pge/docs/r6v_2014_0023/r6v_2014_0023_att_a.pdf

If you have any further questions or concerns, we would be happy to address them.

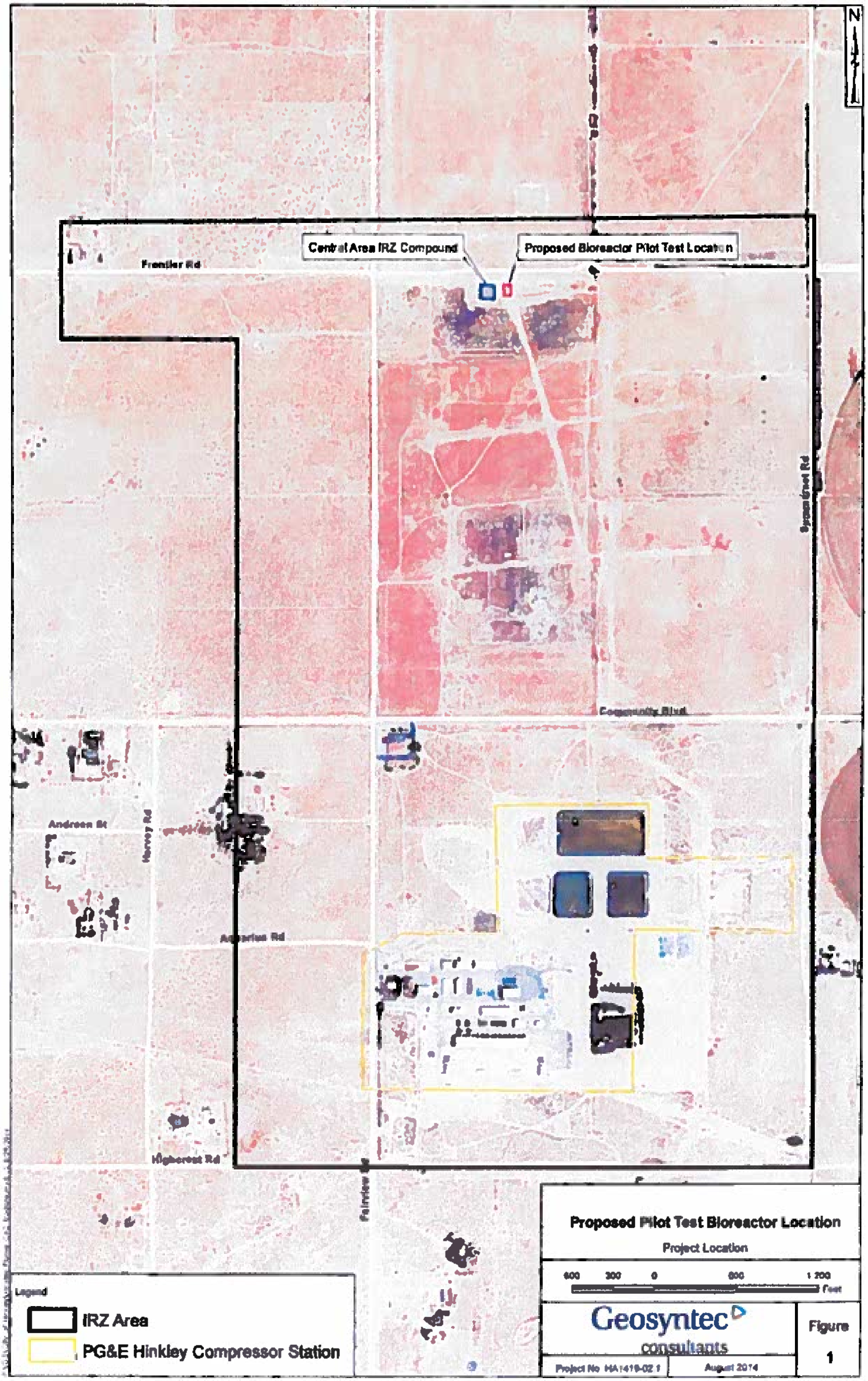
Mark Davidson, Ph.D.
Project Microbiologist

Bruce Marvin, P.E.
Associate Engineer

* * * * *

# ATTACHMENT

# Proposed Pilot Test Bioreactor Location


N
Central Area IRZ Compound
Proposed Bioreactor Pilot Test Location
Frontier Rd
Community Blvd
Sycamore Rd
Andreen St
Harvey Rd
Highcrest Rd
Fairview Rd
Legend
IRZ Area
PG&E Hinkley Compressor Station
Proposed Pilot Test Bioreactor Location
Project Location
600 300 0 600 1 200
Feet
Geosyntec
consultants
Figure
1
August 2014

**Pacific Gas and Electric Company**

**Kevin M. Sullivan**
Director of Chromium Remediation Program

77 Beale Street, B28P
San Francisco, CA 94105
(925) 818-9069 (cell)
kmsu@pge.com

October 7, 2014

Lisa Dernbach
Lahontan Regional Water Quality Control Board
2501 Lake Tahoe Blvd
South Lake Tahoe, CA 96150

Re: Response to IRP Manager's Comments Regarding PG&E's Pilot Test Work Plan, Two-Stage Bioreactor, Hinkley, California

Dear Ms. Dernbach:

Pacific Gas and Electric Company (PG&E) has reviewed the September 4, 2014 letter from Project Navigator, the Independent Review Panel (IRP) Manager for the Hinkley Remediation Project, titled "IRP Manager's Comments Regarding *PG&E's Pilot Test Work Plan, Two-Stage Bioreactor, Hinkley, California*." This letter and the attached memorandum from Geosyntec Consultants (Geosyntec) address the specific comments raised by the IRP manager in the letter. The initial five comments put forth in the letter relating to the decision to pilot test the proposed technology are discussed in this letter and the eight questions posed specifically on the two-stage bioreactor are addressed in the attached memorandum.

*Comment #1: Provide the rationale for proposing the two-stage bioreactor as a contingency plan over chemical reduction/precipitation and WBA exchange technologies. What are the basis for testing an alternate technology since the issuance of the EIR and Addendum #3?*

PG&E has proposed pilot testing the two stage bioreactor as a potential remedial technology for the site. If it is successful in treating hexavalent chromium (Cr6) it may be considered as a potential contingency plan technology. PG&E has considerable experience utilizing chemical reduction/precipitation at the PG&E Topock site and therefore, significant pilot testing would not be required to implement this technology at Hinkley. However, based on PG&E's experience at the Topock site, chemical reduction/precipitation generates a significant amount of waste and requires a significant amount of operations and maintenance (O&M) when implemented. Additionally, as described in detail in response to Comment #3 below, research and experience with WBA resins for Cr(VI) treatment has improved since the issuance of the Feasibility Study Addendum #3, reducing the need for extensive pilot testing of this technology.

The two-stage bioreactor is anticipated to create significantly less waste when implemented and require significantly less O&M than the two treatment technologies discussed above. Therefore, based on Geosytec's experience operating this type of bioreactor for Cr6 reduction, PG&E is proposing to pilot test this technology as an alternative treatment technology for the site, which could potentially lead to implementation as a contingency technology. However, WBA and chemical reduction/precipitation are both still retained as potential treatment technologies.

*Comment #2: What are the advantages of selecting bioremediation technology using acetic acid and phosphoric acid compared to chemical reduction/precipitation as described above for the contingency plan? Is the two-stage bioreactor considered due to implementation factors such as costs, infrastructure, construction duration, treatment capacity vs footprint, etc.? Please provide a comparative analysis.*

As discussed above in response to comment #1, the two-stage bioreactor is anticipated to generate significantly less waste and require less O&M than the WBA or reduction/precipitation. If effective, this technology is expected to provide a lower cost and potentially more sustainable alternative for above ground treatment of Cr6 based on these factors.

*Comment #3: Does PG&E propose to pilot test the two-stage bioreactor in lieu of WBA exchange? If so, please provide the rationale*

Research and experience with WBA resins for Cr(VI) treatment has improved since the issuance of the Feasibility Study Addendum #3. For instance, Coachella Valley Water District, in partnership with the Water Research Foundation and other entities, have been evaluating treatment technologies to remove Cr6 from groundwater. As part of this effort, both reduction coagulation and filtration (RCF) and ion exchange (IX) using both strong and weak base anionic resin was pilot tested, reducing the need for a pilot study of WBA in comparison to the bioreactor technology. All technologies continue to be potentially viable treatment alternatives.

*Comment #4: Is the proposed bioreactor intended to serve as a contingency plan for the IRZ component or both the IRZ and AUs? Please clarify.*

Pilot test is focused on general site conditions and not focused specifically on IRZs or AUs. Testing is being completed to evaluate an alternative treatment technology. If effective, it may be considered for contingency treatment technology. Further discussion on the selection of the location for the pilot test is provided in the attached memorandum.

*Comment #5: What are the requirements for regulatory approval and acceptance for pilot testing (and proposing) a technology other than what were recommended for the contingency plan? Why is PG&E proposing an ex-situ bioreactor when the previous studies did not retain the technology?*

By submitting the Two-Stage Bioreactor Pilot Test Work Plan and Notice of Intent PG&E is requesting Water Board approval to implement the Pilot Test at the site. If proven effective, PG&E may request Water Board approval for use as a contingency technology in the summary report for the Pilot Test.

The feasibility study included a pilot test of a hollow fiber membrane bioreactor and concluded that additional testing would be needed to determine if this technology is viable. There are several key differences between the bioreactor evaluated and the proposed pilot test bioreactor which primarily include O&M costs and proven use of the technology for chromium reduction. The proposed pilot test bioreactor is a fixed film bioreactor (FFBR), whereas the microbial reactor evaluated in the feasibility study was a membrane biofilm reactor (MBfR). The overall mechanism of action of both reactors is similar: providing an energy rich substrate to a population of microorganisms, in a controlled environment, that create reducing conditions – conditions that favor the reduction of Cr6 to a Cr3 complex that precipitates and is removed from solution.

In an MBfR, contaminated water passes through a reaction vessel that has numerous parallel hollow fibers. The hollow fibers have very small pores through which hydrogen gas is pumped, allowing for development of microbial biofilms on the surface of the fibers. MBfRs have extremely small pores through which hydrogen is delivered to the water to be treated. Hydrogen gas not only stimulates microbial activity, it also abiotically reacts with non-target dissolved constituents that tend to clog the pores in the membranes, which also become fouled by the biofilm due to localized microbial growth near the hydrogen emitting pores. As a result, MBfRs have high O&M costs.

In the case of the proposed FFBR, the electron donor is directly mixed into the influent water, and the microbial biofilm develops on surface of the inert plastic media that the water passes over. In both cases, Cr3 is removed from solution within the reactor (gravitationally settling, adsorbing to the biofilm itself or mechanical interception onto surfaces with the reactor). A benefit of FFBR versus MBfRs is that a variety of electron donors can be used and have been proven. In contrast, MBfR typically use hydrogen as the sole electron donor. Hydrogen is flammable (safety issues) and generally costs more than soluble electron donors on a per mole of electron donated basis.

A key difference in the operation of these two types of bioreactors is that a FFBR, particularly one constructed with a large surface area media such as the proposed inert plastic, is able to sustain a larger and more diverse active biomass (heterotrophic bacterial populations are generally more diverse than autotrophic populations). FFBR are also more readily able to accommodate a range of hydraulic conditions while using less complicated mechanical equipment leading to a lower O&M costs.

Numerous examples of FFBR design and construction specific to chromium reduction have been offered in the responses to the "Two Stage Bioreactor" questions (see 1c of the attached memorandum) while, to the best of our knowledge, no literature exists to support the use of an MBfR for Cr6 contaminated water with an influent flow rate of 5gpm or more (as proposed in the pilot test work plan). We are not aware of any pilot or full scale MBfR applications in place that are specifically designed for chromium treatment. Therefore, PG&E would like to move forward with pilot testing the FFBR based on a more proven track record for Cr6 remediation.

Please contact Iain Baker at (415) 265-5196 should you have any questions or require any additional information.

Best Regards,

Iain Baker on behalf of

Kevin Sullivan

Enclosure

Geosyntec consultants

199 S Hudson Ave, Suite 110
Pasadena, California 91101
PH 626.449.0664 x203
www.geosyntec.com

# Memorandum

Date: 3 October 2014

To: Laurie Kemper and Lisa Dernbach
Lahontan Regional Water Quality Control Board

Copies to: Kevin Sullivan, Pacific Gas and Electric Company

Iain Baker, Pacific Gas and Electric Company

From: Mark Davidson, Geosyntec Consultants

Bruce Marvin, Geosyntec Consultants

Subject: Response to IRP Manager's Comments Regarding PG&E's Pilot Test Work Plan, Two-Stage Bioreactor, Hinkley, California (dated September 4, 2014)

---

Geosyntec Consultants, Inc. ("Geosyntec") has reviewed the 4 September 2014 letter from the Independent Review Panel Manager ("IRP Manager") entitled "IRP Manager's Comments Regarding PG&E's Pilot Test Work Plan, Two-Stage Bioreactor, Hinkley, California". This memorandum addresses only the specific questions raised by the IRP Manager regarding the "Two-Stage Bioreactor" (see page 4 of the September 4 letter).

In the responses below, original questions from the IRP Manager are numbered per the 4 September letter and presented in *italics*, and Geosyntec responses are presented in standard typeface, indented beneath the respective question.

*1. Provide example projects where this technology has been tested and proven to treat Cr6 impacted groundwater. Include groundwater influent analysis.*

> The proposed two-stage bioreactor pilot tests further draws on Geosyntec experience from many projects involving biological reduction of hexavalent chromium and full-scale treatment plant operations. Two full-scale example projects are provided below that demonstrate the breadth of influent conditions that have been treated and proven via long-term operations of similar Geosyntec bioreactors. In addition, aboveground bioreactors of various configurations (stationary bed fixed-film, membrane fixed film, activated sludge, fluidized fixed film, vertical flow, horizontal flow, etc) have been

documented in the peer reviewed literature over a broad range of chromium loadings, microbial types, and hydraulic residence times. A description of two proven Geosyntec bioreactor systems and select references from the peer-reviewed literature are provided below.

a. South African Mine (Confidential Client) – results from this project were presented at the 2012 Battelle Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, May 2012) and the results were published in the journal Water SA (Williams et al, July 2014, Vol 40, No. 3, pp 549 – 554, attached).

A fixed-film bioreactor operated for over three years treating up to 10mg/L of Cr6. The bioreactor is a horizontal flow gravel media design that was constructed in a pre-existing concrete box, at the request of the Client. The effluent was oxygenated using an aeration cascade. The bioreactor was operated at flow rates of up to 10 gallons per minute (GPM) and had a hydraulic residence time (HRT) of between 12 and 24 hours, depending on the influent flow rate. The electron donor was citric acid, due to a readily available and cost effective local source. The influent Cr6 was up to 10 mg/L, nitrate as high as 68 mg/L, and sulfate up to 400 mg/L. Effluent concentrations of Cr6 after biofilm development (which took approximately 6 weeks to fully stabilize) were consistently below detect (<10 µg/L), with almost all of the Cr6 reduction occurring in the first several hours of HRT. Based on the success of the first bioreactor, two additional reactors were commissioned, built and operated by Geosyntec.

b. Former Ordinance Facility, northern California (Confidential Client)

Geosyntec was retained in 2010 to assess and eventually retrofit an existing bioreactor system that was not reliably meeting NPDES effluent discharge limits, while incurring high operations costs. Results from this project were presented at the 2014 Battelle Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, May 2014).

The bioreactor was retrofitted to achieve perchlorate, Cr6 and naturally occurring selenium effluent limits. The objectives were to stabilize system operations to allow for additional recovery wells to achieve regulatory compliance. The retrofit added process controls, change from a continuously stirred tank reactor to a stationary submerged bed up-flow reactor-type, as well as replacing high attrition rate polyurethane media with inert plastic media. The two-stage bioreactor system operates at an average flow rate of 32 GPM with a cumulative HRT of approximately 7.5 hours. The electron donor is acetic acid, based on cost effectiveness, which replaced methanol. The Cr6 influent concentration ranges from 30-35 µg/L, perchlorate ranges from 80 to 120 µg/L, and selenium averages 7.9 µg/L. Effluent Cr6 concentrations are consistently below the reporting limit (<0.5 µg/L).

c. The specific use of fixed film bioreactors, of a variety of configurations, electron donors and microbial communities, has also been demonstrated to be viable in the peer-reviewed literature, please see the following sub-set of the literature:

Williams, P.J., Botes, E., Maleke, M.M., Ojo, A., DeFlaun, M., Howell, J., Borch, R., Jordan, R., and van Heerden, E. (2014), Effective bioreduction of hexavalent chromium-contaminated water in fixed-film bioreactors. Water SA., Vol. 40 (3), pp. 549-554.

Cordoba, A., Vargas, P., and Dussan, J., (2008), Chromate reduction by Arthrobacter CR47 in biofilm packed bed reactors. Journal of Hazardous Materials, Vol. 151, pp.274-279.

Sahinkaya, E., Kilic, A., Altun, M., Komnitsas, K., and Lens, P.N.L. (2012), Hexavalent chromium reduction in a sulfur reducing packed-bed bioreactor. Journal of Hazardous Materials, Vol. 219-220, pp. 253-259.

Pazos, M., Branco, M., Neves, I. C., Sanromán, M. A. and Tavares, T. (2010), Removal of Cr(VI) from Aqueous Solutions by a Bacterial Biofilm Supported on Zeolite: Optimisation of the Operational Conditions and Scale-Up of the Bioreactor. Chemical Engineering Technology, Vol. 33, pp. 2008–2014.

Nkhalambayausi-Chirwa, E. M. and Wang, Y.-T. (1997), Hexavalent Chromium Reduction by Bacillus sp. in a Packed-Bed Bioreactor. Environmental Science & Technology, Vol. 31 (5), pp. 1446-1451.

Quintelas C., Fernandes B., Castro J., Figueiredo H., and Tavares T.. Biosorption of Cr(VI) by three different bacterial species supported on granular activated carbon: a comparative study. Journal of Hazardous Materials, Vol. 153 (1-2), pp. 799-809.

Nkhalambayausi-Chirwa, E. M. and Wang, Y.-T. (1997), Chromium(VI) Reduction by Pseudomonas fluorescens LB300 in Fixed-Film Bioreactor. Journal of Environmental Engineering, Vol. 123 (8), pp. 760-766.

Nkhalambayausi-Chirwa, E. M. and Wang, Y.-T. (2004), Modeling hexavalent chromium removal in a Bacillus sp. fixed-film bioreactor. Biotechnology and Bioengineering, Vol. 87, pp. 874–883.

Nancharaiah, Y.V., Dodge, C., Venugopalan, V.P., Narasimhan, S.V., and Francis, A.J., (2010), Immobilization of Cr(VI) and its reduction to Cr(III) phosphate by granular biofilms comprising a mixture of microbes. Applied and Environmental Microbiology, Vol. 76 (8), pp. 2433-2438.

Stasinakisa A.S., N.S. Thomaidisa, D.Mamaisb, M. Karivalia, T.D. Lekkasa. (2003), Chromium species behaviour in the activated sludge process. Chemosphere. Vol. 52 (6), pp.1059–1067.

Pattanapipitpaisal, P., Brown, N.L., and Macaskie, L.E., (2001), Chromate reduction and 16s rRNA identification of bacteria isolated from a Cr(VI)-contaminated site. Applied Microbial Biotechnology, Vol. 57, pp. 257-261.

*2. Provide references regarding the rate constant for Cr6 discussed on page 4 and 5 of the Work Plan.*

The rate constant used in the Work Plan is derived from the South African bioreactor project described in 1a, above. The rate constant was calculated using an influent Cr6 concentration of 10 mg/L, an effluent Cr6 concentration of 0.01 mg/L, and an HRT of 12 hrs. The resulting degradation rate is 13.8 $d^{-1}$ and is considered to be conservative because almost all of the Cr6 treatment occurred in the first several hours of the HRT. This conclusion is validated by the process monitoring data from the northern California site described in 1b, above.

Cr6 reduction rates from the peer-reviewed literature also suggest the Work Plan rate constant is conservative. For example, laboratory column studies found rate constants ranging from 9 $d^{-1}$ (Chirwa and Wang, Environmental Science and Technology, 1997, Vol. 31, p. 1446-1451) to 380 $d^{-1}$ (Dermou et al., Journal of Hazardous Materials, 2005, Vol. 126 (1-3), pp. 78-85).

*3. Why is plastic media selected for Stage One bioreactor? Will using different media effect the hydraulic residence time?*

Plastic media was selected for four primary reasons:

1. plastic media is inert (washed high-density polyethylene) that minimizes the potential for the media to contribute impurities to the effluent

2. plastic media is low-cost and light-weight making it easier to handle during installation and maintenance, if needed;

3. plastic media has a very high surface area to volume ratio leading to a larger surface area of biofilm development than gravel; and

4. plastic media has a high porosity (takes up less space in a given volume) maximizing the HRT for a given reactor size.

Yes, the hydraulic residence time varies with the influent flow rate, the bioreactor dimensions, and the void volume within the bioreactor, and is therefore dependent on the media type used.

*4. The system is designed based on the Central Area IRZ influent concentration. Considering that the ex-situ treatment system is for AUs (which typically treats groundwater with less Cr6 concentration than the Central Area) what is the rationale for selecting the groundwater conditions in the Central Area as a basis for design?*

The rationale for selecting the Central Area IRZ location was to test the bioreactor system with higher influent Cr6 loading than may be needed for AUs as a conservative assessment of system performance. In addition, "slip-streaming" the influent and effluent flows from the pilot test within the IRZ process allows for stress testing of the bioreactor system until Cr6 break-through with minimal or no risk of adverse impacts to the Hinkley remediation program, given subsequent ethanol dosing of the effluent. The Central Area IRZ provided a built-in "safety net" in the unlikely event of no Cr6 treatment in the bioreactor – pilot test effluent will still be dosed with ethanol prior to reinjection within the IRZ area. In addition, the Central Area IRZ has existing extraction and injection wells, piping, and electrical infrastructure, which reduces the costs of the pilot demonstration and eliminates impacts to sensitive ecological areas. Should the bioreactor system subsequently be used as a contingency for the AUs, lowering the influent Cr6 concentration would lead to a lower minimum HRT (and bioreactor volume). An objective of the pilot test is to evaluate the minimum HRT and site-specific Cr6 treatment rate constant.

***5. Why is acetic acid proposed as a carbon amendment reagent instead of ethanol, which is already being used as the IRZ amendment? This would require separate delivery, storage, and handling for a full scale system.***

Acetic acid was selected based on direct experience on previous projects (see above), the ability of a wide-range of microbial communities to directly assimilate acetic acid in microbial respiration process (rather than a step-wise conversion to lower molecular weight organics which may lead to a higher minimum HRT than acetic acid – this will be tested in the ethanol test), a similar electron donating capacity (per mol) as ethanol, and reduced potential pH impacts on the microbial community (estimated 26 $H^+$ produced per mol of ethanol vs. 17 $H^+$ produced per mol of acetate during chromate reduction). Ethanol will also be tested for comparative purposes. Numerous electron donors (ethanol, sodium benzoate, citric acid, acetic acid, and lactic acid) have been reported in the peer-reviewed literature as electron donors for biological Cr6 reduction.

*6. What is the loading capacity of the plastic media for Cr3 precipitation in Stage One? How is the Cr3 precipitation removed from the plastic media or will the media need to be eventually replaced?*

The plastic media in the first stage has adequate capacity for retention of both the microbial biofilm and mechanically intercepted Cr3 precipitates. In the South African bioreactor, Cr3 bio-solids accumulated in the bottom of the bioreactor due to gravitational settling, and similar behavior is expected in the pilot bioreactor. Based on Cr6 influent, flow rates, and pilot test duration, up to 2.5 lbs of Cr3 is anticipated to be produced in the first stage bioreactor during the course of the pilot test. The second stage bioreactor provides bio-active filtration that will further remove Cr3 precipitates that do not settle in in the first stage (if any). The effluent of the second stage will be further filtered to less than 25 microns consistent with the IRZ system to ensure no impacts to the IRZ injection wells. Upon completion of pilot testing the bioreactors will be drained and the media will be washed to remove the biofilm from the media. The bioreactors will be ventilated to dry the media and sludge. Sludge and plastic media will be segregated and removed from the bioreactors. Both waste streams will be sampled for constituents of concern, profiled, and disposed of at an appropriately permitted facility.

*7. How are the microbes in the bio-active sand bed in Stage Two sustained if the incoming water contains, if any, only a trace amount of iron and manganese? What is the food source for the microbes in the sand bed?*

The food source for the second stage bioreactor is residual electron donor (acetic acid or ethanol) and suspended biomass that washes out of the first stage. While the influent to the second stage may not contain iron and manganese, potential full-scale versions of the bioreactor may encounter groundwater with higher concentrations of iron and manganese (either naturally occurring, or as by-products of the IRZ program). Iron and manganese oxidizing bacteria are known to persist despite low organic carbon doses in rapid sand filters that are widely for drinking water treatment. In addition, the aeration cascade and gravel/sand media provides the conditions for abiotic (chemical) oxidation of iron and manganese in the event of low microbial population density in the second stage.

*8. Will an inline static mixer be required to mix the electron donor and phosphoric acid with impacted Cr6 groundwater? How is mixing ensured?*

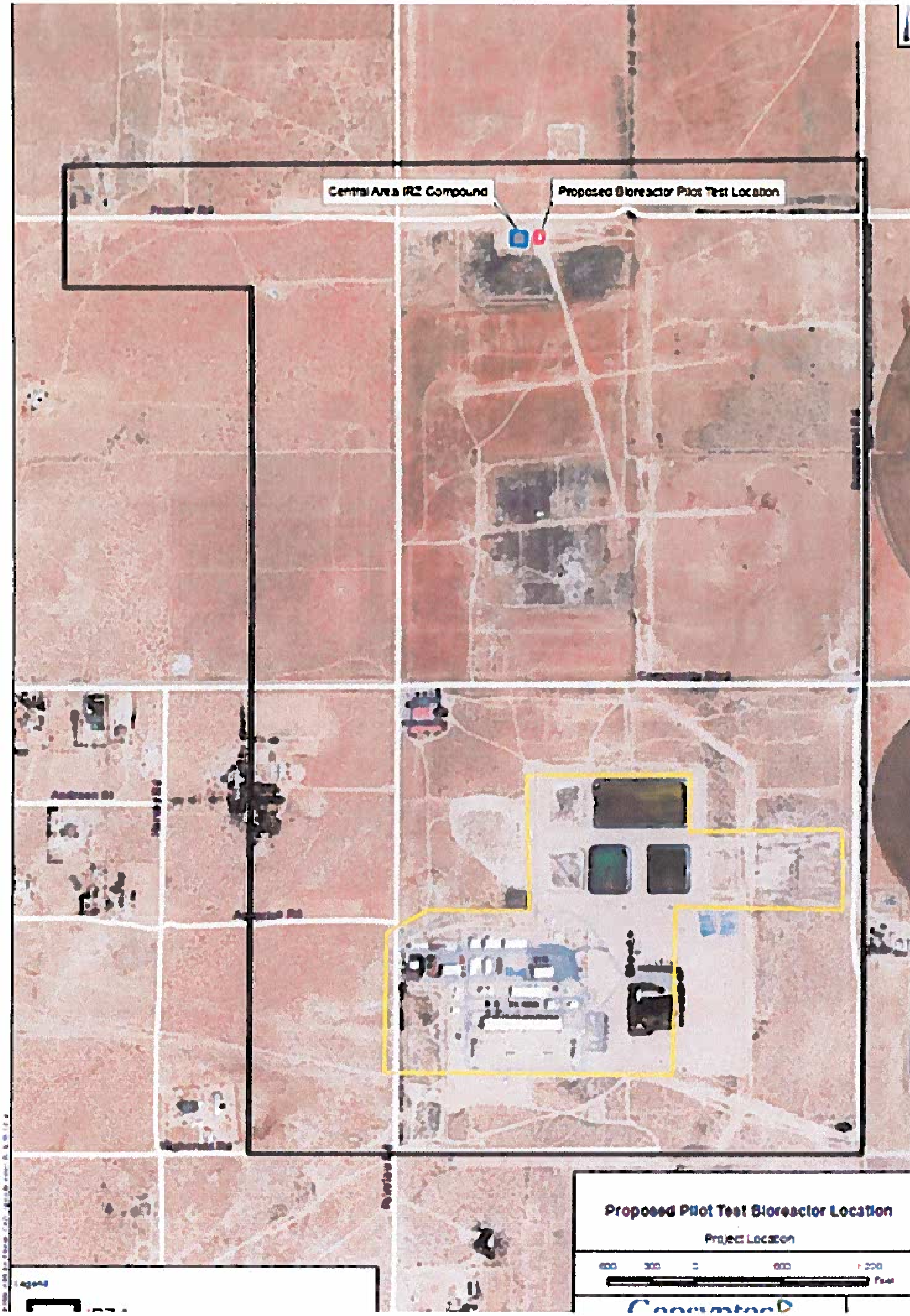
> An inline static mixer is not considered necessary. Electron donor and phosphoric acid will be continuously dosed into the first stage influent. Turbulence within the influent piping and the discharge orifice into the up-flow wet well (the first 3 feet of the bioreactor) will provide adequate mixing prior to overflow onto the first stage media bed. Inline static mixers are prone to bio-fouling and clogging when installed within piping carrying the expected volatile suspended solids concentrations, based on Geosyntec experience.

If you have any further questions or concerns, we would be happy to address them.

Mark Davidson, Ph.D.
Project Microbiologist

Bruce Marvin, P.E.
Associate Engineer

* * * * *


Central Area IRZ Compound
Proposed Bioreactor Pilot Test Location
Proposed Pilot Test Bioreactor Location
Project Location
Feet
Legend

# Project Location within Chromium Plume