GROUNDWATER SOURCE CONTROL TREATABILITY TESTING

NW NATURAL GASCO SITE

Prepared for

NW Natural

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µg/L	micrograms per liter
Anchor	Anchor Environmental L.L.C.
BTEX	benzene, toluene, ethylbenzene, and xylenes
DEQ	Oregon Department of Environmental Quality
DNAPL	dense nonaqueous-phase liquid
EPA	U.S. Environmental Protection Agency
GAC	granular activated carbon
LWG	Lower Willamette Group
mg/L	milligrams per liter
ORP	oxidation-reduction potential
PAH	polynuclear aromatic hydrocarbons
PQL	practical quantitation limit
RPA	Reasonable Potential Analysis
VOC	volatile organic compounds

1 INTRODUCTION

Groundwater treatability testing was performed for NW Natural as discussed previously with the Oregon Department of Environmental Quality (DEQ) and proposed in Appendix B of the *Preliminary Design Report* (Anchor 2008). Preliminary results were discussed with representatives of DEQ on October 1, 2008. This report briefly describes the treatment methods tested and presents the preliminary results of the testing for a likely treatment train. This preliminary information is being submitted to DEQ to support their Reasonable Potential Analysis (RPA) (DEQ 2005) for discharge permit determinations. Additional information needed for the RPA is also presented here, including maximum system flow rates and background concentrations in the receiving water. A complete report of all treatability results and a discussion of the entire study will be submitted to DEQ at a later date.

Anchor Environmental L.L.C. (Anchor) is currently in the process of designing a groundwater source control system for NW Natural. The system will include a barrier wall and extraction wells (Anchor 2008). The groundwater recovered by the source control system will be treated on-site prior to discharge to the Willamette River. The groundwater contains elevated concentrations of cyanide, BTEX (benzene, toluene, ethylbenzene, and xylenes), and polynuclear aromatic hydrocarbons (PAH), which will be removed by a chemical treatment system. DEQ provided a list of preliminary treatment targets for contaminants of concern (Table 1), which are based on chronic water quality criteria (Oregon Administrative Rules, Chapter 340, Division 41, Section 33) , the Joint Source Control Strategy (DEQ and EPA 2005), or DEQ quantitation limits (cadmium, copper, mercury, and zinc).

Various treatment systems have been evaluated, and NW Natural will select a system based on demonstrated performance and long-term costs. The treatment systems being evaluated share some elements in common, including oil/water separation, particle filtration, chemical oxidation, and granular activated carbon (GAC) polishing. Additional treatment steps are specific to the treatment technologies and discussed briefly in the remainder of this section. Based on modeling of pumping rates as presented in the *Preliminary Design Report*, and an assumed safety factor, the maximum flow rate for the treatment system will be 400 gallons per minute (0.58 million gallons per day). Two of the systems that were considered for treating the groundwater were evaluated through treatability testing. These two systems, Advanced

Oxidation and Aeration/Alkaline Chlorination, are discussed in more detail below. The preliminary results of the treatability tests are discussed in Section 3 of this report.

The treatability study findings, reasonable potential analysis results, and other factors were used to determine effluent criteria for DEQ consideration. The proposed effluent criteria are discussed in Section 5.

1.1 Advanced Oxidation

Advanced Oxidation uses ozone, activated by ultraviolet light, for oxidation of contaminants, and may use hydrogen peroxide for additional oxidation. Ten treatability experiments were performed to evaluate the efficacy of several combinations of varying dosages of ozone and hydrogen peroxide. Ozone dosages of 160 and 165 milligrams per liter (mg/L) and hydrogen peroxide dosages of 0, 5, and 10 mg/L were tested. Ultraviolet light was applied at a rate of 3.5 watt-hours per liter for 70 minutes for all of the tests. Water was also passed through a 5-micron particle filter (Aqua-Pure Model AP-110) to remove fine suspended solids and a GAC filter to remove organic compounds remaining after oxidation. For one of the treatability tests, the pH of the water was adjusted to 8.5 (from a starting point of 6.8), but pH adjustment did not significantly affect the overall effectiveness of the treatment. The Advanced Oxidation tests were all run for 90 minutes.

Pre-treatment technologies were also evaluated. Water was treated with exposure to air, oxygen, or ozone for either 20 or 40 minutes in six experiments. The water was circulated through a countercurrent reactor at a rate of 2.5 gallons per minute, and the gas was introduced at a rate of 740 milliliters per minute. Following reaction with the gas, the water was filtered through a 5-micron Aqua-Pure Model AP-110 filter. The 40-minute ozone exposure was selected for pre-treatment of water from MW-01-55 in the Advanced Oxidation treatability tests based on the removal of iron and cyanide in the pre-treatment tests.

Preliminary results for one of the many experiments using Advanced Oxidation (Experiment 7) is presented in Section 3 as representative of the performance capable of this type of treatment system. The treatment train used for this experiment is illustrated in Figure 1. The dosages of ozone and hydrogen peroxide were 165 and 10 mg/L, respectively.

The total treatment time, including 40 minutes of pre-treatment and 90 minutes of Advanced Oxidation was 130 minutes. A number of other experiments were run using varying dosages and contact times, and these results will be presented and discussed in a full report at a later date.

1.2 Aeration/Alkaline Chlorination

Alkaline Chlorination uses sodium hypochlorite to oxidize cyanide. In the treatability tests, alkaline chlorination was combined with aeration to aid in the removal of iron, manganese, and volatile organic compounds (VOC). The alkaline chlorination tests also included a polishing step of OrganoClay adsorption in addition to the GAC to further remove remaining contaminants, although OrganoClay was not found in the testing to provide significant benefit.

Aeration and Alkaline Chlorination processes were combined in the treatability studies to simulate the effects of air stripping and destroying organic compounds, oxidizing cyanide, and oxidizing iron and manganese. Sodium hypochlorite was added (a process known as alkaline chlorination) to produce an elevated oxidation-reduction potential (ORP) greater than 600 millivolts. Sodium hydroxide was also added to further adjust the pH to a level of 10.0 to 10.5. After holding these conditions for approximately 90 minutes, the pH was reduced to approximately 8.5 and held for approximately 30 minutes. The total treatment time was 120 minutes. The treatment train used for this experiment is illustrated in Figure 2.

In an effort to determine if the iron and manganese could be more effectively removed after aeration, aluminum sulfate was added at a dosage of 10 mg/L. This additional step did not significantly improve the overall effectiveness of the treatment, and the results of this test are not presented in this report.

All samples were passed through a 0.5 to 1.0-micron filter to simulate solids removal with sedimentation and filtration. For the treatability tests, the filtration was performed after treating the water by Aeration and Alkaline Chlorination. At full-scale operation this filtered water would be passed through GAC columns for organics removal and through secondary bag filters to capture any carbon fines with adsorbed organics.

After oxidation and filtration, all samples were pumped through an OrganoClay filter to determine if certain organics were preferentially removed prior to GAC polishing. If found to be effective, OrganoClay could reduce the organics loading on the GAC units, thereby lengthening the life of the GAC media. However, little benefit was seen from the OrganoClay. The OrganoClay filter is not included in Figure 2.

Following the oxidation, filtration, and OrganoClay processes, the wastewater was pumped to a GAC filter, which very efficiently removes organic compounds remaining after the aeration phase. The pilot filter was designed to operate at 20 minutes of Empty Bed Contact Time, which would approximate a design value used at full-scale design. At full-scale design, the GAC vessels would employ a lead-lag configuration using two trains of two vessels in series to ensure continuing high performance of the activated carbon process.

After the GAC process, the samples were filtered through a 0.5-micron filter, to capture any carbon fines containing adsorbed organics prior to discharge. In full-scale application, this process would likely be bag filters in parallel, with disposable 0.5-micron bags prior to the sampling point.

Preliminary results for one of the many experiments using Alkaline Chlorination is presented in Section 3 as representative of the performance capable of this type of treatment system. The treatment train used for this experiment is illustrated in Figure 2. A number of other experiments were run using varying reagent dosages, treatment times, and pH, and these results will be presented and discussed in a full report at a later date.

2 EVALUATION OF INSIGNIFICANT CONSTITUENTS

As discussed previously with DEQ, and documented in the October 31, 2006, memorandum from Anchor to DEQ (Anchor 2006), the concentrations of phenols and certain metals in untreated groundwater on-site are insignificant compared with DEQ Preliminary Treatment Targets. This comparison was updated using more recent groundwater data to confirm that the previous conclusions remain valid. Although these comparisons were made for untreated groundwater, additional data for treated groundwater are also discussed as the treatment processes are expected to further reduce concentrations of these constituents.

The results of testing the untreated groundwater for phenolic compounds are presented in Table 2a. Phenolic compounds were analyzed for, but only phenol was detected at low concentrations in groundwater from the wells used as the source of water for the treatability testing (MW-01-55 and PW-01-80). The concentrations of phenol detected in the untreated groundwater samples are much lower than JSCS screening criteria and the DEQ Table 20 and Table 33 values. Therefore the phenol concentrations in site groundwater are already well below the most conservative risk-based screening values. The results of the Alkaline Chlorination tests are presented in Table 3b. None of the phenolic compounds were detected in the final effluent from the Alkaline Chlorination test. Although phenol was detected at low concentrations in the raw groundwater, there was insufficient sample volume to analyze water from the Advanced Oxidation treatability studies for phenolic compounds. Advanced Oxidation is expected to completely destroy phenols due to the extreme oxidation conditions that are achieved by this method.

A summary of groundwater analyses for metals is presented in Table 2b. The data sources for this summary are:

- Samples collected along the shoreline between October 2006 and January 2007
- Samples from 28 wells collected in March 2006 and July 2007 for the Remedial Investigation
- Samples from wells MW-01-55 and PW-01-80 collected in July and August 2008

The average concentration for each of the metals listed in Table 1 was compared to DEQ Preliminary Treatment Target for that metal. Conservatively, the DEQ limit (not including the DEQ PQLs, which were applied to derive the Preliminary Treatment Targets) were compared to the arithmetic mean of the data set plus one standard deviation. Constituents having an

arithmetic mean concentration more than one standard deviation less than the corresponding DEQ limit were identified as insignificant at the site. The metals that are insignificant in site groundwater are chromium, nickel, selenium, and silver. No effluent limits or monitoring for these constituents are proposed in Section 5, because of the low concentrations of these metals in untreated groundwater.

3 TREATABILITY TEST RESULTS

Chemical analyses of water samples from one representative Advanced Oxidation treatment test (Experiment 7) and one representative Alkaline Chlorination treatability test are presented in Tables 3a and 3b. Both of these tables show the results of chemical analyses of water at four different stages of treatment. For both treatment tests, the water was a blend of 80 percent (by volume) from well PW-01-80 and 20 percent from MW-01-55.

These wells were chosen to provide a conservative source of raw water for the test. Well PW-01-80 was selected because the screen zone intersects a DNAPL zone in the alluvium, and represents some of the highest groundwater concentrations of MGP-related contaminants on the site. Well MW-01-55 was selected because it has some of the highest iron and manganese concentrations of any well on the site.

In the Advanced Oxidation test (Table 3a), the water from MW-01-55 was pretreated with ozone to reduce iron concentrations before it was mixed with water from PW-01-80. For the Alkaline Chlorination test (Table 3b) the samples were blended without pretreatment. Although well PW-1-80 was properly purged prior to obtaining the samples, some residual DNAPL was mixed with the groundwater in the samples tested. The presence of DNAPL in groundwater samples, even in small amounts, can cause significant variation in the concentrations of target analytes, even in samples obtained at the same time. The variation in analyte concentrations in the untreated samples on Tables 3a and 3b shows that the presence of DNAPL was a factor, especially for the organic analytes, such as PAHs and BTEX.

3.1 Advanced Oxidation Test Results

Samples were collected at the beginning of treatment (0 minutes), and after 20, 60, and 90 minutes of treatment. The 90-minute sample was also passed through a household-type GAC filter. The results for 90-minute treatment presented in this report are representative of the capabilities of the Advanced Oxidation.

The results presented in the 0-, 20-, and 60-minute columns in Table 3a are provided to demonstrate the progress of treatment and do not reflect final effluent quality. Only the 90-minute treatment results are appropriate for the RPA (with the exception of arsenic as discussed below).

Chemical data for organic compounds show that the destruction efficiency for PAHs and the BTEX compounds exceeded 99.9 percent for Advanced Oxidation. Chlorinated hydrocarbons (trichloroethene, tetrachloroethene, and vinyl chloride) were not detected in any of the samples.

All of the metals concentrations in the treated groundwater except for arsenic were well below the preliminary DEQ treatment target concentrations (Table 1). Treatment to achieve the chronic water quality criterion for arsenic may present a problem for all of the identified treatment methods, although the results of the study may underestimate the treatment capabilities for the following reasons:

- The untreated groundwater selected for treatability testing is representative of the most contaminated groundwater at the site. Typical influent concentrations to the treatment system are expected to be less than the concentrations in the water used for the treatability tests.
- The GAC appears to have leached arsenic into the treated water for the 90-minute test sample. Comparing the untreated water to the 60-minute treatment, a removal efficiency for arsenic was greater than 85 percent (0.52 micrograms of arsenic per liter [μg/L] of water in the 60-minute treatment sample as compared to 3.54 μg/L in the untreated sample). Only the 90-minute sample was passed through the GAC filter, and the arsenic concentration in that sample increased by orders of magnitude (to 21.9 μg/L, six times higher than the arsenic concentration in the untreated water).

Treatment to the preliminary target concentration of 0.14 μg/L of arsenic appears infeasible to achieve consistently in full-scale operation. The treatability test results indicate that reducing arsenic concentrations below 1 μg/l is not reliably achievable for a full-scale treatment system. As discussed in Section 4 of this report, the background concentration (geometric mean) of arsenic in the Willamette River (upstream of the Portland Harbor site) is 0.48 μg/L

Cyanide removal was assessed using total cyanide and free cyanide analyses. Total cyanide concentrations were reduced from 1,240 to 10 μg/L, as compared to the water quality criterion of 140 μg/L. The free cyanide results for Experiment 7 were all affected by high background concentrations in the laboratory, reflected in the method blanks. As a result of

the data validation review, the free cyanide concentration for the 90-minute sample was changed from 4 μg/L to non-detect at the method reporting limit (10 μg/L). Since laboratory contamination would have artificially elevated the actual concentration, it is likely that the free cyanide concentration was below the DEQ treatment target (5.2 μg/L). The pre-validation free cyanide results are noted in Table 3a. In Experiment 10, in which the treatment was identical to that of Experiment 7 except that the pH was adjusted, the free cyanide result for the 90-minute sample was 5 J μg/L ("J" indicates an estimated value because the concentration is less than the method reporting limit). Given that all these results are very near the practical limits of quantitation for any of these cyanide results, results of, for example, 5 and 10 μg/L free cyanide are essentially the same in terms of laboratory accuracy. These practical limitations of the analytical methods for cyanide should be factored into any full-scale treatment system performance monitoring criteria as part of a final discharge permit.

As noted at the beginning of this section, only the 90-minute treatment result on Table 3a is representative of anticipated final effluent quality. The elevated concentration of free cyanide in the 60-minute sample reflects the conversion of recalcitrant cyanide complexes to free cyanide complexes by partial treatment. The drop in total cyanide concentrations between the 20-minute and 60-minute samples documents the conversion of recalcitrant cyanide complexes (which are captured in the total cyanide analysis) to more easily treated free cyanide species. During the additional 30 minutes of treatment (between the 60-minute and 90-minuite samples), the additional free cyanide is destroyed, as reflected in the low total and free cyanide concentrations in the 90-minute sample.

At DEQ's request, samples were also analyzed for available cyanide. The available cyanide concentrations appear to be an unreliable indicator of cyanide prevalence as indicated by the concentrations of available cyanide that exceed both the concentrations of free cyanide (0- and 90-minute samples) and total cyanide (90-minute sample). The results of the available cyanide tests did not change significantly among the four samples. All of the available cyanide results were qualified as estimated values because the percent recovery in the laboratory control sample (118 percent) exceeded the limit (115 percent). This would indicate that the available cyanide results are biased high, which suggests that the actual effectiveness of the treatment is greater than indicated by the analytical results.

3.2 Alkaline Chlorination Test Results

Samples of the water blended from the two wells were analyzed prior to treatment ("Untreated Influent" in Table 3b), and after each of the sequential treatment steps: Aeration/Alkaline Chlorination, OrganoClay polishing, and GAC polishing. The "Granular Activated Carbon" column in Table 3b represents the fully treated water, and the concentrations in this column are representative of the capabilities of the Aeration/Alkaline Chlorination. As with the Advanced Oxidation test, arsenic concentrations increased after polishing with OrganoClay and GAC. These results indicate that arsenic was leached from these media and the full-scale treatment would need to be modified to eliminate this source of arsenic.

The concentrations of BTEX compounds and PAHs (except for naphthalene) were all reduced to below detection in the treatability test, and the concentration of naphthalene was reduced by more than 99.9 percent.

Metals concentrations were all reduced to below the preliminary DEQ treatment targets, except for arsenic. As with Advanced Oxidation, arsenic appears to have been reduced by the primary treatment and reintroduced in the polishing step. However, the results of both treatment tests indicate that treatment to the preliminary treatment target is infeasible and an alternative treatment target based on best available treatment technology is appropriate.

The concentration of total cyanide was reduced to well below the preliminary treatment target (treatment to 20 μg/L, as compared to the target of 140 μg/L). Water samples were not analyzed for free cyanide. However, the result for available cyanide (non-detect with a reporting limit of 2 μg/L) is lower than the preliminary treatment target for free cyanide (5.2 μg/L).

4 BACKGROUND CONCENTRATIONS

Recent Willamette River water quality data collected by the Lower Willamette Group (LWG) were evaluated to compile background concentrations of the constituents of interest in the river near the Gasco site. Samples collected upstream of the Portland Harbor Superfund site, at or above River Mile 11, were considered in this evaluation because per U.S. Environmental Protection Agency (EPA) discussions with LWG, these samples are being used as representative of river conditions upstream of Portland Harbor related chemical sources. A statistical summary of the data from these samples is presented in Table 4. The table presents both the geometric mean, used for the Human Health RPA, and the 90th percentile, used for the Toxics RPA, as well as other significant parameters (sample population, range, and arithmetic mean). It is notable that even the minimum value for arsenic is above the DEQ's proposed preliminary treatment target. Thus, the actual additional impact of low levels of arsenic discharging from a treatment system would likely be minimal.

5 PROPOSED EFFLUENT CRITERIA

Anchor evaluated the results of both treatability tests using the DEQ's RPA and effluent-limit spreadsheet. The effluent from the treatment system should meet the criteria with the potential exceptions of arsenic and benzo(a)pyrene. DEQ has recognized that the arsenic limit for protection of human health is generally beyond the limits of treatment and often below ambient background concentrations. DEQ has also recognized that limits for some constituents, including benzo(a)pyrene and mercury are below the practical quantitation limits (PQL) for chemical analysis. In cases where health-based standards are below PQL, DEQ guidance calls for establishing limits at the PQLs for those constituents.

Proposed average monthly concentration limits are presented in Table 5. The development of the values in this table consider:

- The results of the bench-scale treatability tests
- Practical considerations of scale-up from laboratory treatability tests to the full-scale effluent treatment system
- Willamette River background concentrations (discussed in Section 4)
- Significance of constituent concentrations in untreated groundwater (discussed in Section 2)
- The ability of the analytical methods to reliably measure chemical concentrations at levels near detection limits without resulting in false positive measurements
- Dilution and data-confidence factors built into the DEQ effluent-limit spreadsheets
- DEQ PQLs for the chemical analyses.

Table 5 presents the Preliminary DEQ Treatment Targets alongside the proposed average monthly concentration limits for comparison. The rationale for each of the proposed limits is also briefly presented in the table. These proposed effluent criteria would be protective of human health and the environment, based on an evaluation performed using the DEQ RPA spreadsheets, as well as reasonably and reliably achievable by the treatment system.

In the interest of thoroughly addressing all of the constituents that DEQ previously identified as constituents of potential interest, Table 5 includes proposed limits for all of those constituents for which Preliminary Treatment Targets are identified in Table 1 with the following exceptions. No effluent limits are proposed for:

- Constituents that are insignificant in untreated groundwater at the site, as discussed in Section 2
- Collective parameters, such as Total BTEX and Total PAHs, for which concentrations of individual constituents (e.g. benzene for Total BTEX and benzo(a)pyrene for Total PAHs) will provide a reliable indicator of complete treatment

Although effluent criteria are indicated for all of the remaining constituents in Table 5, treatment success would be reliably indicated by monitoring a selected list of indicator parameters in the permit. The operations and maintenance plan for the system would include an initial monitoring period to confirm that the concentrations of indicator parameters are representative of effluent quality and protective of human health and the environment.

6 REFERENCES

Anchor Environmental, L.L.C. 2006. October 31, 2006 Memorandum to Oregon DEQ. Subject: Groundwater Discharge Limits in Attachment CC to Second Addendum ; Groundwater Source Control Pilot Plan

Anchor Environmental, L.L.C. 2008. *Preliminary Design Report Groundwater Source Control NW Natural Gasco Site*. Prepared for NW Natural.

DEQ. (Oregon Department of Environmental Quality). 2005. *Reasonable Potential Analysis for Toxic Pollutants*. Internal Management Directive. September 2005.

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TABLES

Table 1
Preliminary DEQ Treatment Targets
Gasco Site

Parameter	Units	Preliminary DEQ Treatment Target
Arsenic	µg/L	0.14
Cadmium	µg/L	0.1 *
Chromium VI	µg/L	11
Chromium III	µg/L	67
Copper	µg/L	5 *
Lead	µg/L	0.54
Mercury	µg/L	1 *
Nickel	µg/L	49
Selenium	µg/L	35
Silver	µg/L	5 *
Zinc	µg/L	100 *
Iron	µg/L	1,000
Manganese	µg/L	100
Free Cyanide	µg/L	5.2
Total Cyanide	µg/L	140
TPH	mg/L	1
Oil & Grease	mg/L	10 & 15
pH		6.5 - 8.5
Temperature	F	68
Benzene	µg/L	25
Toluene	µg/L	dropped
Ethylbenzene	µg/L	dropped
Xylene	µg/L	dropped
Total BTEX	µg/L	250
Trichloroethene	µg/L	30
Tetrachloroethene	µg/L	3.3
Vinyl Chloride	µg/L	2.4
Benzo(a)anthracene	µg/L	1 *
Benzo(b)Fluoranthene	µg/L	1 *
Benzo(k)Fluoranthene	µg/L	1 *
Benzo(a)pyrene	µg/L	1 *
Chrysene	µg/L	1 *
Dibenzo(a,h)anthracene	µg/L	1 *
Indeno(1,2,3-cd)pyrene	µg/L	1 *
Anthracene	µg/L	dropped
Fluoranthene	µg/L	dropped
Fluorene	µg/L	dropped
Naphthalene	µg/L	dropped
Pyrene	µg/L	dropped
Dibenzofuran	µg/L	dropped
Total PAHs	µg/L	250
2-chlorophenol	µg/L	dropped
2,4-dichlorophenol	µg/L	dropped
2,4-dimethylphenol	µg/L	dropped
2-methyl-4,6-dinitrophenol	µg/L	dropped
2-methylphenol (o-creosol)	µg/L	dropped
2-nitrophenol	µg/L	dropped
4-nitrophenol	µg/L	dropped
pentachlorophenol	µg/L	dropped
phenol	µg/L	dropped
2,4,5-trichlorophenol	µg/L	dropped
2,4,6-trichlorophenol	µg/L	dropped
Total Phenols	µg/L	1

Note:
* Preliminary Treatment Target is equal to the DEQ quantitation limit

Table 2a
Phenols in Untreated Groundwater
Gasco Site

Location ID:	**MW-01-55**	**PW-01-80**
Sample ID:	**MW-1-55-072808**	**PW-1-80-072808**
Sample Date:	**7/28/08**	**7/28/08**
2-Chlorophenol	0.48 UJ	12 UJ
2,4-Dimethylphenol	3.8 UJ	9500 UJ
Dinitro-o-cresol (4,6-Dinitro-2-methylphenol)	1.9 UJ	48 UJ
2-Methylphenol (o-Cresol)	0.48 UJ	12 UJ
2-Nitrophenol	0.48 UJ	1200 UJ
4-Nitrophenol	1.9 UJ	48 UJ
Phenol	**0.21 J**	**33 J**
Pentachlorophenol	0.95 UJ	24 UJ
2,4,5-Trichlorophenol	0.48 UJ	12 UJ
2,4-Dichlorophenol	0.48 UJ	1200 UJ
2,4,6-Trichlorophenol	0.48 UJ	12 UJ

Notes:

Bold = Detected result

J = Estimated value

UJ = Compound not detected above estimated detection limit

All concentrations are presented as micrograms of constituent per liter of water.

Table 2b
Evaluation of Metals in Untreated Groundwater
Gasco Site

Constituent	Sample Population	Preliminary DEQ Treatment Target (µg/L)	Concentration Range (µg/L)	Arithmetic Mean (µg/L)	Standard Deviation (µg/L)	Conclusion
Arsenic	93	0.14	0.38 - 44	5.8	5.7	Retain for consideration
Cadmium	78	0.094	0.020 - 0.57	0.13	0.16	Retain for consideration
Chromium (total)	87	11	0.19 - 26	2.9	4.3	Insignificant presence; drop from consideration
Copper	93	2.7	0.050 - 111	5.1	16	Retain for consideration
Lead	88	0.54	0.008 - 13	0.9	2.1	Retain for consideration
Mercury	78	0.012	0.020 - 0.73	0.16	0.10	Retain for consideration
Nickel	91	49	0.27 - 164	15	30	Insignificant presence; drop from consideration
Selenium	76	35	0.20 - 10	3.0	3.1	Insignificant presence; drop from consideration
Silver	75	0.12	0.005 - 0.15	0.046	0.045	Insignificant presence; drop from consideration
Zinc	93	33	1.8 - 19,200	341	1,999	Retain for consideration
Iron	58	1,000	1,670 - 2,490,000	190,484	432,768	Retain for consideration
Manganese	54	100	265 - 23,100	4,480	4,691	Retain for consideration

Notes:

The data summarized in this table were gathered for:
- the Gasco Offshore Investigation from nearshore borings (38 samples)
- the treatability tests from wells MW-01-55 and PW-01-80 (4 samples for selected constituents)
- the Remedial Investigation (includes 28 wells screened at less than 100-foot depth sampled in 2006 and 2007 for a total of 16 to 51 samples depending on the constituent--outliers more than one standard deviation greater than the mean were not included in developing the statistics for this summary)

Samples from open borings were field filtered; samples from wells were not filtered.

For the development of the statistics in this summary, the full reporting limit was used for constituents not detected in the sample.

For the purpose of comparing concentrations in untreated groundwater to Preliminary DEQ Treatment Targets, DEQ quanitation limits were ignored. Therefore, lower limits were used in this table for cadmium, copper, mercury, silver, and zinc than the values presented in Table 1.

The conclusion regarding retaining a constituent for further consideration is based on comparing the arithmetic mean plus the standard deviation to the Preliminary DEQ Treatment Target. Constituents for which the mean plus one standard deviation is less than the Treatment Target are identified as insignificant.

Table 3a
Chemical Data for Treated Groundwater
Advanced Oxidation Treatment
Gasco Site

Sample ID: **Advanced Oxidation Treatment Duration:**		**GS-WG-C-E7-0** **0 minutes**		**GS-WG-C-E7-20** **20 minutes**		**GS-WG-C-E7-60** **60 minutes**		**GS-WG-C-E7-90** **90 minutes**	
Total Metals (µg/L)									
Arsenic	SW6020	**3.54**		**0.41**	**J**	**0.52**		**21.9**	
Cadmium	SW6020	0.058	U	0.022	U	0.020	U	0.067	U
Chromium	SW6020	**0.64**		**0.72**		**1.7**		**1.27**	
Copper	SW6020	**14.4**		**8.94**		**12.9**		**1.46**	
Lead	SW6020	**0.43**		**0.01**	**J**	**0.125**		0.02	U
Manganese[1]	SW6010	NA		NA		NA		**16.5**	
Mercury	SW7470	0.2	U	0.2	U	0.2	U	0.2	U
Nickel	SW6020	**2.9**		**3.73**		**3.58**		**7.05**	
Zinc	SW6020	**604**	**J**	**97.8**	**J**	**46.3**	**J**	**10**	**J**
Iron	SW6010	**71,300**		**804**		**1,520**		**25.1**	
Cyanides (µg/L)									
Free Cyanide[2]	ASTM D4282-02	10	UJ	10	UJ	**65**	**J**	10	UJ
Total Cyanide	E335.4	**1,240**		**1,290**		**320**		**10**	
Available Cyanide	OIA-1677	**12**	**J**	**10**	**J**	**19**	**J**	**13**	**J**
WAD Cyanide	A4500E	**590**		**420**		**160**		**6**	**J**
Volatile Organic Compounds (µg/L)									
Benzene	SW8260	**5,400**		**1,000**		**18**		**0.86**	
Toluene	SW8260	**91**		**15**		**0.51**		**0.13**	**J**
Ethylbenzene	SW8260	**340**		**32**		**0.99**		**0.07**	**J**
m,p-Xylene	SW8260	**160**		**15**		**0.21**	**J**	0.5	U
o-Xylene	SW8260	**95**		**12**		**0.23**	**J**	0.5	U
Tetrachloroethene	SW8260	25	U	5	U	0.5	U	0.5	U
Trichloroethene	SW8260	25	U	5	U	0.5	U	0.5	U
Vinyl chloride	SW8260	25	U	5	U	0.5	U	0.5	U
Polynuclear Aromatic Hydrocarbons (µg/L)									
Benzo(a)anthracene	SW8270C	**46**		**0.14**		**0.46**		**0.0038**	**J**
Benzo(b)fluoranthene	SW8270C	**52**		**0.14**		**0.6**		0.016	U
Benzo(k)fluoranthene	SW8270C	**19**		**0.046**		**0.19**		0.016	U
Benzo(a)pyrene	SW8270C	**54**		**0.13**		**0.51**		0.016	U
Chrysene	SW8270C	**57**		**0.17**		**0.6**		0.016	U
Dibenzo(a,h)anthracene	SW8270C	**5.9**		**0.014**	**J**	**0.067**		0.016	U
Indeno(1,2,3-c,d)pyrene	SW8270C	**50**		**0.13**		**0.59**		0.016	U
Acenaphthene	SW8270C	**160**		**5.3**		**0.14**		**0.0055**	**J**
Anthracene	SW8270C	**60**		**0.61**		**0.21**		0.016	U
Fluoranthene	SW8270C	**190**		**1.5**		**1.4**		**0.014**	**J**
Fluorene	SW8270C	**86**		**5.3**		**0.18**		**0.0041**	**J**
Naphthalene	SW8270C	**4,400**		**510**		**19**		**0.5**	
Pyrene	SW8270C	**200**		**1.6**		**1.6**		**0.013**	**J**

Table 3a
Chemical Data for Treated Groundwater
Advanced Oxidation Treatment
Gasco Site

Sample ID: **Advanced Oxidation Treatment Duration:**		**GS-WG-C-E7-0** **0 minutes**	**GS-WG-C-E7-20** **20 minutes**	**GS-WG-C-E7-60** **60 minutes**	**GS-WG-C-E7-90** **90 minutes**
Other Semivolatile Organic Compound (µg/L)					
Dibenzofuran	SW8270C	**15**	**0.84**	**0.035**	0.016 U

Notes:

Bold = Detected result

µg/L - micrograms per liter

The 90-minute treatment also included a granular activated carbon polish.

1 - The disolved concentration is presented for manganese. The 0-, 20-, and 60-minute samples were not analyzed (NA).

2 - Free cyanide concentrations presented in this table reflect elevated laboratory background that affected the method blank. Concentrations originally reported by the laboratory are:

Free Cyanide (prevalidation results)	10 U	5 J	**65**	4 J

Data qualifiers:

J = Estimated value

U = Compound not detected above reporting limit

UJ = Compound not detected above estimated detection limit

Table 3b
Chemical Data for Treated Groundwater
Alkaline Chlorination Treatment
Gasco Site

Alkaline Chlorination Treatment Description:		Untreated Influent	Aeration/ Alkaline Chlorination	OrganoClay	Granular Activated Carbon
Total Metals (µg/L)					
Arsenic	SW6020	**5**	4 U	**5.3**	**61.5**
Cadmium	SW6020	**0.03**	0.02 U	**0.03**	0.02 U
Chromium	SW6020	**0.8**	**0.2**	0.02 U	0.2 U
Copper	SW6020	**3.1**	**1.2**	**1.7**	**0.4**
Lead	SW6020	**1.4**	**0.19**	**0.58**	**0.29**
Manganese	SW6010	**5,660**	**607**	**337**	**27.4**
Mercury	SW7470	0.2 U	0.2 U	0.2 U	0.2 U
Nickel	SW6020	**3.1**	**1.6**	**9.1**	**3.5**
Zinc	SW6020	**831**	**6.2**	**4.9**	**3**
Iron	SW6010	**132,000**	**994**	**407**	**150**
Cyanides (µg/L)					
Total Cyanide	E335.4	**1,300**	**310**	10 U	**20**
Available Cyanide	OIA-1677	**8**	**4**	**3**	2 U
Amenable Cyanide		10 U	10 U	10 U	10 U
Volatile Organic Compounds (µg/L)					
Benzene	SW8260	**3,800**	**500**	**150**	0.5 U
Toluene	SW8260	**60**	**12**	**14**	0.5 U
Ethylbenzene	SW8260	**140**	**22**	**3.8**	0.5 U
m,p-Xylene	SW8260	**56**	**9.8**	**1.6**	0.5 U
o-Xylene	SW8260	**42**	**9.1**	**1.6**	0.5 U
Tetrachloroethene	SW8260	NA	NA	NA	NA
Trichloroethene	SW8260	NA	NA	NA	NA
Vinyl chloride	SW8260	NA	NA	NA	NA
Polynuclear Aromatic Hydrocarbons (µg/L)					
Benzo(a)anthracene	SW8270C	**29**	22 U	0.21 U	0.20 U
Benzo(b)fluoranthene	SW8270C	**36**	4.3 U	0.21 U	0.20 U
Benzo(k)fluoranthene	SW8270C	**12**	4.3 U	0.21 U	0.20 U
Benzo(a)pyrene	SW8270C	**38**	4.3 U	0.21 U	0.20 U
Chrysene	SW8270C	**35**	4.3 U	0.21 U	0.20 U
Dibenzo(a,h)anthracene	SW8270C	**6**	4.3 U	0.21 U	0.20 U
Indeno(1,2,3-c,d)pyrene	SW8270C	**31**	4.3 U	0.21 U	0.20 U
Acenaphthene	SW8270C	**110**	**45**	**0.46**	0.20 U
Anthracene	SW8270C	**28**	**5.1**	**0.44**	0.20 U
Fluoranthene	SW8270C	**90**	**8.5**	**0.32**	0.20 U
Fluorene	SW8270C	**55**	**26**	**0.23**	0.20 U
Naphthalene	SW8270C	**1600**	**910**	**25**	**0.22**
Pyrene	SW8270C	**120**	**9.3**	0.21 U	0.20 U
Semivolatile Organic Compounds (µg/L)					
Dibenzofuran	SW8270C	**56**	**9.8**	**1.6**	0.5 U
2-Chlorophenol	SW8270C	11 U	11 U	**0.69**	0.5 U
2,4-Dimethylphenol	SW8270C	88 U	88 U	4.4 U	4.4 U
4,6-Dinitro-2-methylphenol	SW8270C	44 U	43 U	2.1 U	2 U
2-Methylphenol (o-Cresol)	SW8270C	11 U	11 U	0.51 U	0.5 U

Table 3b
Chemical Data for Treated Groundwater
Alkaline Chlorination Treatment
Gasco Site

Alkaline Chlorination Treatment Description:		Untreated Influent		Aeration/ Alkaline Chlorination		OrganoClay		Granular Activated Carbon	
Semivolatile Organic Compounds (µg/L) continued									
2-Nitrophenol	SW8270C	11	U	11	U	0.51	U	0.5	U
4-Nitrophenol	SW8270C	22	U	43	U	2.1	U	2	U
Phenol	SW8270C	**220**		**33**		**17**		0.5	U
Pentachlorophenol	SW8270C	22	U	22	U	1.1	U	1	U
2,4,5-Trichlorophenol	SW8270C	11	U	11	U	0.51	U	0.5	U
2,4-Dichlorophenol	SW8270C	11	U	11	U	0.51	U	0.5	U
2,4,6-Trichlorophenol	SW8270C	11	U	11	U	0.51	U	0.5	U

Notes:

Bold = Detected result

µg/L - micrograms per liter

U = Compound not detected above reporting limit

These data have not been validated

The groundwater treatment included Aeration/Alkaline Chlorination followed by OrganoClay adsorption and Granular Activated Carbon (GAC) adsorption. Samples were collected for analysis following each of these three treatment steps. The GAC results represent the quality of final effluent. Arsenic data indicate possible leaching of arsenic from the OrganoClay and GAC adsorbents into the treated water.

Table 4
Willamette River Background Concentrations
Gasco Site

Parameter	Number of Samples Analyzed	Minimum Value	Maximum Value	Arithmetic Mean	Geometric Mean	90th Percntile
Arsenic	18	0.25	0.54	0.41	0.40	0.48
Cadmium	18	0.01	0.03	0.020	0.019	0.020
Chromium, Total	18	0.25	1.68	0.69	0.55	1.56
Chromium VI	0					
Copper	18	0.68	3.68	1.49	1.25	3.54
Lead	18	0.09	0.86	0.30	0.23	0.80
Mercury	18	0.020	0.080	0.037	0.031	0.080
Nickel	18	0.45	1.93	0.92	0.83	1.78
Selenium	18	0.10	0.70	0.23	0.21	0.23
Silver	18	0.003	0.052	0.01	0.011	0.034
Zinc	18	2.20	6.38	3.92	3.64	6.18
Iron	0					
Manganese	0					
Free Cyanide	0					
Total Cyanide	0					
Benzene	0					
Toluene	0					
Ethylbenzene	0					
Xylene	0					
Total BTEX	0					
Trichloroethene	0					
Tetrachloroethene	0					
Vinyl Chloride	0					
Benzo(a)anthracene	18	0.0021	0.010	0.0066	0.0059	0.0078
Benzo(b)Fluoranthene	18	0.0020	0.0092	0.0073	0.0064	0.0092
Benzo(k)Fluoranthene	18	0.0014	0.011	0.0082	0.0064	0.011
Benzo(a)pyrene	18	0.0016	0.0086	0.0067	0.0057	0.0086
Chrysene	18	0.0013	0.011	0.0081	0.0063	0.011
Dibenzo(a,h)anthracene	18	0.0017	0.0072	0.0058	0.0052	0.0072
Indeno(1,2,3-cd)pyrene	18	0.0021	0.0084	0.0057	0.0053	0.0066
Anthracene	18	0.0011	0.0078	0.0059	0.0047	0.0078
Fluoranthene	18	0.0024	0.010	0.0078	0.0070	0.0097
Fluorene	18	0.0026	0.011	0.0064	0.0060	0.0072
Naphthalene	18	0.0064	0.043	0.018	0.015	0.037
Pyrene	18	0.0023	0.0094	0.0077	0.0070	0.0094
Dibenzofuran	18	0.0071	0.029	0.010	0.0087	0.015
2-chlorophenol	18	0.015	0.017	0.015	0.015	0.016
2,4-dichlorophenol	18	0.024	0.027	0.024	0.024	0.025
2,4-dimethylphenol	18	0.32	0.36	0.33	0.33	0.34
2-methyl-4,6-dinitrophenol	18	0.013	0.015	0.013	0.013	0.014
2-methylphenol (o-creosol)	18	0.060	0.067	0.061	0.061	0.064
2-nitrophenol	18	0.014	0.016	0.014	0.014	0.015
4-nitrophenol	18	0.54	0.60	0.55	0.55	0.58
pentachlorophenol	18	0.029	0.061	0.031	0.031	0.031
phenol	18	0.020	0.067	0.027	0.025	0.050
2,4,5-trichlorophenol	18	0.026	0.029	0.026	0.026	0.027
2,4,6-trichlorophenol	18	0.037	0.042	0.038	0.038	0.039

Notes:

Summary based on Round 2a and Round 3 surface water samples collected for the Lower Willamette Group at and above River Mile 11, between November 2004 and March 2007.

All results presented in micrograms of constituent per liter of water.

Full reporting limit was used for non-detects in this table.

Table 5
Proposed Average Monthly Concentration Limits
Gasco Site

Constituent	Preliminary DEQ Treatment Target (µg/L)	Proposed Monthly Limits (µg/L)	Rationale for Proposed Limit
Arsenic	0.14	1	Expectation to reasonably achieve consistently in full-scale treatment based on testing
Cadmium	0.1	5	Expectation to reasonably achieve consistently in full-scale treatment based on testing, and proposed limit is much lower than the output of the DEQ effluent limit spreadsheet
Chromium (total)	11	None	Constituent is insignificant at the site. See Section 2 and Table 2b.
Copper	5	5	DEQ quantitation limit, and proposed limit is much lower than the output of the DEQ effluent limit spreadsheet
Lead	0.54	0.8	Willamette River background, and expectation to reasonably achieve consistently in full-scale treatment based on testing
Mercury	1	1	DEQ preliminary limit (DEQ quantitation limit)
Nickel	49	None	Constituent is insignificant at the site. See Section 2 and Table 2b.
Selenium	35	None	Constituent is insignificant at the site. See Section 2 and Table 2b.
Silver	5	None	Constituent is insignificant at the site. See Section 2 and Table 2b.
Zinc	100	100	DEQ preliminary limit (DEQ quantitation limit)
Iron	1,000	1,000	DEQ preliminary limit (DEQ Table 20, Fresh, Chronic)
Manganese	100	100	DEQ preliminary limit (DEQ Table 20, Fresh, Chronic)
Cyanide (free)	5.2	10	Expectation to reasonably achieve consistently in full-scale treatment based on testing
Cyanide (total)	140	140	DEQ preliminary limit (DEQ Table 33a, Human Health)
TPH	1 mg/L	None	Toxic components are addressed by constituent-specific analyses
Oil & Grease	10 & 15 mg/L	None	Toxic components are addressed by constituent-specific analyses
pH	6.5 - 8.5	6.5 - 8.5	DEQ preliminary limit
Temperature	68° F	68° F	DEQ preliminary limit

Table 5
Proposed Average Monthly Concentration Limits
Gasco Site

Constituent	Preliminary DEQ Treatment Target (µg/L)	Proposed Monthly Limits (µg/L)	Rationale for Proposed Limit
Benzene	25	40	DEQ Table 20, Human Health, Fish Consumption (the basis for the Preliminary DEQ Treatment Target is unclear)
Total BTEX	250	None	Demonstrated ability to reduce constituent concentrations to well below the preliminary Total BTEX limit. Benzene monitoring would confirm ongoing effectiveness.
Tetrachloroethylene	3.3	3.3	DEQ preliminary limit (DEQ Table 33a, Human Health, Fish Consumption)
Trichloroethylene	30	30	
Vinyl chloride	2.4	2.4	
Benzo(a)anthracene	1	1	DEQ preliminary limit (DEQ quantitation limit)
Benzo(b)Fluoranthene	1	1	DEQ preliminary limit (DEQ quantitation limit)
Benzo(k)Fluoranthene	1	1	DEQ preliminary limit (DEQ quantitation limit)
Benzo(a)pyrene	1	1	DEQ preliminary limit (DEQ quantitation limit)
Chrysene	1	1	DEQ preliminary limit (DEQ quantitation limit)
Dibenzo(a,h)anthracene	1	1	DEQ preliminary limit (DEQ quantitation limit)
Indeno(1,2,3-cd)pyrene	1	1	DEQ preliminary limit (DEQ quantitation limit)
Total PAHs	250	None	Demonstrated ability to reduce constituent concentrations to well below the preliminary Total PAH limit. Benzo(a)pyrene monitoring would confirm ongoing effectiveness.
Total Phenols	1	None	Constituent is insignificant at the site. See Section 2 and Table 2a.

Notes:
µg/L - micrograms of constituent per liter of water
The development of the proposed limits is discussed in Section 5

FIGURES

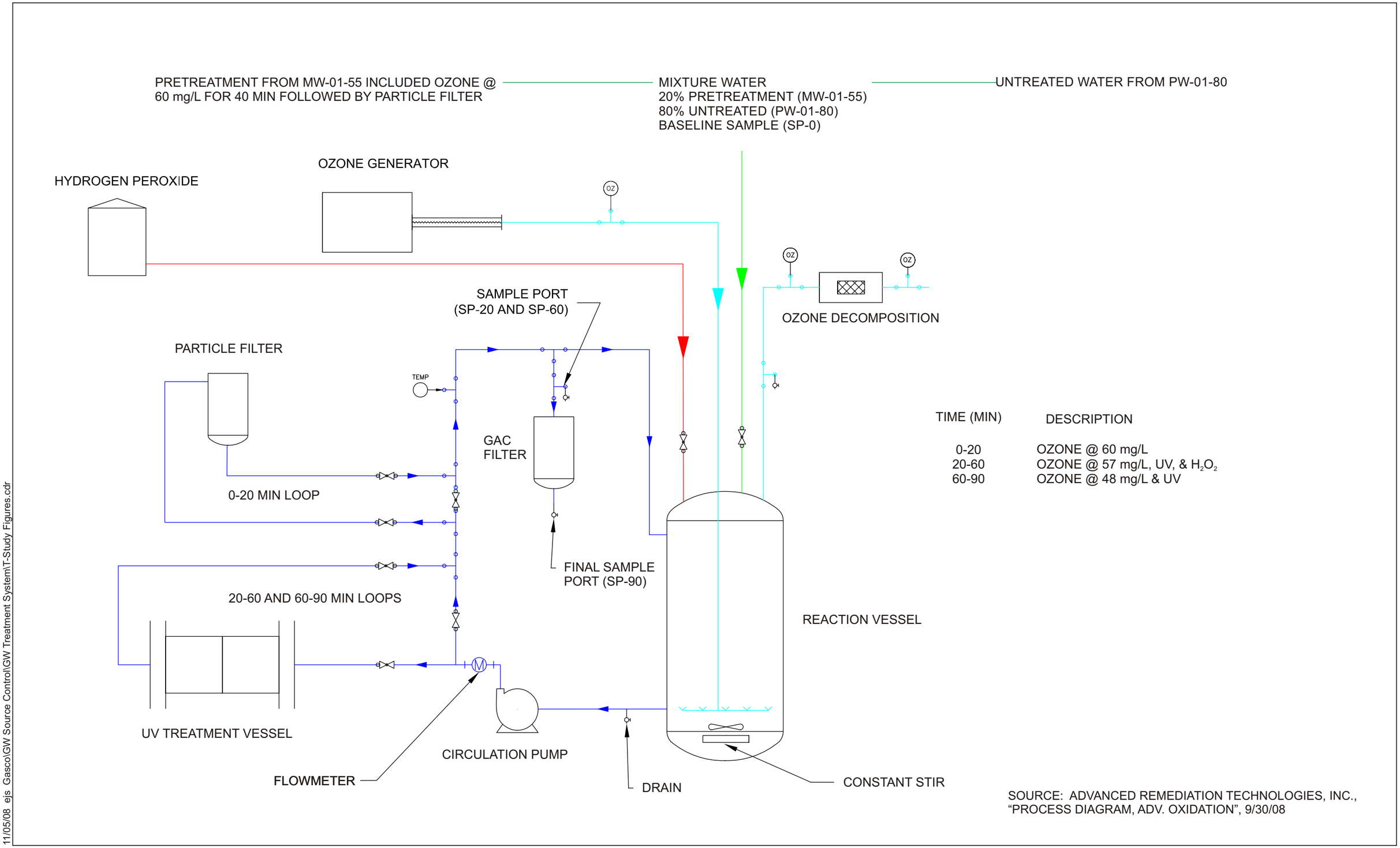

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Figure 1
Schematic of Advanced Oxidation Treatability Test
Groundwater Source Control Treatability Testing
Gasco, Portland, Oregon

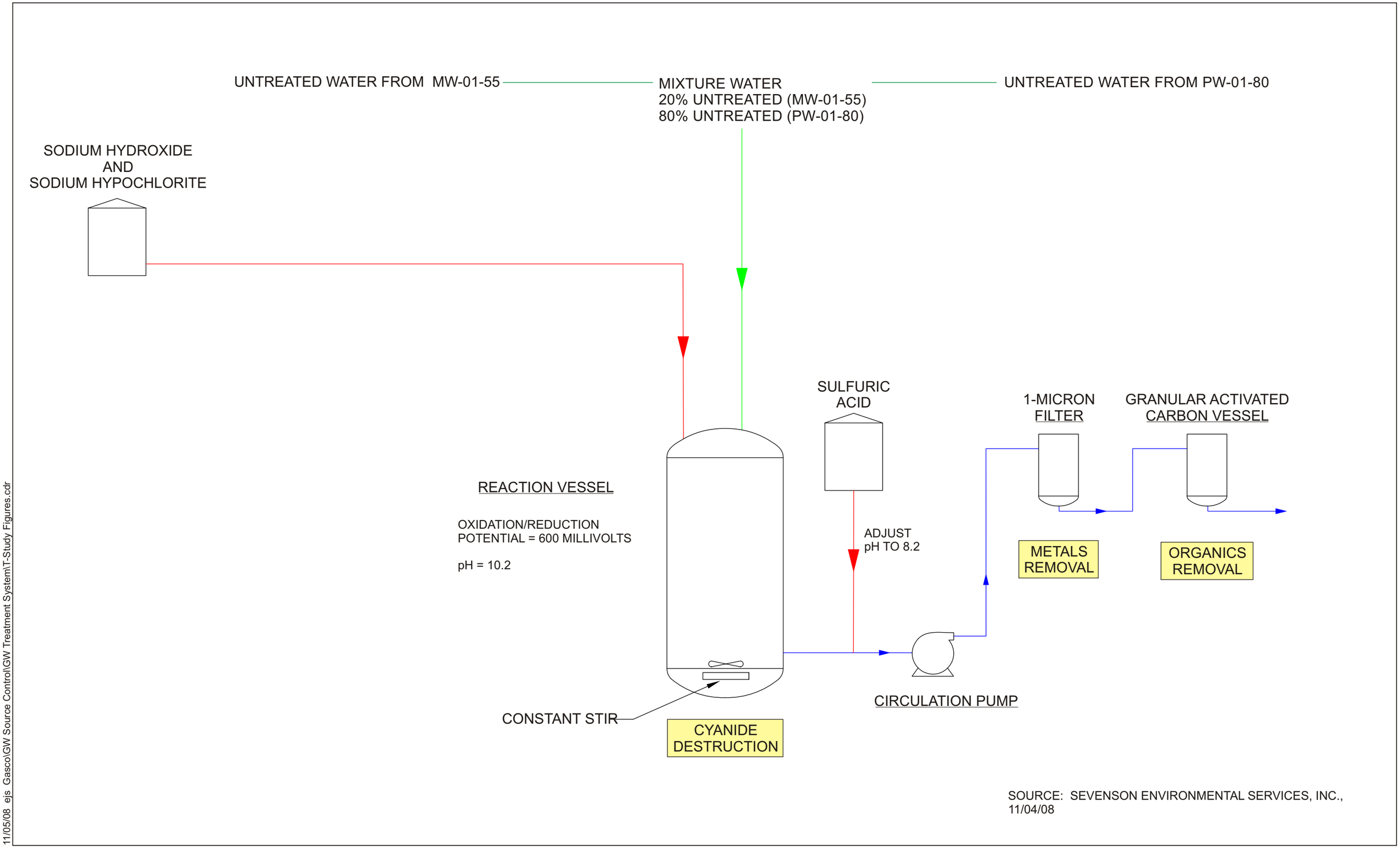

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Figure 2
Schematic of Advanced Aeration/Alkaline Chlorination Test
Groundwater Source Control Treatability Testing
Gasco, Portland, Oregon