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LETTER REGARDING RESPONSES TO REGULATOR COMMENTS ON FEASIBILITY STUDY CHEMICAL OXIDATION AT OPERABLE UNIT 4 (OU 4) WITH TRANSMITTAL LETTER NTC ORLANDO FL
12/22/2000
HARDING LAWSON ASSOCIATES

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Harding Lawson Associates

December 22, 2000 Document No.: 2545.036

Commanding Officer
SOUTHNAVFACENGCOM
ATTN: Ms. Barbara Nwokike, Code 187300
Naval Facilities Engineering Command
2155 Eagle Drive
North Charleston, SC 29406

SUBJECT: **Feasibility Study Report - Operable Unit (OU) 4**
Chemical Oxidation Alternative and Response to Comments
Naval Training Center (NTC), Orlando, Florida
Contract No. N62467-89-D-0317/CTO 135

Dear Barbara:

Harding Lawson Associates (HLA) is pleased to submit as attachments to this letter two documents: 1) the Response to Comments for the Draft NTC Orlando Operable Unit (OU) 4 Feasibility Study (FS), and 2) the revised Chemical Oxidation FS Alternative.

The Response to Comments (Attachment A) includes our responses to comments on the Draft FS Report made by the Florida Department of Environmental Protection and USEPA. We have also included copies of calculations that we inadvertently omitted from the Draft FS, and are the topic of discussion of several of the comments.

Typically we have issued redline/strikeout versions of draft documents to allow a review of the edits before going final. However, the majority of the revisions to the Draft FS necessary to respond to comments were relatively minor, and we believe are adequately addressed in this submittal. An exception to this is the Chemical Oxidation Alternative. Because the Draft FS evaluated potassium permanganate using primarily literature information, substantial revisions were necessary to incorporate the results of the pilot study. Changes include updated dosage rates, chemical costs, and rental of the feed system rather than purchase. To expedite review of these changes and allow the Final FS to be issued, we have included all of the chemical oxidation revisions as Attachment B to this letter.

The Chemical Oxidation Alternative contains the revised FS sections 5.1.3 (Alternative V-3: Chemical Oxidation and Enhanced Biodegradation) and Sections 6.0 through 6.2.1 (Comparative Analysis of VOC Alternatives). These sections have been revised based upon the results from the field pilot study of chemical oxidation at OU 4. All references within the enclosed document, such as other sections and appendices, pertain directly to the Draft FS Report.

All of the remaining remedial alternatives have also been updated to reflect the current project status. For example, the IRA (which remains a key component of most of the VOC alternatives) description and annual costs have been revised to reflect the change from recirculation wells to groundwater extraction, treatment, and disposal via sanitary sewer. The latest sewer fees (as

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provided by CH2M HILL) have also been incorporated into the antimony groundwater extraction alternatives.

Based on the revisions to the VOC remedial alternatives and subsequent comparison, the Chemical Oxidation Alternative is the most cost effective of the "active" VOC alternatives (both present and future worth) and would remediate the northern PCE source area within one year. Relevant cost figures and tables for each of the VOC remedial alternatives have been revised and included in Attachment B. Present and future worth cost calculations, PCE oxidation kinetics calculations, and groundwater modeling figures of the full-scale chemical oxidation system have also been included within this submittal as appendices for your review.

The Final FS Report is now complete, pending your comments on the enclosed Chemical Oxidation Alternative. We believe the alternative evaluations are accurate and more than adequate to support the selection of the final remedy for OU 4. We plan on submitting the Final FS on or before January 20, 2001. In order to support this schedule, we ask that review comments on the Chemical Oxidation Alternative be returned to HLA no later than January 12, 2001.

If you have questions or comments regarding this document, please contact me at (781) 213-5652 or John Kaiser at (407) 522-7570.

Very truly yours,

HARDING LAWSON ASSOCIATES

Mark J. Salvetti

Mark J. Salvetti, P.E.
Task Order Manager

Enclosures

cc:

W. Hansel (SDIV)
D. Grabka (FDEP)
N. Rodriguez (USEPA)
S. Tsangaris (CH2M HILL)
S. McCoy (Tetra Tech NUS)
R. Allen (HLA)
J. Kaiser (HLA)
File

ATTACHMENT A

PROJECT REVIEW COMMENTS

FEASIBILITY STUDY
OPERABLE UNIT 4, STUDY AREAS 12, 13, AND 14 – AREA C
NAVAL TRAINING CENTER
ORLANDO, FLORIDA

PROJECT REVIEW COMMENTS

FEASIBILITY STUDY
OPERABLE UNIT 4, STUDY AREAS 12, 13, AND 14 – AREA C
NAVAL TRAINING CENTER
ORLANDO, FLORIDA

U.S. Environmental Protection Agency, Region 4 – Nancy Rodriguez

1. **The description of the remedial measures in Section 4 states that there are two sub-options for each of these remedial measures. For example, the description of Alternative V-6 (FS, p. 4-40) states that the groundwater extraction wells could be operated:**

   (1) until groundwater concentrations reach MCLs or (2) could be operated until concentrations are reduced sufficiently to allow natural attenuation to reduce levels before groundwater reaches Lake Druid.

   Both options are said to be evaluated in this FS, but both options and the related costs are not apparent in Table 5-8 or 6-1. The individual cost summary tables in Section 5 describe the estimated duration of the active remedial measures and the estimated duration for Monitored Natural Attenuation. The cost for operating the remedial measures until groundwater concentrations reach MCLs is not clearly stated. Please clarify the text if just one cost option is presented.

   The two treatment level options will be labeled "A" and "B" to enhance their identity, as has been done in Figures 6-1 and 6-2. The two options exist for Alternatives V-5, V-6 and V-7. Therefore, on tables for these alternatives, they will be referred to as V-5A and V-5B (or V-6A and V-6B, or V-7A and V-7B). Furthermore, in the text where these alternatives are discussed, the appropriate label of Option A or Option B will be used in the discussion. For example, Alternative V-6 (Groundwater Treated to Drinking Water Standards) presented in Table 5-8, will now be labeled Alternative V-6A, and Alternative V-6 (Groundwater Treated to Site-Specific Remedial Goals) presented in Table 5-9, will now be labeled Alternative V-6B. In Table 6-1 the differences between the options (where applicable) in the Alternative columns V-5, V-6 and V-7 will be more fully explained in footnotes 2 and 3. Cost breakdowns are presented separately in Appendix D in Tables D-5 through D-10, where the options are identified with the labels "A" and "B". The text on page 5-76 under <u>Cost</u> for Alternative V-6 states that the present worth costs are presented in Tables 5-8 and 5-9, depending on the remedial goal of the air stripper system, either Florida drinking water standards (Table 5-8) or a site-specific concentration along with natural attenuation to ultimately achieve these standards (Table 5-9). The text under <u>Cost</u> for Alternatives V-5 and V-7 on pages 5-59 and 5-93 will be modified to state the same. It was noted when preparing this response that Table 5-6 inadvertently references Natural Attenuation Monitoring for 37 years, and Tables 5-8 and 5-10 inadvertently reference Natural Attenuation Monitoring for 108 years. These will be changed to "groundwater monitoring" to reflect the text and backup costs presented in Tables D-5, D-7 and D-9 for VOC groundwater monitoring.

2. **<u>(From EPA's letter dated December 8, 1998, OU4 RI Comments)</u>** ***...some VOC concentrations in groundwater were approximately 20 percent of the solubility limit for PCE, which is strongly***

suggestive of NAPL presence. The text also states that a residual source for PCE probably has migrated downward in the aquifer beneath the source area and has become immobile (RI, p.7-4). **These observations are restated in the FS on page1-15.**

The possible source area for DNAPL under Building 1100 is addressed by remedial measures V-3 through V-7. But all of these measures require more than 30 years to reduce contaminant concentrations to drinking water standards (p.6-5 and Table 6-1), which indicates that the proposed remedial measures are not effective in a reasonable time frame. The cleanup time estimates for the PCE plume are not well documented in the report, so EPA can not comment on the results. However, the estimated cleanup times are so long for the estimated costs, that these may not be appropriate remedial measures for this site. The cleanup time estimates may be correct, but EPA can not confirm them with the data presented. Additional comments regarding one of the methods used to estimate the cleanup times are presented in the next comment.

Cleanup times for ex-situ treatment technologies were inadvertently excluded from the appendix material but are attached to this Response to Comments package and will be included in the appendix of the final FS report. Although the durations are lengthy, they represent the estimated time necessary to achieve drinking water standards in OU 4 groundwater. Numerous case studies have frequently demonstrated how difficult remediation of DNAPL source areas can be. Pump and treat systems operating for decades have been unable to permanently achieve drinking water standards. We believe the durations estimated in the FS represent reasonable cleanup times for the remedial technologies available today and evaluated in the FS.

3. **Regarding the Batch Flush Model cleanup time calculations in Appendix G and Appendix I, the Kd for antimony is given first in Appendix G as 52 mg/L. Then the Kd value was changed to 13.6, apparently because the resulting calculated cleanup time looked more reasonable according to notes written on Appendix G, p. 2/2, 12/14/98. The Kd used in Appendix I is also assumed to be 13.6 without supporting data.**

The original Kd estimate agrees closely with a value of 45 mg/L in the EPA Guidance Document (TBD, Part 5, Table 43). Kd is a basic physical parameter which should not be altered because the result looks more reasonable without supplying site specific supporting data.

The velocity and the distance to the discharge area (length of contaminant travel) in the Batch Flush calculations in Appendix G can be controlled by the remedial measure. Under natural conditions, a pore volume flushes at a rate depending on the hydraulic conductivity, porosity and hydraulic gradient. Cleanup time estimates are based on the number of dilutions required to flush out the contaminant with clean water. Wells installed for a

remedial measure replace the natural discharge area and become man-made discharge areas. Pumping changes the natural hydraulic gradient and groundwater velocity near the wells, accelerating the natural flush rate upgradient from the well. This reduces the calculated flush time, so changing the velocity in the Batch Flush calculation is both more defendable and more manageable than changing the Kd without supporting data. The velocity and distance used for cleanup time estimates becomes a function of the number of wells used and the average distance to the nearest well.

Flush time estimates remain proportional to the assumptions used in Appendix G, so the cleanup time estimates presented in Appendix G are not unreasonable. I make these points, in part, because the cleanup time calculations for the PCE plume in the northern part of this area are not well documented in the report and the calculated cleanup times for the PCE plume are very long.

HLA uses a K_d value of 13.6 mg/L derived from the USEPA Soil Transport and Fate Database for a loamy sand, which is believed to be more representative of site soils than sandy loam (32 to 93 mg/L). The 45 mg/L referenced by the commentor is from a range reported by Atomic Energy of Canada, Limited (AECL) and presents a range from 10 to 550 with geometric mean of 45 (no specific soil descriptions are provided other than that they represent four major soil types – sand, silt, clay and organic material).

Although increasing the velocity in the Batch Flush calculation would decrease the estimated cleanup time, there are limits to the allowable well discharge, and hence velocity, based on avoiding excessive drawdown. It is also reasonable to assume that site-specific K_d values could be determined prior to final design of a pumping system to address the antimony contamination. However, as it is recommended that groundwater VOCs be addressed prior to the antimony, the design and installation of an antimony remedial system is several years away.

As previously discussed, cleanup time calculations for the PCE plume were inadvertently excluded from the appendix but have been attached for reference and will be included in the final FS report.

4. **The calculations presented in Appendix I, Plume Migration Calculations, include an estimate of the duration of the IRA operation dated January 27, 1999. The retardation factor for PCE is given as 13. The source cited for this factor is Appendix H. Appendix H contains Air Stripping Emissions Calculations and does not include an estimate of the retardation factor for PCE. VOCs seem to be relatively mobile in this aquifer. From TBD Part 5, Table 39, it is estimated that the retardation factor for PCE to be between 3 and 6 depending the fraction of organic carbon (f_{oc}) in the aquifer. This would decrease the IRA duration estimate. Site specific estimates for the parameters needed to get a site specific retardation factor of PCE**

are not presented. Further, a retardation factor was not found in Appendix H as indicated in the report.

Calculations for the retardation factor of PCE were inadvertently excluded from the appendix material, but are discussed below and will be included in the appendix of the final FS report. The retardation factor for PCE was calculated based on an average total organic carbon content at the site of 6,000 mg/kg (from the RI Report), a K_{OC} value of 364 ml/g for PCE, soil porosity of 0.3, and bulk density of 1.7. The retardation factor derivation is included with the attached cleanup time calculations for the ex-situ treatment alternatives.

Florida Department of Environmental Protection – David Grabka

1. **Natural Attenuation at this site has been through reductive dechlorination of PCE and TCE. The treatment alternatives V-3 (In Situ Treatment by Chemical Oxidation), V-4 (In Situ Treatment by Air Sparging), and V-5 (Recirculation Wells) for the northern plume VOC source areas will apparently change the conditions in the treatment area from anaerobic to aerobic for the amount of time the treatment systems are operating, potentially longer. Source reduction to levels where natural attenuation, as calculated in the treatability study, will complete treatment prior to groundwater discharging to Lake Druid is a component of several of the treatment alternatives. The potential upset in the natural attenuation already occurring at the site by oxygenating a portion of the aquifer should be considered in the report.**

   Any upsets to natural attenuation from source area treatment are expected to be localized and temporary (during implementation and a short period after). Alternatives V-4 (air sparging) and V-5 (recirculation wells) would only temporarily increase dissolved oxygen content in the source area. However, natural attenuation is a downgradient remedy. Chemical oxidation treatment byproducts are carboxolic acids, water, and chloride. It is also recognized potassium permanganate can act as a biocide. Based on the potassium permanganate pilot study, aquifer pH will not significantly decrease, likely due to the natural buffering capacity of the aquifer. Although the microbial population within the source area will likely be reduced by the potassium permanganate, this effect will not occur in downgradient of the treatment zone, and bacteriological populations should increase after treatment is completed.

   While it is likely that biological activity will temporarily cease within the source area, the relatively small volume of chemicals added to a large volume of water does not significantly alter background conditions. Air sparging and recirculation wells will create aerobic conditions within the source area for the source area treatment duration (2 years and 15 years, respectively), but will revert back to background conditions well within the 10 year period before monitored natural attenuation commences. Additional wording with respect to natural attenuation impacts will be added to the text.

2. **The report should discuss in more detail the operational history of the IRA recirculation wells, including problems encountered, lessons learned and whether any of the problems encountered would make the use of recirculation wells technically infeasible. The latest information verbally related by Bechtel casts some doubt as to the long term effectiveness of using recirculation wells.**

   The IRA recirculation wells have been shut down due to operational problems. The IRA system is now a pump and treat system, where extracted water is pumped into an air stripper, and the treated water is then discharged into Lake Druid. Operational difficulties with the IRA recirculation wells are discussed in more detail in Section 2.3 of the FS report. The "Implementability" paragraph in the Detailed Analysis of Alternative V-5 will be expanded in include the IRA discussion in Chapter 2 and to discuss the problems that might make the use of recirculation wells as a final OU 4 remedy technically infeasible.

3. **The first paragraph on page 1-6 states that "monitoring well and direct-push technology have shown that (the northern) plume is <u>likely</u> confined to Area C along the northern property line, and does not extend into the condominium property located north of OU 4." Any groundwater monitoring that occurs at the site will have to confirm that the plume is confined to Area C and that a treatment system does not cause the plume to migrate onto the condominium property.**

   Groundwater monitoring along the property line should be performed to confirm that the plume is confined to Area C. Reference to this monitoring will be added to the text. However, this component is considered to be a design detail and capital and O&M costs are considered incidental to the existing costs in the FS for each alternative. Well installations and monitoring costs would be relatively small and similar for all alternatives (V-2 through V-7), and would not affect selection of the preferred alternative.

4. **There are a few areas of the report that still specify Florida SCGs instead of SCTLs. These should be corrected. On page 3-14, beryllium is identified as being detected at concentrations exceeding the SCGs. Beryllium was not detected at concentrations exceeding the SCTLs.**

   The text will be updated to reflect the revised risk assessment, which used 1999 SCTLs. All references to SCG values will be changed to 1999 SCTL values.

5. **The addition of the 5-year site review costs for the VOC treatment alternatives and for the antimony plume treatment alternatives may overestimate costs. It is assumed that 5-year reviews will be conducted for the entire OU 4 site and not for each component of the site. This should be explained in the text.**

There are redundancies in 5-year site review costs for the VOC and antimony treatment alternatives. As noted by the commentor, the redundancies may overestimate costs associated with review of the entire site when treatment alternative costs are combined. The text in Section 5.0 will be expanded to explain that total treatment alternative costs are for comparative purposes only and are not necessarily representative of the entire site.

Florida Department of Environmental Protection – Bill Neimes

1. **Executive Summary – Figures ES-2 and ES-3 have been inadvertently misplaced for each other. Figure ES-2 should represent the future worth costs for VOC alternatives V-1 through V-7 and Figure ES-3 should show the present worth costs for Antimony alternative A-1 through A-4.**

   Agreed. Figures ES-2 and ES-3 will be corrected to correspond with the text.

2. **Section 5.0, State's Acceptance – This report notes that since the State has participated in partnering team meetings and have concurred with the issuance of this report, the State has accepted the Feasibility Study. I would have to disagree in that the State, through its partnering meetings, have only conceptually accepted the recommended technology of choice. In reviewing this report in detail there are several assumptions which require further explanation before the State will approve of this Feasibility Study.**

   It is assumed that once comments have been addressed to the regulators' satisfaction, all team members will be in agreement with the contents of the report. If there are any unresolved issues at the time of issuing the final report, the text will be revised accordingly.

3. **Section 5.1.3.1 (Page 5-21), $KMnO_4$ Injection. Petition for Variance – As we discussed and you are aware, prior to injection of potassium permanganate, the Department would require the facility to submit the proper documentation to petition for a variance for violating the secondary standards of color, manganese, and pH. Since these are all secondary standards and no primary standards should be violated via this process, there should be no difficulties in obtaining a variance from the Department for these constituents. I have worked with OGC several times on this process and can assist you through this paperwork process.**

   Primary drinking water standards will not be violated, but a petition for variance of secondary standards will need to be submitted as noted. Discussion regarding a need for petition for variance will be added to the "Compliance with ARARs" paragraph in Detailed Analysis of Chemical Oxidation (p 5-27). HLA has petitioned for and has been granted a variance for the pilot test. It is also recognized that the variance is company-specific and another variance will be required by the firm responsible for the full-scale remedial action.

4. **Section 5.1.3.1 (Page 5-21), $KMnO_4$ Injection. Groundwater Model – The groundwater model (Wellhead Protection Area) assumes a homogeneous aquifer with a hydraulic conductivity of 40 ft/day. This report notes that the hydraulic conductivity in the upper portion of this aquifer (down to 25 feet below land surface) is only 10 ft/day. The consultant should run the model with this lower conductivity value to determine what effects a lower conductivity would have on this model.**

   More formal modeling that recognizes the various permeability strata has been performed in preparation for the pilot test. Pilot test results and a more rigorous modeling will be incorporated into this report for use in the alternative evaluation. Decreasing the permeability will likely result in a lower pumping flow rate but also will result in an extended treatment time. The increased treatment time will probably be offset by the decrease in chemical costs related to dosing a lower flow rate.

5. **Section 5.1.3.1 (Page 5-21), $KMnO_4$ Injection. Injection Well – Page 5-21 of the report mentions that a PVC cased well will be installed to a depth of 40 feet. Please explain how the potassium permanganate will be distributed through the aquifer if the injection well is not screened throughout the aquifer.**

   The text in Section 5.1.3.1 has been revised to reflect the experience gained during the KMnO4 pilot study. Because of the varying hydraulic conductivity with depth, separate injection wells will be installed to treat the shallow and deep portions of the plume. These wells will each be screened to overlap the portion of the aquifer targeted by each well. It is assumed that the potassium permanganate will be evenly distributed along the full length of the screen, which is valid based upon pilot test results. The text will be clarified accordingly.

6. **Section 5.1.6.1, Alternative V-6 – The length of time estimated to cleanup the groundwater to achieve MCL's via pump and treat was given at 108 years. Such a time frame appears to be quite excessive, especially since there was no justification of this to support such a time frame. A groundwater model and the assumptions for this model would be necessary to justify these apparent excessive time frames. It also is ironic that Alternative V-6B (which specifies pump and treat for 59 years and natural attenuation for 30 years) would require less time overall than a more aggressive pump and treat alternative (89 years versus 108 years). How can one justify natural attenuation taking less time than pump and treat?**

   Calculations were inadvertently left out of the FS Report appendix but have been attached to this Response to Comments package for reference and will be included in the appendix of final FS report. Calculations were performed using the Wellhead Protection Area model (WHPA) and a batch flush model to support the 108-year cleanup duration (to achieve MCLs). They required an estimate of the total source area mass (6,000 pounds), the vertical and horizontal distribution of this mass, and the initial concentrations of VOCs in extracted groundwater. Calculations were performed assuming that 2 groundwater extraction wells will be installed, each pumping at a flow rate of 40 gpm. Please note that the treatment time for Alternative V-6B is 59 years of active treatment and 30 plus years of natural attenuation (inferring that the upper-end of this range is undefined and actual total time will be longer than the 108 years total for Alternative 6A). Extending natural attenuation costs longer than 30 years was not considered relevant for present worth computations.

7. **Appendix D, Tables D-9 and D-10 – The present worth calculation for Alternative V-7A and V-7B omitted the treatment system O&M cost. Thus the actual cost for operating this system will be much more expensive than that indicated in this report. I have included a table noting this difference.**

Present Worth Costs for Alternative V-7				
	Reported Alternative V-7A Costs	Actual Alternative V-7A Costs	Reported Alternative V-7B Costs	Actual Alternative V-7B Costs
O&M Costs UV Oxidation	$299,214	$1,862,407	$290,286	$1,806,837
Total O&M Costs	$929,115	$2,492,308	$921,106	$2,437,657
Total Capital and O&M Costs	$1,318,678	$2,881,871	$1,310,669	$2,827,220
Total Costs	$1,450,545	$3,170,058	$1,441,736	$3,109,942

From this table we see that the total present worth costs for Alternative V-7A and V-7B have more than doubled from the costs reported in this document. These costs would appear to be more representative of this technology as it is highly unlikely that the costs for this type of treatment would be less expensive than the costs for a conventional air stripper under Alternative V-6A and Alternative V-6B. (The present worth costs for Alternative V-6A and Alternative V-6B was reported as $1,868,725 and $1,843,974, respectively.

The present worth costs for Alternative V-7A and V-7B will be corrected and subsequent discussions and cost presentations within the report adjusted accordingly. Fortunately, the increased costs for Alternatives V-7A and V-7B only affirm the preference for the less costly in-situ remedial alternatives.

The costs of virtually all of the alternatives will be revised for the final report, as changing the IRA from recirculation wells to groundwater extraction and disposal must be addressed. The chemical oxidation alternative will also be revised to incorporate the experience gained during the KMnO4 pilot study.

8. **Appendix D, Table D-14 – There are some costs items that have been omitted from Alternative A-4. These items include: (1) Cost for a Replacement NP Treatment System – The cost data includes an original NP treatment system. However, vendor information indicates that this system will last for a period of five years at most. Based on an estimated operational period of nine years, this cost data should include two NP treatment systems. (2) System Maintenance – The labor cost to operate and maintain this system is estimated to be the same as that to operate and maintain the system with a direct discharge to the POTW. However, vendor information notes that it will take 2-4 hours per week of labor to maintain this system. Therefore, the O&M costs for this alternative should be more than O&M costs for pumping and discharging directly to the POTW.**

   The capital costs presented in Table D-14 will be refined to include replacement costs for the NP-7050 unit (5 years after start-up) and O & M costs will be updated to reflect the anticipated additional weekly labor hours (4) for general maintenance of the system as requested.

9. **Appendix E, NP-7050 Unit – The assumption for groundwater influent information appear to be low. For example do you expect there will not be any suspended solids when pumping raw groundwater directly to the microfiltration unit. In addition, the dissolved solids value of 20 mg/l appears to be low. Information should be collected during a pump test to determine specifics for TDS and TSS.**

   The assumptions for groundwater influent information are based upon pumping tests that were performed at OU4 in the vicinity of the IRA wells. For confirmation, an additional pumping test would be performed in the antimony plume prior to design of the system. However, the assumptions used in the FS are adequate to properly evaluate this alternative.

10. **Appendix F, Hydrogen Release Compound Design Calculations, Spreadsheet – Although I could follow many of the spreadsheet calculations provided in this appendix, there were a few computations which I could not derive. It would be beneficial if either the consultant or Regenesis could provide the Department a copy of this spreadsheet program so that we can determine if all the assumptions provided are reasonable.**

   A copy of the current version of this program and explanations of the basis for the models may be found on the Regenesis web page (www.regenesis.com). The current version is different than the one used for the draft FS, and there is yet another new version undergoing beta testing now. Regenesis is constantly upgrading and improving this software to reflect the current state of knowledge regarding this developing technology. Although the specific amounts of HRC may be different and will alter the costs slightly, this portion of the total cost of the alternative is relatively small and will not affect the comparative analysis.

11. **Appendix F, Hydrogen Release Compound Design Calculations, Safety Factor – I have noted a safety factor of 130X (676 lbs/5 lbs.) when computing the required HRC poundage for the source area. I realize that this safety factor is based on the necessity to fill all boreholes with HRC, however this factor of safety appears to be excessive. Are there methods of diluting HRC so that the applied dosage of HRC per borehole could be somewhat less than 40 pounds?**

There is a "safety factor" or overage included (1.67 times increase) for borehole size, but not nearly as great as that inferred by the commentor (130 times increase). The required number of pounds (5 lbs.) is the stoichiometric quantity of HRC necessary to provide the required hydrogen for reaction with the PCE and TCE. The adjusted HRC mass (405 lbs.) is the stoichiometric quantity multiplied by hydrophobic sorption and competing microbial process factors, and other uncertainties provided by the model. The overage of 1.67 can be reduced by using a smaller diameter borehole or by mixing HRC with other materials. However, for FS costing purposes, this safety factor seems reasonable, especially considering that injection of the HRC from the borehole into the saturated overburden to enable a more widespread contact with the contaminated groundwater may also be considered in the design.

A site-specific pilot during the design phase will likely be required to support a more accurate estimation of the necessary HRC mass. However, the assumptions used in the FS are reasonable and adequate to evaluate this remedial technology.

12. **Precipitation of Antimony – With the addition of a reducing agent within the antimony plume, it is likely that the concentration of sulfate in the groundwater will be reduced to hydrogen sulfide. Any dissolved hydrogen sulfide may combine with the dissolved antimony to form an antimony sulfide precipitate (Sb_2S_3 or stibnite). Metal sulfide precipitates typically have very low solubility products. Thus the addition of HRC may not only mitigate the dissolved chlorinated groundwater plume but also may mitigate the dissolved antimony plume. The consultant should review the chemistry of this to determine what effects a reducing environment will have on antimony precipitation.**

Factors requiring consideration would be whether the sulfate reduction actually happens and to what degree, and what are the possible affects from the presence of other competing metals (Fe, Mn, As, etc). These are difficult to assess in theory and apply to a field scenario with any accuracy. HLA is unaware of any fixation technologies for antimony that have been fully demonstrated to be permanent remedial technologies. However, as part of the pilot test for HRC application in the adjacent southern VOC plume, measurements of antimony, sulfate, sulfide, and other indicators can be measured to more readily observe the effects of HRC within the antimony plume.

PROJECT NTC Orlando OU4 FS
SUBJECT Alternative Duration Calculations

Need to determine pumping duration for the groundwater extraction option for the OU4 source area.

Assumptions

Total Mass PCE = 6,000 lb
Ave Fraction TOC = 0.006 (From OU4 RI) 6000 mg/kg

K_{oc}

PCE = 364 ml/g DCE = 49 ml/g
TCE = 126 ml/g VC = 57 ml/g

$1 + \frac{\rho (f_{oc})(K_{oc})}{\theta}$

GW Concentration at Source

Assume 30 lb/yr enters lake. Assume all PCE.

Source cross-section is approximately 50 feet wide, ~~35 feet deep~~ $= 1050\ ft^2$ ← This is for 30' wide!
$A = 1750\ ft^2$ for 50'

Gradient (from WHPA simulation) = 0.008 ft/ft

Velocity = (40 ft/day)(0.008)/0.30 = 1 ft/day

Flow = $(1050\ ft^2)(1\ ft/day) = 1050\ ft^3/day$ or 1750 cfd

$\left(\frac{1050\ ft^3}{day}\right)\left(\frac{365\ d}{yr}\right)\left(\frac{7.48\ gal}{ft^3}\right)\left(\frac{3.78\ l}{gal}\right) = 1.084 \times 10^7\ l/yr$ or $1.807\ l/yr$

$(30\ lb/yr)(454\ g)\left(\frac{1\times10^6\ \mu g}{g}\right) = 1.36 \times 10^{10}\ \mu g/yr$ enters lake

∴ Ave GW conc. @ source = $\frac{1.36\times10^{10}}{1.084\times10^7} = 1255\ \mu g/l$ or $754\ \mu g/l$

Seems to low.

Me too!

But is direct function of assumptions

What is this for??

Calculate Retardation Factor

Based on K_{oc}, PCE retards more than any of the other VOCs.

$$R_f = 1 + \frac{\rho (f_{oc})(K_{oc})}{\theta}$$

$$= 1 + \frac{(1.7)(0.006)(364)}{0.3} = 13$$

From RI, average TOC for aquifer = 6,000 mg/kg.

$$f_{oc} = \frac{6000 \text{ mg}}{1 \times 10^6 \text{ mg}} = 0.006$$

Change in VOC Concentrations

Assume VOC concentration decreases logarithmically during pumping:

$$C = C_o e^{-\alpha T}$$

Assuming need to achieve MCLs; ∴ $C = 3\ \mu g/l$ @ $T = t$

$$3 = C_o e^{-\alpha T}$$

$$\ln \frac{3}{C_o} = -\alpha T$$

$$\alpha = \frac{\ln C_o/3}{T}$$

$$C = C_o e^{-\left[\frac{\ln C_o/3}{T}\right] t}$$

$$\bar{C} = \int_0^T C_o e^{-\left[\frac{\ln C_o/3}{T}\right] t}$$

$$= C_o \left[\frac{-T}{\ln C_o/3}\right] e^{-\left[\frac{\ln C_o/3}{T}\right] t} \Bigg|_0^T$$

$$= C_o \left[\frac{-T}{\ln C_o/3}\right] \left(e^{-\ln C_o/3} - 1\right)$$

$$\text{Mass} = Q \times C_o \left[\frac{T}{\ln C_o/3}\right] \left(1 - e^{-\ln C_o/3}\right)$$

Harding Lawson Associates
Engineering
and
Environmental Services

SHEET 3 OF 4
JOB NO. 02545.51
DATE Dec 14, 1998
COMPUTED BY MJS
CHECKED BY WKM

PROJECT NTC Orlando OU4
SUBJECT Alternative Duration Calcs

$$T = \frac{Mass}{Q\,C_o} \ln C_o/3 \left[\frac{1}{1 - e^{-\ln C_o/3}} \right]$$

C_o = STO 1
Mass = STO 2
Flow = STO 3
C = STO 4
µg/l

$$\frac{Mass}{Q\,C_o} = \frac{lb}{(gal/min)(\mu g/l)} \cdot \left(\frac{454\,g}{lb}\right)\left(\frac{1\times10^6\,\mu g}{g}\right) \Big/ \left(\frac{3.78\,l}{gal}\right)\left(\frac{1440\,min}{day}\right)$$

$$= 83,400$$

$$T(days) = 83,400 \left[\frac{Mass\,(lb)}{Q\,(gpm)\,C_o\,(\mu g/l)} \right] \ln \underset{C}{C_o/3} \left[\frac{1}{1 - e^{-\ln \underset{C}{C_o}/3}} \right]$$

Have 2 extraction wells (from WHPA simulation), each running at 40 GPM. One well is in the source area north of the surge tank. The other is along the north wall of the laundry building.

Assume C_o Well 1 = 5000 µg/l, and Mass = 4000
∴ Well 2 Mass = 2000 ; $C_o = \left(\frac{2000}{\cancel{6000}\ 4000}\right)(3) = \cancel{1,667}$ 2,500 µg/l 12/21/98 MJS

Solve for T 12/21 MJS

why not 2000/4000 ??

$T_{Well\,1}$ = 12382 days = 34 yrs

$T_{Well\,2}$ = ~~15,838~~ 11,232 days = ~~43~~ 31 yrs 12/21/98 MJS

However, K of the first 20 feet = 10 ft/day
K of next 20 feet = 40 ft/day

So of the 40 gpm, 8 gpm is from the shallow aquifer, and 32 gpm is from the ~~shallow~~ deep. And most of the source mass is located in the low conductivity zone.

Assume 2/3 of the mass is shallow (10 ft/day)

PROJECT NTC Orlando OU4
SUBJECT Alternative Duration Calcs

Recalculate times with consideration of the source distribution.

$$T_{well\,1} = (34\,yrs)(2/3)\left(\frac{40}{8}\right) = 113 \text{ yrs}$$

$$T_{well\,2} = (\cancel{43}\,31\,yrs)(2/3)\left(\frac{40}{8}\right) = \cancel{144}\,103 \text{ yrs}$$ 12/21/98 MJS

Now recalculate durations assuming C = 500 μg/l (Assuming this concentration is adequate for NA

$$T = 83{,}400\left[\frac{Mass\,(lb)}{Q(gpm)\,C_o(\mu g/l)}\right] \ln \frac{C_o}{500}\left[\frac{1}{1-e^{-\ln C_o/500}}\right]$$

Again, C_o Well 1 = 5000, Mass = 4000
C_o Well 2 = ~~1667~~ 2500, Mass = 2000 12/21/98 MJS

$T_{well\,1}$ = 4267 days = 11.7 yrs
$T_{well\,2}$ = ~~4302~~ 3356 days = ~~11.8~~ 9.2 yrs 12/21/98 MJS

Now adjust for source distribution

$$T_{well\,1} = (11.7)(2/3)(40/8) = 39 \text{ yrs}$$

$$T_{well\,2} = (\cancel{11.8}\,9.2)(2/3)(40/8) = \cancel{39}\,31 \text{ yrs}$$ 12/21/98 MJS

12/29/98 MJS **NA Recalc**

Assume need C = 80 μg/l

$T_{well\,1}$ = (19.2 yrs)(2/3)(40/8) = 64 yrs
$T_{well\,2}$ = (16.2 yrs)(2/3)(40/8) = 54 yrs

Ave = 59 yrs

ATTACHMENT B

CHEMICAL OXIDATION ALTERNATIVE
(SECTIONS 5.1.3 AND 6.0–6.2.1.3)

5.1.3 Alternative V-3: Chemical Oxidation and Enhanced Biodegradation This alternative consists of injecting $KMnO_4$ into the groundwater at the source area of the northern plume at OU 4 to chemically destroy the chlorinated compounds in dissolved and non-aqueous phases. This alternative also entails injecting a lactic acid producing compound (HRC™) within the southern plume to enhance ongoing natural biodegradation of chlorinated compounds. The IRA continues operating to treat groundwater in the downgradient plume west of the source area remediation. After completion of the chemical oxidation in the source area, MNA will be used to achieve surface water standards at Lake Druid and eventually MCLs. A detailed description of this alternative is presented in Section 5.1.3.1 and technical assessment is presented in Section 5.1.3.2. Vendor information used to develop this alternative is included in Appendix E.

5.1.3.1 **Detailed Description** This alternative, chemical oxidation and enhanced biodegradation, is intended to address VOC contamination within the source areas of the northern and southern plumes at OU 4, reducing concentrations of PCE, TCE, and cis-DCE to Florida surface water standards for discharge into Lake Druid and eventually to Florida drinking water standards (see Table 3-3). As will be discussed in further detail in the following sections, it is anticipated that chemical oxidation within the northern plume source area will be able to reduce source area groundwater concentrations to site-specific standards, based on the results of a field pilot test conducted at OU4. When combined with MNA, it is sufficient to meet the Florida surface water standards at Lake Druid. The downgradient portion of the northern plume will continue to be treated by operating the existing IRA wells until the downgradient groundwater (between Port Hueneme Avenue and Lake Druid, see Figure 2-1) has met Florida surface water standards and then MNA will be used to reduce the contaminant levels down to drinking water standards. Enhanced biodegradation within the southern plume is anticipated to be able to reduce VOC contamination to meet Florida drinking water standards.

A process flow diagram depicting how this remedial alternative will meet the overall remedial objectives for the northern and southern plumes is shown on Figure 5-1. *In situ* chemical oxidation treatment will be used to remediate the source area of the northern plume. Contaminant concentrations will be reduced to a site-specific remedial goal, defined as the concentration at which MNA would be capable of meeting surface water standards (8 $\mu g/\ell$ for PCE) by the time groundwater naturally discharges into Lake Druid. Based on a previous natural attenuation study of OU 4, the contaminant concentration decreases by a factor of 3 to 10 within the groundwater plume between Building 1100 and Lake Druid (HLA, 1998b). With a Florida surface water standard of 8 $\mu g/\ell$ for PCE and an attenuation reduction factor of 3 to 10, PCE concentrations in groundwater leaving the source area must be in the range of 24 to 80 $\mu g/\ell$. It is estimated that chemical oxidation treatment in the source area will take 1 year (see Appendix G, relevant material is attached) to meet this site-specific RGO. Upon

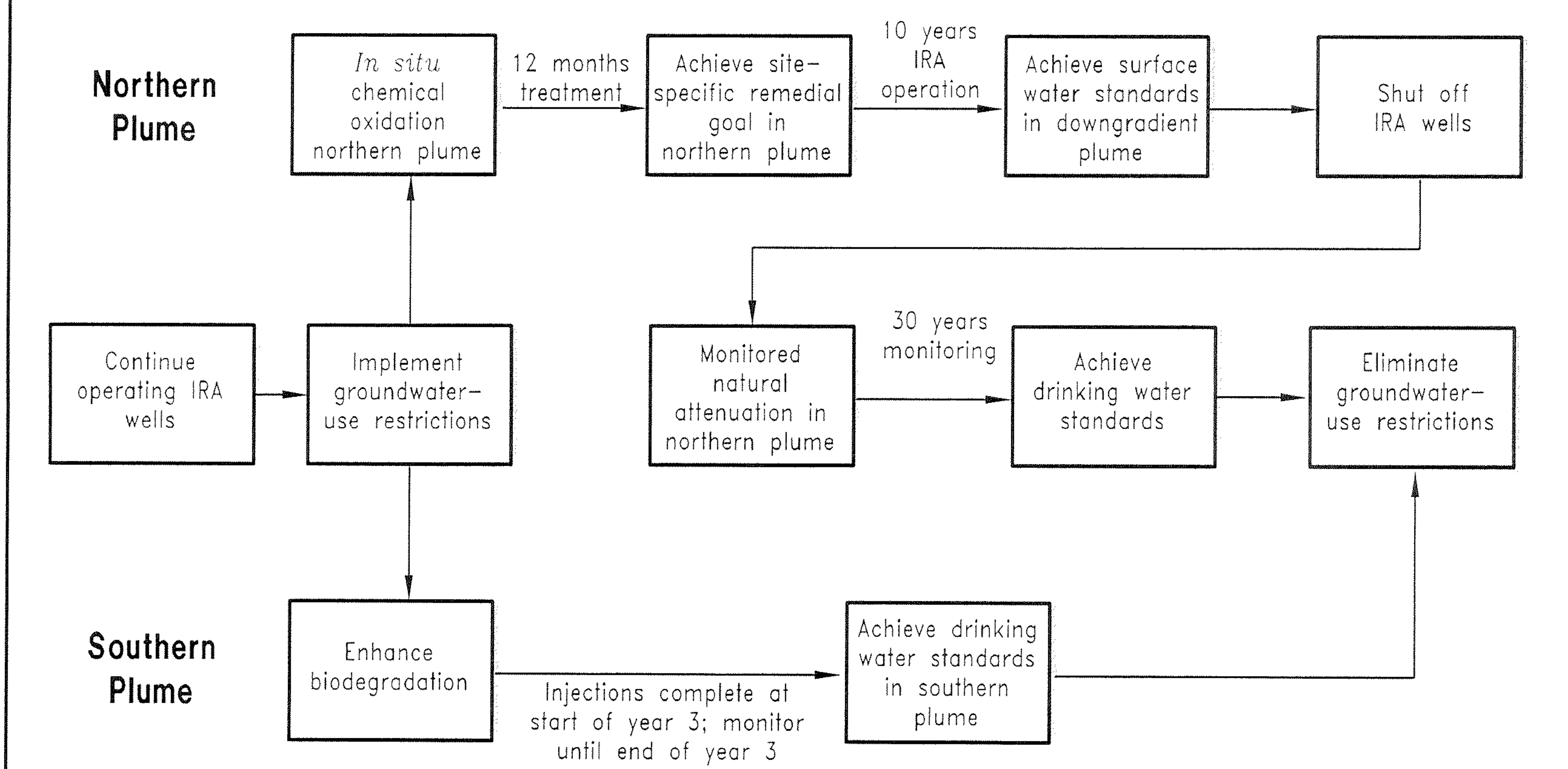

FIGURE 5-1
REMEDIAL ALTERNATIVE V-3
CHEMICAL OXIDATION AND ENHANCED BIODEGRADATION PROCESS FLOW DIAGRAM

FEASIBILITY STUDY
OPERABLE UNIT 4

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P:\CAD\02545\02545-11\FSY\02545638.DWG, VC-BB 12/14/00 13:33:46, R2000 completion of the 1-year treatment period, the remaining low-level contaminants within the source area plume would be treated to surface water standards using MNA. For estimating purposes, the total duration for remediation of the VOC contamination (both the northern and southern plumes) using this alternative will be 40 years.

The downgradient VOC plume would be addressed by the existing IRA as discussed previously. It is anticipated that it will require approximately 10 years before the untreated zone of contaminated water (located between the downgradient extraction well of the chemical oxidation system/HRC™ injection points and the IRA wells) is treated by the IRA wells (see Appendix I). The IRA wells will be shut down once this zone of water is treated to surface water standards. The IRA duration estimate also assumes that no significant VOC mass (greater than 24 to 80 $\mu g/\ell$) migrates beyond the source area once treatment of the source area with $KMnO_4$ begins. VOCs from the source area will be captured by extraction wells and treated using $KMnO_4$.

Chemical oxidation will likely affect subsurface conditions within the source area and may temporarily cause cessation of biological activity. Treatment byproducts of chemical oxidation at neutral pH are carboxylic acids, manganese dioxide (MnO_2), chloride, and water. The effects of chemical oxidation will likely decrease biological activity within the source area, but will not significantly affect natural attenuation downstream of the source area.

Although natural attenuation should achieve surface water standards prior to the plume discharging into the lake, MCLs will not be achieved until dissolution of any remaining unoxidized source has occurred. For estimation purposes, MNA will begin once the IRA wells have been shut down (estimated 10-year duration) and will require 30 years to achieve MCLs, although the duration could potentially be longer or shorter. Should MNA not readily achieve surface water standards, the individual IRA wells could be restarted to ensure continued compliance with Florida surface water standards for groundwater discharging into the lake, or an enhanced biodegradation program could be implemented for the northern plume. Neither of these two contingent actions have been evaluated for this alternative.

Figure 5-1 also depicts how enhanced biodegradation using HRC™ will be used to remediate the southern plume to drinking water standards. It is anticipated that contaminant concentrations will be reduced to Florida drinking water standards from the source area down to the IRA wells within a 3-year period (Appendix F). As with the northern plume, should enhanced biodegradation not readily achieve surface water standards in the southern plume, the individual IRA wells could be restarted to ensure continued compliance with Florida surface water standards for groundwater discharging into the lake.

Major components of this alternative include the following:

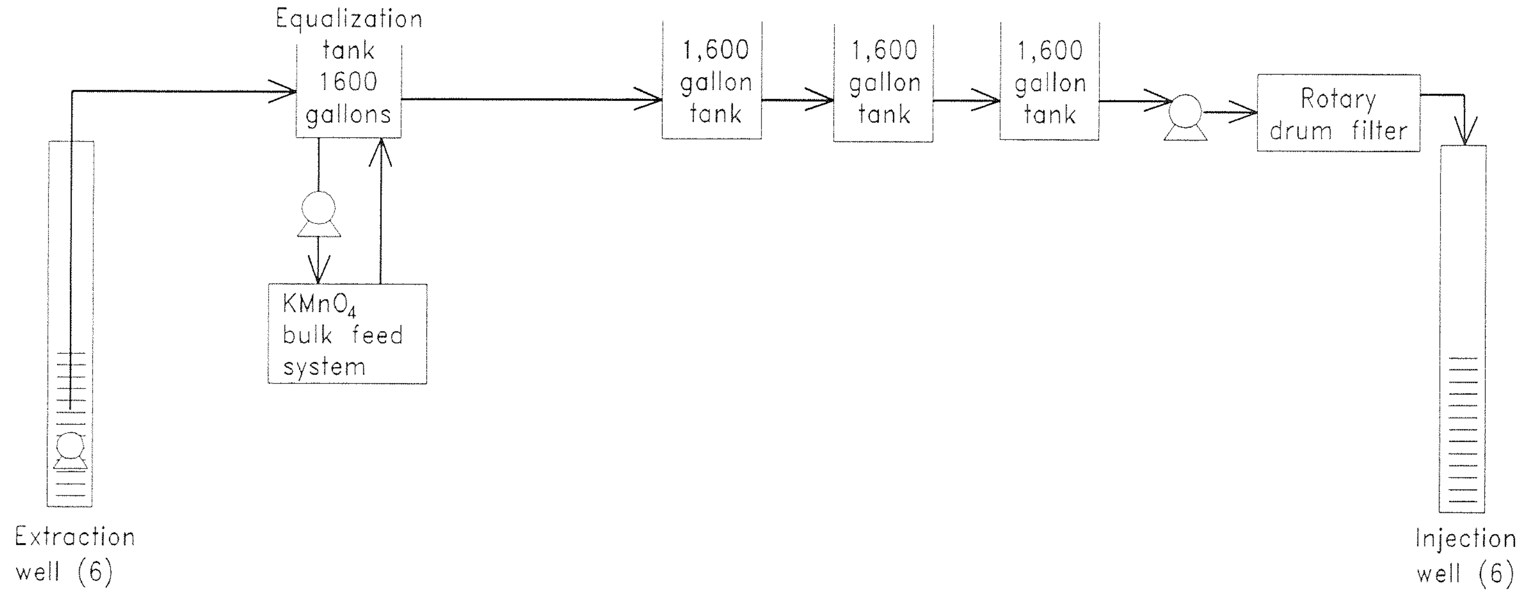
- treatability studies
- groundwater-use restrictions until RAOs are achieved
- Florida underground injection control variance for $KMnO_4$ injection
- $KMnO_4$ injection and extraction wells (northern plume)
- $KMnO_4$ storage and metering system
- chemical oxidation monitoring points
- HRC™ injection (southern plume)
- enhanced biodegradation monitoring network (southern plume)
- phase-out operation of IRA system
- natural attenuation monitoring
- source area soil sampling
- 5-year site reviews

The treatment process and conceptual layout for the chemical oxidation component of this alternative (northern plume) are depicted on Figures 5-2 and 5-3. The treatment process and conceptual layout for implementing enhanced biodegradation (southern plume) are depicted on Figures 5-4 and 5-5.

Treatability Studies. A pilot study was conducted from February to July 2000 to evaluate *in situ* chemical oxidation of the source area within the northern VOC plume using $KMnO_4$ and is described in detail in section 1.5.3, the final $KMnO_4$ workplan (HLA, 1999), and an interim letter report issued in July 2000. A final pilot study report will be issued in late December 2000 or early January 2001. This study established that $KMnO_4$ effectively reduces VOC source area concentrations and allowed improved quantification of system design parameters and costs.

In order to fully implement this alternative at OU 4, a pilot-scale test would be necessary to evaluate the enhanced biodegradation component within the southern VOC plume. This would involve the injection of HRC™ in a series of points upgradient of the existing monitoring wells OLD-13-39B and OLD-13-27A (Figure 5-5), and monitoring for a period of approximately 6 months. The pilot study would help determine the feasibility and effectiveness of enhanced biodegradation and provide design and cost information for full-scale application (e.g., data collected from the test would assist in refining the estimated quantity of HRC™ needed for full-scale implementation and duration of treatment).

Groundwater-Use Restrictions. Section 5.1.2.1 presents a detailed description of the groundwater-use restrictions proposed for OU 4. In addition to these details, the following discussion describes the duration of the groundwater-use restrictions as they support the remedial Alternative V-3.



NOT TO SCALE

LEGEND

$KMnO_4$	Potassium permanganate
	Pump

FIGURE 5-2
TREATMENT PROCESS TRAIN
ALTERNATIVE V-3:
***IN SITU* CHEMICAL OXIDATION**
(NORTHERN PLUME)

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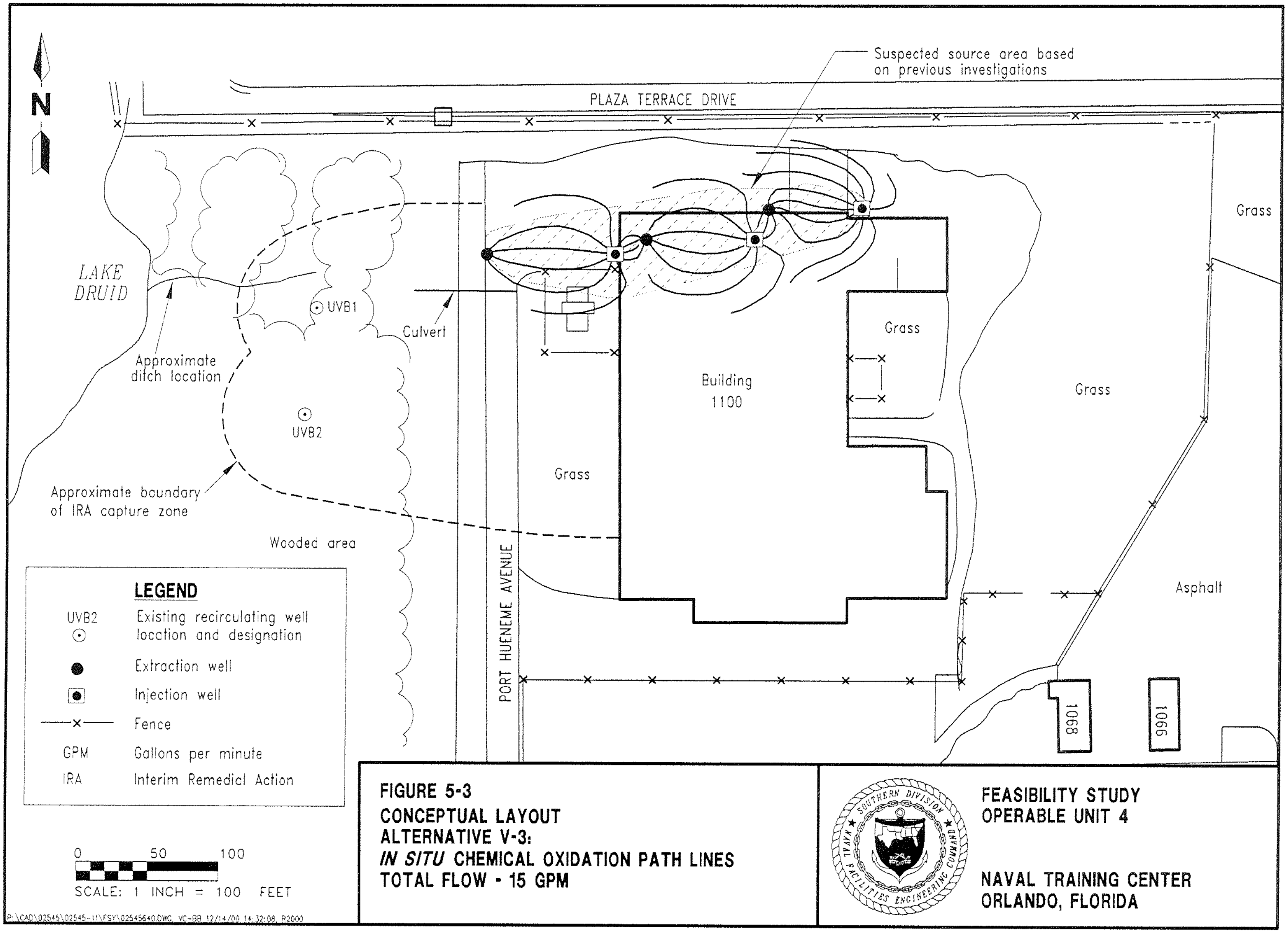

FIGURE 5-3
CONCEPTUAL LAYOUT
ALTERNATIVE V-3:
***IN SITU* CHEMICAL OXIDATION PATH LINES**
TOTAL FLOW - 15 GPM

FEASIBILITY STUDY
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As previously discussed, this FS assumes 40 years will be required for Alternative V-3 to achieve all RAOs. Because of this duration, institutional controls in the form of groundwater-use restrictions will be required to minimize potential risk to future residents from using groundwater as a drinking water source. Groundwater-use restrictions will be implemented prior to chemical oxidation and enhanced biodegradation remedial activities. These restrictions will be continued throughout the operation of the IRA and use of MNA until contaminant levels meet MCLs in both the northern and southern plumes. Once the entire groundwater plume has been treated to Florida drinking water standards, the groundwater-use restrictions will be eliminated.

<u>$KMnO_4$ Injection and Extraction Wells (Northern Plume)</u>. A numerical, three dimensional groundwater flow model (Visual MODFLOW or VMODFLOW) was used to design the $KMnO_4$ injection system. Visual MODFLOW is widely used by consulting firms, educational institutions, and government agencies, such as the USGS and USEPA. Figure 5-3 illustrates the results of the VMODFLOW simulation.

Three groundwater circulation cells will be required to adequately treat the source area. Each circulation cell will consist of two injection/extraction well pairs, one pair screened to the base of the hard layer (shallow zone, approximately 0 to 20 ft bgs), and one pair screened below the hard layer (deep zone, approximately 20 to 35 ft bgs). This arrangement will allow separate treatment of the shallow and deep zones (i.e., above and below the hard layer). The injection/extraction wells for the central circulation cell (four wells total) will be installed at an angle beneath Building 1100 to avoid access problems inside the building. The western and central circulation cells will be operating at approximately 6 gpm total (2 gpm in the shallow zone and 4 gpm in the deep zone), while the eastern circulation cell will operate at approximately 3 gpm (1 gpm in the shallow zone and 2 gpm in the deep zone). These flow rates were selected to ensure the source area is within the treatment zone. The VMODFLOW simulation results are presented in Appendix G (see attached material).

Each extraction and injection well will be constructed of 4-inch diameter, polyvinyl chloride (PVC) casing with slotted screens. The shallow wells will be installed to approximately 20 feet bls with 10 feet of screen. The deep wells will be installed to approximately 35 feet bls and screened below the hard layer from 20 to 35 feet bls. The injection and extraction wells installed beneath Building 1100 will be installed at an angle using sonic drilling. The low overhead in the building limits drill rig access and drilling capabilities. The point of entry for these angled wells will be approximately 12 feet from the edge of the building. The shallow wells will be drilled at a 27 degree angle from ground surface to a total length of 42 feet and screened over the last 20 feet. The angled, deep injection and extraction wells will be drilled to a total length of 50 feet at a 43.5 degree angle from ground surface and will be screened over the last 20 feet. Screen lengths of the angled wells will be sufficient to cover the appropriate vertical aquifer thickness (i.e., 10 feet shallow and 15 feet deep).

Groundwater from each extraction well will be pumped via a submersible pump to a single 1600-gallon equalization tank (Figure 5-2). A transfer pump will circulate water from the equalization tank to the $KMnO_4$ feed system and then back to the tank. Based upon pilot test results, this FS assumes that over the period of treatment, an average of 1 gram per liter (g/ℓ) of $KMnO_4$ will be added to the extracted groundwater stream. After dosage, the treated groundwater will be pumped to three unstirred 1,600-gallon tanks piped in series. Calculations regarding the number of tanks based on PCE oxidation kinetics are presented in Appendix E (see attached material). These tanks will provide the required residence time to allow the $KMnO_4$ to oxidize any VOCs present in the extracted groundwater to below Florida drinking water standards. The treated water is then pumped through a rotary drum filter to remove particulates, and distributed via appropriate valving and flow meters to the three injection well pairs. Reinjected water will comply with State of Florida regulatory limits and the terms of the Underground Injection Control (UIC) permit for the site.

The $KMnO_4$ pilot study conducted in February 2000 established that approximately 2 pore volumes are required to treat the source area. Based upon numerical modeling results, two pore volumes can be flushed through the shallow zone (0 to 20 ft bgs) within approximately 1 year of operation. The time required for 2 pore volumes to flush through the deep zone is likely to be much shorter (4 to 6 months) due to higher hydraulic conductivity. It was assumed for estimating purposes that the entire system will operate for one year.

<u>$KMnO_4$ Storage and Metering System</u>. The above-ground treatment system used during the pilot study consisted of extraction and injection pumps, two $KMnO_4$ drum feeders, two 1,600-gallon tanks, and cartridge filters. This above-ground system was rented from Carus Chemical for $8,500 per month. This FS assumes the full-scale feed system will also be supplied by Carus on a rental basis. Carus is currently developing a second generation family of $KMnO_4$ feed systems specifically for groundwater remediation.

At the anticipated average $KMnO_4$ dosage of 1 g/ℓ, this alternative will consume approximately 82 kilograms (180 pounds) of $KMnO_4$ per day. During the latter stages of treatment, $KMnO_4$ feed may only be makeup to reach 1 g/ℓ. However, the cost of this alternative assumes 180 lbs/day of $KMnO_4$ will be required for the full duration of treatment. Currently, 42 drums of $KMnO_4$ remain on-site, left over from the field-scale pilot test. These drums will reduce the required amount of $KMnO_4$ that must be ordered from Carus and result in cost savings.

<u>Chemical Oxidation Monitoring Points</u>. Groundwater monitoring points will be installed in both the shallow and deep zones to monitor VOC concentrations and monitor the progress of the injected $KMnO_4$. Five shallow zone and two deep zone

monitoring wells will be installed between each injection and extraction well pair (a total of 15 shallow and 6 deep wells). Shallow monitoring wells will be installed to 20 feet bgs (screened from 5 to 20 feet bgs) using direct-push technology, both outside and within the building. However, direct-push methods are not capable of penetrating the hard sand layer present at approximately 20 feet bgs. Therefore, monitoring wells screened in the deep zone below Building 1100 will be installed from outside the building using angled sonic drilling as discussed earlier for the extraction and injection wells.

Samples will be collected from each monitoring well every two months and analyzed for VOCs. Monthly samples of the treatment system influent will be analyzed for VOCs. Monthly samples of the treatment system effluent will be analyzed for VOCs and TAL metals to ensure the injected water complies with State of Florida drinking water standards and UIC permit requirements. Based on the $KMnO_4$ pilot study results, the presence of $KMnO_4$ in groundwater can be determined by visual observations and increasing groundwater specific conductance. Groundwater color will vary from pale yellow, to amber, to brown, and finally, to purple. Purple groundwater indicates the presence of unreacted $KMnO_4$ because all organics at that location have been oxidized.

<u>HRC™ Injection (Southern Plume)</u>. Alternative V-3 also entails injecting a Hydrogen Release Compound (HRC™) into the southern plume to enhance the ongoing natural biodegradation of chlorinated compounds. HRC™ is a polyacetate ester specially formulated for slow release of lactic acid upon hydration. As previously discussed in Section 4.1.3.3, the lactic acid is metabolized by indigenous anaerobic bacteria to produce hydrogen. The resulting hydrogen can be used by reductive dehalogenators to dechlorinate chlorinated hydrocarbons.

The HRC™ compound has the consistency of thick paste. The HRC™ would be injected into the groundwater via small diameter boreholes advanced by hollow-stem auger or direct-push methods, or injected through groundwater monitoring wells. A reciprocating pump would be used to inject the compound down the borehole or well. Figure 5-4 depicts this treatment process.

Prior to injection, a predesign investigation would be performed to better refine the vertical and horizontal confines of the southern plume source area. HRC™ would then be injected within the source area at points spaced between 8 and 12 feet apart arranged in a grid pattern. The compound is injected the full depth of the contaminated saturated zone (assumed to be approximately 40 feet). To treat the downgradient plume, lines of injection points that transect the plume (hereon referred to as injection barriers) would be positioned downgradient of the source area. Injection at these barriers would be performed only once to treat downgradient VOCs in solution and adhered to saturated soil. Injection at the source area is estimated to require multiple applications (once a year for 3 years). Figure 5-5 shows the approximate positioning of the gridded injection points within the source area and the injection barriers within the downgradient portion of the plume.

Modeling (using a proprietary software provided by the HRC™ vendor) of HRC™ use indicates that approximately 5,900 pounds of HRC™ are required in the downgradient injection barriers (first year only) and approximately 680 pounds per year (for a 3 year period) is needed in the source area. HRC™ usage is based upon the following assumptions:

- maximum concentration of PCE and TCE in the southern plume source area is 800 $\mu g/\ell$ and 500 $\mu g/\ell$, respectively
- seepage velocity is approximately 224 ft/year (assuming a hydraulic conductivity of 40 ft/day; see Appendix F)
- competing electron acceptors are oxygen and sulfate at 1.0 mg/ℓ and 16.0 mg/ℓ, respectively

For FS purposes only, HRC™ usage computation sheets for the source area and for the downgradient injection barriers are provided in Appendix F. If this alternative is selected as the preferred remedial action, a detailed design to assess HRC™ application requirements would be performed upon completion of the treatability study.

Enhanced Biodegradation Groundwater Monitoring. Following the initial injection of HRC™, groundwater monitoring will commence to provide a means of monitoring the progress of the enhanced biodegradation in the southern plume. Wells located within the source area and between the source area and the downgradient IRA wells will be sampled every three months during the duration of the three years of treatment. Analytes would include PCE, TCE, cis-DCE, VC, ethene/ethane, volatile fatty acids (i.e., lactic, proprionic, acetic and pyruvic acids) and natural attenuation parameters such as oxygen, nitrate, iron (II), sulfate, sulfide, methane, oxidation-reduction potential (ORP), pH, temperature, carbon dioxide, alkalinity, and chloride. For FS cost estimating purposes, it is assumed that a total of 5 existing and 11 new groundwater monitoring wells will be used for the monitoring of the enhanced biodegradation process in the southern plume. If this alternative is selected, a groundwater monitoring plan would be prepared detailing well positions, sampling frequency, and analytical program. This plan would be submitted for regulatory review and approval prior to implementation.

Phase-Out Operation of IRA System. Upon start-up of the chemical oxidation treatment system in the northern plume, it is anticipated that it will require approximately 10 years before the residual downgradient plume (plume between the chemical oxidation treatment zone and the IRA wells) will be treated by the IRA system to meet surface water standards at the Lake Druid shoreline. This duration is based on groundwater seepage velocity and considers retardation for

PCE (see Appendix I). Wells between Building 1100 and Lake Druid will be used to monitor the performance of the IRA system and indicate when the IRA wells may be turned off, and at which point monitored natural attenuation will commence. MNA is discussed in the paragraphs below.

Monitored Natural Attenuation (MNA). Upon the shutdown of IRA wells, natural attenuation processes will be monitored. Monitoring will serve two purposes: to confirm that natural attenuation processes will effectively reduce the remaining VOC concentrations such that surface water standards will continue to be maintained at the shoreline of Lake Druid without IRA well operation; and to observe further reduction in VOC concentrations. These data will also be used for refinement of estimates for cleanup times to reach Florida drinking water standards. This monitoring period is expected to be 30 years.

Wells located within the source area, between the source area and the IRA wells, and downgradient to the Lake Druid shoreline, initially will be sampled every 3 months after the IRA wells have been shut down. Thereafter, the sampling frequency may be reduced depending upon natural attenuation assessment results. Analytes would include PCE, TCE, cis-DCE, VC, ethene/ethane, and natural attenuation parameters such as oxygen, nitrate, iron (II), sulfate, sulfide, methane, ORP, pH, temperature, carbon dioxide, alkalinity, and chloride. For FS cost estimating purposes, it is assumed that approximately 18 existing monitoring wells would be monitored on an annual basis. Following the selection of this remedial alternative, a natural attenuation monitoring plan would be prepared detailing well positions, sampling frequency, and analytical program. This plan would be submitted for regulatory review and approval prior to implementation.

Source Area Soil Sampling. As previously discussed in Section 3.2.3, the RI revealed that PCE concentrations in surface soil do not exceed residential or industrial SCTLs (8,900 and 17,000 μg/kg, respectively), but do exceed the groundwater leachability SCTL (30 μg/kg). Investigations performed in the Building 1100 Surge Tank area (ABB-ES, 1997b) did not identify any highly contaminated soils that would suggest the presence of residual NAPL in the vadose zone soil. Rather, the highest PCE concentrations in vadose zone soils ranged from 133 μg/kg to 260 μg/kg, generally located within the 4-foot interval below the northwest corner of the Building 1100 floor slab. The highest concentration detected in surface soil beneath paved areas at the exterior of the building was 110 μg/kg located at the north end of the building.

The low concentrations detected in the vadose zone are likely attributable to the volatilized fraction from contaminated saturated soils that has collected and adsorbed to vadose zone soil beneath the floor slab and pavement. The presence of the building slab and pavement likely minimize any PCE migration potential, if it exists. However, to confirm that vadose zone soil concentrations will decrease through groundwater remedial actions, soil sampling would be performed at the areas where PCE concentrations were previously found to exceed the groundwater leachability SCTL. This soil sampling would be performed upon achieving Florida drinking water standards at the site.

<u>Five-Year Reviews</u>. A detailed description of the 5-year site review process is presented in Section 5.1.1.1. In addition to these activities, treatment performance and groundwater monitoring data will be summarized and evaluated. This evaluation will include an assessment of the reduction in contaminant concentrations in both VOC plumes, the effectiveness of the chemical oxidation and enhanced biodegradation treatment for the periods of operation, and an assessment for supporting the IRA system shutdown. Once these treatment processes are complete and IRA operation has ceased, reviews will include assessing the effectiveness of natural attenuation to maintain contaminant concentrations below SWQSs at the shoreline of Lake Druid and to reduce concentrations further to drinking water standards.

5.1.3.2 **Technical Criteria Analysis** This section presents the technical criteria analysis of the Alternative V-3 compared against the seven criteria in Table 5-1.

<u>Overall Protection of Human Health and the Environment</u>. The VOC-contaminated groundwater, if used for drinking water, and contaminant migration to Lake Druid pose unacceptable risks to future residents at OU 4. Alternative V-3 relies on chemical destruction (chemical oxidation), biological processes (enhanced biodegradation and natural attenuation), and physical removal (air stripping) of the VOCs in the groundwater to eliminate these human health risks. Groundwater-use restrictions will be implemented temporarily to minimize potential human exposure to the groundwater until contaminants can be reduced to Florida drinking water standards.

As depicted in the remedial alternative process flow diagram (Figure 5-1), chemical oxidation would be used to treat the northern plume source area groundwater to VOC concentrations sufficient to achieve Florida surface water standards by the time the plume reaches Lake Druid. The existing IRA would continue to treat the contaminated groundwater plume downgradient of the source area until Florida surface water standards are achieved. Natural attenuation would complete the reduction of contaminants in the source and downgradient areas to Florida MCLs. Biodegradation of VOCs would also be enhanced to meet Florida surface water and drinking water standards in the southern plume. Groundwater-use restrictions will be required to eliminate groundwater exposure pathways because the VOC contaminant plumes at OU 4 will continue to pose a potential risk to future residents during operation of the remedial actions. Once the entire OU 4 groundwater plume has been treated to MCLs, the groundwater-use restrictions will be eliminated. The combination of the chemical oxidation treatment, enhanced biodegradation, continued operation of the existing IRA, and implementation of groundwater-use restrictions will ensure that public health and the environment are properly protected.

Compliance with ARARs. In the short-term, this alternative would comply with the chemical-specific ARARs for VOCs in groundwater discharging into a surface water body. However, it will not comply with State drinking water standards until MNA of the downgradient plume is complete.

This alternative emphasizes treatment of the VOC source area reducing the overall operation of the IRA and expediting the time to achieve these ARARs. Monitoring of the groundwater quality at the point of compliance near the lake edge and at the source area would be used to ensure compliance with the ARARs.

$KMnO_4$ injection may cause an exceedance of certain Florida secondary drinking water standards and would therefore, require a petition to the Florida Department of Environmental Protection for a UIC variance to exceed these standards. The variance is company-specific and must be acquired by the firm responsible for the full-scale remedial action.

Long-Term Effectiveness and Permanence. This alternative is focused on the treatment of VOC contamination within the source area and the downgradient plume prior to it discharging into Lake Druid. Based on the field pilot-scale test results, chemical oxidation would chemically destroy the organic COCs permanently and reduce source area groundwater concentrations to site-specific standards, based on the results of the field pilot test. Furthermore, the potential presence of residual DNAPL does not adversely affect the chemical process. The field pilot-scale test is described in detail in Section 1.5.3, the final $KMnO_4$ workplan (HLA, 1999), and an interim letter report issued in July 2000. The pilot study will be used to establish the detailed site-specific performance and design parameters prior to implementing this remedial technology.

Enhanced biodegradation is a proven technology that permanently destroys chlorinated solvents, especially when natural biological degradation is already being observed at OU 4. Pilot studies performed at other sites and available vendor information can provide assistance on assessing the ability of HRC™ to enhance the complete dechlorination of PCE, TCE, and cis-DCE (Dooley *et al.*, 1999; Koenigsburg and Norris, 1999; Murray *et al.*, 2000; Koenigsburg, 2000). However, as part of the design phase, field pilot tests at OU 4 would be required to optimize the injection distribution, quantity, and frequency of HRC™ injections.

The IRA pump and treat system permanently removes volatile organic contaminants from groundwater. Groundwater treatment and natural attenuation durations were also prepared based on site-specific hydraulic characteristics to determine the applicable short-term or long-term permanence of the groundwater-use restrictions. This permanence will vary based on the remedial goals of the active treatment systems within the source areas and the use of natural attenuation throughout the groundwater plume to achieve MCLs.

Reduction of Toxicity, Mobility, and Volume Through Treatment. This alternative would reduce the toxicity, mobility, and volume of VOCs in the OU 4 groundwater. This would be accomplished through the chemical destruction of the VOCs *in situ* in the northern plume by chemical oxidation. Enhanced biodegradation would be used to biologically destroy the VOCs *in situ* in the southern plume. The downgradient plume would continue to be treated by the existing IRA system, which intercepts and physically removes the VOCs from the groundwater. Estimated emissions of the off-gas from the IRA air stripper are approximately 2.4 lb/day (CH2M Hill, 2000), which is in compliance with Florida air quality requirements (less than 13.7 lbs/day), but the contaminants are not destroyed. Based on the continued operation of the IRA system, the small volume of vapor emissions would not require collection or treatment. However, vapor emissions will be monitored as part of the treatment system operation to ensure compliance with the FDEP air regulations. If treatment is found to be required, an emissions treatment system could be added. MNA, implemented once surface water criteria can be achieved without IRA operation, uses naturally occurring *in situ* biodegradation to reduce the toxicity and volume of VOCs.

Short-Term Effectiveness. This remedial alternative will achieve the remedial goals for groundwater quality by treatment of the VOCs using *in situ* chemical oxidation, enhanced *in situ* biodegradation, IRA wells and natural attenuation. Chemical oxidation and enhanced biodegradation would have operating durations of approximately 1 year and 3 years, respectively. However, contaminant reduction to drinking water standards is assumed to require a total of 40 years. Due to the long-term operation of the remedial actions, groundwater-use restrictions will provide the necessary short-term effectiveness in protecting the public from the existing contaminants. There would be only slight exposures to workers performing well installations, treatment process operations, and groundwater monitoring during these time frames. The residuals produced by the air stripper (vapor emissions) are expected to be negligible, not exceeding 2.4 lb/day (CH2M Hill, 2000), far below the FDEP limit of 13.7 lb/day. Air emissions would also continue to be monitored to ensure they do not exceed FDEP air quality standards.

Implementability. Construction of a chemical oxidation treatment system would be relatively easy to implement using a mobile $KMnO_4$ storage and feed system, as would installation of the $KMnO_4$ injection and groundwater extraction wells. Figure 5-2 presents the $KMnO_4$ treatment process and Figure 5-3 presents a conceptual layout of the proposed injection and extraction wells.

Drilling beneath Building 1100 may prove challenging because the wells will be drilled at an angle. Angled drilling is not uncommon and various drillers have been contacted in regard to the feasibility and cost of angled well installation. Similarly, injection of the HRC™ would be readily implementable in that it requires only basic drilling techniques. The presence of the hard layer makes using conventional augering more attractive than direct push methods for injection of the HRC™. The IRA system is already constructed (converted recirculating wells to pump and treat) and will continue operation.

The required utilities are also readily available at the site. Building 1100 is currently vacant and construction of the treatment systems will not interfere with any ongoing operations at NTC, Orlando.

<u>Cost</u>. The present worth cost for Alternative V-3 is estimated to be $1,472,000. A breakdown of this cost is presented in Table 5-4. The present worth cost includes direct, indirect, and O&M costs for groundwater treatment using chemical oxidation (12 months) and enhanced biodegradation (3 years) for the northern and southern VOC plumes, respectively, and the IRA wells (10 years) for the downgradient plume (Figure 5-1). Groundwater monitoring of the downgradient plume would be conducted during the 10 years of IRA operation and natural attenuation monitoring would be conducted for 30 years upon the shut-down of the IRA wells to ensure that the VOC plume achieves drinking water standards. Air monitoring would also be conducted on the IRA air stripper. These system operation durations have been estimated based on actual site hydrogeologic characteristics and operational data. Administrative O&M costs for the 5-year reviews, and groundwater-use restrictions presented in the limited action remedial alternatives, have also been included in this cost estimate.

The direct cost was estimated to be $347,000, which includes site preparation, all remedial construction activities, and a short report summarizing the remedial action. The indirect cost was approximately $149,000 and includes health and safety costs, administrative fees, engineering and design and construction support services, and the pilot-test of the enhanced biodegradation treatment technology for the southern VOC plume. The present worth O&M cost for all of the treatment systems O&M and 5-year site reviews was estimated to be $843,000 over the 40-year duration. The contingency for this alternative is approximately $134,000. The detailed present worth cost calculations are included in Appendix D (see attached material).

Table 5-4
Cost Summary for Alternative V-3: *In Situ* Chemical Oxidation and Enhanced Biodegradation to Drinking Water Standards

Feasibility Study
Operable Unit 4
Naval Training Center
Orlando, Florida

Cost Item	Cost
DIRECT COSTS	
Groundwater-Use Restrictions	$10,000
Site Preparation and Mobilization	$15,052
In Situ Chemical Oxidation System (Northern Plume)	$239,175
HRC™ Injection System (Southern Plume)	$84,375
Total Direct Cost	$348,602
INDIRECT COSTS	
Health and Safety	$11,000
Administration and Permitting	$22,500
Engineering and Design	$40,000
Pilot-Test of HRC™ System	$25,000
Construction Support Services	$50,000
Total Indirect Cost	$148,500
Total Capital Cost (Direct + Indirect)	$497,102
OPERATION AND MAINTENANCE (O&M) COSTS	
In Situ Chemical Oxidation Operation (12 months)	$182,444
HRC™ O&M (for 3 years of operation)	
Present Worth - System Operation Years 2 and 3 (6%, 1 and 2 years)	$33,060
Present Worth - HRC™ Monitoring (6%, 3 years)	$46,911
IRA Wells (10 years)	
Present Worth - System Operation (6%, 10 years)	$313,548
Present Worth - GW Monitoring in Capture Area (6%, 10 years)	$78,384
Monitored Natural Attenuation (10 to 40 years, a 30-year period)	
Present Worth - Entire VOC Plume (6%, 10-40 years)	$140,270
5-Year Site Reviews (every 5 years for 42 years)	
Present Worth - 5-Year Site Reviews (6%, 40 years)	$48,633
Total O&M Cost (present worth)	$843,250

See notes at end of table.

Table 5-4 (Continued)
Cost Summary for Alternative V-3: *In Situ* Chemical Oxidation and Enhanced Biodegradation to Drinking Water Standards

Feasibility Study
Operable Unit 4
Naval Training Center
Orlando, Florida

Cost Item	Cost
O&M COSTS (Continued)	
Total Capital and O&M Cost	$1,340,352
Contingency (10%)	$134,035
Total Cost of Alternative V-3: *In Situ* Chemical Oxidation and Enhanced Biodegradation to Drinking Water Standards	$1,474,387

Notes: HRC™ = Hydrogen Release Compound™ .
IRA = Interim Remedial Action.
VOC = volatile organic compound.
% = percent.

6.0 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

Remedial alternatives for OU4 groundwater were developed and individually evaluated in Chapters 4.0 and 5.0, respectively, using the seven technical criteria recommended in the NCP. For comparative purposes, these criteria are grouped into the following categories:

- threshold criteria
- primary balancing criteria
- modifying criteria

As presented in Chapter 5.0, the first two sets of criteria were used to evaluate each alternative individually. This chapter presents a comparison of remedial alternatives with respect to these threshold and primary balancing criteria. This comparison is intended to provide technical information to support selection of a preferred alternative. While the FDEP, USEPA, and OPT have reviewed this FS, the modifying criteria, consisting of State and community acceptance, are more appropriately evaluated after the public comment period on the Proposed Plan. It is anticipated these modifying criteria will be used in conjunction with the remedial alternative comparison presented herein to select the appropriate remedial alternatives for the VOC and antimony plumes at OU 4.

6.1 OVERALL APPROACH TO COMPARATIVE ANALYSIS. As presented in Chapter 4.0, remedial alternatives were developed to accomplish the RAOs identified for groundwater at OU 4. The RAOs are based on protecting human health by eliminating or minimizing exposure to COCs in groundwater. In addition, SARA emphasizes the use of treatment technologies that reduce the toxicity, mobility, or volume of contaminants rather than technologies that solely prevent exposure. The threshold and primary balancing criteria identified above are used to streamline the comparison between alternatives, while ensuring compliance with the RAOs. Components of these criteria are described below.

6.1.1 Threshold Criteria Because the selected remedy must be protective of human health and the environment, as well as comply with ARARs, the following threshold criteria are essential:

- overall protection of human health and the environment
- compliance with ARARs.

An individual assessment of each alternative with respect to these criteria was presented in Sections 5.1 and 5.2 for the VOC and antimony groundwater plumes, respectively. An overall comparative analysis of alternatives using threshold criteria for each of the plumes is presented in Section 6.2.

6.1.2 Primary Balancing Criteria Primary balancing criteria consist of the following five components:

- long-term effectiveness and permanence
- reduction of toxicity, mobility, and volume
- short-term effectiveness
- implementability
- cost

These criteria are used to provide an assessment of the permanence of each remedial alternative, while ensuring their implementability and cost-effectiveness. These criteria ensure the use of treatment technologies that reduce the toxicity, mobility, or volume of contaminants rather than technologies that solely prevent exposure. An individual assessment of each alternative with respect to these criteria is presented in Chapter 5.0. A comparative analysis of each of the alternatives using primary balancing criteria is presented in Section 6.2.

As part of the cost-effectiveness evaluation, both the present and future worth costs were calculated for each of the remedial alternatives. In accordance with USEPA guidance (USEPA, 1988), the costs for each of the remedial alternatives presented in Chapter 5.0 were present worth values for capital and O&M costs. However, this presentation assumes that the required present worth funds would be available now for the government to set aside for future use, while receiving compounding interest on the original principle deposited. In actuality, the U.S. government sets aside funds on an annual basis. This would support the evaluation of future worth costs as they more accurately reflect the costs that would be incurred by the U.S. Navy on a "pay-as-you-go" basis to construct and operate the remedial alternatives until RGOs were achieved at OU 4. These future worth costs are also presented for each of the remedial alternatives in Section 6.2, along with a comparison evaluation among these alternatives.

6.2 COMPARATIVE ANALYSIS. The following subsections present a comparison between alternatives for the VOC and antimony groundwater plumes using the seven NCP threshold and primary balancing criteria. Remedial alternatives for the VOC plumes are compared to each other in Section 6.2.1.

6.2.1 Comparative Analysis for VOC Plume Alternatives A comparative analysis was conducted for the seven remedial alternatives capable of addressing the VOC plumes at OU 4. In addition, three of these remedial alternatives were evaluated using a combination of active groundwater treatment to a site-specific remedial goal and MNA to achieve drinking water standards. As previously defined, the site-specific remedial goal is a calculated concentration (approximately 24 to 80 $\mu g/\ell$ for PCE) at which MNA would be capable of meeting surface water standards

(8 μg/ℓ for PCE) by the time groundwater naturally discharges into Lake Druid. Alternatives discussed within this FS are identified as follows:

- V-1: No action
- V-2: Limited action
- V-3: Chemical oxidation and enhanced biodegradation
- V-4: Air sparging and enhanced biodegradation
- V-5: Recirculating wells and enhanced biodegradation
- V-6: Groundwater extraction and diffused aeration
- V-7: Groundwater extraction and UV/oxidation

6.2.1.1 **Comparison of Threshold Criteria** The following comparison is made between remedial alternatives that could be implemented to remediate the VOC plume at OU 4 with respect to two criteria: (1) overall protection of human health and the environment and (2) compliance with ARARs.

Overall Protection of Human Health and the Environment. According to the RI (HLA, 2000), contaminants in OU 4 groundwater present risks to human health if groundwater is used as a drinking water source, or from ingestion and dermal exposure to surface water at the shore of Lake Druid. All alternatives, including Alternative V-1, would prevent potential surface water exposure by continuing IRA operation, thereby minimizing migration of VOCs to Lake Druid. Unlike Alternative V-1, Alternatives V-2 through V-7 also protect future residential receptors from ingestion of contaminated groundwater. This is achieved through the implementation of groundwater-use restrictions. These groundwater-use restrictions would last for an indefinite time under Alternative V-2. Alternatives V-3 through V-7 would implement temporary groundwater-use restrictions until FDEP drinking water standards are attained.

Alternatives V-3 and V-4 utilize *in situ* chemical oxidation and air sparging, respectively, to treat the northern VOC plume. Remedial Alternatives V-3, V-4 and V-5 all use enhanced *in situ* biodegradation to remediate the southern VOC plume. Chemical oxidation and air sparging have been assumed to be incapable of achieving drinking water standards within the source area. This is due to the difficulty of injecting the $KMnO_4$ or air homogeneously within the saturated zone and possible presence of DNAPL stringers. As a result, these two alternatives would rely on MNA to biodegrade the residual VOC concentrations to FDEP drinking water standards. A field pilot-scale test was conducted in February 2000 to evaluate the effectiveness of VOC oxidation using potassium permanganate. Test results indicate that VOC destruction efficiencies up to 99.99% can be achieved. An air sparging pilot-scale test performed at OU 4 in May 1998 revealed that Alternative V-4 is likely to be protective of human health, providing an effective means to extract the stripped contaminants (vapor phase) from beneath the hard layer is implemented. Based on the ongoing natural degradation of VOCs at OU 4 and published experience by Harding ESE (Dooley *et al.*, 1999; Murray *et al.*, 2000) and others (Koenigsburg and Norris, 1999; Koenigsburg, 2000) with the use of HRC™ to remediate chlorinated VOCs, it was assumed for this evaluation that enhanced biodegradation would be effective on the southern VOC plume. However, a pilot-test of the HRC™ would be required to support the design of the remedial alternative.

The remaining *in situ* alternative, V-5, utilizes recirculating wells to remediate the northern plume source area. Recirculating wells were used as the OU 4 IRA until mid-2000, when the IRA was converted to a pump and treat system due to operational and maintenance difficulties associated with the recirculating wells. This remedial alternative would be protective of human health and the environment when combined with the temporary groundwater-use restrictions. Alternative V-5 may not be technically feasible, however, based on previous experiences with the former IRA system (see Section 2.3).

Alternatives V-6 and V-7 (diffused aeration and UV/oxidation, respectively) would provide an aggressive groundwater extraction and treatment system to directly remove contaminants from the shallow aquifer. Alternatives V-6 and V-7 are proven techniques (i.e., pump-and-treat) for removing the bulk of contamination, but experience has shown that attainment of drinking water standards may be technically impractical.

Compliance with ARARs. Alternatives V-3 through V-7 are anticipated to eventually achieve all chemical-specific ARARs. Alternatives V-1 and V-2 do not use source treatment and therefore achieve only surface water standards at Lake Druid through the continued operation of the IRA for an indefinite period of time. Alternatives V-3 and V-4 rely on MNA to ultimately achieve FDEP drinking water standards. Alternatives V-5, V-6, and V-7 are capable of achieving drinking water standards through mechanical treatment processes, but have long operating durations of 27 to 108 years. Secondary evaluations of Alternatives V-5, V-6, and V-7 were prepared for treatment to the site-specific remedial goal and the use of MNA to complete the degradation to drinking water standards. In some cases, this would reduce the overall duration to achieve drinking water standards within the OU 4 plume.

6.2.1.2 **Comparison of Primary Balancing Criteria** A comparison was made between the remedial alternatives with respect to the following NCP criteria: (1) long-term effectiveness and permanence; (2) reduction in toxicity, mobility, and volume; (3) short-term effectiveness; (4) implementability; and (5) cost. These criteria are discussed for each alternative detail within Section 5.1.

Long-Term Effectiveness and Permanence. Risk from potential consumption of source area and downgradient groundwater for Alternative V-1 will likely remain without remedial action within the source area and reduction of contaminants to meet drinking water standards. The IRA, which would continue to operate within all seven alternatives, including Alternative V-1, provides a permanent reduction in contaminant concentration and risk prior to groundwater naturally discharging to Lake Druid but only in the portion of the aquifer between the IRA and the lake. Alternative V-2 implements permanent administrative actions (groundwater-use restrictions) in addition to the IRA to manage residual risk and prevent possible human exposure from consumption of groundwater.

Alternatives V-3 through V-7 are all essentially equal in regard to long-term effectiveness and permanence. They all ultimately provide permanent reduction in contaminant concentrations such that no controls (administrative or physical) of residual risk would be required. However, temporary groundwater-use restrictions and associated groundwater monitoring would be implemented until drinking water standards were achieved within the OU 4 plume. Alternatives V-3 and V-7 produce the least treatment residuals in that contaminants from both the northern and southern plumes are chemically and/or biologically destroyed. Alternatives V-4, V-5, and V-6 utilize physical (stripping) processes that transfer the northern plume contaminants from the groundwater to off-gas, which is discharged to the atmosphere, assuming Florida air regulations are not exceeded. Vapor-phase GAC was assumed for the first year of operation on both Alternatives V-4 and V-5 (Appendix H), after which the emissions were estimated to meet the Florida air emission standards.

Reduction of Toxicity, Mobility, and Volume. Other than that accomplished through unmonitored natural transformation processes, Alternatives V-1 and V-2 would not reduce the toxicity, mobility, or volume of contaminants within the source areas. (The IRA, implemented in all alternatives, reduces the toxicity and volume of contaminants in the *downgradient* plume. Because of its position, it also intercepts and treats the plume prior to discharge into Lake Druid). Alternatives V-3, V-4, and V-5 provide a reduction in toxicity and volume of contaminants in the northern VOC source area groundwater by physically removing (stripping) contaminants from the groundwater. Alternatives V-6, V-7, and to some degree V-3, reduce the toxicity, mobility, and volume of the contaminants in the northern VOC source area due to the hydraulic control afforded by groundwater extraction and chemical or physical treatment of the VOCs. By extracting groundwater from strategic locations, the hydraulic flow paths would be controlled, preventing contaminant migration plus providing extraction and treatment.

Short-Term Effectiveness. Because there would be no treatment of the source area, remedial duration to meet drinking water standards was expected to be indefinite for Alternative V-1. This was true for Alternative V-2 as well, except that groundwater-use restrictions would be implemented indefinitely to protect future residential receptors from ingesting groundwater.

Remedial Alternatives V-3 through V-7 would institute temporary groundwater-use restrictions to protect residential receptors for the short-term until drinking water standards were achieved through treatment. Alternative V-5 was expected to provide the quickest reduction in groundwater contaminant concentrations, potentially meeting RAOs within 27 years. In contrast, RAOs would likely be achieved by Alternatives V-6 and V-7 within a time period exceeding 80 years. After active source reduction, Alternatives V-3 and V-4 both rely on MNA to achieve RAOs, for which a standard duration of 30 years was used in accordance with USEPA guidance (USEPA, 1988). A longer period may be required for natural attenuation to reach Florida drinking water standards.

The remedial duration for Alternative V-5 is based on the assumption that contaminant removal for a recirculating well would be approximately 4 times faster (27 years) than a conventional extraction well. This is due to the vertical flow component associated with recirculation wells, which is more efficient at flushing contamination from stratified aquifers. The remedial duration for Alternative V-5 is primarily dictated by the time required to naturally flush residual downgradient contaminants (concentrations that meet surface water standards at Lake Druid) to concentrations below drinking water standards (27 years). Duration calculations are based on site-specific hydrogeologic characteristics, as discussed in Paragraph 5.1.5.1 and detailed calculations presented in Appendix I.

A WHPA simulation for Alternatives V-6 and V-7 (which both use conventional extraction wells) predicted that two extraction wells each pumping at 40 gpm would be capable of capturing both the northern source area plume and the southern area plume. Calculations also indicated that these two extraction wells would be capable of reducing PCE concentrations to drinking water standards within approximately 108 years and to the site-specific remedial goal within 59 years. WHPA simulation results and associated calculations are presented in Appendix G.

Alternatives V-3 and V-4 would use chemical and physical treatment processes, respectively, within the source area of the northern plume to achieve the site-specific remedial goal, but rely on long-term MNA to reduce contaminants to drinking water standards.

No alternatives present any major exposures to remedial workers or the community. However, alternatives that have long treatment system O&M durations could generally be expected to present the greatest exposure to workers. The estimated treatment durations for Alternatives V-6 and V-7 are 108 years for drinking water standards or 59 years for site-specific remedial goals. The source area treatment duration for Alternative V-5 was estimated to be 27 years (drinking water standards) or 15 years (site-specific remedial goals). The source area treatment duration for Alternatives V-3 and V-4 were estimated to be 1 year and 2 years, respectively. However, these durations would not achieve drinking water standards, but would rely on an indefinite period of time for MNA to achieve drinking water standards (NCP uses maximum of 30 years). All of the remedial alternatives would have a treatment component that would discharge organic vapors to ambient air at concentrations that meet Florida air emission standards (the

IRA for all alternatives plus source area treatment for Alternatives V-4, V-5, and V-6).

Implementability. Alternatives V-1 and V-2 would be the easiest to implement because they only include the continued operation of the IRA system, groundwater monitoring, groundwater-use restrictions (V-2 only), and 5-year site reviews.

Alternative V-3 requires installation of several injection and extraction wells, of which 4 will be installed at an angle. Treatment system equipment is readily available from Carus Chemical Company and can be rented. Source area treatment by chemical oxidation is expected to require no more than one year. For Alternative V-4, an air sparging system, which is relatively straightforward to implement, would be constructed using basic practices and readily available equipment. The presence of the hard layer would require the advancement of additional borings to enable collection of stripped vapors from the groundwater.

Alternative V-5 would entail the construction of four recirculating wells in the northern VOC source area. Installation would also require hydraulic modeling, use of specially designed equipment, and contractors that are technically trained for construction of this innovative system. However, design and construction would be simplified based on the site-specific experience gained through installation of the former IRA wells at the site.

Alternatives V-6 and V-7 are the most labor intensive due to the *ex situ* treatment duration, associated utilities, and system maintenance. Although these alternatives would both require the same groundwater extraction system, Alternative V-6 (diffused aeration) would be easier to operate and maintain than V-7 (UV/oxidation) because the treatment process involves a simpler operation (physical stripping using diffused aerators versus chemical addition and UV chamber operation).

Cost. Table 6-1 summarizes the present worth costs estimated for remedial alternatives that could be used to treat the VOC-contaminated groundwater at OU 4. Figure 6-1 presents these costs in a graphical presentation for comparison purposes. Costs for treatment goal options A and B are included in Table 6-1 and Figure 6-1 for Alternatives V-5, V-6. and V-7. These present worth costs, presented in Appendix D (see attached material), include direct and indirect capital costs, system O&M, system and groundwater monitoring to ensure performance, monitoring of the groundwater plume, and 5-year site reviews. Present worth cost calculations used an assumed interest rate of 6 percent.

The cost estimates also incorporated treatment durations based on site-specific hydrogeologic characteristics at OU 4 (e.g., 108 years for Alternative V-6 and V-7). A fixed duration of 30 years (USEPA, 1988) was used only when an indefinite time was required to achieve the drinking water standard RGOs. These instances included the no action and limited action alternatives (continued

Table 6-1
Summary of Comparative Analysis for Volatile Organic Compound Plume Remedial Alternatives

Feasibility Study
Operable Unit 4
Naval Training Center
Orlando, Florida

Alternative:	V-1 No Action	V-2 Limited Action	V-3 Chemical Oxidation & Enhanced Biodegradation	V-4 Air Sparging & Enhanced Biodegradation	V-5 Recirculating Wells & Enhanced Biodegradation	V-6 Diffused Aeration	V-7 UV/Oxidation
Groundwater Remediation							
Groundwater extracted?	No	No	Yes	No	No	Yes	Yes
Organics reduced?	Yes (IRA)	Yes (IRA)	Yes	Yes	Yes	Yes	Yes
Estimated time until IRA is shut down (years):	Indefinite	Indefinite	10	10	15	10	10
Estimated time to achieve drinking water standards (years):	Indefinite	Indefinite	40+	40+	[2]27/[3]45+	[2]108/[3]89+	[2]108/[3]89+
Plume contained?	Yes (IRA)	Yes (IRA)	Yes (IRA)	Yes (IRA)	Yes (IRA)	Yes	Yes
Source area toxicity reduced?	No	No	Yes	Yes	Yes	Yes	Yes
Source area remedy permanent?	DNA	DNA	Yes	Yes	Yes	Yes	Yes
MCLs attained?	No	No	[4]Yes	[4]Yes	Yes	Yes	Yes
Source treatment residuals produced?	DNA	DNA	No	Yes	Yes	[1]No	No
Operation and Maintenance (Excluding IRA)							
North plume treatment O&M duration (yrs)	DNA	DNA	30+	30+	[2]27/[3]45+	[2]108/[3]89+	[2]108/[3]89+
South plume treatment O&M duration (yrs)	DNA	DNA	3	3	3	[5]DNA	[5]DNA

See notes at end of table.

Table 6-1 (Continued)
Summary of Comparative Analysis for VOC Plume Remedial Alternatives

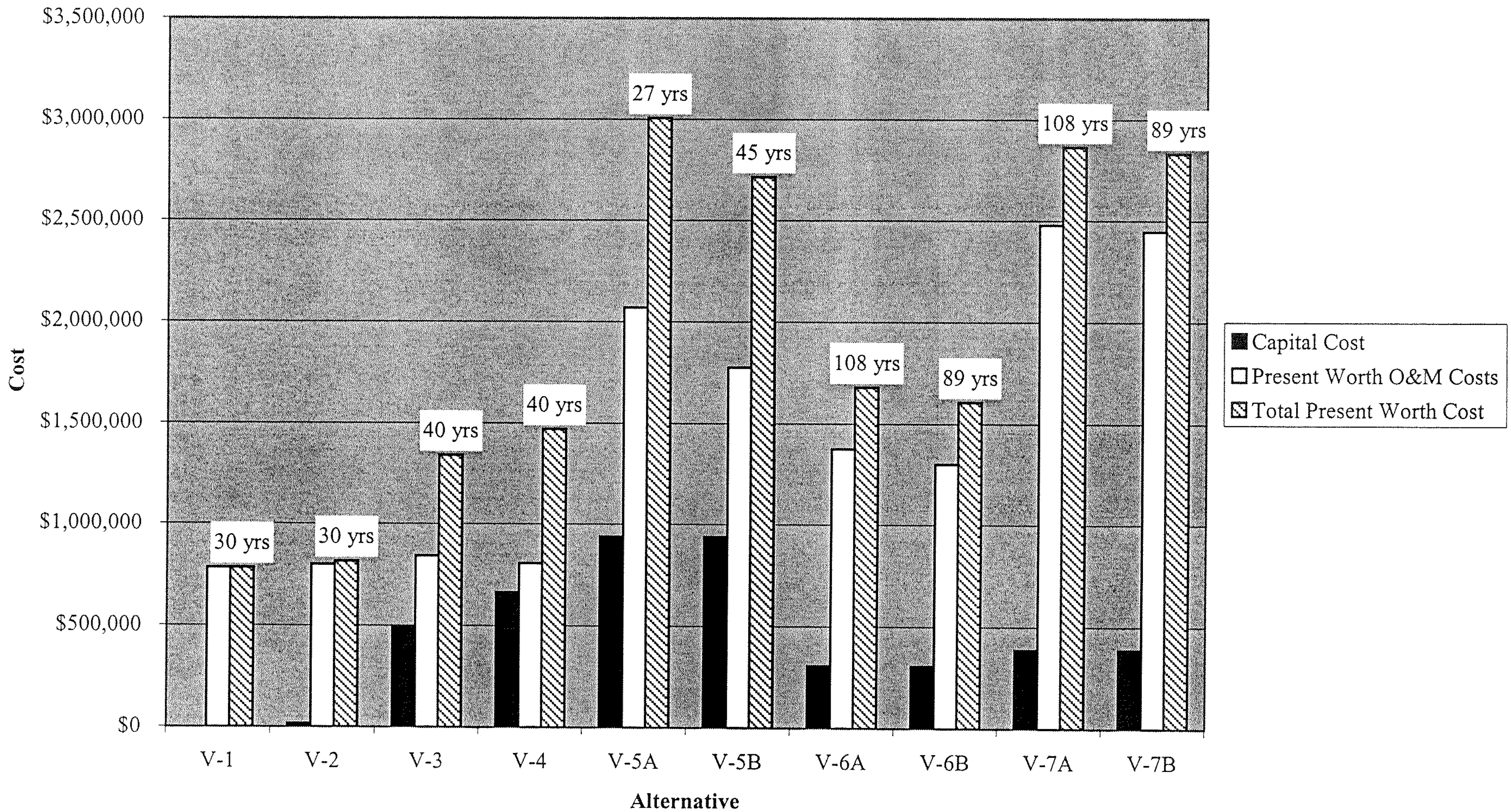
Feasibility Study
Operable Unit 4
Naval Training Center
Orlando, Florida

Alternative:	V-1 No Action	V-2 Limited Action	V-3 Chemical Oxidation and Enhanced Biodegradation	V-4 Air Sparging and Enhanced Biodegradation	V-5 Recirculating Wells & Enhanced Biodegradation	V-6 Diffused Aeration	V-7 UV/Oxidation
Operation and Maintenance (Excludes IRA) (Continued)							
Utilities maintenance	DNA	DNA	Yes	Yes	Yes	Yes	Yes
Groundwater monitoring	No	Yes	Yes	Yes	Yes	Yes	Yes
Costs							
Capital	DNA	$16,500	$497,102	$663,832	$938,027	$305,505	$386,732
Present worth	$861,140	$897,762	$1,474,387	$1,617,711	[2]$3,308,022/[3]2,986,580	[2]$1,848,589/[3]1,768,681	[2]$3,151,344/[3]3,115,843
Future worth	$3,034,793	$3,116,789	$3,130,492	$3,488,874	[2]$7,347,475/[3]6,277,945	[2]$53,216,854/[3]17,137,564	[2]$110,281,921/[3]28,704,064

[1] Air emissions meet FDEP air regulations without further treatment.
[2] Option A - MCL RGO.
[3] Option B - Site-specific RGO with natural attenuation to meet MCLs.
[4] MCLs eventually attained through monitored natural attenuation.
[5] Groundwater extraction and ex situ treatment addresses both the north and south plumes together.

Notes: VOC = volatile organic compound.
UV = ultraviolet.
IRA = Interim Remedial Action.
DNA = does not apply.
MCL = maximum contaminant level.
O&M = operation and maintenance.
FDEP = Florida Department of Environmental Protection.
RGO = remedial goal option.

Figure 6-1
Present Worth Costs
VOC Alternatives V-1 through V-7



(A is MCL RGO, B is site-specific RGO, see Section 6.2.1.2) operation of the IRA system), and the use of MNA as a polishing step to achieve the RGOs (e.g., Alternatives V-3 and V-4).

As would be expected, Alternative V-1, no action, had the lowest present worth cost, relying on the continued operation of the IRA wells to ultimately achieve drinking water standards in the VOC plume. Limited action, Alternative V-2, had only slightly higher present worth costs, but would provide limited protection by eliminating the potential exposure to the contaminated groundwater.

Of the three *in situ* treatment alternatives, chemical oxidation of the source area using potassium permanganate and enhanced biodegradation (V-3) had the lowest total present worth cost. Air sparging and SVE (Remedial Alternative V-4) was only $135,000 more than V-3, and recirculation well treatment (V-5) was approximately $1,400,000 to $1,650,000 more expensive than V-3. All three of these *in situ* remedial alternatives (V-3, V-4 and V-5) relied on enhanced biodegradation of the southern VOC plume and natural attenuation to achieve FDEP drinking water standards.

Based on historical USEPA remediation data, *ex situ* treatment technologies are typically more expensive than *in situ* treatment technologies when operated to achieve drinking water standards. However, the present worth cost of diffused aeration (V-6) was only $272,000 and $137,000 higher in cost than *in situ* remedial alternatives V-3 and V-4, respectively, and thus comparable to the present worth costs of the *in situ* alternatives. The present worth costs of UV/oxidation (V-7) was approximately two times that of Alternatives V-3 and V-4.

The present worth costs were also evaluated to identify the potential cost savings through the use of MNA to reduce residual VOC concentrations down to drinking water standards, rather than continued operation of the mechanical treatment system. The reductions in present worth cost ranged from approximately $300,000 for the recirculation well and enhanced biodegradation alternative, V-5, to $30,000 for UV/oxidation (V-7).

As discussed earlier in Section 2.1.2, present worth cost estimates assume that the funds are available today to be set aside compounding interest until they are needed to pay for the remedial alternative construction and annual O&M. In reality, the U.S. Navy funds the construction and operation of the remedial alternatives on an annual basis, as needed. Therefore, the use of future worth more accurately reflects the costs that would be incurred to achieve drinking water standards in the VOC plume of OU 4. These future worth costs are summarized on Figure 6-2 and a detailed cost estimate is provided in Appendix J (see attached material). Future worth costs were based on a 3 percent inflation rate.

Based on a review of Figure 6-2, the previous conclusions made using the present worth costs are not significantly altered. The least expensive remedial alternative using estimated future worth costs is V-1, the no-action alternative, at approximately $2,760,000. This remedial alternative is approximately $75,000 less costly than Alternative V-2, the limited action alternative. This cost difference is related to incurred capital costs, five-year site reviews and associated sampling/monitoring. Alternative V-3 is comparable to Alternatives V-1 and V-2, despite higher capital costs, due to shorter IRA system operation (10 years compared with 30 years, respectively).

The remaining remedial alternatives are ranked as follows based on future worth costs:

(3) V-3, Chemical oxidation/enhanced biodegradation ($2,846,000),

(4) V-4, Air sparging/SVE/enhanced biodegradation ($3,172,000),

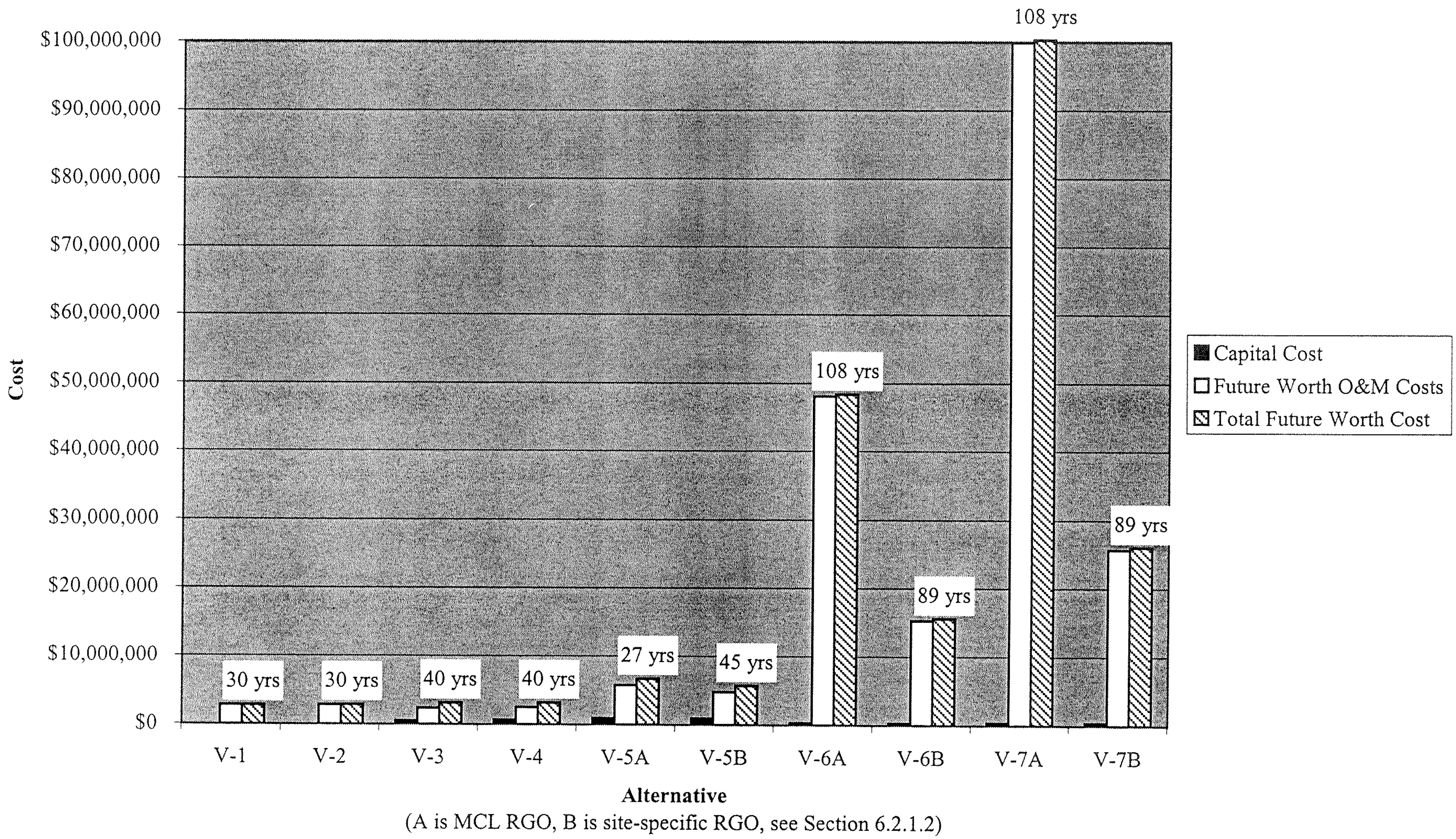
(5) V-5, Recirculation wells/enhanced biodegradation ($5,707,000 to $6,680,000),

(6) V-6, Diffused aeration ($15,580,000 to $48,379,000), and

(7) V-7, UV/oxidation ($26,095,000 to $100,256,000).

Ranges in future worth costs are provided for Alternatives V-5, V-6, and V-7 based on continuous flushing to reach the RGOs versus a reduced operating duration of the active groundwater treatment technologies (flushing) and the use of MNA to achieve the RGOs. MNA would be used to reduce the residual VOC concentrations remaining in the groundwater plume after the active treatment systems achieved the site-specific remedial goals (e.g., 89 years total duration versus 108 years). Treatment to site-specific RGOs then using MNA results in dramatic cost savings for Alternatives V-5, V-6 and V-7 when assessing the future worth costs of these alternatives. The future worth costs of Alternatives V-6 and V-7 are typical of groundwater extraction and *ex situ* treatment systems for VOC-contaminated groundwater because of their long treatment durations and resultant excessive operation and maintenance costs.

Figure 6-2
Future Worth Costs
VOC Alternatives V-1 through V-7



6.2.1.3 Summary of Comparative Analysis for VOC Plume Alternatives Table 6-1 presents a summary of the comparative analysis of the VOC plume remedial alternatives for OU 4. The evaluation criteria presented within this table provide a detailed evaluation of the individual remedial alternatives in their ability to achieve the seven NCP screening criteria. This summary table also supports the overall comparison of remedial alternatives to support the State and community acceptance process. Table 6-1 also presents capital, total present worth and total future worth costs for each remedial alternative to further support this evaluation and selection of the preferred remedial alternative.

Even though this detailed evaluation has been conducted to compare the abilities of the seven remedial alternatives to achieve the RAOs, uncertainties still exist. Uncertainties for Remedial Alternative V-3 include the $KMnO_4$ demand of the source area and the ability to effectively deliver the potassium permanganate to the entire source area. Even small changes in chemical demand and/or duration would significantly affect both the present and future worth costs of V-3. A pilot-test is also recommended for HRC™ treatment of the southern VOC plume to refine the design and costs of the treatment system for this remedial component of Alternatives V-3, V-4, and V-5.

Remedial Alternative V-4 was developed on the assumption that the VOC vapors stripped from the contaminated groundwater would readily pass through the holes in the impervious layer, and that the bulk of contamination was contained within the higher zone of conductivity. If the deep sparge air can not readily pass through the hard layer, air sparging would be less effective for remediating the lower portion of the source area. The majority of VOC contamination within the hard layer would also be inaccessible to the sparge air, further reducing the effectiveness of this alternative.

Remedial Alternative V-5 has the shortest duration of all the VOC treatment alternatives that were evaluated. However, this conclusion is based solely on an assumed treatment duration of 27 years (four times faster than pump-and-treat) to reduce the VOC concentrations to drinking water standards. Longer durations could significantly increase the already high O&M costs associated with this alternative.

Remedial Alternatives V-6 and V-7 have the least uncertainties based on their proven effectiveness, but also have the highest future worth costs.

APPENDIX D

DETAILED PRESENT WORTH COST BREAKDOWNS
(CHEMICAL OXIDATION ALTERNATIVE ONLY)

TABLE D-3

ALTERNATIVE V-3: IN-SITU CHEMICAL OXIDATION AND ENHANCED BIOREMEDIATION TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
DIRECT COSTS				
Groundwater Use Restrictions	1	LS	$10,000.00	**$10,000**
Site Preparation and Mobilization [Northern Plume]				
Storage Trailer	0	month	$150.00	$0
Office Trailer	12	month	$250.00	$3,000
Trailer Delivery, Setup, Removal	2	each	$1,000.00	$2,000
Treatment System Concrete Pad (30' x 30')	0	LS	$4,000.00	$0
Fencing:				
Treatment Area for equip/controls (30' x 30')	120	ft	$2.84	$341
Trailer Area (40' x 80')	240	ft	$2.84	$682
Gates	2	each	$95.00	$190
Office Equipment Rental	0	month	$2,000.00	$0
Utility Connections for trailer, sys equip, controls	1	LS	$4,000.00	$4,000
Toilet/water cooler service	52	wks	$50.00	$2,600
Miscellaneous Equipment	1	LS	$1,000.00	$1,000
Decon Equipment and Pad:				
Pressure Washer with Water Tank	0	month	$500.00	$0
Plastic Sheeting, Drums, Pumps, Hoses, Supplies	0	LS	$3,000.00	$0
Labor (Site Preparation)				
Laborers (2 men @ 10 hrs/day)	2	days	$320.00	$640
Foreman/Superintendent (1 man @ 10 hrs/day)	1	days	$600.00	$600
Subtotal Site Preparation/Mobilization [Northern Plume]				**$15,052**
In-Situ Chemical Oxidation System [Northern Plume]				
(3 extraction well clusters pumping @ 6, 6, and 3 gpm each; 3 injection well clusters at same flows)				
Injection, Extraction and Monitoring Well Installation				
Sonic Mob/Demob (drillers and equip)	1	each	$2,000.00	$2,000
DPT Mob/Demob (drillers and equip)	1	each	$150.00	$150
Vert. Well Sonic Install. (8 wells @ 4" ID, PVC, 20'/35' bls)	220	ft	$65.00	$14,300
Angled Well Sonic Install. (4 wells @ 4" ID, PVC, 42'/50' lf)	184	lf	$100.00	$18,400
Vert. Well Sonic Install. (1 well @ 2" ID, PVC, 35' bls)	35	ft	$55.00	$1,925
Angled Well Sonic Install. (3 wells @ 2" ID, PVC, 40' lf)	120	lf	$90.00	$10,800
MicroWell DPT Installation (15 wells, 20' bls)	4	days	$400.00	$1,600
Extraction Well Vault	6	each	$2,500.00	$15,000
Extraction Pumps	6	pumps	$1,000.00	$6,000
Per Diem/Lodging (3 men @ 5 days)	15	days	$100.00	$1,500
Decontamination	10	hrs	$100.00	$1,000
Misc. Equipment and Supplies	1	LS	$2,000.00	$2,000
Electric Power Supply and Water Supply for H&S				
Utility Pole	0	poles	$550.00	$0
Power Cable	25	ft	$10.00	$250
Telephone line for Telemetry	100	ft	$10.00	$1,000
Water Service Connection	0	each	$1,000.00	$0
Gauge, curb box, appurtenances	0	each	$1,000.00	$0

TABLE D-3

ALTERNATIVE V-3: IN-SITU CHEMICAL OXIDATION AND ENHANCED BIOREMEDIATION
TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
Piping and Equipment				
RWs to treatment system (2" ID, PVC)	400	ft	$20.00	$8,000
Equalization Tank Rental (Incl. Mob/demob; 12 months)	12	mo	$300.00	$3,600
Treatment System Rental (includes the following):	12	mo	$10,000.00	$120,000
KMnO4 Mix Tank Rental (Incl. Mob/demob; 3 tanks)	0	mo	$300.00	$0
Centrifugal Feed Pumps (25 GPM each)	0	each	$5,000.00	$0
KMnO4 Feed System (12 mo. rental + $4K mob/demob)	0	mo	$1,800.00	$0
Rotary Drum Filter	0	each	$3,000.00	$0
Flow Meters	0	each	$300.00	$0
Valves, piping, controls, gauges, etc.	0	LS	$5,000.00	$0
Instrumentation Controls	0	LS	$20,000	$0
Labor				
1 Carus Technician	5	days	$1,200.00	$6,000
3 men @ 3 weeks @ 50 hrs/week	450	hr	$32.00	$14,400
1 Engineer/Foreman @ 3 weeks @ 50 hrs/week	150	hr	$75.00	$11,250
Subtotal Chemical Oxidation [Northern Plume]				**$239,175**
TOTAL DIRECT COSTS [Northern Plume]				**$264,227**
INDIRECT COSTS [Northern Plume]				
Health and Safety				$1,000
Administrative Fees				$7,500
Engineering and Design				$20,000
Construction Support Services				$20,000
TOTAL INDIRECT COSTS [Northern Plume]				**$48,500**
TOTAL CAPITAL COSTS [Northern Plume]				**$312,727**
ENHANCED BIODEGRADATION				
Site Prep and Mobilization [Southern Plume]				
Decon Equipment and Pad:				
Pressure Washer with Water Tank	0	month	$500.00	$0
Plastic Sheeting, Drums, Pumps, Hoses, Supplies	0	LS	$3,000.00	$0
Subtotal Site Prep/Mobilization [Southern Plume]				$0
HRC Injection System (Initial Injection) [Southern Plume]				
HRC Injection Points				
Mob/Demob (drillers and equip)	1	each	$1,500.00	$1,500
Advance boreholes (59 borings @1.5" & 2" ID, 45' bls)	2655	ft	$10.00	$26,550
HRC	5900	lb	$5.75	$33,925
HRC Injection Equipment (tank/pumps)	2	wks	$1,000.00	$2,000
Per Diem/Lodging (3 men @ 10 days)	30	days	$100.00	$3,000
Decontamination	10	hrs	$100.00	$1,000
Misc. Equipment and Supplies	1	LS	$2,000.00	$2,000

TABLE D-3

ALTERNATIVE V-3: IN-SITU CHEMICAL OXIDATION AND ENHANCED BIOREMEDIATION TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
HRC Monitoring Network				
Mob/Demob [included in Injection System]	0	each	$1,500.00	$0
Well Installation (11 wells @2" ID, PVC, 45' bls)	495	ft	$20.00	$9,900
Per Diem/Lodging (3 men @ 5 days)	15	days	$100.00	$1,500
Decontamination	10	hrs	$100.00	$1,000
Misc. Equipment and Supplies	1	LS	$2,000.00	$2,000
TOTAL DIRECT COSTS [Southern Plume]				**$84,375**
INDIRECT COSTS [Southern Plume]				
Health and Safety				$10,000
Administrative Fees				$15,000
Pilot Test of HRC				$25,000
Engineering and Design				$20,000
Construction Support Services				$30,000
TOTAL INDIRECT COSTS [Southern Plume]				**$100,000**
TOTAL CAPITAL COSTS [Southern Plume]				**$184,375**
OPERATION & MAINTENANCE COSTS				
In-Situ Chemical Oxidation System O&M (12 months operation)				
Chemicals				
KMnO4 Cost* (Dosage @ 1 g/L)	51,970	lb	$1.19	$61,844
KMnO4 Freight Cost	3	deliveries	$4,500.00	$13,500
Utilities				
Groundwater Extraction Pumps	12	month	$300.00	$3,600
Treatment System	12	month	$400.00	$4,800
System Maintenance				
Labor (1 operator @ 4 hrs/day, 7 days/wk, 52 weeks)	365	days	$180.00	$65,700
KMnO4 Feed System	12	month	$500.00	$6,000
Subtotal Chemical Oxidation System O&M				**$155,444**
Sampling and Monitoring				
(Includes 2 QA/QC Samples for each sampling event)				
Treatment System Influent Grab Samples (1 per month):				
TCL VOCs	14	samples	$150.00	$2,100
Treatment System Effluent Grab Samples (1 per month):				
TCL VOCs and TAL Inorganics	14	samples	$300.00	$4,200
Monitoring Well Samples (1 every two months, 21 wells)				
TCL VOCs	138	samples	$150.00	$20,700
Subtotal GW Sampling and Monitoring				**$27,000**
Total Chemical Oxidation System O&M Cost (12 mos.)				**$182,444**

TABLE D-3

ALTERNATIVE V-3: IN-SITU CHEMICAL OXIDATION AND ENHANCED BIOREMEDIATION
TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
HRC O&M (Injection in Source Area Only for Year 2 and 3)				
Mob/Demob (drillers and equip)	1	each	$1,500.00	$1,500
Advance boreholes (17 borings @1.5" & 2" ID, 45' bls)	765	ft	$10.00	$7,650
HRC	680	lb	$7.00	$4,760
HRC Injection Equipment (tank/pumps)	1	wks	$1,000.00	$1,000
Per Diem/Lodging (3 men @ 4 days)	12	days	$100.00	$1,200
Decontamination	10	hrs	$100.00	$1,000
Misc. Equipment and Supplies	1	LS	$2,000.00	$2,000
Subtotal HRC Treatment O&M (yrs 2 and 3)				**$19,110**
Present Worth HRC (O&M) Costs @ i = 6%, n = 2-3 yrs				**$33,060**
HRC Monitoring O&M (annual for 3 years)				
16 Wells + 2QA/QC = 18 Samples				
Associate Scientist	50	hrs	$60.00	$3,000
Technician	60	hrs	$45.00	$2,700
ODCs (PPE, sampling equip, expendibles)	1	lump sum	$1,000.00	$1,000
Analysis-HRC Parameters	18	samples	$200.00	$3,600
Analysis-TCL Organics (VOCs only)	18	samples	$150.00	$2,700
Summary Data Report:				
Mid-level Engineer	20	hrs	$75.00	$1,500
Senior Scientist	10	hrs	$90.00	$900
Staff Engineer	20	hrs	$60.00	$1,200
ODCs	1	lump sum	$950.00	$950
Subtotal HRC Annual Monitoring Costs (yrs 1-3)				**$17,550**
Present Worth HRC Monitoring @ i = 6%, n = 3 yrs				**$46,911**
IRA System (annual for 10 years)				
Engineer (8 hr/mo data analysis, reporting)	96	hr	$85.00	$8,160
Technician (12 hr/mo O&M site visits, reporting)	144	hr	$60.00	$8,640
Air Samples - Lab (1 sample/quarter, TO12)	4	each	$120.00	$480
Influent/Effluent Samples - Lab (3 samples/mo, 8012)	36	each	$150.00	$5,400
Electrical (5 hp and (2) 1 hp pumps, 10 hp blower)	111,690	kw-hr	$0.08	$8,935
POTW Discharge Fee (operational flow rate of 10 gpm)	5,256	1,000 gals	$1.90	$9,986
Misc Supplies	1	LS	$1,000.00	$1,000
Subtotal IRA System O&M				**$42,602**
Present Worth IRA System O&M @ i = 6%, n = 10 yrs				**$313,548**
GW Monitoring within Downgradient Plume (annual costs - 10 yrs)				
GW Sampling & Monitoring Program within IRA Capture Area (years 1-10)				
6 Wells + 1 QA/QC = 7 Samples				
Scientist	30	hours	$60.00	$1,800
Technician	40	hours	$45.00	$1,800

TABLE D-3

ALTERNATIVE V-3: IN-SITU CHEMICAL OXIDATION AND ENHANCED BIOREMEDIATION
TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
ODCs (PPE, sampling equip, expendibles)	1	LS	$1,000.00	$1,000
Analyses - TCL Organics (VOCs only)	10	samples	$150.00	$1,500
Summary Data Report:				
Mid-Level Engineer	20	hours	$75.00	$1,500
Senior Scientist	10	hours	$90.00	$900
Staff Engineer	20	hours	$60.00	$1,200
ODCs	1	LS	$950.00	$950
Subtotal Annual IRA Capture Area GW Monitoring				**$10,650**
Present Worth IRA GW Monitoring @ i = 6%, n = 10 yrs				**$78,384**
Monitored Natural Attenuation O&M (annual costs - 30 yrs)				
GW Sampling & Monitoring Program for MNA within the entire VOC plume (yrs 11-40)				
18 Wells + 2QA/QC = 20 Samples				
Scientist	50	hrs	$60.00	$3,000
Technician	60	hrs	$45.00	$2,700
ODCs (PPE, sampling equip, expendibles)	1	lump sum	$1,000.00	$1,000
Analysis-Natural Attenuation Parameters	20	samples	$200.00	$4,000
Analysis-TCL Organics (VOCs only)	20	samples	$150.00	$3,000
Summary Data Report:				
Mid-level Engineer	20	hrs	$75.00	$1,500
Senior Scientist	10	hrs	$90.00	$900
Staff Engineer	20	hrs	$60.00	$1,200
ODCs	1	lump sum	$950.00	$950
Subtotal Annual MNA O&M				**$18,250**
Present Worth MNA O&M @ i = 6%, n = 11 to 40 yrs				**$140,270**
Five-year Site Reviews (every 5 years for 40 years)				
Meetings (attendance only)				
Senior Scientist	8	hrs	$90.00	$720
Mid-level Engineer	8	hrs	$75.00	$600
ODCs	1	lump sum	$100.00	$100
Evaluate Data/Current Situation				
Senior Scientist	20	hrs	$90.00	$1,800
Mid-level Engineer	40	hrs	$75.00	$3,000
ODCs (includes photocopying, etc.)	1	lump sum	$500.00	$500
Five-year Report				
Senior Scientist	40	hrs	$90.00	$3,600
Mid-level Engineer	60	hrs	$75.00	$4,500
Staff Engineer	40	hrs	$60.00	$2,400
ODCs (includes photocopying, etc.)	1	lump sum	$1,000.00	$1,000
Subtotal Five-Year Site Review Costs				**$18,220**
Present Worth 5-Yr Site Review @ i = 6%, n = 5,10,..40 yrs				**$48,633**

TABLE D-3

ALTERNATIVE V-3: IN-SITU CHEMICAL OXIDATION AND ENHANCED BIOREMEDIATION
TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
TOTAL PRESENT WORTH O&M COSTS				**$843,250**
TOTAL CAPITAL COSTS AND PRESENT WORTH O&M COSTS				**$1,340,352**
CONTINGENCY @10 PERCENT				**$134,035**
TOTAL PRESENT WORTH COST OF ALTERNATIVE V-3				**$1,474,387**

*The total amount of $KMnO_4$ required is 65,650 lbs. There are already 42 drums of $KMnO_4$ (330 lbs ea.) at the site left over from the pilot test. Thus, the amount of $KMnO_4$ required to make up this difference is costed here.

APPENDIX E

COST BACKUP AND VENDOR INFORMATION
(CHEMICAL OXIDATION ALTERNATIVE ONLY)

Harding Lawson Associates
Engineering
and
Environmental Services

SHEET 1 OF 3
JOB NO. 44241/0254550
DATE DEC. 1, 2000
COMPUTED BY SNG.
CHECKED BY WAM

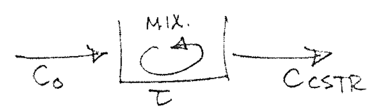
PROJECT NTC ORLANDO OU4
SUBJECT REACTOR KINETICS

OBJECTIVE: Calculate the number of tanks required to meet the treatment system effluent requirement for PCE (3 $\mu g/L$).

ASSUME:
- Treatment system influent is 5000 $\mu g/L$.
  based upon pilot test operation, this is a good assumption.
- Total flow to treatment system is 15 gpm.
  based upon Visual Modflow results.
- Tanks hold 1500 gallons
  based upon use during pilot test.
- Reaction rate constants are as given in the included figures, and are based on Carus laboratory testing data, which is also included.
- First tank can be represented as a CSTR, since water is pumped from it, dosed with $KMnO_4$, then pumped back in the first tank, creating a mixing effect. This effect is assumed to be similar to mixing with an agitator.
- Tanks are in series.

CALC'S: residence time, τ = 1500 gal. / 15 gpm = 1.67 hr.

for the first tank (CSTR), $\frac{C_{CSTR}}{C_0} = \frac{1}{1+k\tau}$



Assume $C_0 = 5000\ \mu g/L$, $\tau = 1.67$ hr, $k = 0.91$/hr ($KMnO_4$ dose of 1 g/L)

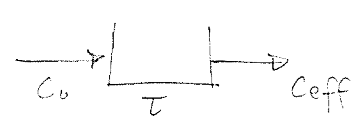
then:

$$\frac{C_{STR}}{C_0} = \frac{1}{1+k\tau}$$

$$C_{STR} = C_0/(1+k\tau) = 5000/[1+(0.91)(1.67)] = 1987\ \mu g/L \checkmark$$

The rest of the tanks are unstirred, or plug-flow.

for PFRs, $\frac{C_{eff}}{C_0} = e^{-k\tau}$



for n PFRs in series, $\frac{C_{eff}}{C_0} = (e^{-k\tau})^n$

The objective is to achieve $C_{eff} \leq 3\ \mu g/L$.

Harding Lawson Associates
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and
Environmental Services

SHEET 2 OF 3
JOB NO. 44241/0254550
DATE DEC 1, 2000
COMPUTED BY SWG.
CHECKED BY WAM

PROJECT NTC ORLANDO OU4
SUBJECT REACTOR KINETICS

Assume $C_0 = C_{CSTR} = 1987\ \mu g/L$, $\tau = 1.67\ hr$, $k = 0.91/hr$, $C_{eff} = 3\ \mu g/L$.

then the number of tanks (PFRs) required to achieve $3\ \mu g/L$ is:

$$\frac{C_{eff}}{C_{CSTR}} = \left(e^{-k\tau}\right)^n$$

$$\frac{3}{1987} = \left(e^{-(0.91)(1.67)}\right)^n$$

$$\ln\left(\frac{3}{1987}\right) = -(0.91)(1.67)n$$

$n = 4.27 \sim 5$ PFRs required to achieve $3\ \mu g/L$
(6 tanks total, including CSTR).

This is too many tanks. Try a higher $KMnO_4$ dose of 1.5 g/L, thus $k = 1.365/hr$. (see "PCE $KMnO_4$ Oxidation Kinetics" figure)

Assume $C_0 = 5000\ \mu g/L$, $\tau = 1.67\ hr$, $k = 1.365/hr$

then for CSTR: $C_{CSTR} = C_0/(1 + k\tau)$

$$C_{CSTR} = 5000/[1 + (1.365)(1.67)] = 1527\ \mu g/L.$$

for PFRs: $$\frac{C_{eff}}{C_{CSTR}} = \left(e^{-k\tau}\right)^n$$

$$\frac{3}{1527} = \left(e^{-(1.365)(1.67)}\right)^n$$

$$\ln\left(\frac{3}{1527}\right) = -(1.365)(1.67)n$$

$n = 2.74 \sim 3$ PFRs required (4 total, incl CSTR)

This number is more reasonable. Note that C_0 will decrease with time and system flow will decrease as well, since deeper zone will be treated more quickly than the shallow zone (because hydraulic conductivity is 4X greater), thus $KMnO_4$ dose will be decreased accordingly.

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and
Environmental Services

JOB NO. 44241/0254550
DATE DEC 1, 2000
COMPUTED BY SWG.
CHECKED BY WAM

PROJECT NTC ORLANDO OU4
SUBJECT REACTOR KINETICS

Therefore, the PCE effluent concentration with 1 CSTR, 3 PFRs is:

$$\frac{C_{eff}}{C_{CSTR}} = (e^{-k\tau})^n$$

$$C_{eff} = C_{CSTR}(e^{-k\tau})^n$$

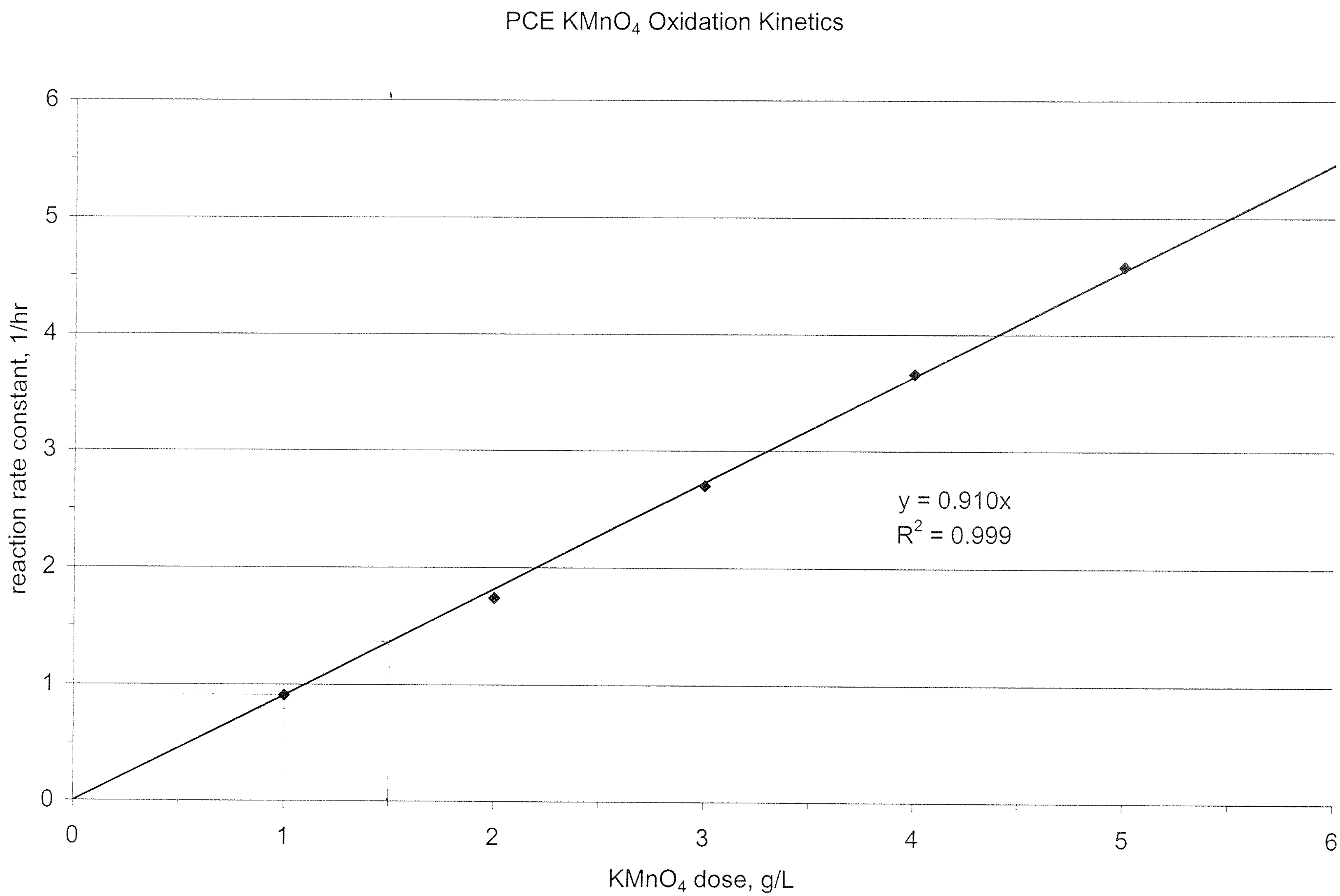
$$C_{eff} = (1527)(e^{-(1.365)(1.67)})^3$$

$$C_{eff} = 1.66 \text{ ug/L}$$

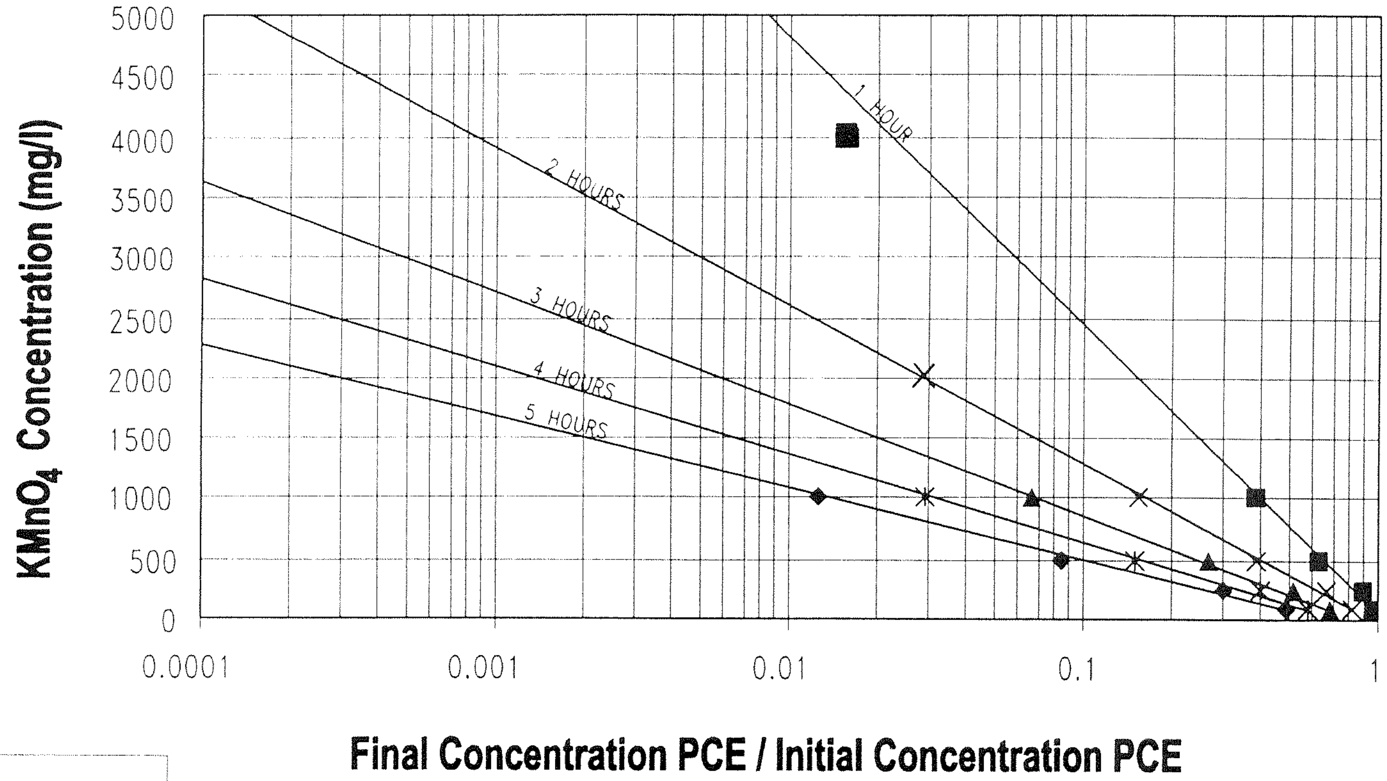
The objective of ≤ 3 ug/L of PCE in the effluent will be met with 1 CSTR, 3 PFRs at a $KMnO_4$ dose of 1.5 g/L.

X

WAM



PCE KMnO4 Oxidation Kinetics
reaction rate constant, 1/hr
KMnO4 dose, g/L
y = 0.910x
R2 = 0.999
0
1
2
3
4
5
6



LEGEND

◆	5 Hours
✳	4 Hours
▲	3 Hours
×	2 Hours
■	1 Hour
mg/l	Milligrams per liter
$KMnO_4$	Potassium permanganate
PCE	Tetrachloroethene

FIGURE 2-1
PCE OXIDATION RATES

K:\02545\02545-10\TRS\02545584.DWG VC-VC 09/03/99 14:39:09 ACAD14

SOUTHERN DIVISION NAVAL FACILITIES ENGINEERING COMMAND

TREATABILITY STUDY WORK PLAN NO. 3
DATA COLLECTION PLAN FOR ASSESSING
IN SITU CHEMICAL OXIDATION USING
POTASSIUM PERMANGANATE, OPERABLE UNIT 4
NAVAL TRAINING CENTER
ORLANDO, FLORIDA

Harding Lawson Associates
Engineering and Environmental Services

SHEET 1 OF 5
JOB NO. 44241/02545550
DATE December 8, 1999
COMPUTED BY [illegible]
CHECKED BY [illegible]

PROJECT NTC Orlando OU4
SUBJECT CSTR Reactions

Objective: Look at $KMnO_4$/PCE reaction rates and calculate CSTR performance.

Calculate Reaction Rate Constants

Literature indicates reaction is First Order:

$$-\ln \frac{C_A}{C_{A_0}} = kt$$

For 1000 mg/l $KMnO_4$ (Data from bench-scale tests)

$$T = 1\text{hr} ; -\ln \frac{C_A}{C_{A_0}} = -\ln\left(\frac{1.225}{3.170}\right) = 0.951$$

$$0.951 = k(1\text{hr})$$

$$k = 0.951\ \text{hr}^{-1}$$

T = 2hr (Data From App. B)

$$-\left(\ln \frac{0.486}{3.147}\right) = 1.868$$

$$1.868 = k(2\ \text{hr})$$

$$k = 0.934\ \text{hr}^{-1}$$

T = 3hr (Data From Fig 2-1)

$$-\ln(0.067) = 2.70$$

$$2.70 = 3k$$

$$k = 0.90\ \text{hr}^{-1}$$

T = 4hr (Data From Fig 2-1)

$$-\ln(0.029) = 4k$$

$$k = 0.89\ \text{hr}^{-1}$$

T = 5 (Data From App. B)

$$-\ln(0.0127) = 5k$$

$$k = 0.873\ \text{hr}^{-1}$$

Ave = 0.91

Harding Lawson Associates
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and
Environmental Services

SHEET 2 OF 5
JOB NO. 44241/0254550
DATE December 8, 1999
COMPUTED BY MJR
CHECKED BY WKM

PROJECT UTC Orlando OU4
SUBJECT CSTR Reactions

For 2000 mg/l (Pull data off Figure 2-1)

$T = 1\,hr$; $C_A/C_0 = 0.161$

$-\ln(0.161) = k$

$k = 1.83$

$T = 2\,hr$

$-\ln 0.029 = 2k$

$k = 1.77$

Ave = 1.74

$T = 5\,hr$

$-\ln(0.0003) = 5k$

$k = 1.62$

✓

For 3000 mg/l (Pull Data off Fig 2-1)

$T = 1\,hr$

$-\ln(0.058) = k$

$k = 2.85$

$T = 3\,hr$

Ave = 2.70

$-\ln(0.00048) = 3k$

$k = 2.55$

✓

For 4000 mg/l (Pull Data off Fig 2-1)

$T = 1\,hr$

$-\ln(0.0225) = k$

$k = 3.79$

$T = 2\,hr$

k = 3.66

$-\ln(0.00087) = 2k$

$k = 3.53$

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SHEET [illegible] OF [illegible]
JOB NO. 44241/0254550
DATE December 8, 1999
COMPUTED BY [illegible]
CHECKED BY [illegible]

PROJECT NTC Orlando OU4
SUBJECT CSTR Reactions

For 5000 mg/l (Pull Data Off Fig 2-1)

$T = 1$ hr

$-\ln(0.0085) = k$

$k = 4.77$

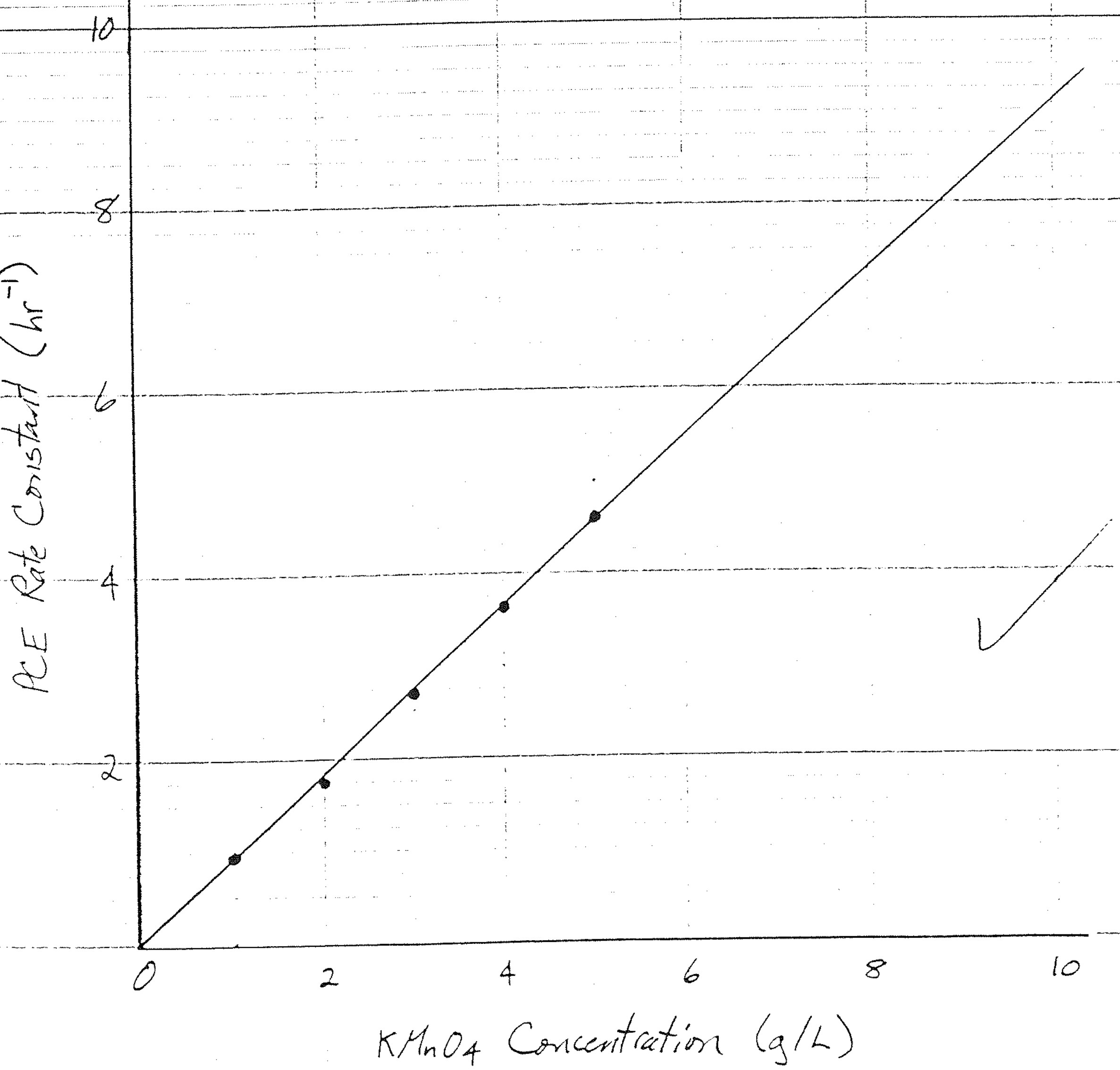
$T = 2$ hr

$-\ln(0.00015) = 2k$

$k = 4.39$

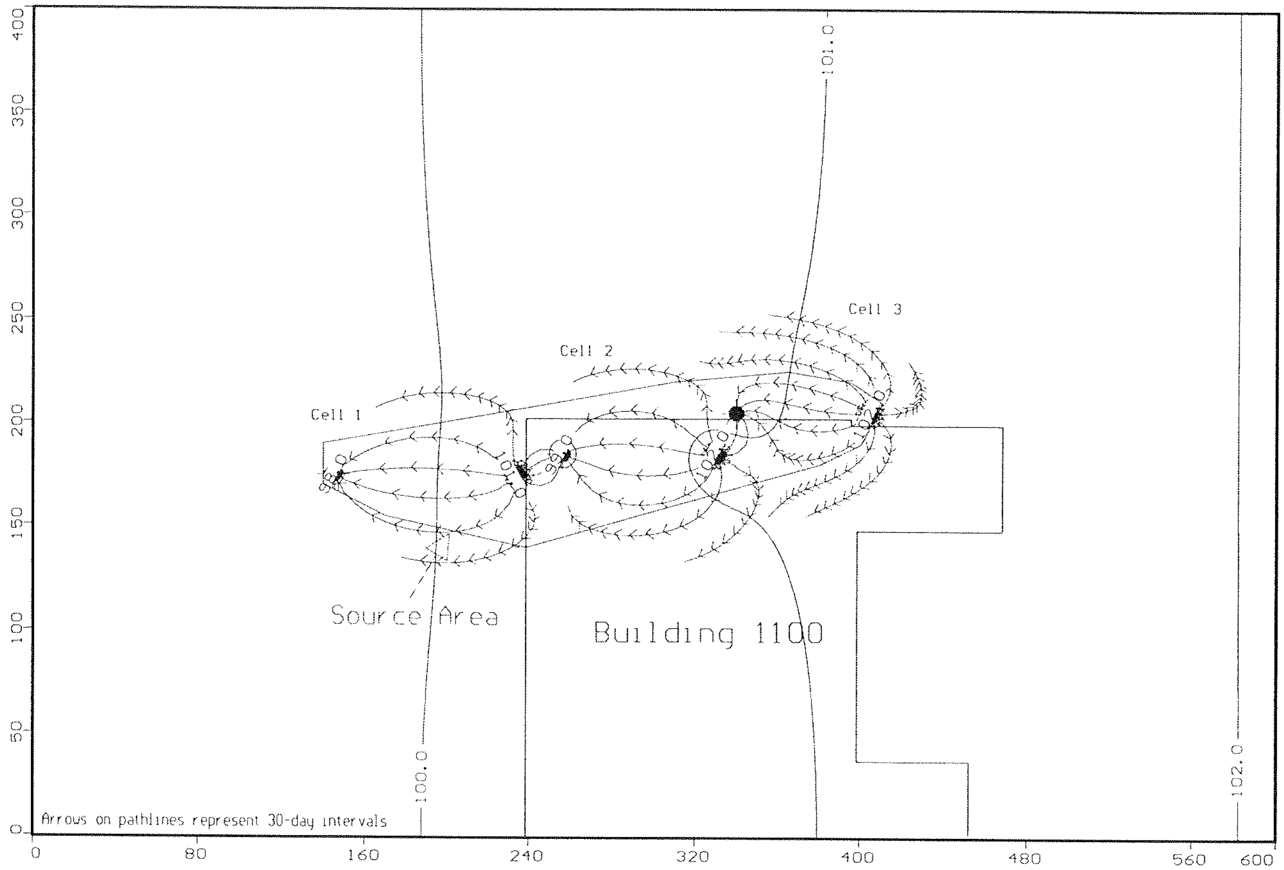
$\left.\begin{matrix} k = 4.77 \\ k = 4.39 \end{matrix}\right\}$ Ave = 4.58 ✓

PCE KMnO4 Rate Constant

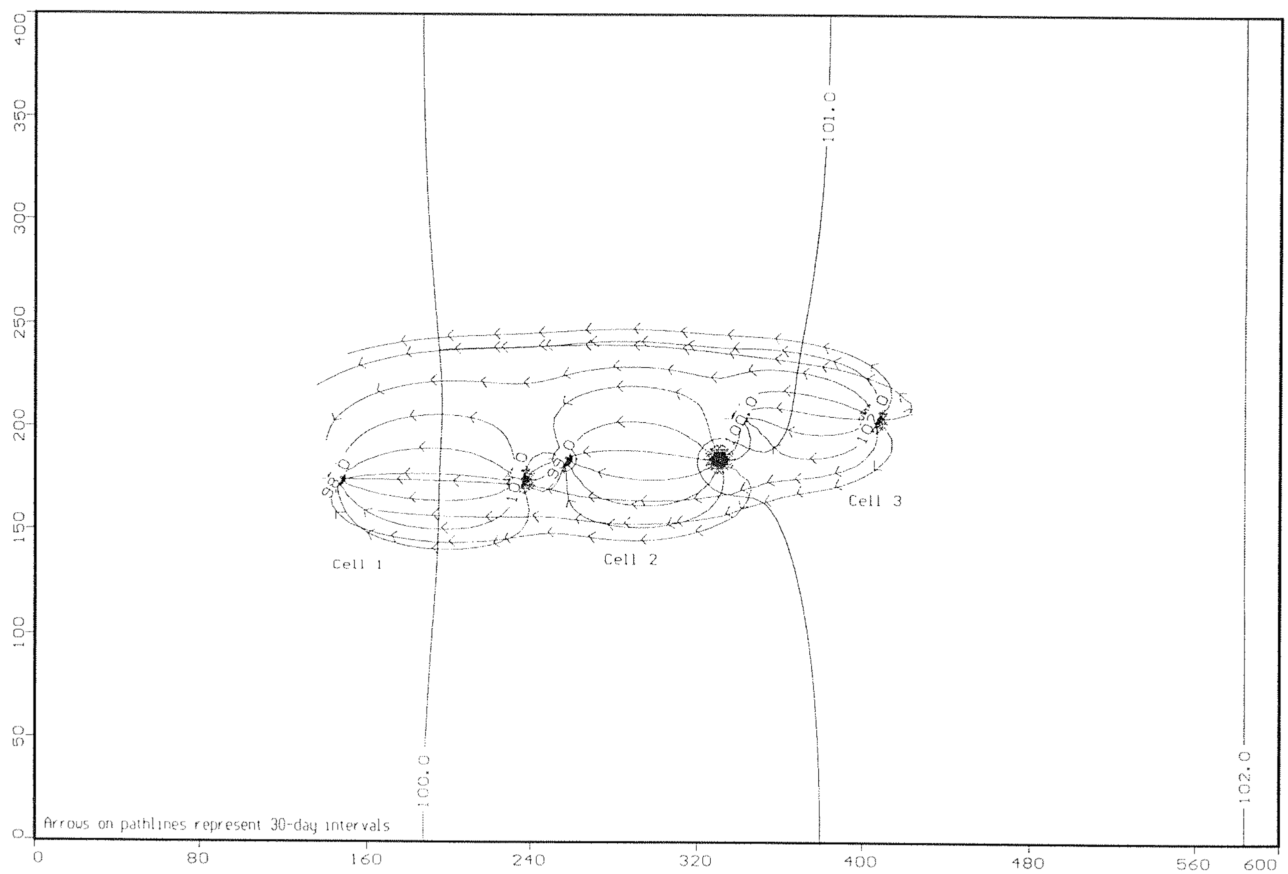


APPENDIX G

VISUAL MODFLOW AND WELLHEAD PROTECTION AREA MODEL CALCULATIONS (CHEMICAL OXIDATION ALTERNATIVE ONLY)

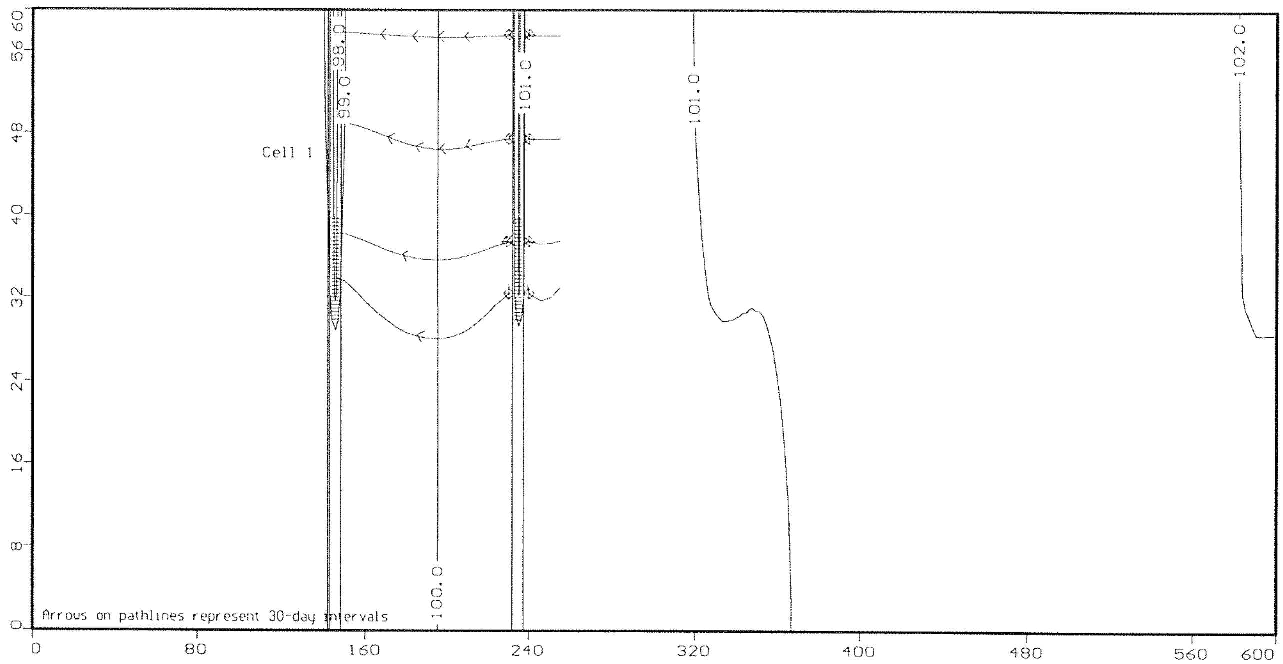


Harding ESE Project: NTC Orlando OU4 Description: KMnO4 Injection Pathlines Modeller: Steven Giese 1 Dec 00	Visual MODFLOW v.2.7.1, (C) 1995–1997 Waterloo Hydrogeologic, Inc. NC: 92 NR: 48 NL: 12 Current Layer: 1



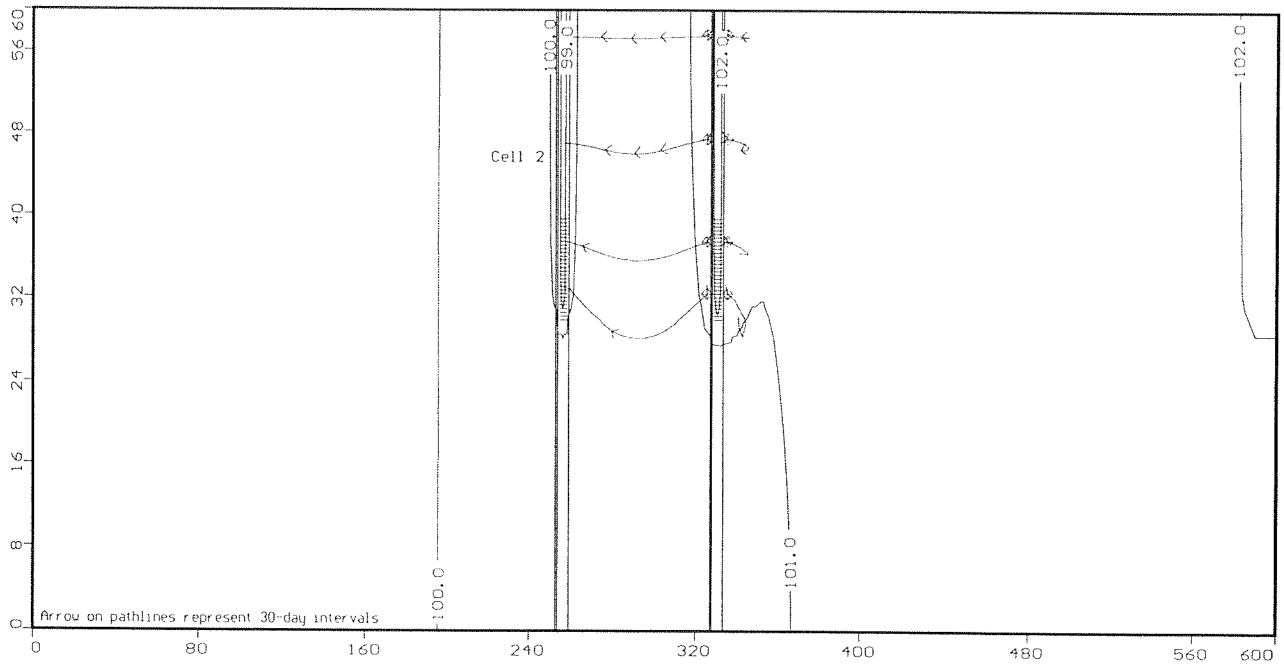
Harding ESE
Project: NTC Orlando OU4
Description: KMnO4 Injection Pathlines
Modeller: Steven Giese
15 Dec 00

Visual MODFLOW v.2.7.1, (C) 1995–1997
Waterloo Hydrogeologic, Inc.
NC: 92 NR: 48 NL: 12
Current Layer: 5



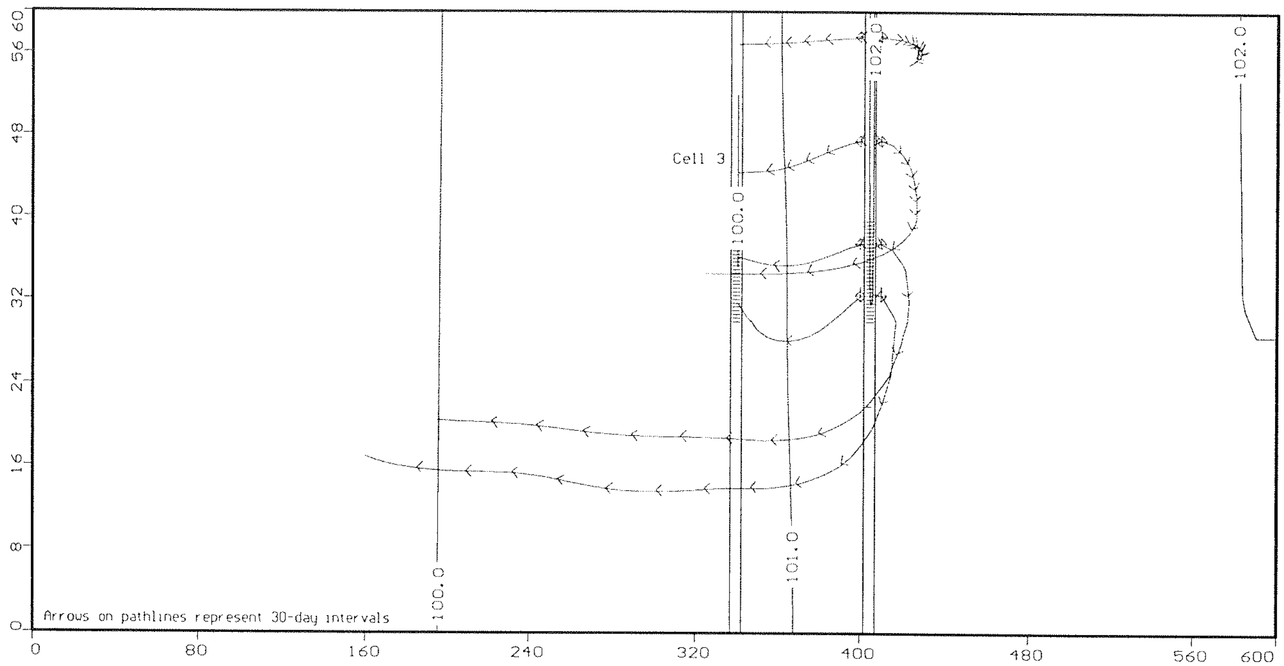
Harding ESE
Project: NTC Orlando OU4
Description: KMnO4 Injection Pathlines
Modeller: Steven Giese
1 Dec 00

Visual MODFLOW v.2.7.1, (C) 1995–1997
Waterloo Hydrogeologic, Inc.
NC: 92 NR: 48 NL: 12
Current Row: 28



Harding ESE
Project: NTC Orlando OU4
Description: KMnO4 Injection Pathlines
Modeller: Steven Giese
1 Dec 00

Visual MODFLOW v.2.7.1, (C) 1995–1997
Waterloo Hydrogeologic, Inc.
NC: 92 NR: 48 NL: 12
Current Row: 25



Harding ESE Project: NTC Orlando OU4 Description: KMnO4 Injection Pathlines Modeller: Steven Giese 1 Dec 00	Visual MODFLOW v.2.7.1, (C) 1995–1997 Waterloo Hydrogeologic, Inc. NC: 92 NR: 48 NL: 12 Current Row: 20

APPENDIX J

DETAILED FUTURE WORTH COST BREAKDOWNS (CHEMICAL OXIDATION ALTERNATIVE ONLY)

TABLE J-3

ALTERNATIVE V-3: FUTURE WORTH IN-SITU CHEMICAL OXIDATION AND ENHANCED BIODEGRADATION TO TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
DIRECT COSTS				
Groundwater Use Restrictions	1	LS	$10,000.00	**$10,000**
Site Preparation and Mobilization [Northern Plume]				
Storage Trailer	0	month	$150.00	$0
Office Trailer	12	month	$250.00	$3,000
Trailer Delivery, Setup, Removal	2	each	$1,000.00	$2,000
Treatment System Concrete Pad (30' x 30')	0	LS	$4,000.00	$0
Fencing:				
Treatment Area for equip/controls (30' x 30')	120	ft	$2.84	$341
Trailer Area (40' x 80')	240	ft	$2.84	$682
Gates	2	each	$95.00	$190
Office Equipment Rental	0	month	$2,000.00	$0
Utility Connections for trailer, sys equip, controls	1	LS	$4,000.00	$4,000
Toilet/water cooler service	52	wks	$50.00	$2,600
Miscellaneous Equipment	1	LS	$1,000.00	$1,000
Decon Equipment and Pad:				
Pressure Washer with Water Tank	0	month	$500.00	$0
Plastic Sheeting, Drums, Pumps, Hoses, Supplies	0	LS	$3,000.00	$0
Labor (Site Preparation)				
Laborers (2 men @ 5 days @ 10 hrs/day)	2	days	$320.00	$640
Foreman/Superintendent (1 man @ 10 hrs/day)	1	days	$600.00	$600
Subtotal Site Preparation/Mobilization [Northern Plume]				**$15,052**
In-Situ Chemical Oxidation System [Northern Plume]				
(3 extraction well pairs pumping @ 6, 6, and 3 gpm each; 3 injection well pairs at same flows)				
Groundwater Extraction Wells				
Sonic Mob/Demob (drillers and equip)	1	each	$2,000.00	$2,000
DPT Mob/Demob (drillers and equip)	1	each	$150.00	$150
Vert. Well Sonic Install. (8 wells @ 4" ID, PVC, 20'/35' bls)	220	ft	$65.00	$14,300
Angled Well Sonic Install. (4 wells @ 4" ID, PVC, 42'/50' lf)	184	lf	$100.00	$18,400
Vert. Well Sonic Install. (1 well @ 2" ID, PVC, 35' bls)	35	ft	$55.00	$1,925
Angled Well Sonic Install. (3 wells @ 2" ID, PVC, 40' lf)	120	lf	$90.00	$10,800
MicroWell DPT Installation (15 wells, 20' bls)	4	days	$400.00	$1,600
Extraction Well Vault	6	each	$2,500.00	$15,000
Extraction Pumps	6	pumps	$1,000.00	$6,000
Per Diem/Lodging (3 men @ 5 days)	15	days	$100.00	$1,500
Decontamination	10	hrs	$100.00	$1,000
Misc. Equipment and Supplies	1	LS	$2,000.00	$2,000
Electric Power Supply and Water Supply for H&S				
Utility Pole	0	poles	$550.00	$0
Power Cable	25	ft	$10.00	$250
Telephone line for Telemetry	100	ft	$10.00	$1,000
Water Service Connection	0	each	$1,000.00	$0
Gauge, curb box, appurtenances	0	each	$1,000.00	$0

TABLE J-3

ALTERNATIVE V-3: FUTURE WORTH IN-SITU CHEMICAL OXIDATION AND ENHANCED BIODEGRADATION TO TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
Piping and Equipment				
RWs to treatment system (2" ID, PVC)	400	ft	$20.00	$8,000
Equalization Tank Rental (Incl. Mob/demob; 12 months)	12	mo	$300.00	$3,600
Treatment System Rental (includes the following):	12	mo	$10,000.00	$120,000
KMnO4 Mix Tank Rental (Incl. Mob/demob; 4 tanks)	0	mo	$500.00	$0
Centrifugal Feed Pumps (25 GPM each)	0	each	$5,000.00	$0
KMnO4 Feed System (12 mo. rental + $4K mob/demob)	0	mo	$1,800.00	$0
Rotary Drum Filter	0	each	$3,000.00	$0
Flow Meters	0	each	$300.00	$0
Valves, piping, controls, gauges, etc.	0	LS	$5,000.00	$0
Instrumentation Controls	0	LS	$20,000	$0
Labor				
1 Carus Technician	5	days	$1,200.00	$6,000
3 men @ 3 weeks @ 50 hrs/week	450	hr	$32.00	$14,400
1 Engineer/Foreman @ 3 weeks @ 50 hrs/week	150	hr	$75.00	$11,250
Subtotal Chemical Oxidation System [Northern Plume]				**$239,175**
TOTAL DIRECT COSTS [Northern Plume]				**$264,227**
INDIRECT COSTS [Northern Plume]				
Health and Safety				$1,000
Administrative Fees				$7,500
Engineering and Design				$20,000
Construction Support Services				$20,000
TOTAL INDIRECT COSTS [Northern Plume]				**$48,500**
TOTAL CAPITAL COSTS [Northern Plume]				**$312,727**
ENHANCED BIODEGRADATION				
Site Prep and Mobilization [Southern Plume]				
Decon Equipment and Pad:				
Pressure Washer with Water Tank	0	month	$500.00	$0
Plastic Sheeting, Drums, Pumps, Hoses, Supplies	0	LS	$3,000.00	$0
Subtotal Site Prep/Mobilization [Southern Plume]				$0
HRC Injection System (Initial Injection) [Southern Plume]				
HRC Injection Points				
Mob/Demob (drillers and equip)	1	each	$1,500.00	$1,500
Advance boreholes (59 borings @1.5" & 2" ID, 45' bls)	2655	ft	$10.00	$26,550
HRC	5900	lb	$5.75	$33,925
HRC Injection Equipment (tank/pumps)	2	wks	$1,000.00	$2,000
Per Diem/Lodging (3 men @ 10 days)	30	days	$100.00	$3,000
Decontamination	10	hrs	$100.00	$1,000
Misc. Equipment and Supplies	1	LS	$2,000.00	$2,000

TABLE J-3

ALTERNATIVE V-3: FUTURE WORTH IN-SITU CHEMICAL OXIDATION AND ENHANCED BIODEGRADATION TO TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
HRC Monitoring Network				
Mob/Demob [included in Injection System]	0	each	$1,500.00	$0
Well Installation (11 wells @2" ID, PVC, 45' bls)	495	ft	$20.00	$9,900
Per Diem/Lodging (3 men @ 5 days)	15	days	$100.00	$1,500
Decontamination	10	hrs	$100.00	$1,000
Misc. Equipment and Supplies	1	LS	$2,000.00	$2,000
TOTAL DIRECT COSTS [Southern Plume]				**$84,375**
INDIRECT COSTS [Southern Plume]				
Health and Safety				$10,000
Administrative Fees				$15,000
Pilot Test of HRC				$25,000
Engineering and Design				$20,000
Construction Support Services				$30,000
TOTAL INDIRECT COSTS [Southern Plume]				**$100,000**
TOTAL CAPITAL COSTS [Southern Plume]				**$184,375**
OPERATION & MAINTENANCE COSTS				
In-Situ Chemical Oxidation System O&M (12 months operation)				
Chemicals				
KMnO4 Cost (Dosage @ 1 g/l)	51,970	lb	$1.19	$61,844
KMnO4 Freight Cost	3	deliveries	$4,500.00	$13,500
Utilities				
Groundwater Extraction Pumps	12	month	$300.00	$3,600
Treatment System	12	month	$400.00	$4,800
System Maintenance				
Labor (1 operator @ 4 hrs/day, 7 days/wk, 52 weeks)	365	days	$180.00	$65,700
KMnO4 Feed System	12	month	$500.00	$6,000
Subtotal Chemical Oxidation System O&M				**$155,444**
Sampling and Monitoring				
(Includes 2 QA/QC Samples for each sampling event)				
Treatment System Influent Grab Samples (1 per month):				
TCL VOCs	14	samples	$150.00	$2,100
Treatment System Effluent Grab Samples (1 per month):				
TCL VOCs and TAL Inorganics	14	samples	$300.00	$4,200
Monitoring Well Samples (1 every two months, 21 wells)				
TCL VOCs	138	samples	$150.00	$20,700
Subtotal GW Sampling and Monitoring				**$27,000**
Future Worth Chemical Oxidation O&M Cost (12 mo.)				**$182,444**

TABLE J-3

ALTERNATIVE V-3: FUTURE WORTH IN-SITU CHEMICAL OXIDATION AND ENHANCED BIODEGRADATION TO TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
HRC O&M (Injection in Source Area Only for Year 2 and 3)				
Mob/Demob (drillers and equip)	1	each	$1,500.00	$1,500
Advance boreholes (17 borings @1.5" & 2" ID, 45' bls)	765	ft	$10.00	$7,650
HRC	680	lb	$7.00	$4,760
HRC Injection Equipment (tank/pumps)	1	wks	$1,000.00	$1,000
Per Diem/Lodging (3 men @ 4 days)	12	days	$100.00	$1,200
Decontamination	10	hrs	$100.00	$1,000
Misc. Equipment and Supplies	1	LS	$2,000.00	$2,000
Subtotal Annual HRC Treatment O&M (yrs 2 and 3)				**$19,110**
Future Worth HRC O&M @ i = 3%, n = 2-3 yrs				**$39,959**
HRC Monitoring O&M (annual for 3 years)				
16 Wells + 2QA/QC = 18 Samples				
Associate Scientist	50	hrs	$60.00	$3,000
Technician	60	hrs	$45.00	$2,700
ODCs (PPE, sampling equip, expendibles)	1	lump sum	$1,000.00	$1,000
Analysis-HRC Parameters	18	samples	$200.00	$3,600
Analysis-TCL Organics (VOCs only)	18	samples	$150.00	$2,700
Summary Data Report:				
Mid-level Engineer	20	hrs	$75.00	$1,500
Senior Scientist	10	hrs	$90.00	$900
Staff Engineer	20	hrs	$60.00	$1,200
ODCs	1	lump sum	$950.00	$950
Subtotal HRC Annual Monitoring Costs (yrs 1-3)				**$17,550**
Future Worth HRC Monitoring @ i = 3%, n = 3 yrs				**$54,247**
IRA System (annual for 10 years)				
Engineer (8 hr/mo data analysis, reporting)	96	hr	$85.00	$8,160
Technician (12 hr/mo O&M site visits, reporting)	144	hr	$60.00	$8,640
Air Samples - Lab (1 sample/quarter, TO12)	4	each	$120.00	$480
Influent/Effluent Samples - Lab (3 samples/mo, 8012)	36	each	$150.00	$5,400
Electrical (5 hp and (2) 1 hp pumps, 10 hp blower)	111,690	kw-hr	$0.08	$8,935
POTW Discharge Fee (operational flow rate of 10 gpm)	5,256	1,000 gals	$1.90	$9,986
Misc Supplies	1	LS	$1,000.00	$1,000
Subtotal IRA System O&M				**$42,602**
Future Worth IRA System O&M @ i = 3%, n = 10 yrs				**$488,385**
GW Monitoring within Downgradient Plume (annual costs - 10 yrs)				
GW Sampling & Monitoring Program within IRA Capture Area (years 1-10)				
6 Wells + 1 QA/QC = 7 Samples				
Associate Scientist	30	hours	$60.00	$1,800
Technician	40	hours	$45.00	$1,800

TABLE J-3

ALTERNATIVE V-3: FUTURE WORTH IN-SITU CHEMICAL OXIDATION AND ENHANCED BIODEGRADATION TO TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
ODCs (PPE, sampling equip, expendibles)	1	LS	$1,000.00	$1,000
Analyses - TCL Organics (VOCs only)	7	samples	$150.00	$1,050
Summary Data Report:				
Mid-Level Engineer	20	hours	$75.00	$1,500
Senior Scientist	10	hours	$90.00	$900
Staff Engineer	20	hours	$60.00	$1,200
ODCs	1	LS	$950.00	$950
Subtotal Annual IRA Capture Area GW Monitoring				**$10,200**
Future Worth IRA GW Monitoring @ i = 3%, n = 10 yrs				**$116,933**
Monitored Natural Attenuation O&M (annual costs - 30 yrs)				
GW Sampling & Monitoring Program for Natural Attenuation within the entire VOC plume (yrs 11-40)				
18 Wells + 2QA/QC = 20 Samples				
Associate Scientist	50	hrs	$60.00	$3,000
Technician	60	hrs	$45.00	$2,700
ODCs (PPE, sampling equip, expendibles)	1	lump sum	$1,000.00	$1,000
Analysis-Natural Attenuation Parameters	20	samples	$200.00	$4,000
Analysis-TCL Organics (VOCs only)	20	samples	$150.00	$3,000
Summary Data Report:				
Mid-level Engineer	20	hrs	$75.00	$1,500
Senior Scientist	10	hrs	$90.00	$900
Staff Engineer	20	hrs	$60.00	$1,200
ODCs	1	lump sum	$950.00	$950
Subtotal Annual MNA Costs				**$18,250**
Future Worth MNA O&M @ i = 3%, n = 11 to 40 yrs				**$1,166,850**
Five-year Site Reviews (every 5 years for 40 years)				
Meetings (attendance only)				
Senior Scientist	8	hrs	$90.00	$720
Mid-level Engineer	8	hrs	$75.00	$600
ODCs	1	lump sum	$100.00	$100
Evaluate Data/Current Situation				
Senior Scientist	20	hrs	$90.00	$1,800
Mid-level Engineer	40	hrs	$75.00	$3,000
ODCs (includes photocopying, etc.)	1	lump sum	$500.00	$500
Five-year Report				
Senior Scientist	40	hrs	$90.00	$3,600
Mid-level Engineer	60	hrs	$75.00	$4,500
Staff Engineer	40	hrs	$60.00	$2,400
ODCs (includes photocopying, etc.)	1	lump sum	$1,000.00	$1,000
Subtotal Five Year Site Review Costs				**$18,220**
Future Worth 5-Yr Site Reviews @ i = 3%, n = 5,10,..40 yrs				**$299,981**

TABLE J-3

ALTERNATIVE V-3: FUTURE WORTH IN-SITU CHEMICAL OXIDATION AND ENHANCED BIODEGRADATION TO TREAT GW TO DRINKING WATER STANDARDS

	Quantity	Unit	Unit Cost	Total Cost
TOTAL FUTURE WORTH O&M COSTS				$2,348,800
TOTAL CAPITAL COSTS AND PRESENT WORTH O&M COSTS				$2,845,902
CONTINGENCY @10 PERCENT				$284,590
TOTAL FUTURE WORTH COST OF ALTERNATIVE V-3				$3,130,492

*The total amount of $KMnO_4$ required is 65,650 lbs. There are already 42 drums of $KMnO_4$ (330 lbs ea.) at the site left over from the pilot test. Thus, the amount of $KMnO_4$ required to make up this difference is costed here.