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ADDENDUM NO. 3
TO THE
PRELIMINARY DESIGN REPORT
FOR THE
GROUNDWATER REMEDIAL ACTION
REVISION 0
ISSUED MAY 8, 2001

CRAB ORCHARD NATIONAL WILDLIFE REFUGE
PCB OPERABLE UNIT - SITES 32/33
MARION, ILLINOIS

September 2001

for

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Section 1
Background

The Preliminary Design Report for the Groundwater Remedial Action – Revision 0 for Sites 32/33 at the PCB Operable Unit (the PD Report) was issued on 8 May 2001. Preliminary review comments on the PD Report were provided by the U.S. Fish and Wildlife Service (F&WS) on 23 May 2001. A conference call was held on 24 May 2001 to discuss the preliminary review comments from the F&WS. As agreed during the conference call, Addendum No. 1 to the PD Report was prepared and issued on 26 June 2001. Addendum No. 1 included estimates of the total volatile organic compound (VOC) mass present in each of the primary VOC source areas, and the VOC mass removal that is estimated to be achievable at each VOC source area using the multi-phase extraction (MPE) and soil vapor extraction (SVE) systems as configured in the PD Report.

Addendum No. 1 was discussed during Technical Working Group (TWG) meeting #6 held at the Refuge headquarters on 11/12 July 2001. At the meeting, modifications of the source area treatment systems were proposed by RMT and Schlumberger. The purpose of the modifications is to address the expected difficulties in recovering significant quantities of VOCs from the clay soil in the source areas, due to the relatively low permeability and high moisture retention capacity of the clay. During TWG meeting #6, it was agreed that updated estimates of the effect over time of the proposed treatment system modifications on the VOC plumes downgradient of the source areas following implementation of the proposed modifications would be prepared, using the groundwater contaminant transport model developed for the Focused Feasibility Study (FS) Report. These updated estimates were requested to assist in evaluating the overall effectiveness of the proposed modifications in mitigating groundwater contamination associated with Sites 32/33 by removal of VOCs from the source areas, as defined in the Explanation of Significant Differences (ESD) issued by the United States Environmental Protection Agency (USEPA) in June 2000.

Addendum No. 2 to the PD Report was issued on 28 August 2001. This addendum provided updated estimates of the effectiveness of the proposed and alternative remedial action approaches, as discussed during TWG meeting #6. A conference call was held on 5 September to discuss preliminary review comments on Addendum No. 2. Additional information requested during the conference call to assist in evaluation and final selection of the remediation approach for each VOC source area included the following:

- Simulations of expected groundwater quality improvements over time for the following additional remediation approaches at the Building I-1-23 source area, using the groundwater contaminant transport model:
    - Use of MPE, SVE, and horizontal groundwater extraction wells for the Upper Sand unit, all operated for 2 years then shut down, followed by use of a groundwater pump-and-treat system for the Upper Sand
    - Use of MPE with pneumatic fracturing for the Upper Clay unit, and use of MPE, SVE, and horizontal groundwater extraction wells for the Upper Sand unit, all operated for 2 years then shut down
    - Reliance on only monitored natural attenuation, with the objective of using the model to estimate the time required to attain the groundwater Cleanup Standards (drinking water standards Maximum Contaminant Levels - MCLs) at all locations
- A listing of the key advantages and disadvantages for use of a permeable reactive barrier (PRB) or hydraulic control (groundwater pump-and-treat system) for the VOC source area at Building I-1-23
- Estimates of the capital and present worth costs for use of a PRB or a groundwater pump-and-treat system at the Building I-1-23 source area

Addendum No. 2 was also discussed during TWG meeting #7 held at the Refuge on 12 September 2001. At that meeting, the following additional information was also requested:

- A comparison of the use of a PRB or a groundwater pump-and-treat system for the Building I-1-23 source area with the standard Superfund Selection-of-Remedy criteria
- Estimated volume of soil, VOC mass removal, and costs associated with potential excavation and off-site disposal of VOC-contaminated soil at the Building I-1-23 source area

This Addendum No. 3 to the PD Report provides the additional information requested during the conference call on 5 September and at TWG meeting #7. Clarification of certain information presented in Addendum No. 2 is also included.

Section 2
Building I-1-23 Area

2.1 Additional Model Simulations

2.1.1 MPE with Groundwater Pump-and-Treat for Upper Sand

The groundwater contaminant transport model was used to prepare simulations of the improvement in groundwater quality over time that would result from the following remediation approach for the Building I-1-23 source area:

- MPE wells, SVE wells, and horizontal groundwater extraction wells for the Upper Sand unit, operated for 2 years then shut down
- One vertical extraction well pumping from the Upper Sand unit in the source area at 10 gpm during years 3 through 10 after startup of the remediation system, then shut down at the end of year 10
- Use of monitored natural attenuation (MNA) after year 10

These simulations are identified as Case 8 for the I-1-23 source area, as shown in Table 1. Figures showing the model simulations for the approach described above are included in Attachment 1 (I-1-23 area, Case 8). The simulations show the comparative level of improvement in groundwater quality that is likely to be seen over the evaluation time periods of 5, 10, 20, 30, and 40 years after the start of remediation, resulting from the simulated remediation systems.

2.1.2 MPE for Upper Sand and Upper Clay

The groundwater contaminant transport model was used to prepare simulations of the improvement in groundwater quality over time that would result from the following additional remediation approach for the Building I-1-23 source area:

- MPE wells with pneumatic fracturing for the Upper Clay unit
- MPE wells, SVE wells, and horizontal groundwater extraction wells for the Upper Sand unit
- Operation of the well systems for 2 years, then shut down
- Use of MNA after the 2-year source area treatment phase

These simulations are identified as Case 9 for the I-1-23 source area, as shown in Table 1. Figures showing the model simulations for the approach described above are included

in Attachment 1 (I-1-23 area, Case 9). The simulations show the comparative level of improvement in groundwater quality that is likely to be seen over the evaluation time periods of 5, 10, and 20 years after the start of remediation, resulting from the simulated remediation systems. The estimated total VOC mass in the source area and the estimated VOC removal that is achievable using the remediation approach described above are summarized in Table 2 of this addendum.

2.1.3 Conclusions from Additional Model Simulations

The model run for Case 8 for the Building I-1-23 source area shows results that are consistent with, and could be estimated from, the results from Case 1 and Case 6. Case 8 shows that, as long as hydraulic control of the VOC source by use of groundwater extraction from the Upper Sand unit is occurring, the source will be contained and natural attenuation processes will relatively rapidly produce significant improvement in groundwater quality between Building I-1-23 and the lake. However, when groundwater extraction from the Upper Sand ceases, the VOC plume will return at significant concentrations in only a few years. This is due to the large percentage of VOC source material that would remain following 2-year operation of the source area remediation system as described under Case 8. Operation of a groundwater pump-and-treat system for 8 years following the initial 2-year source area treatment phase would provide no groundwater improvement advantage compared with use of only hydraulic control from the outset. An additional finding from the Case 8 model simulations is that pumping at only 10 gpm from the Upper Sand should provide very effective hydraulic control of the source area VOCs without causing undesirable hydraulic influence on the source areas at the Repository and at Buildings I-1-2/I-1-3, as seen in Case 6 where a pumping rate of 20 gpm is simulated.

The model run for Case 9 for the Building I-1-23 source area shows results that are consistent with, and could be anticipated from, the results from Case 1, Case 3, and Case 4. As shown in Table 2, the estimated total VOC mass removal efficiency for Case 9 (treatment of Upper Sand and Upper Clay) is 43% removal of the mass in the overall source area. As expected, the model results from the Case 9 simulations show groundwater improvements that are better than the Case 1 results (22% mass removal), but worse than the Case 3 results (70% mass removal) and the Case 4 results (90% mass removal). The Case 9 results also clearly show that use of MPE to treat the entire Upper Clay portion of the source area, combined with MPE/SVE/horizontal wells for treatment of the Upper Sand, will result in only limited long-term improvement in groundwater quality, and that the VOC plume will continue to regenerate over time due to the remaining source material that cannot be removed with this technology.

2.2 Time to Attain Cleanup Standards Using MNA Only

F&WS requested that the contaminant transport model be used to estimate the time that would be needed for the groundwater quality to meet the Cleanup Standards (MCLs) at all locations within and downgradient of the Building I-1-23 source area using monitored natural attenuation (MNA) only. This estimate would be used as a basis for comparison with the projected rates of groundwater quality improvement for the various remediation approaches that are being considered for the I-1-23 source area.

To use the contaminant transport model for the requested simulation, it is necessary to estimate the rate of degradation or decay of the VOC source material due to the action of only natural attenuation processes. With an estimate of this degradation rate, the model could be used to prepare simulations of the improvement in the groundwater quality downgradient of the source area over time. However, it is very difficult to make an accurate estimation of the source material degradation rate. There are many site-specific variables that influence the natural degradation of chlorinated VOCs (CVOCs). There is also a lack of general technical data and information that could be used to make an accurate estimate of this type. The technical literature does, however, contain many references indicating that CVOC source materials are very persistent in clay soil (e.g., DNAPLs in the subsurface, by Pankow and Cherry, 1996). Direct evidence of this finding is also available from the soil and groundwater chemistry data developed for Sites 32/33, which show that CVOCs released onto the ground surface at the identified source areas several decades ago are still present at elevated concentrations in the soil. It is likely that natural attenuation processes alone would require many more decades before groundwater quality at all site locations would approach the specified Cleanup Standards (MCLs). The accuracy of any model runs that would be performed to attempt to simulate groundwater improvements from MNA alone would only be as good as the accuracy of the estimate of the degradation rate of the CVOC source material. Due to the inability to make such an estimate that would fall within any reasonable confidence range around the true degradation rate, use of the model to simulate the time required to achieve MCLs with reliance on only natural attenuation processes was considered to be inappropriate and inadvisable.

However, it has been demonstrated with previous modeling runs (e.g., comparing results from Case 1, Case 3, and Case 4 for I-1-23) that the groundwater plume will adjust fairly quickly to changes in the source concentrations, but will not decrease until the source concentrations decrease. Therefore, we can conclude that the I-1-23 plume will not achieve MCLs until the source has degraded sufficiently, over the course of many decades.

Section 3
Technical Assessment of PRB and Pump-and-Treat Technologies

A listing of the key advantages and disadvantages for use of a permeable reactive barrier (PRB) or hydraulic control (groundwater pump-and-treat system) for the VOC source area at Building I-1-23 is shown in Tables 3 and 4, respectively. The comments listed in these tables pertain to the use of PRB and pump-and-treat technologies in general, not necessarily to the use of these technologies specifically for Sites 32/33 of the PCBOU.

Questions regarding the expected performance of a PRB for the Buildings I-1-2/I-1-3 source area or for the Building I-1-23 source area have been raised by reviewers of Addendum No. 2. A list of these questions and a brief response are presented below.

- ***How many years have full-scale PRBs been in use for treating CVOCs at other sites ?***

  Response: The first commercial full-scale PRB was installed in San Francisco in December 1994. Since then, 43 full-scale *in situ* systems have been installed to remove VOCs from groundwater, in addition to 21 *in situ* pilot systems. Initially, these pilots systems were intended to provide "proof of concept" data, and more recently, to demonstrate innovative construction methods.

- ***Will the zero-valent iron in the PRB eventually be completely consumed (oxidized), resulting in no treatment of the VOCs ?***

  Response: There are many processes such as water corrosion, VOC degradation, dissolved oxygen reduction, and sulfate reduction that may consume the iron. These processes are not independent of one another and also depend on site conditions such as groundwater flow velocity, inorganic aqueous concentrations, VOC concentrations, biological activity, and temperature. All of these factors make it difficult to gauge with certainty the time required to consume the iron in a PRB.

  If water corrosion were to remain constant over time at a typical rate of 0.1 to 1.0 mmol/kg Fe/day, the iron is predicted to last between 49 and 490 years. However, Reardon (1995) noted declining hydrogen production over time at room temperature. This decline in corrosion rate was likely due to mineral precipitate formation on the surface of the iron over long periods of time. Sorel et al. (2000; 2001) found that the groundwater pH at the first commercial PRB in Sunnyvale, California, continues to increase from a value of 7.5 in the upgradient aquifer to a value of about 11 in the PRB, and that dissolved hydrogen concentrations approach solubility limits. Clearly, water corrosion is still occurring at significant rates at this site after 6 years.

Groundwater data for Sites 32/33 show dissolved oxygen (DO) concentrations ranging from 0.1 to 5.2 mg/L with an average of 1.6 mg/L. Based on a PRB cross-sectional area at the Building I-1-23 location of 7,000 ft^2 (350 ft x 20 ft), a groundwater flow velocity of about 90 ft/yr, and an aquifer porosity of 0.3, the annual amount of DO entering the PRB would be 8,563 g/yr (267.6 mole/yr). DO is reduced by the following reaction:

$$4Fe^{\circ} + 3O_{2(aq)} + 12H^{+} \rightarrow 4Fe^{3+} + 6H_2O$$

Since four moles of iron are consumed for every three moles of DO, the annual iron consumption rate would be 19,925 g/yr (356.8 mol/yr). By comparison, if the PRB contains 630 tons of iron, the annual water corrosion rate would be 1,165,806 to 11,658,062 g/yr. Therefore, adding in the amount of iron consumed by DO, the iron lifetimes estimated above would be reduced to between 48 and 482 years.

Furthermore, given that volatile organic concentrations entering the PRB will be a maximum of about 52,000 µg/L (0.3969 mmol/L) of trichloroethene and 10,000 µg/L (0.1042 mmol/L) of cis-1,2-dichloroethene, the iron consumed by reductive dechlorination is 1.4 mmol/L. Therefore, the annual iron reductive dehalogenation consumption rate for the PRB would be 418,194 g/yr. Adding this consumption rate to the above rates yields an iron lifetime between 47 to 356 years.

Sulfate concentrations at the site range from 14 to 2,260 mg/L, with an average of 404 mg/L. Given the assumed PRB dimensions and annual groundwater flow velocity, the flux of sulfate into the PRB would be 76,356 g/yr (795 mol/yr). If all the sulfate is reduced, an additional 177,563 g/yr (3,179 mol/yr) of iron would be consumed. The effect of sulfate reduction would not alter the expected iron lifetime of 47 to 361 yr.

Other factors such as desaturation of the iron and oxidation by atmospheric oxygen would also affect the lifetime of the iron. Although there is some uncertainty in the conditions that may exist decades in the future, it seems reasonable to expect the iron in the PRB will last for many decades.

- ***What is the likelihood that the PRB would become plugged with inorganic scale or bio-fouling, which would cause the groundwater to flow around the PRB ? How many years of operation are expected before plugging of the PRB may occur ?***

Response: Gillham et al. (2001) documented the migration of mineral precipitates through a bench-scale column of iron in a long-term test. Gillham et al.'s research verified what various research groups had visually observed. The conclusion is that it would take even longer for complete porosity loss to occur than the rate at which the precipitation front moves through the PRB. In fact, in long-term column tests by Gillham et al., Eykholt (1999), and Sass (2001), complete porosity loss did not occur, even in cases where the precipitate had migrated through the entire column (i.e., effluent aqueous inorganic concentrations equaled influent concentrations). For example, Gillham et al. determined a maximum porosity loss due to carbonate formation of about 20% of the original porosity. In addition, these researchers found that the hydraulic conductivity of their systems only declined by a factor of two or three.

Gillham et al. (2001) reported that the reactivity of the iron was low behind the zone of carbonate precipitate migration. Vikesland et al. (2000) also showed that various inorganic precipitates can reduce iron reactivity.

Given an average groundwater alkalinity at this site of about 365 mg/L, 690 mg/L of calcium carbonate may form. Based on a PRB containing an iron-sand mixture with a porosity of 0.3, a flowrate of 90 ft/yr, and a porosity loss of 20% before precipitate migration begins, the carbonate precipitate may migrate into the PRB at a rate of about 0.1 ft/yr.

- ***How many years of operation are expected before plugging of the PRB may occur?***

Response: As discussed above, long-term column tests indicate that carbonate precipitates, which generally represent the largest amount of precipitate formed, should not reduce the hydraulic conductivity by more than a factor of two to three.

It is, however, important to note that the influent water used by these researchers contained no dissolved oxygen. Dissolved oxygen has resulted in a significant loss in hydraulic conductivity in bench-scale column tests (Mackenzie et al., 1997; Fort, 2000; and ETI, unpublished data) and field-scale above-ground and *in situ* fixed-bed reactors. A PRB installed to treat radionuclides in groundwater with high levels of dissolved oxygen and nitrate (120 mg/L) suffered from significant cementation after 2 years (Gu, 2001). Nitrate, like dissolved oxygen, is readily reduced by iron and forms goethite (α-FeOOH) (Ritter, 2000), which can cause cementation and reductions in hydraulic conductivity. Mackenzie et al. and Fort both used iron-sand mixtures to overcome the loss in hydraulic conductivity.

Dissolved oxygen concentrations in wells that are upgradient of proposed PRB locations near Buildings I-1-2/I-1-3 (33MWC-13 and 33MWC-24) and Building I-1-23 (33MWC-21) are very low (less than 1 ppm), and should not pose a significant problem in either location.

- ***If a PRB becomes physically plugged with mineral precipitate, etc., how would it be repaired?***

Response: The objective of rejuvenation of the granular iron would be to restore the permeability loss due to precipitates and to remove the precipitate from the iron to restore lost reactivity of the iron. Possible rejuvenation methods may include:

i) Using ultrasound to break-up the precipitate;

ii) Using pressure-pulse technology to break-up the precipitate;

iii) Jetting the PRB with water under high pressure; and

iv) Using solid-stem augers to agitate the PRB.

To date, these possible rejuvenation methods have not been needed and only ultrasound has been tested in a few limited field-scale tests to determine its effectiveness. At this point, it can only be stated that these methods may prove to be successful in rejuvenating a PRB.

- ***The VOC concentrations in the groundwater approaching the PRB at the I-1-23 location would be > 20,000 µg/L. Full-scale PRBs have only been used at other sites with VOC concentrations that are typically < 500 µg/L. Is a PRB capable of effectively treating VOC concentrations at the levels expected at the I-1-23 source area ?***

  Response: The VOC concentrations approaching a PRB are expected to be in the range of 1,000 to 5,000 µg/L based on site data, not at concentrations in the range of ≥ 20,000 µg/L. A PRB is capable of effectively degrading high concentrations of VOCs, including the concentrations expected from the VOC source areas at Sites 32/33. Many sites are designed using the highest historical field concentrations at or just upgradient of the PRB location. However, some of the PRBs have observed lower concentrations than those used for the design. Treatment effectiveness also depends on the placement of the PRB with respect to the maximum observed concentrations.

  However, there are several PRB installations that have documented high concentrations, such as:

  - Warren AFB, upgradient TCE concentrations 4.5 mg/L (Heneman et al., 2001)
  - Belfast, Ireland, upgradient TCE 30 to 70 mg/L (Jefferis et. al., 1997)
  - Australian site, > 100 mg/L (Duran et al., 2000)

  RTDF web site [www.rtdf.org], Full-Scale Installations:

  - Caldwell Trucking, TCE 7 mg/L
  - Copenhagen Frieght Yard, Denmark, 4 mg/L
  - Germany, PCE 17 mg/L
  - Rocky Flats, CVOCs 6 mg/L
  - Shaw AFB, SC, total CVOCs > 24 mg/L
  - Elizabeth City, TCE 5 mg/L
  - Vapokon, Denmark, > 5 mg/L

  A granular iron PRB can degrade very high VOC concentrations provided the required residence time within the PRB is achieved.

- ***Will bench-scale or pilot-scale treatability tests be required ?***

  Response: With high VOC concentrations, a bench-scale test using the site groundwater is recommended during the design process. The main purpose for the testing is to assess possible competitive effects with the VOC concentrations in contact with the granular iron. Although adequate detention time within the PRB can be designed without treatability testing using the PRB vendor's data base, a column test will allow a refinement of the detention time design criteria, and use of a design safety factor to ensure that the iron will degrade the expected VOC concentrations.

- ***Would a PRB cause the natural groundwater flow patterns and gradients to change ?***

  Response: The granular iron has a typical hydraulic conductivity of 5×10^{-2} cm/sec, which is substantially greater than the conductivity in the Upper Sand unit. Even accounting for mixing with sand and a factor of two to three decline due to long-term inorganic precipitate formation, the hydraulic conductivity should be greater than or similar to the Upper Sand unit. Groundwater modeling has shown that even continuous PRBs that have hydraulic conductivities somewhat less than the surrounding aquifer will not significantly divert flow around the sides. Thus, if a PRB has a hydraulic conductivity similar to or higher than the natural formation, as oriented perpendicular to groundwater flow, and is keyed into a lower permeability geological unit, existing groundwater flow patterns should be unaffected.

  Both groundwater modeling and real-world experience has shown that if PRBs are not oriented perpendicular to groundwater flow or if vertical gradients exist, groundwater flow patterns can be altered. Since PRBs generally have higher permeability than the surrounding formation, they can act as conduits (i.e., path of least resistance) to redistribute groundwater flow. This is a localized effect, generally only redistributing groundwater within a few feet to 10 feet from the PRB. The higher the permeability of the PRB relative to the surrounding aquifer, the greater the effect on groundwater flow patterns will be.

- ***What is the probability that contaminated groundwater could flow beneath the PRB, or find other pathways to bypass the reactive zone of the PRB ?***

  Response: At the I-1-23 site, the hydraulic conductivity (K) of the PRB will be equal to or greater than that of the Upper Sand aquifer in which it occurs. If the K of the PRB equal that of the Upper Sand aquifer, contaminated groundwater will pass through it with no effect on flowpaths. If the K of the PRB is higher than that of the Upper Sand, groundwater will preferentially flow through the PRB, not around it, since the PRB will be the path of least resistance. Vertically, the K of the overlying/underlying Upper Clay/Lower Clay units are much lower than that of the PRB, and thus flow will tend to preferentially flow through the more permeable PRB, not above or below it. Similarly, at the I-1-2/I-1-3 site, the PRB will be more permeable than the Upper Clay, Upper Sand, or Lower Clay units; the PRB will tend to funnel contaminated groundwater through it, not around it.

- ***How can treatment performance and the physical condition of a PRB be measured or monitored ?***

  Response: The treatment performance can be measured by conventional methods. For organic performance, monitoring of wells upgradient, within, and downgradient of the PRB would be performed. To monitor the hydraulic performance, water heads would be monitored in wells at either end of the PRB, or below if it is possible, with tracking of trends in the hydraulic head values over time.

- ***Would the existing buried utilities in the vicinity of Building I-1-23 be a problem for construction of a PRB at that location ?***

  Response: Many sites where PRBs are installed have underground utilities. Some construction methods, such as jetting or vertical hydraulic fracturing, can work between the

utilities. These construction methods are injection-type methods that only require boreholes every few feet or few tens of feet.

Alternatively, if excavation is required, there are two methods of dealing with buried utilities that have been used at existing PRB installations. One method would be to bypass or reroute the existing utilities until the excavation is complete. This method was recently used at a site in Needham, MA, where a PRB was installed down one side of a street in a residential area. The second method could be used for some shallow utilities. At one site, a gas line ran across the PRB alignment. The gas line was excavated on both sides extending several feet away from the PRB location. Concrete was then poured into the excavation around the gas line and allowed to cure. When the trench for the PRB was excavated, the concrete casing protected the gas line and supported it across the open PRB trench.

- ***Would the natural chemical characteristics of groundwater at the site be altered by a PRB to the extent that the groundwater chemistry may have a detrimental effect on the trees that are planned to be planted near the lake for phytoremediation of the shallow groundwater ?***

  Response: Interactions with granular iron in the PRB treatment zone cause a change in the groundwater inorganic chemistry, including increased pH, and decreased redox potential, alkalinity, and calcium concentrations. Monitoring results from existing iron PRBs indicate that the inorganic parameters in the iron-treated groundwater are buffered by the aquifer (O'Hannesin and Gillham, 1998; Vogan et al., 1999; Warner et al., 1998; Gallant, 1997). In downgradient aquifer wells, usually within 5 to 10 feet of the iron zone, pH values rebound close to the upgradient values, alkalinity increases, and E_H shifts to the natural aquifer conditions. Because of this buffering effect and the return to "natural" groundwater conditions, it is not expected that the groundwater chemistry conditions downgradient of the PRB will have any effect on the phytoremediation plantings.

Section 4
Estimated Costs for Building I-1-23 Source Area Remediation

Estimated capital costs, annual operation and maintenance costs, and present-worth costs (over 30 years) for specific remedial alternatives to address the Building I-1-23 source area and plume were prepared. These alternatives include the following:

- Permeable reactive barrier (Table 5)
- Groundwater extraction and treatment (Table 6)
- Multi-phase extraction for Upper Clay and Upper Sand units (Table 7)
- Multi-phase extraction for Upper Clay and Upper Sand units followed by groundwater extraction and treatment (Table 8)
- Excavation of shallow contaminated soil (Table 9) (This is not a stand-alone alternative.)

The estimates are intended to be used primarily for comparative evaluation of the alternatives, and do not represent the equivalent of "total project" costs. For example, none of the estimates include preparation of planning documents such as the Construction Quality Assurance Plan, the Quality Assurance Project Plan/Field Sampling Plan, the Safety, Health, & Emergency Response Plan, the Operation & Maintenance Plan, etc. Costs associated with use of phytoremediation for the I-1-23 plume are also not included in any of the estimates. The estimates are expected to be within the standard accuracy range for Feasibility Study evaluations of remedial alternatives (-30% to +50%). Each of the alternatives and the associated cost estimates are discussed further below. A summary of the estimated costs is included in Table 10.

4.1 Permeable Reactive Barrier

The cost estimates (Table 5) assume that a single PRB would be installed across the full width of the VOC plume originating from the I-1-23 source area. The approximate location of the PRB is shown on Figure 1 (this figure also shows the approximate location of a PRB that would be installed across the plume that moves to the west from the I-1-2/I-1-3 source area). This alternative was simulated in model run Case 5 (see Addendum No. 2). The estimates shown in Table 5 are based on a proposal provided by EnviroMetal Technologies. A copy of the proposal is included in Attachment 2. The estimates do not include the cost for relocation of any existing buried utilities that may be required to install the PRB.

4.2 Groundwater Extraction and Treatment

This alternative includes use of a single vertical groundwater extraction well screened in the Upper Sand unit at the location of the highest VOC concentrations in the source area. The well would pump continuously at 10 to 20 gpm. This alternative was simulated in model run Case 6 (see Addendum No. 2). The cost estimates for this alternative (Table 6) assume that a new Treatment Building would be constructed on the northern side of the existing fence at Building I-1-23. Treatment equipment consisting primarily of a packaged liquid-phase activated carbon system, and possibly a low-profile air stripper, would be used. A schematic diagram showing the extraction and treatment system is shown on Figure 2. The treated effluent would be conveyed through a buried force main from the Treatment Building to a new outfall at the lake.

4.3 Multi-Phase Extraction for Upper Clay and Upper Sand Units

This alternative includes use of MPE wells with enhancement by pneumatic fracturing to treat the VOC sources within the Upper Clay unit. The Upper Sand unit would also be treated using MPE wells, SVE wells, and horizontal groundwater extraction wells to dewater the sand, as had been previously proposed. This alternative was simulated in model run Case 9; the model figures are included in Attachment 1 in this Addendum No. 3.

The systems for treatment of the air and groundwater would be nearly identical to the facilities proposed for the I-1-23 area in the PD Report – Rev. 0. A new North MPE Building would be constructed near Building I-1-23 to house the MPE skids and air treatment equipment. The extracted groundwater (approximately 100 gpm) would be pumped to the existing wastewater Treatment Building near the lake, where some of the existing steel tanks would be used with several new equipment components to treat the groundwater. After approximately 2 years of treatment, all systems would be shut down. The cost estimates do not include the following items: abandonment of wells after completion of the active treatment phase; dismantling or salvaging of treatment equipment after use; or confirmation sampling of soil in the source area during or after completion of the active treatment phase. In addition, the cost estimates assume that the active treatment phase using the MPE system will be completed in 2 years. As shown in Table 7, the annual operation and maintenance (O&M) costs are relatively high. If the actual required operating period is longer than 2 years, the O&M costs would increase proportionately.

4.4 Multi-Phase Extraction for Upper Clay and Upper Sand Units followed by Groundwater Extraction and Treatment

This alternative also includes use of MPE wells with enhancement by pneumatic fracturing to treat the VOC sources within the Upper Clay unit. The Upper Sand unit would also be treated

using MPE wells, SVE wells, and horizontal groundwater extraction wells to dewater the sand, as had been previously proposed. After operating the MPE system for 2 years, all MPE equipment would be shut down. A single vertical groundwater extraction well screened in the Upper Sand unit at the location of the highest VOC concentrations in the source area would then be used to capture dissolved VOCs that would persist in the Upper Sand due to the large mass of VOC source material that will not be removed by the MPE system. The well would pump continuously at 10 to 20 gpm. This specific alternative was not simulated in a model run, but the expected results on the VOC plume can be generally interpolated from the modeling results for the other simulations, and be most similar to the result from Case 6, with containment of the source provided by continuous operation of a single vertical extraction well.

Because a long-term groundwater pump-and-treat system would be required at the I-1-23 source area, it was assumed that a new Treatment Building would be constructed near I-1-23 that would be sized to house all of the treatment equipment needed for both the initial 2-year MPE operation period, and for the long-term pump-and-treat system that would follow. The existing wastewater Treatment Building near the lake would not be used in this alternative. After the MPE operation period, some of the MPE treatment equipment would remain for use to treat the groundwater from the single vertical extraction well, particularly the liquid-phase activated carbon system and associated controls/instrumentation. The detailed cost estimate for this alternative is included in Table 8. The same cost estimate clarifications for the alternative described above (MPE without long-term pump-and-treat) apply to this alternative.

4.5 Excavation of Shallow Contaminated Soil

At the request of the USEPA, cost estimates were prepared for excavation and off-site disposal of VOC-contaminated soil within the Upper Clay unit at the I-1-23 source area. Based on the existing soil characterization data for the source area, it was estimated that approximately 520 cubic yards of clay containing 32.8 pounds of total VOCs could be excavated in this area. This assumes excavating to approximately 12 feet bgs in the area near SB-201, SB-202, and SB-203 (Figure 4-19 in the Preliminary Design Report). To access this volume of soil, an additional 100 cubic yards of uncontaminated soil located above the contaminated soil would also have to be removed. For comparison, it is estimated that a total of 48 pounds of VOCs are currently present in the Upper Clay unit at this source area. So, excavation of the 520 cubic yards of soil would remove approximately 68% of the total VOC mass in the Upper Clay unit at the I-1-23 source area. The estimated costs for excavation and off-site disposal of the clay as a hazardous waste are shown in Table 9.

Additional VOC mass in the Upper Clay exists near SB-212, but it is below approximately 7 feet of uncontaminated soil, and the majority of the mass exists in the saturated zone, from approximately 12 to 20 feet bgs and extends into the Upper Sand unit. This complicates the excavation process and is best addressed via the groundwater treatment technology.

Section 5
Comparison With Selection-of-Remedy Criteria

At the request of the Illinois Environmental Protection Agency (IEPA), two of the remedial alternatives being considered to address the Building I-1-23 source area were compared with the standard Superfund Selection-of-Remedy criteria. The two alternatives evaluated include the following:

- Groundwater extraction and treatment
- Permeable reactive barrier

A summary of the comparison is included in Table 10.

Section 6
Clarifications for Addendum No. 2

6.1 VOC Removal Efficiency at Building I-1-23 Area

The estimated average VOC removal efficiency for the overall source area at I-1-23 shown in Table 2 in Addendum No. 2 (39%) applied to only the mass removal efficiency in the Upper Sand unit. This level of treatment of the Upper Sand unit would produce an estimated VOC removal efficiency of 22% for the overall source area (Upper Clay and Upper Sand units). This point has been clarified in Table 2 of this Addendum No. 3. In addition, the descriptions of the model run "Cases" shown in Table 1 of this Addendum No. 3 have also been revised to note this clarification.

6.2 Clarification of Model Run Case 2 for Buildings I-1-2/I-1-3 Area

A question received from a reviewer of Addendum No. 2 was as follows:

> ***The simulation for use of a PRB at the I-1-2/I-1-3 area (Case 2) seems to show that a PRB installed on the western side of the buildings would help reduce the VOC plume that migrates to the east and north from the source area. Why does this occur ?***

The answer to this question is associated with the set-up of the contaminant transport model required to simulate the effect of a PRB. To simulate a PRB, it was necessary to represent the PRB in the model as a line of closely spaced nodes. This required using a tighter grid spacing for the overall model domain, not just at the specific location of the PRB. The Current Conditions simulation (t = 0 years) included as the first figure under each Case presented in Addendum No. 2 is based on the original model set-up and calibration, which did not include the tighter grid spacing used for the PRB simulations.

An additional model figure showing Current Conditions (t = 0 years) using the model with the refined (tighter) grid is included in Attachment 3 in this Addendum No. 3. This Current Conditions simulation using the tighter grid spacing shows a more narrow, longer plume migrating east and north of I-1-2/I-1-3. This is a result of reduced numerical dispersion (higher degree of accuracy), caused by the tighter grid spacing and smaller time increments of transport. In areas of large concentration gradients, such as in the source area, a tighter grid spacing and smaller time increments for transport calculations result in an improved, more accurate simulation. Thus, the plume is narrower and longer, because advective flow along the

groundwater flow paths dominates over the dispersion, more than when the grid spacing is more coarse.

Future time simulations indicate that the plume east of I-1-2/I-1-3 will reduce in size over time, whether or not the PRB is in place on the western side of Buildings I-1-2/I-1-3. This is a result of the natural attenuation processes in the aquifer. The rate of degradation of TCE in the groundwater that is used in the calibration of the model to represent current conditions is maintained at exactly the same rate in simulations of future conditions. This can be seen on the figures for I-1-2/I-1-3 - Natural Attenuation (Case 3) in Addendum No. 2. This shows a reduction in size of the eastern plume over time, similar to that for Case 2 with the PRB in place, but different in shape because of the numerical dispersion caused by a coarser grid spacing for the Case 3 run. While the apparent shapes of the plumes look different under Case 2 and Case 3, due to numerical dispersion, the plume decreases over time in both cases. Since the PRB is on the westward-flowing portion of the plume, it has virtually no effect on the eastward-flowing portion of the plume. The reduction in size that takes place is solely from natural attenuation.

The effect of the tighter grid for the model calibration can also be seen on the figures for simulation of a PRB for the I-1-23 source area (see Case 5 in Addendum No. 2).

Table 1
Summary of Groundwater Quality Simulations Using Groundwater Contaminant Transport Model

VOC SOURCE AREA	DESCRIPTION OF SIMULATIONS	MODEL RUN NO.	CURRENT CONDITIONS	YEARS AFTER START OF REMEDIAL ACTION				
				5	10	20	30	40
Buildings I-1-2/I-1-3 Area	Case 1 MPE wells with pneumatic fracturing operated for 2 years then shut down (no PRB).	520	X	X	X	X		
	Case 2 PRB with zero-valent iron in west plume (no source area treatment).	522	X	X	X	X		
	Case 3 MNA only (no active source area treatment).	417	X	X	X	X		
Building I-1-23 Area	Case 1 MPE wells, SVE wells, and horizontal groundwater extraction wells in Upper Sand operated for 2 years, then all shut down. 39% VOC removal from Upper Sand; 22% VOC removal from overall source area.	520	X	X	X	X		
	Case 2 MPE and SVE wells in Upper Sand operated for 2 years, then shut down. Horizontal groundwater extraction wells operated at 100 gpm continuously from initial system startup. 39% VOC removal from Upper Sand; 22% VOC removal from overall source area.	519	X	X	X	X		
	Case 3 MPE wells, SVE wells, and horizontal groundwater extraction wells in Upper Sand and Upper Clay operated for 2 years, then shut down. 70% VOC removal from overall source area.	521	X	X	X	X		
	Case 4 MPE wells, SVE wells, and horizontal groundwater extraction wells in Upper Sand and Upper Clay operated for 2 years, then shut down. 90% VOC removal from overall source area.	526	X	X	X	X		

Table 1 (Continued)
Summary of Groundwater Quality Simulations Using Groundwater Contaminant Transport Model

VOC SOURCE AREA	DESCRIPTION OF SIMULATIONS	MODEL RUN NO.	CURRENT CONDITIONS	YEARS AFTER START OF REMEDIAL ACTION				
				5	10	20	30	40
Building I-1-23 Area (continued)	Case 5 PRB with zero-valent iron. No source area treatment.	522	X	X	X	X		
	Case 6 Continuous pumping with one vertical groundwater extraction well at 20 gpm. No MPE/SVE wells.	525	X	X	X	X		
	Case 7 MNA only (no active source area treatment).	417	X	X	X	X		
	Case 8 Years 0 to 2: MPE wells, SVE wells, and horizontal groundwater extraction wells in Upper Sand operated for 2 years, then all shut down. 39% VOC removal from Upper Sand; 22% VOC removal from overall source area. Years 2 to 10: One vertical extraction well pumping from Upper Sand in source area at 10 gpm. Year 10 and beyond: MNA only.	529	X	X	X	X	X	X
	Case 9 MPE with pneumatic fracturing in Upper Clay. MPE wells, SVE wells, and horizontal groundwater extraction wells in Upper Sand. All operated for 2 years, then shut down. 43% VOC removal from overall source area. No PRB.	531	X	X	X	X		
Repository Area	MNA only (no active source area treatment). *	417	X	X	X	X		

Notes:
MPE = Multi-phase extraction
SVE = Soil vapor extraction
PRB = Permeable reactive barrier
MNA = Monitored natural attenuation
* = Effects of the phytoremediation component of the remedial action were not simulated in the model run.
Only Case 8 and Case 9 for the Building I-1-23 area are included in this Addendum No. 3. Refer to Addendum No. 2 for modeling results for all other simulations listed in this table.

Table 2
Estimated VOC Mass and Removal Efficiency

AREA	NEAREST SOIL BORING LOCATION	TYPE OF EXTRACTION WELL	NUMBER OF WELLS	RADIUS OF INFLUENCE (ft)	WELL SCREEN INTERVAL (ft bgs)	WELL SCREEN LENGTH (ft)	VOLUME WITHIN TREATMENT ZONE (cf)	AVERAGE VOC CONCENTRATION (ppm)	AVERAGE SOIL DENSITY (lb/cf)	VOC MASS WITHIN TREATMENT ZONE (lb)	VOC MASS WITHIN 1 mg/kg ISOCONTOUR (EVS) (lb)	RANGE OF REMOVAL EFFICIENCY (%) (7)	AVERAGE ESTIMATED ACHIEVABLE VOC REMOVAL FROM SOURCE AREA (%)	PERCENT OF CONCENTRATION/ MASS REMAINING AFTER TREATMENT (%)
I-1-2	SB-102	PF/MPE	3	20	10 - 15	5	17,898	8.3	129	19	--			
	SB-133	PF/MPE	3	20	20 - 30	10	35,796	11.5	129	53	--			
	SB-133	PF/MPE	2	20	13 - 23	10	23,864	5.9	129	18	--	35% to 75% (4)		
									Totals	91	289	(Avg. 55%)	17%	83%
I-1-3	SB-127	PF/MPE	6	20	10 - 20	10	71,592	9.9	129	91	--			
	SB-115	PF/MPE	6	20	18 - 38	20	143,184	13.6	129	251	--			
	SB-126	PF/MPE	2	20	27 - 42	15	35,796	57.7	129	266	--	35% to 75% (4)		
									Totals	609	861	(Avg. 55%)	39%	61%
I-1-23 (US only)	SB-217	MPE	2	10	40 - 45	5	2,983	4.5	128	2	--			
	SB-202	SVE	5	25	20 - 35	15	139,828	1.3	128	24	--			
	--	Horizontal	--	--	--	--	--	--	--	16 (5)	--	45% to 70%		
									Totals	42	62 (6)	(Avg. 58%)	39% (6)	61%
I-1-23 (US & UC)	SB-217	MPE	2	10	40 - 45	5	2,983	4.5	128	2	--			
	SB-202	SVE	5	25	20 - 35	15	139,828	1.3	128	24	--			
	--	Horizontal	--	--	--	--	--	--	--	16 (5)	--			
	EVS estimate									48 (8)		35% to 70% (9)		
									Totals	90	110	(Avg. 53%)	43%	57%

Notes:

1. Average VOC concentrations are selected from discrete soil samples collected from soil borings located within the treatment zone. See Table 4-2 Preliminary Design Report, May 2001.
2. A 5% reduction in the volume within the treatment zone was made to account for overlapping zones of influence for each well.
3. The mass within the treatment zone for the horizontal wells at I-1-23 is estimated to be the dissolved phase within the capture zone of the horizontal wells.
4. Pneumatic fracturing contractor estimates a recovery rate increase of 5x to 10x; a 5x multiplier was applied to the estimated removal efficiency range previously established for clay.
5. Includes dissolved-phase VOC mass outside of soil treatment zone that is recoverable via pumping with the horizontal wells.
6. Approximately 48 lb. VOCs were estimated in the Upper Clay zone in Addendum No. 1 of the PD Report; so, 58% x 42 lb/(110 lb - 48 lb) = 39% removal of source material in the Upper Sand. Assumes no VOC removal from Upper Clay.
7. Within the treatment zone only.
8. Assume all identified Upper Clay source areas will be within treatment zones using MPE and pneumatic fracturing.
9. Use the average of the range of the most conservative removal efficiency rates for US and UC intervals.

PF/MPE = MPE well where pneumatic fracturing is applied.
US = Upper sand unit.

Table 3
Permeable Reactive Barrier - Advantages and Disadvantages

ADVANTAGES	DISADVANTAGES
■ Provides *in situ* CVOC destruction, rather than only migration control as with an impermeable barrier. ■ Functions "passively" with no ongoing energy input or maintenance requirements. ■ Does not significantly alter natural groundwater flow patterns or gradients. ■ No surface structures other than monitoring wells are required. ■ Does not require specific locations of all VOC source zones or "hot spots" to be known. ■ Contaminants are not brought to the ground surface, thereby preventing potential inter-media transfer (e.g., no VOC emissions to air or VOC discharges to surface water). ■ No contaminant residuals or treatment waste products are generated. ■ Has proved to be effective for CVOC treatment at several full-scale installations. ■ Does not mix contaminated and uncontaminated groundwater in the aquifer.	■ Installation by trenching methods is typically limited to depths of 50 feet or less. (This is not likely a concern at I-1-2/I-1-3, but may be a concern at I-1-23, where the bottom of the Upper Sand dips to below 42 feet bgs or deeper. ■ VOC plume must be well characterized and delineated. ■ Oldest full-scale PRBs are <10 years old. Therefore, knowledge regarding long-term physical performance, treatment performance, and maintenance requirements is limited. ■ May require rerouting of existing buried utilities in the I-1-23 area. ■ Difficult to accurately measure results in terms of total VOC mass destroyed over time. ■ Relies on natural groundwater flow velocities to transport dissolved VOCs from source area to reaction zone at PRB; therefore, rate of VOC mass destruction is relatively slow.

Table 4
Groundwater Extraction and On-site Treatment for Hydraulic Source Control - Advantages and Disadvantages

ADVANTAGES	DISADVANTAGES
■ Highly effective at containing the source and reducing plume concentrations. ■ Has proved to be effective for groundwater remediation at numerous sites. ■ Can be readily expanded, if required, to include additional extraction wells, increased extraction flowrates, etc. ■ Does not require specific locations of all VOC source zones or "hot spots" to be known. ■ In some cases, extracted groundwater can be discharged directly to an existing sanitary sewer system for treatment at a municipal treatment plant. ■ Uses conventional construction methods and equipment for groundwater extraction and treatment. ■ Groundwater treatment will result in destruction of VOCs, when appropriate processes and equipment are used. ■ Systems can be automated and remotely monitored/controlled to require only intermittent operator attention. ■ Can be located in known source zone to provide source remediation. ■ Can measure results in terms of total VOC mass destroyed over time.	■ Operation of at least the groundwater extraction component of the system is required as long as sources of dissolved VOCs remain. ■ May require long-term operation and maintenance of groundwater treatment facilities. ■ Completion of the NPDES permit or air emission permit process may be required. ■ Typically removes VOC source material at a slower rate than other *in situ* technologies.

Table 5
Opinion of Probable Cost
Permeable Reactive Barrier for
Building I-1-23 VOC Source Area

ITEM OF WORK	COST ESTIMATES QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Mobilization	1	Estimate	$50,000	$50,000		Oversight personnel, contractor personnel, and equipment.
Trenching	15,750	SF	$20	$315,000		Assuming 350 ft long, 45 ft deep, 2.5 ft wide.
Soil Disposal	2,188	Ton	$20	$43,750		Assumes excavated soil will require off-site, non-hazardous disposal; 1.5t/cy.
Iron Material	945	Ton	$450	$425,250		Assumes bulk density of 0.08 tons/cubic foot, bottom 35' of trench filled with iron/sand-mixture.
Additional Fill Material (sand mixed with iron)	1,463	Ton	$15	$21,940		Assumes 2:1 and 4:1 ratio of iron:soil in US and UC portions of PRB respectively.
Monitoring Well Installation	6	Well	$1,500	$9,000		Assumes installation of 6 new wells required for monitoring program.
Subtotal					$864,940	
INDIRECT CAPITAL COSTS						
Bench-scale Testing	1	LS	$15,000	$15,000		
Data Review	1	LS	$2,500	$2,500		
Final Design (5% of direct costs)	1	LS	$43,000	$43,000		RMT.
Field Design/Implementation Assistance	1	LS	$7,500	$7,500		EnviroMetal.
Site License Fee for Use of Zero-Valent Iron PRB	1	LS	$130,000	$130,000		15% of direct capital costs to EnviroMetal.
Subtotal					$198,000	
CONSTRUCTION MANAGEMENT						
Engineering/Oversight (8% direct costs)	1	LS	$69,000	$69,000		Construction oversight and documentation.
Health and Safety Monitoring	1	LS	$2,000	$2,000		Field monitoring equipment and documentation.
Subtotal					$71,000	
Subtotal - Direct & Indirect Capital Costs					$1,133,940	
ANNUAL OPERATION & MAINTENANCE COSTS						
Site Inspection	12	Visit	$500	$6,000		Assumes monthly inspections.
Compliance Monitoring	1	Year	$30,000	$30,000		Estimate.
Subtotal					$36,000	
SUB-TOTAL					$1,133,940	
CONTINGENCY (20%)					$226,800	
PRESENT WORTH OF ANNUAL O & M OVER 30-YEAR PERIOD					$446,700	Assumes a discount rate of 7 percent over a 30-year period.
TOTAL PRESENT WORTH COST WITH CONTINGENCY*					$1,807,440	

* -30% to +50% accuracy range.

Assumes PRB bed will have a life of 30+ years. If bed requires replacement, approximately $1,000,000 per replacement effort can be assumed.

Table 6
Opinion of Probable Cost
Groundwater Extraction and Treatment for
Building I-1-23 VOC Source Area

ITEM OF WORK	COST ESTIMATES QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight personnel, contractor personnel, and equipment.
Extraction Well Installation	1	Well	$5,000	$5,000		Assumes one extraction well to pump at 10 to 20 gpm.
Extraction Well Pump and Controls	1	Pump	$2,000	$2,000		
Access Road to Treatment Building	1	LS	$10,000	$10,000		
Treatment Building	1	LS	$50,000	$50,000		Including heating and ventilating.
Electrical Power and Controls	1	LS	$20,000	$20,000		
Mechanical Installation	1	LS	$10,000	$10,000		
Holding Tanks	2	Tank	$2,500	$5,000		
Control Panel and PLC Programming	1	LS	$15,000	$15,000		
Carbon Treatment System	1	Each	$15,000	$15,000		
Filters, Flow Meter, Sampler	1	LS	$5,000	$5,000		
Trenching/Conveyance and Discharge Piping	1,000	LF	$25	$25,000		Assuming 4 ft deep trench and 2-inch PVC piping.
Outfall	1	LS	$2,500	$2,500		
Misc. Equipment	1	LS	$15,000	$15,000		
Startup/System Shakedown	100	Hours	$75	$7,500		
Monitoring Well Installation	6	Well	$1,500	$9,000		Assumes installation of 6 new wells required for monitoring program.
Subtotal					$206,000	
INDIRECT CAPITAL COSTS						
Final Design	1	LS	$35,000	$35,000		
Permit Application	1	LS	$5,000	$5,000		Treated groundwater discharge permit application.
Subtotal					$40,000	
CONSTRUCTION MANAGEMENT						
Engineering/Oversight	1	LS	$15,000	$15,000		Construction oversight and documentation.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Subtotal					$16,000	
Subtotal - Direct & Indirect Capital Costs					$262,000	
ANNUAL OPERATION & MAINTENANCE COSTS						
Site Inspection	12	Visit	$500	$6,000		Assumes monthly inspections.
Compliance Monitoring	1	Year	$30,000	$30,000		Estimate.
Treatment System Operation	12	Month	$2,500	$30,000		Includes 16 hr/mo labor, equipment (assumes 1 pump replaced and well cleaned every 2 years), and power.
Carbon Replacement	12	Month	$600	$7,200		Assumes 10 lb/day carbon usage at $2.00/lb carbon.
Treatment System Monitoring	12	Month	$500	$6,000		Assumes 2 samples (influent and effluent) per month for VOCs.
Permit Renewal Applications	0.2	Applic.	$5,000	$1,000		Discharge permit renewal application every 5 years @ $5,000/application.
Outfall Inspection/Clearing	1	Year	$500	$500		
Administrative Costs	1	Year	$10,000	$10,000		Includes reporting.
Subtotal					$90,700	
SUB-TOTAL					$262,000	
CONTINGENCY (20%)					$52,400	
PRESENT WORTH OF ANNUAL O & M OVER 30-YEAR PERIOD					$1,125,500	Assumes a discount rate of 7 percent over a 30-year period.
TOTAL PRESENT WORTH COST WITH CONTINGENCY*					$1,439,900	

* -30% to +50% accuracy range.

Table 7
Opinion of Probable Cost
Multi-phase Extraction for
Building I-1-23 VOC Source Area*

ITEM OF WORK	COST ESTIMATES QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Multi-Phase Extraction System (used during years 1-2)						
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment for both systems.
Access Road to Treatment Building	1	LS	$10,000	$10,000		
Treatment Building	1	LS	$50,000	$50,000		Assumes use of the existing wastewater treatment building for groundwater treatment.
Electrical Power and Controls	1	LS	$25,000	$25,000		New treatment building to be used for MPE operations only.
Mechanical Installation	1	LS	$50,000	$50,000		
MPE Well Installation - Vertical Wells	352	VF	$50	$17,600		Assumes 12 wells (6 extraction and 6 vent) to 16 ft bgs and 4 wells to 40 feet bgs.
Groundwater Extraction Wells - Horizontal	500	LF	$200	$100,000		Assumes 2 horizontal extraction wells with pumps.
Well Heads	14	Each	$500	$7,000		
Extraction Line Piping - 1-inch	300	LF	$5	$1,500		
Extraction Line Piping - 2-inch	400	LF	$8	$3,200		
Discharge Line Piping - 3-inch	650	LF	$10	$6,500		
Trenching	1,350	LF	$35	$47,250		Conveyance, discharge, and utility line trenching.
Soil Disposal	750	Ton	$20	$15,000		Assumes 500 cy to be disposed at 1.5 t/cy; offsite, non-hazardous disposal.
MPE Skid	2	Each	$25,000	$50,000		
Carbon Treatment System - Liquid Phase	1	LS	$35,000	$35,000		Assumes 5,000 lb vessels and initial carbon supply.
Carbon Treatment System - Vapor Phase	1	LS	$10,000	$10,000		Assumes 2,000 lb vessels and initial carbon supply.
Pneumatic Fracturing	1	LS	$15,000	$15,000		Fracturing of 10-foot thick layer in of Upper Clay unit.
Control Panel and PLC Programming	1	LS	$25,000	$25,000		
Holding Tank	1	Tank	$5,000	$5,000		
Outfall	1	LS	$5,000	$5,000		
Misc. Equipment	1	LS	$10,000	$10,000		
Startup/ System Shakedown	200	Hours	$75	$15,000		
Subtotal					$513,050	
INDIRECT CAPITAL COSTS						
Final Design (10% of direct capital costs)	1	LS	$51,000	$51,000		
Permit Application	1	LS	$10,000	$10,000		Treated groundwater discharge permit application.
Subtotal					$61,000	

Table 7
Opinion of Probable Cost (continued)
Multi-phase Extraction for
Building I-1-23 VOC Source Area*

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
CONSTRUCTION MANAGEMENT						
Engineering/Oversight (8% of direct capital costs)	1	LS	$41,000	$41,000		System construction oversight and documentation.
Health and Safety Monitoring	1	LS	$5,000	$5,000		Health and Safety Plan preparation, field monitoring equipment, documentation.
Subtotal					$46,000	
Subtotal - Direct & Indirect Capital Costs					$620,050	
ANNUAL OPERATION & MAINTENANCE COSTS - Years 1-2						
Site Inspection	12	Visit	$500	$6,000		Assumes monthly inspections.
Compliance Monitoring;	1	Year	$30,000	$30,000		
Treatment System Operation	12	Month	$15,000	$180,000		Includes 80 hr/mo labor, equipment, and power (50 hp assumed).
Carbon Replacement - Liquid Phase	12	Month	$3,000	$36,000		Assuming 50 lb/day carbon usage at $2.00/lb carbon.
Carbon Replacement - Vapor Phase	12	Month	$1,800	$21,600		Assuming 30 lb/day carbon usage at $2.00/lb carbon.
Treatment System Monitoring	12	Month	$1,500	$18,000		Assumes 4 samples (vapor and water influent and effluent) per month for VOCs.
Permit Renewal Applications	0.2	Applic.	$5,000	$1,000		Discharge permit renewal application every 5 years @ $5,000/application.
Outfall Inspection/Clearing	1	Year	$500	$500		
Administrative Costs	1	Year	$20,000	$20,000		Includes data evaluation, reporting, project management.
Subtotal					$313,100	
SUB-TOTAL					$620,050	
CONTINGENCY (20%)					$124,000	
PRESENT WORTH OF ANNUAL O & M FOR YEARS 1-2					$566,100	Assumes a discount rate of 7 percent.
TOTAL PRESENT WORTH COST WITH CONTINGENCY**					$1,310,150	

* Includes treatment of Upper Clay and Upper Sand units.

** -30% to +50% accuracy range.

Table 8
Opinion of Probable Cost
Multi-phase Extraction Followed by Groundwater Extraction and Treatment for Building I-1-23 VOC Source Area*

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
DIRECT CAPITAL COSTS						
Multi-Phase Extraction System (used during years 1-2)						
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight and construction personnel and equipment for both systems.
Access Road to Treatment Building	1	LS	$10,000	$10,000		
Treatment Building	1	LS	$75,000	$75,000		Assumes new building will house both MPE and groundwater treatment systems.
Electrical Power and Controls	1	LS	$25,000	$25,000		
Mechanical Installation	1	LS	$50,000	$50,000		
MPE Well Installation - Vertical Wells	352	VF	$50	$17,600		Assumes 12 wells (6 extraction and 6 vent) to 16 ft bgs and 4 wells to 40 feet bgs.
Groundwater Extraction Wells - Horizontal	500	LF	$200	$100,000		Assumes 2 horizontal extraction wells with pumps.
Well Heads	14	Each	$500	$7,000		
Extraction Line Piping - 1-inch	300	LF	$5	$1,500		
Extraction Line Piping - 2-inch	400	LF	$8	$3,200		
Discharge Line Piping - 3-inch	650	LF	$10	$6,500		
Trenching	1,350	LF	$35	$47,250		Conveyance, discharge, and utility line trenching.
Soil Disposal	750	Ton	$20	$15,000		Assumes 500 cy to be disposed at 1.5 t/cy; offsite, non-hazardous disposal.
MPE Skid	2	Each	$25,000	$50,000		
Settling Tank Relocation	1	LS	$2,000	$2,000		Relocation of settling tank from existing WWT building to new treatment building.
Carbon Treatment System - Liquid Phase	1	LS	$35,000	$35,000		Assumes 5,000 lb vessels and initial carbon supply
Carbon Treatment System - Vapor Phase	1	LS	$10,000	$10,000		Assumes 2,000 lb vessels and initial carbon supply
Pneumatic Fracturing	1	LS	$15,000	$15,000		Fracturing of 10-foot thick layer in of Upper Clay unit.
Control Panel and PLC Programming	1	LS	$25,000	$25,000		
Holding Tank	1	Tank	$5,000	$5,000		
Outfall	1	LS	$5,000	$5,000		
Misc. Equipment	1	LS	$15,000	$15,000		
Startup/ System Shakedown	200	Hours	$75	$15,000		
Pump-and-Treat System (used during years 3-30)						
Extraction Well Installation	1	Well	$5,000	$5,000		
Extraction Well Pump	1	Pump	$2,000	$2,000		
Holding Tank	0	Tank	$0	$0		Assumes MPE system component can be utilized.
Product Separator and Tank	0	LS	$0	$0		Assumes MPE system component can be utilized.
Control Panel and PLC Programming	1	LS	$5,000	$5,000		Assumes some adjustments to system installed for MPE will be required.
Carbon Treatment System	0	Each	$0	$0		Assumes treatment system installed for MPE system can be utilized.
Instrumentation	1	LS	$5,000	$5,000		
Trenching - Conveyance and Discharge Piping	0	LF	$0	$0		Assumes piping installed for MPE system can be utilized.
Outfall	0	LS	$0	$0		Assumes outfall installed for MPE system can be utilized.
Misc. Equipment	1	LS	$15,000	$15,000		Assumes alternate items such as flow meters, transfer pumps required for downsizing.
Startup/System Shakedown	100	Hours	$75	$7,500		
Monitoring Well Installation	6	Well	$1,500	$9,000		Assumes installation of 6 new wells
Subtotal					$593,550	
INDIRECT CAPITAL COSTS						
Final Design (10% of direct capital costs)	1	LS	$59,000	$59,000		
Permit Application	1	LS	$10,000	$10,000		Treated groundwater discharge permit application.
Subtotal					$69,000	

Table 8
Opinion of Probable Cost (continued)
Multi-phase Extraction Followed by Groundwater Extraction and Treatment for Building I-1-23 VOC Source Area*

ITEM OF WORK	COST ESTIMATES					COMMENTS
	QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	
CONSTRUCTION MANAGEMENT						
Engineering/Oversight (8% of direct capital costs)	1	LS	$47,000	$47,000		System construction oversight and documentation.
Health and Safety Monitoring	1	LS	$5,000	$5,000		Health and Safety Plan preparation, field monitoring equipment, documentation.
Subtotal					$52,000	
Subtotal - Direct & Indirect Capital Costs					$714,550	
ANNUAL OPERATION & MAINTENANCE COSTS - Years 1-2						
Site Inspection	12	Visit	$500	$6,000		Assumes monthly inspections.
Compliance Monitoring	1	Year	$30,000	$30,000		
Treatment System Operation	12	Month	$15,000	$180,000		Includes 80 hr/mo labor, equipment, and power (50 hp assumed).
Carbon Replacement - Liquid Phase	12	Month	$3,000	$36,000		Assuming 50 lb/day carbon usage at $2.00/lb carbon.
Carbon Replacement - Vapor Phase	12	Month	$1,800	$21,600		Assuming 30 lb/day carbon usage at $2.00/lb carbon.
Treatment System Monitoring	12	Month	$1,500	$18,000		Assumes 4 samples (vapor and water influent and effluent) per month for VOCs.
Permit Renewal Applications	0.2	Applic.	$5,000	$1,000		Discharge permit renewal application every 5 years @ $5,000/application.
Outfall Inspection/Clearing	1	Year	$500	$500		
Administrative Costs	1	Year	$20,000	$20,000		Includes data evaluation, reporting, project management.
Subtotal					$313,100	
ANNUAL OPERATION & MAINTENANCE COSTS - Years 3-30						
Site Inspection	12	Visit	$500	$6,000		Assumes monthly inspections.
Compliance Monitoring	1	Year	$30,000	$30,000		
Treatment System Operation	12	Month	$2,500	$30,000		Includes 16 hr/mo labor, equipment, and power (1 hp assumed).
Carbon Replacement	12	Month	$600	$7,200		Assumes 10 lb/day carbon usage at $2.00/lb carbon.
Treatment System Monitoring	12	Month	$500	$6,000		Assumes 2 samples (influent and effluent) per month for VOCs.
Permit Renewal Applications	0.2	Applic.	$5,000	$1,000		Discharge permit renewal application every 5 years @ $5,000/application.
Outfall Inspection/Clearing	1	Year	$500	$500		
Administrative Costs	1	Year	$10,000	$10,000		Includes reporting.
Subtotal					$90,700	
SUB-TOTAL					$714,550	
CONTINGENCY (20%)					$142,900	
PRESENT WORTH OF ANNUAL O & M FOR YEARS 1-2					$566,100	Assumes a discount rate of 7 percent.
PRESENT WORTH OF ANNUAL O&M FOR YEARS 3-30					$898,600	Assumes a discount rate of 7 percent.
TOTAL PRESENT WORTH COST WITH CONTINGENCY**					$2,322,150	

* Includes treatment of Upper Clay and Upper Sand units.
** -30% to +50% accuracy range.

Table 9
Opinion of Probable Cost
Excavation of Shallow Contaminated Soil and Groundwater Extraction and Treatment for Building I-1-23 VOC Source Area*

ITEM OF WORK	COST ESTIMATES QUANTITY	UNIT	UNIT PRICE	COST	SUBTOTAL	COMMENTS
DIRECT CAPITAL COSTS						
Soil Excavation at Building I-1-23: Offsite Disposal (Characteristically Hazardous)						
Mobilization/Site Preparation	1	LS	$5,000	$5,000		Oversight and construction personnel and equipment.
Clearing and Grubbing	0	Acre	$4,000	$0		
Soil Excavation	620	CY	$15	$9,300		520 CY of soil is contaminated; 100 CY must be removed to access it.
Utility Relocation	1	LS	$5,000	$5,000		Assumes utilities in the area of soil to be excavated.
Soil Transport	780	Ton	$50	$39,000		Transport R/T from CONWR to Peoria, IL. (520 CY @ 1.5 ton/CY).
Backfill & Site restoration	520	CY	$20	$10,400		Re-use 100 CY of uncontaminated soil, formerly above contaminated areas.
Soil Disposal	780	Ton	$120	$93,600		Assumes RCRA (D-listed) direct disposal at Peoria, IL. PCB conc. <50 ppm.
Monitoring Well Abandonment and Replacement	126	VF	$70	$8,800		Abandonment and replacement of 33MWC-07 and 33MWC-23.
Demobilize	1	LS	$2,500	$2,500		
Level "C" contingency	10%	%	$173,600	$17,400		10% of contractor costs due to slower pace of work & PPE costs.
Union contingency	2%	%	$173,600	$3,500		2% of contractor costs due to higher labor costs, schedule adjustments.
Subtotal					$194,500	
Groundwater Extraction/Treatment System						
Mobilization/Site Preparation	1	LS	$10,000	$10,000		Oversight personnel, contractor personnel, and equipment.
Extraction Well Installation	1	Well	$5,000	$5,000		Assumes one extraction well to pump at 10 to 20 gpm.
Extraction Well Pump and Controls	1	Pump	$2,000	$2,000		
Access Road to Treatment Building	1	LS	$10,000	$10,000		
Treatment Building	1	LS	$50,000	$50,000		Including heating and ventilating.
Electrical Power and Controls	1	LS	$20,000	$20,000		
Mechanical Installation	1	LS	$10,000	$10,000		
Holding Tanks	2	Tank	$2,500	$5,000		
Control Panel and PLC Programming	1	LS	$15,000	$15,000		
Carbon Treatment System	1	Each	$15,000	$15,000		
Filters, Flow Meter, Sampler	1	LS	$5,000	$5,000		
Trenching/Conveyance and Discharge Piping	1,000	LF	$25	$25,000		Assuming 4 ft deep trench and 2-inch PVC piping.
Outfall	1	LS	$2,500	$2,500		
Misc. Equipment	1	LS	$15,000	$15,000		
Startup/System Shakedown	100	Hours	$75	$7,500		
Monitoring Well Installation	6	Well	$1,500	$9,000		Assumes installation of 6 new wells required for monitoring program.
Subtotal					$206,000	
INDIRECT CAPITAL COSTS						
Soil Excavation at Building I-1-23: Offsite Disposal (Characteristically Hazardous)						
Design/Planning	1	LS	$13,600	$13,600		7% of direct capital costs
Project Management	1	LS	$9,700	$9,700		5% of direct capital costs
Bidding & Contracting	1	LS	$9,700	$9,700		5% of direct capital costs
Permitting	1	LS	$5,000	$5,000		
Construction Observation & Documentation	1	LS	$19,500	$19,500		10% of direct capital costs
Documentation Report	1	LS	$7,500	$7,500		
Union contingency	10%	%	$29,200	$2,900		10% of PM and O&D costs for dealing with union-specific issues
Subtotal					$67,900	
Groundwater Extraction/Treatment System						
Final Design	1	LS	$35,000	$35,000		
Permit Application	1	LS	$5,000	$5,000		Treated groundwater discharge permit application.
Engineering/Oversight	1	LS	$15,000	$15,000		Construction oversight and documentation.
Health and Safety Monitoring	1	LS	$1,000	$1,000		Field monitoring equipment and documentation.
Subtotal					$56,000	
Subtotal - Direct & Indirect Capital Costs					$524,400	
ANNUAL OPERATION & MAINTENANCE COSTS						
Site Inspection	12	Visit	$500	$6,000		Assumes monthly inspections.
Compliance Monitoring	1	Year	$30,000	$30,000		Estimate.
Treatment System Operation	12	Month	$2,500	$30,000		Includes 16 hr/mo labor, equipment (assumes 1 pump replaced and well cleaned every 2 years), and power.
Carbon Replacement	12	Month	$600	$7,200		Assumes 10 lb/day carbon usage at $2.00/lb carbon.
Treatment System Monitoring	12	Month	$500	$6,000		Assumes 2 samples (influent and effluent) per month for VOCs.
Permit Renewal Applications	0.2	Applic.	$5,000	$1,000		Discharge permit renewal application every 5 years @ $5,000/application.
Outfall Inspection/Clearing	1	Year	$500	$500		
Administrative Costs	1	Year	$10,000	$10,000		Includes reporting.
Subtotal					$90,700	
SUB-TOTAL					$524,400	
CONTINGENCY (20%)					$104,900	
PRESENT WORTH OF ANNUAL O & M OVER 30-YEAR PERIOD					$1,125,500	Assumes a discount rate of 7 percent.
TOTAL PRESENT WORTH COST WITH CONTINGENCY**					$1,754,800	

* Includes treatment of both Upper Clay and Upper Sand units.
** -30% to +50% accuracy range.

Table 10
Summary of Estimated Costs - Remedial Alternatives for Building I-1-23 VOC Source Area

ALTERNATIVE	CAPITAL COST*	ANNUAL OPERATION & MAINTENANCE COST	PRESENT WORTH COST OVER 30 YEARS**
Permeable reactive barrier	$1,333,940	$36,000	$1,807,440
Groundwater extraction and treatment	$262,000	$90,700	$1,439,900
Excavation of shallow contaminated soil and groundwater extraction and treatment	$524,400	$90,700	$1,754,800
Multi-phase extraction for Upper Clay and Upper Sand units	$620,050	$313,100	$1,310,150***
Multi-phase extraction for Upper Clay and Upper Sand units followed by groundwater extraction and treatment	$714,550	$313,100 (years 1, 2) $90,700 (years 2-30)	$2,322,150

Notes:
1. Refer to Tables 5 through 8 for a detailed breakdown of the estimates.
2. All costs are in year 2001 dollars.

* Base cost, does not include 20 percent contingency.
** Includes a 20 percent capital cost contingency.
*** Present worth cost for 2 years only.

Table 11
Comparison of Remedial Alternatives for Building I-1-23 Area with Superfund Selection-of-Remedy Criteria
Protection of Human Health and the Environment

ALTERNATIVE	REDUCTION OF PRESENT AND FUTURE RISKS	MEANS OF REDUCING RISK LEVELS	OVERALL DEGREE OF PROTECTION
Groundwater extraction and treatment	The human health risk assessment previously prepared for this site and approved by the USEPA concluded there are presently no unacceptable health risks associated with exposure to contaminated groundwater. Potential future health risks are reduced by removing CVOCs from the groundwater.	CVOCs are removed by adsorption onto activated carbon.	Provides improvement of an already acceptable level of protection by effectively capturing and removing dissolved CVOCs in groundwater within and near the CVOC source area.
Permeable reactive barrier (PRB)	The human health risk assessment previously prepared for this site and approved by the USEPA concluded there are presently no unacceptable health risks associated with exposure to contaminated groundwater. Potential future health risks are reduced by *in situ* destruction of CVOCs.	CVOCs are destroyed via chemical reactions.	Provides improvement of an already acceptable level of protection by *in situ* destruction of dissolved CVOCs in groundwater flow from the CVOC source area.

Table 11 (Continued)
Comparison of Remedial Alternatives for Building I-1-23 Area with Superfund Selection-of-Remedy Criteria
Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)

ALTERNATIVE	COMPLIANCE WITH ARARs
Groundwater extraction and treatment	This alternative would remediate the CVOC plume associated with the I-1-23 source area to concentrations approaching the Cleanup Standards (MCLs) in a shorter time and over broader areas of the site than any other alternative considered or evaluated. Compliance with all other ARARs identified in the Focused Feasibility Study - Revision 1 (January 2000) is expected to be achievable.
Permeable reactive barrier (PRB)	This alternative would also remediate the CVOC plume associated with the I-1-23 source area to concentrations approaching the Cleanup Standards in a relatively short time, although the rate of improvement would be somewhat slower than with the groundwater extraction and treatment alternative. Compliance with all other ARARs identified in the Focused Feasibility Study - Revision 1 (January 2000) is expected to be achievable.

Table 11 (Continued)
Comparison of Remedial Alternatives for Building I-1-23 Area with Superfund Selection-of-Remedy Criteria
Long-term Effectiveness and Permanence

ALTERNATIVE	MAGNITUDE OF RESIDUAL RISK	NATURE OF LONG-TERM MANAGEMENT	POTENTIAL FOR FUTURE EXPOSURE	NEED FOR REPLACEMENT	LONG-TERM RELIABILITY
Groundwater extraction and treatment	Very low risk from residual CVOCs remaining in treated groundwater discharge to surface water due to negligible CVOC concentrations. However, spent activated carbon from treatment system would require handling and off-site disposal or regeneration.	Operation, maintenance, and monitoring of groundwater extraction and treatment system required as long as CVOC source material remains.	Potential exposures to VOCs in extracted groundwater and spent carbon remain the same over the operational life of the system. No other future exposures would occur.	Treatment system components may require replacement.	Highly reliable for capturing source area contaminants, effectively treating extracted groundwater, and remediating VOC plumes, especially at sites where natural attenuation processes are active.
Permeable reactive barrier (PRB)	No residual risks would exist since all treatment occurs *in situ* and there are no potential exposures to low CVOC concentrations remaining in groundwater after passing through the PRB.	No operating requirements or costs after PRB is constructed. Only long-term monitoring of physical and treatment performance is expected. The need for periodic maintenance of PRB is uncertain due to lack of long-term full-scale PRB experience.	No future exposure risks would exist since all treatment occurs *in situ* and there are no potential exposures to low CVOC concentrations remaining in groundwater after passing through the PRB.	Replacement of PRB is unlikely to be required.	Several full-scale PRBs have proven to be reliable over several years. However, the original PRB was installed at a site in 1994, and therefore long-term reliability is uncertain.

Table 11 (Continued)
Comparison of Remedial Alternatives for Building I-1-23 Area with Superfund Selection-of-Remedy Criteria
Reduction of Toxicity, Mobility, and Volume

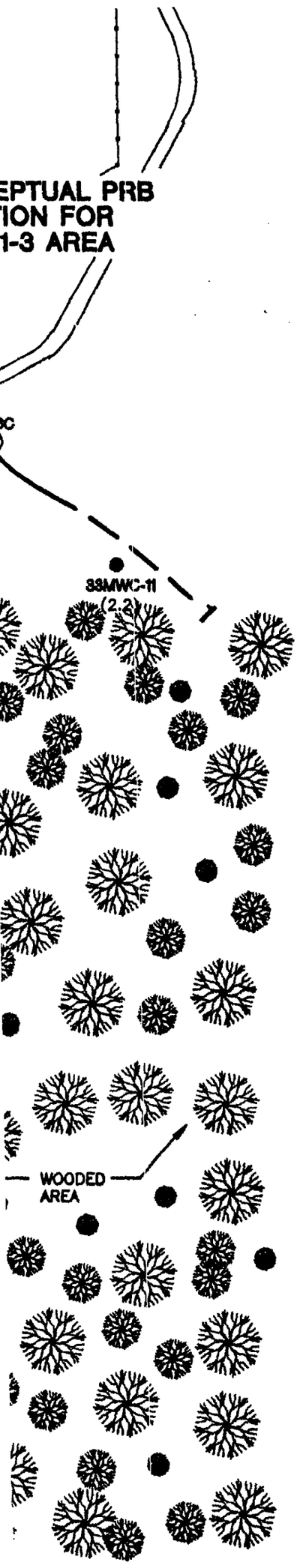
ALTERNATIVE	REDUCTION IN TOXICITY, MOBILITY, AND VOLUME	RESIDUALS REMAINING AFTER TREATMENT
Groundwater extraction and treatment	Effectively reduces CVOC mass and mobility in the aquifer by removing dissolved CVOCs with extracted groundwater at source area. CVOCs transferred to activated carbon in treatment system would persist unless spent carbon is thermally regenerated.	Spent activated carbon containing CVOCs would require disposal or regeneration. CVOC concentrations in groundwater following treatment would be sufficiently low to allow discharge to surface water following permit application approval.
Permeable reactive barrier (PRB)	Toxicity, mobility, and mass of CVOCs would be substantially reduced by destruction via chemical reactions within the PRB. Gaseous reaction end-products include ethene, ethane, and carbon dioxide.	CVOC concentrations in groundwater exiting the PRB would be sufficiently low to allow natural attenuation processes to effectively restore groundwater quality downgradient of the PRB.

Table 11 (Continued)
Comparison of Remedial Alternatives for Building I-1-23 Area with Superfund Selection-of-Remedy Criteria
Adverse Impacts During Remediation (Short-term Effectiveness)

ALTERNATIVE	COMMUNITY PROTECTION	WORKER PROTECTION	ENVIRONMENTAL IMPACTS	TIME REQUIRED FOR REMEDIATION
Groundwater extraction and treatment	No potential hazards or health exposures expected due to construction or operation. All work is within a secure-access manufacturing plant.	Potential exposure to contaminated groundwater, soil (drilling cuttings), and CVOCs in spent activated carbon exists during construction and operation phases. Hazards can be adequately addressed using standard personal protective equipment and safety procedures.	CVOC concentrations in groundwater following treatment would be sufficiently low to prevent impacts at the point of discharge.	Operation of extraction and treatment system required as long as CVOC source material remains in soil. Time frames of many decades are possible.
Permeable reactive barrier (PRB)	No potential hazards or health exposures expected due to construction or operation. All work is within a secure-access manufacturing plant.	Potential exposure to contaminated soil from PRB trench excavation exists. Hazards can be adequately addressed using standard personal protective equipment and safety procedures. No potential worker exposures following completion of construction phase.	No potential impacts likely as long as PRB functions properly.	PRB must provide effective treatment as long as CVOC source material remains in soil. Time frames of many decades are possible.

Table 11 (Continued)
Comparison of Remedial Alternatives for Building I-1-23 Area with Superfund Selection-of-Remedy Criteria
Implementability

ALTERNATIVE	IMPLEMENTABILITY	RELIABILITY	CONSTRUCTABILITY	AGENCY APPROVAL AND COORDINATION
Groundwater extraction and treatment	Easy to implement.	Highly reliable remediation effectiveness and physical systems.	Standard technology with numerous vendors and contractors capable of construction. Easily constructable at this site.	Technology is standard and widely accepted by regulatory agencies. Agency approval of discharge permit application required for treated groundwater discharge to surface water. Approval of U.S. F&WS required if treated effluent discharged to local sanitary sewer.
Permeable reactive barrier (PRB)	Expected to be implementable based on preliminary engineering assessment and feasibility review by PRB technology contractor. Patented technology with limited number of contractors with patent implementation rights. Site use licensing required by patent holder.	Several full-scale PRBs have proved to be reliable over several years. Therefore, short-term reliability is likely. However, the original PRB was installed at a site in 1994, and therefore long-term reliability is uncertain.	Readily constructable at I-1-2/I-1-3 location due to relatively thin and shallow Upper Sand unit. Also constructable at I-1-23 location, although construction methods more challenging due to thicker and deeper Upper Sand unit.	Many full-scale PRBs have been approved by USEPA and state agencies over the last several years. USEPA guidance documents recognize PRBs as a promising innovative solution for groundwater remediation at sites with recalcitrant CVOC sources. The IEPA has expressed support for use of PRBs at this site.



NOTES

1. SOURCE: BASE MAP FROM "1998 TCE INVESTIGATION, WORKPLAN AND PILOT STUDY FOR THE PCB OPERABLE UNIT AT THE CRAB ORCHARD NATIONAL WILDLIFE REFUGE SUPERFUND SITE, MARION, ILLINOIS" REV. 1, MAY 1998, PREPARED BY FLUOR DANIEL GTI.
2. * INDICATES WELL IS SCREENED ACROSS THE UPPER SAND UNIT. OTHER BORINGS AND MONITORING WELLS ARE COMPLETED IN THE UPPER CLAY AND/OR THE UPPERMOST PORTION OF THE UPPER SAND UNIT.
3. CVOC DATA FOR MONOITORING WELLS 33MWC-07, 33MWC-08, 33MWC-09, 33MWC-13, 33MWC-21, 33MWC-24, 33MWC-27, 33MWC-30, AND 33MWC-42 THROUGH 33MWC-49, AND FROM ALL "SB-" DESIGNATED BORINGS ARE FROM THE FALL 2000 INVESTIGATION. CVOC DATA FOR THE REMAINING WELLS ARE FROM THE DECEMBER 1998 SAMPLING EVENT. CVOC DATA FROM THE "GP-" DESIGNATED GEOPROBE LOCATIONS ARE FROM MAY THROUGH JULY 1998.
4. TOTAL CVOC VALUE REPORTED AT 33MWC-24 INCLUDES 22,000 ug/L OF TENTATIVELY IDENTIFIED COMPOUND, 1,1,2-TRICHLORO-1,2,2-ETHANE.
5. LOCATION OF ALL WOODED AREAS NOT SHOWN.
6. THIS FIGURE ADAPTED FROM FIGURE NO. 5-1 IN PRELIMINARY DESIGN REPORT - REVISION 0, ISSUED MAY 7, 2001.

0 200' 400'

SCALE: 1"=200'

NO.	BY	DATE	REVISION	APP'D.
2.				
1.				
0.				

PROJECT:

CRAB ORCHARD NWR - PCB O.U.
MARION, ILLINOIS

SHEET TITLE:

CONCEPTUAL PRB LOCATIONS

DRAWN BY: SIEWERTD	SCALE: 1"=200'	PROJ. NO. 4781.07
CHECKED BY: TEG		FILE NO.47810727PRB.DWG
APPROVED BY: TEG	DATE PRINTED: SEP 25 2001	FIGURE 1
DATE: SEPTEMBER 2001		

RMT.
744 Heartland Trail
Madison, WI 53717-1934
P.O. Box 8923
Madison, WI 53708-8923
Phone: 608/831-4444

Revision Level

Drawing Name: J:\04781\07\478107109.dwg
Operator Name: SIEWERTD
Scale: 1"=1'
Dwg Size: 301180 Bytes
Plot Date: Wednesday, September 19, 2001
Plot Time: 11:50.59 AM
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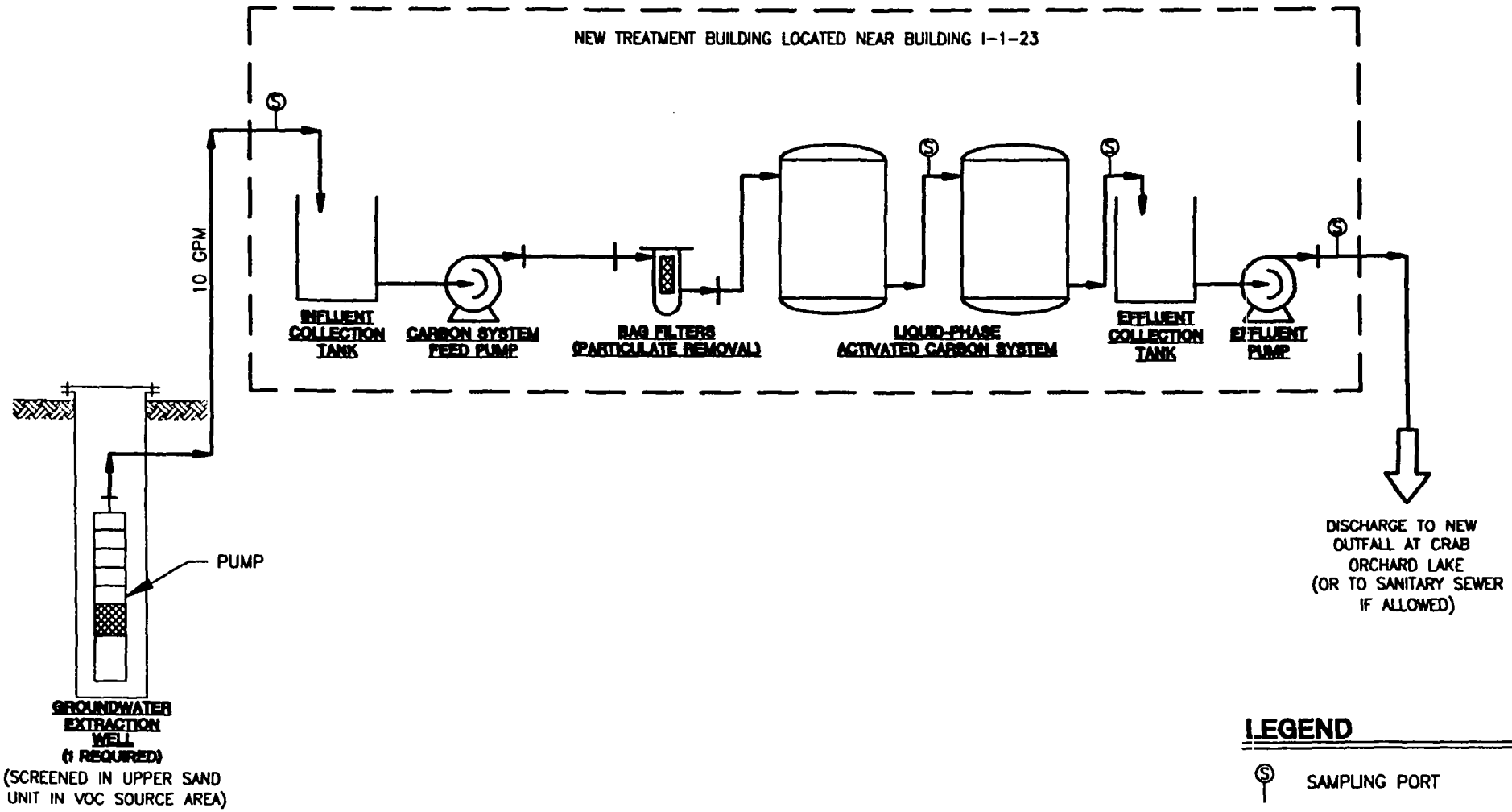
Attached Image's: No images attached



RMT INC.

PROCESS FLOW DIAGRAM
GROUNDWATER EXTRACTION & TREATMENT SYSTEM
FOR BUILDING I-1-23 VOC SOURCE AREA

CRAB ORCHARD NWR PCB O.U.
MARION, ILLINOIS

DRAWN BY:	SIEWERTD
APPROVED BY:	TEG
PROJECT NO.	04781.07
FILE NO.	478107109.DWG
DATE:	SEPTEMBER 2001

FIGURE 2

Attachment 1
Building I-1-23 Area
Model Run Figures for Cases 8 and 9

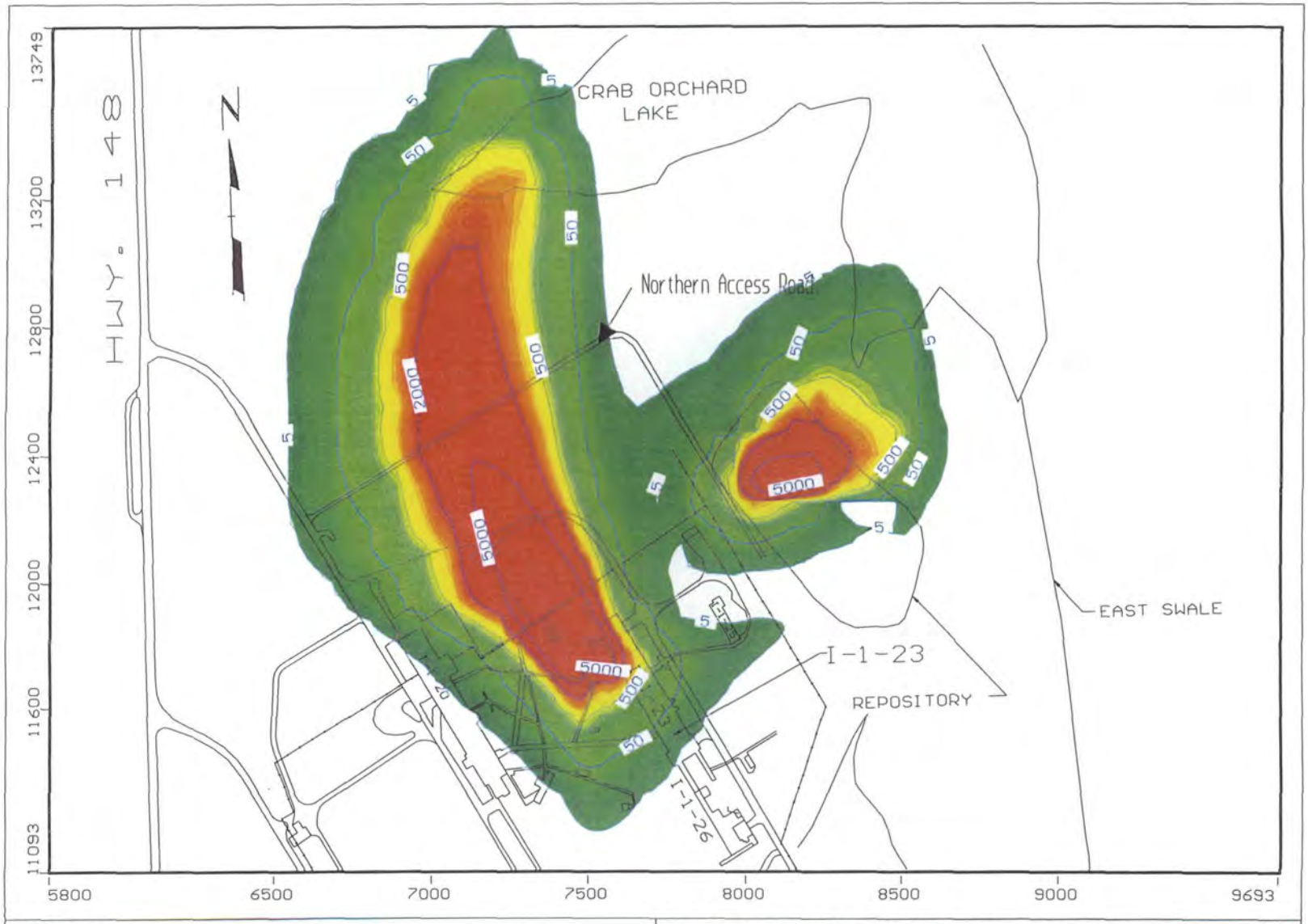
Building I-1-23 Area
Case 8

Years 0 to 2: MPE wells, SVE wells, and horizontal groundwater extraction wells in Upper Sand operated for 2 years, then all shut down. 39% VOC removal from Upper Sand; 22.2% VOC removal from overall source area.

Years 2 to 10: One vertical extraction well pumping from Upper Sand in source area at 10 gpm.

Year 10 and beyond: MNA only.

Model Run No. 529



RMT, Inc.
Project: CRAB ORCHARD Crab520
Description: Current Conditions Simul.
Modeller: TCE,ppb t=0 yr
22 Aug 01

Visual MODFLOW v.2.8.2, (C) 1995-1999
Waterloo Hydrogeologic, Inc.
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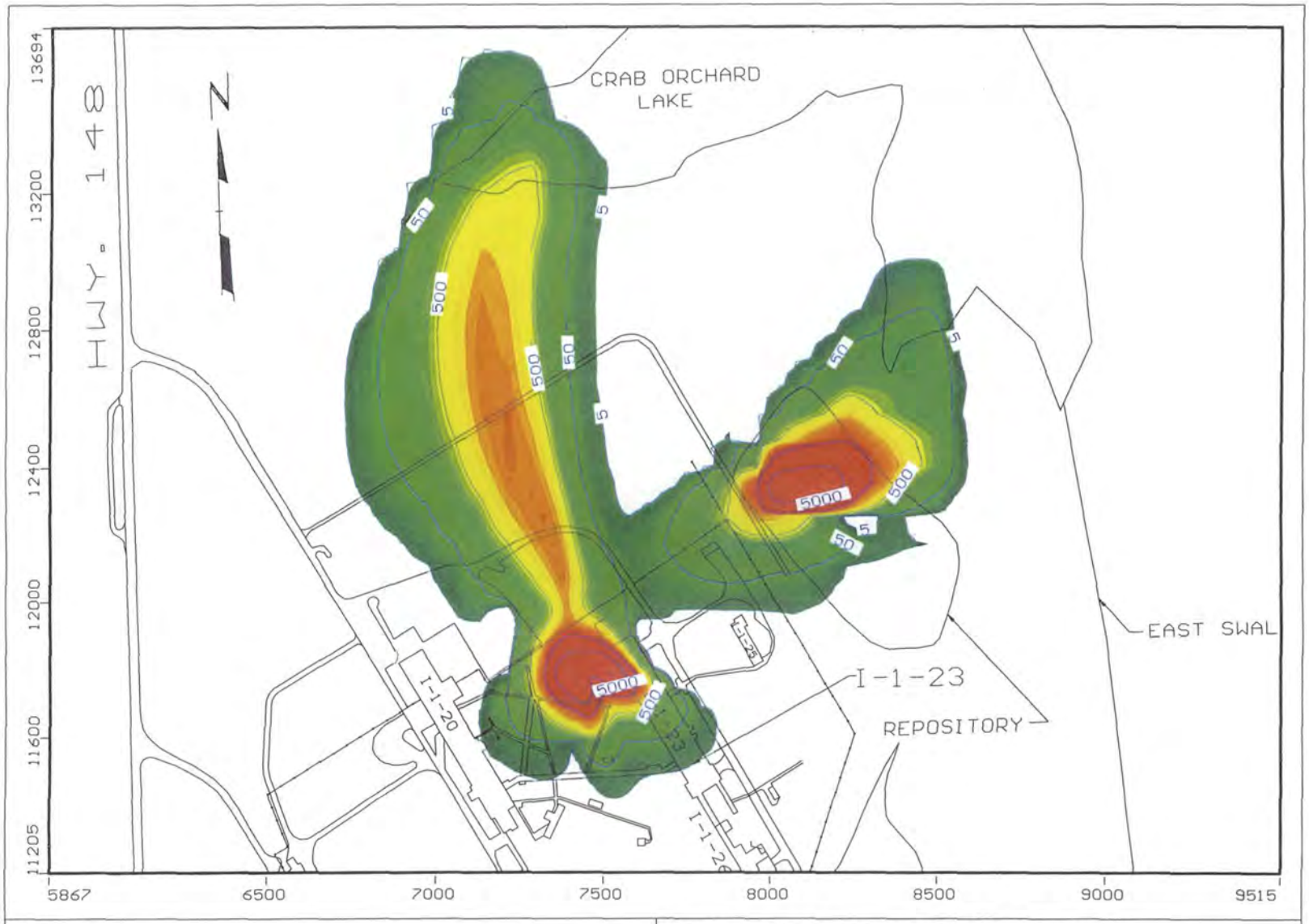

RMT, Inc.
Project: CRAB ORCHARD Crab529
Description: MPE/SVE 2yr;pump 2+8 yr
Modeller: TCE,ppb t=5 years
9 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
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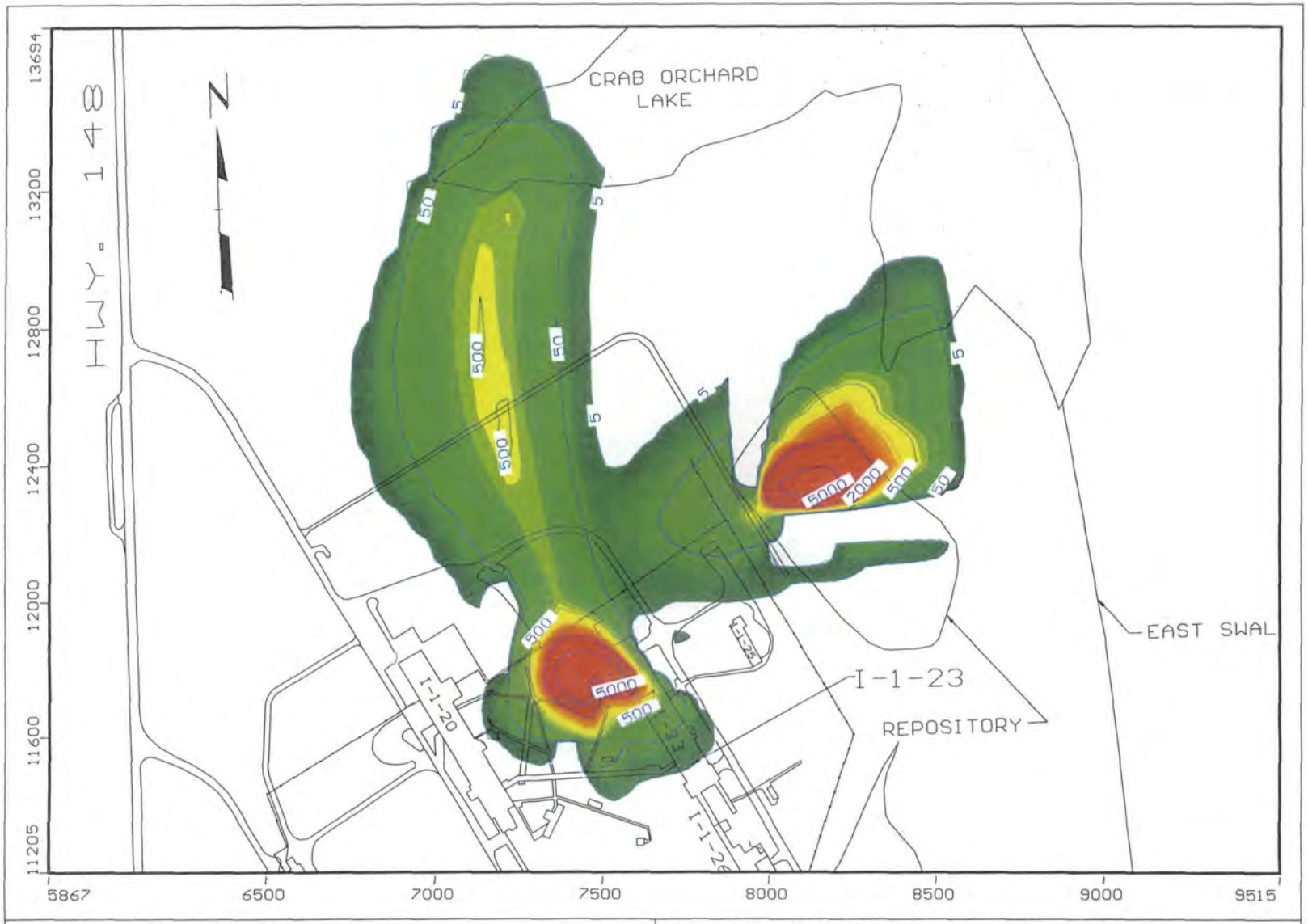
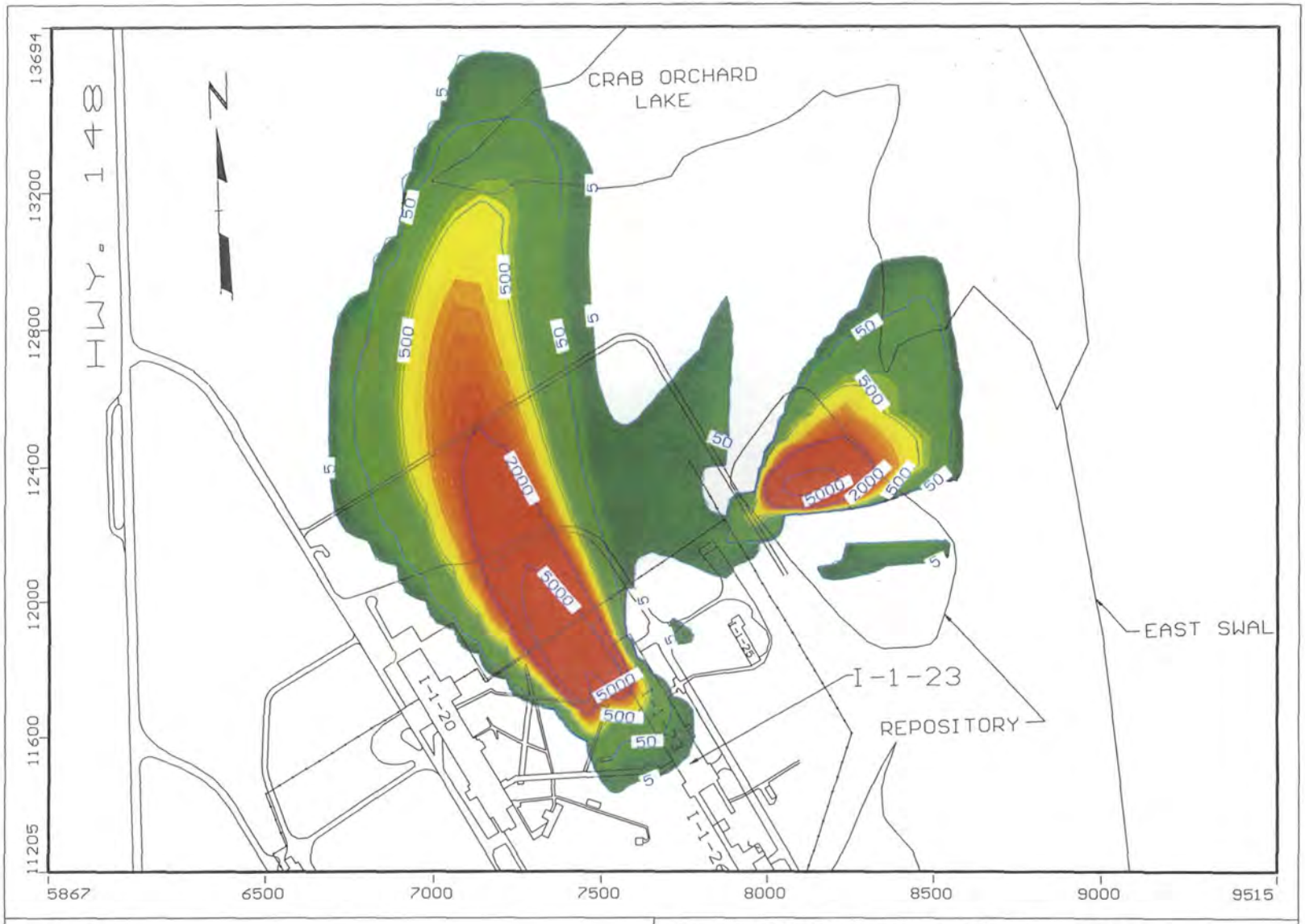


RMT, Inc.
Project: CRAB ORCHARD Crab529
Description: MPE/SVE 2yr;pump 2+8 yr
Modeller: TCE,ppb t=10 years
9 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 119 NR: 135 NL: 5
Current Layer: 2



RMT, Inc.
Project: CRAB ORCHARD Crab529
Description: MPE/SVE 2yr;pump 2+8 yr
Modeller: TCE,ppb t=20 years
9 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995-1999
Waterloo Hydrogeologic, Inc.
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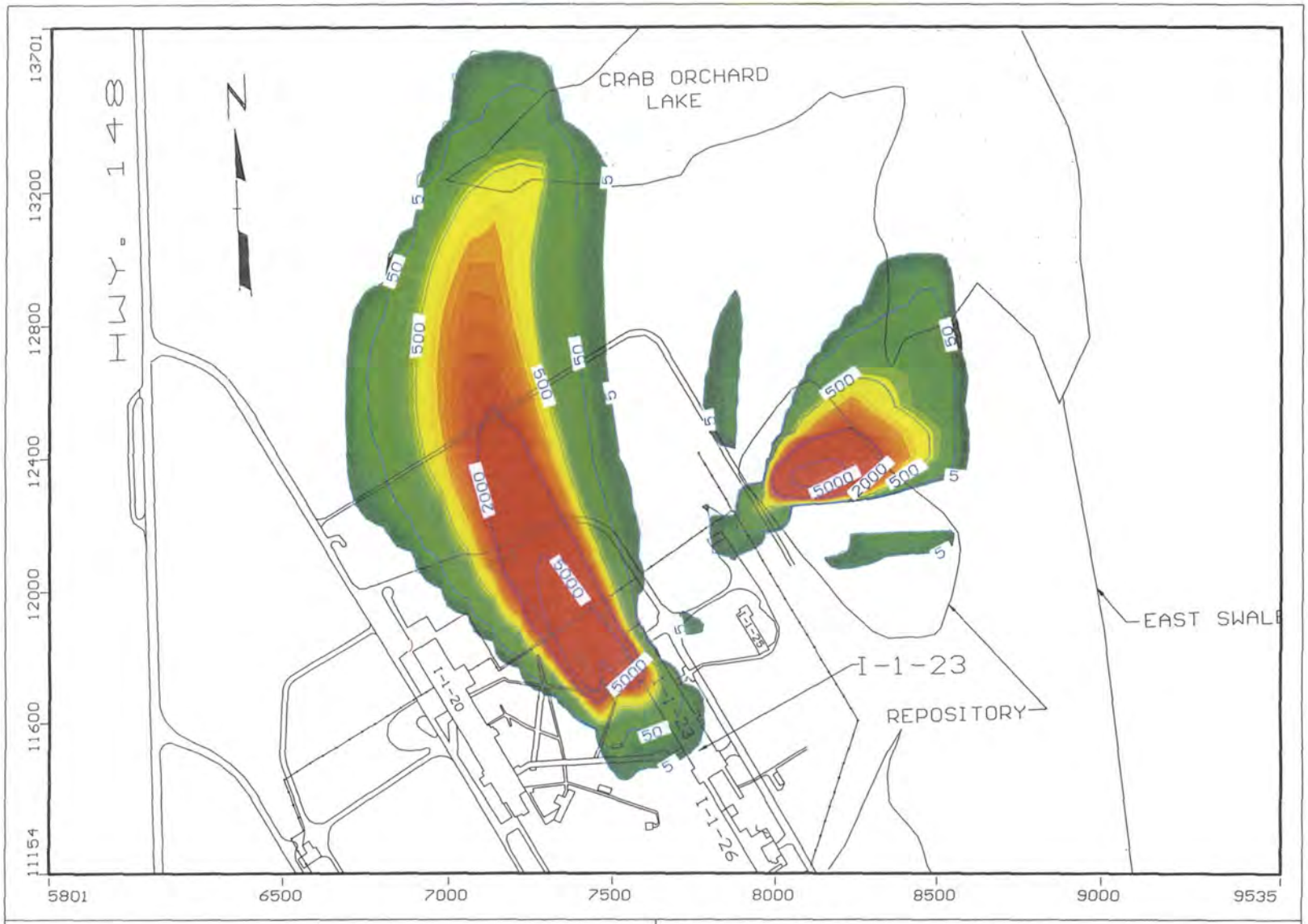
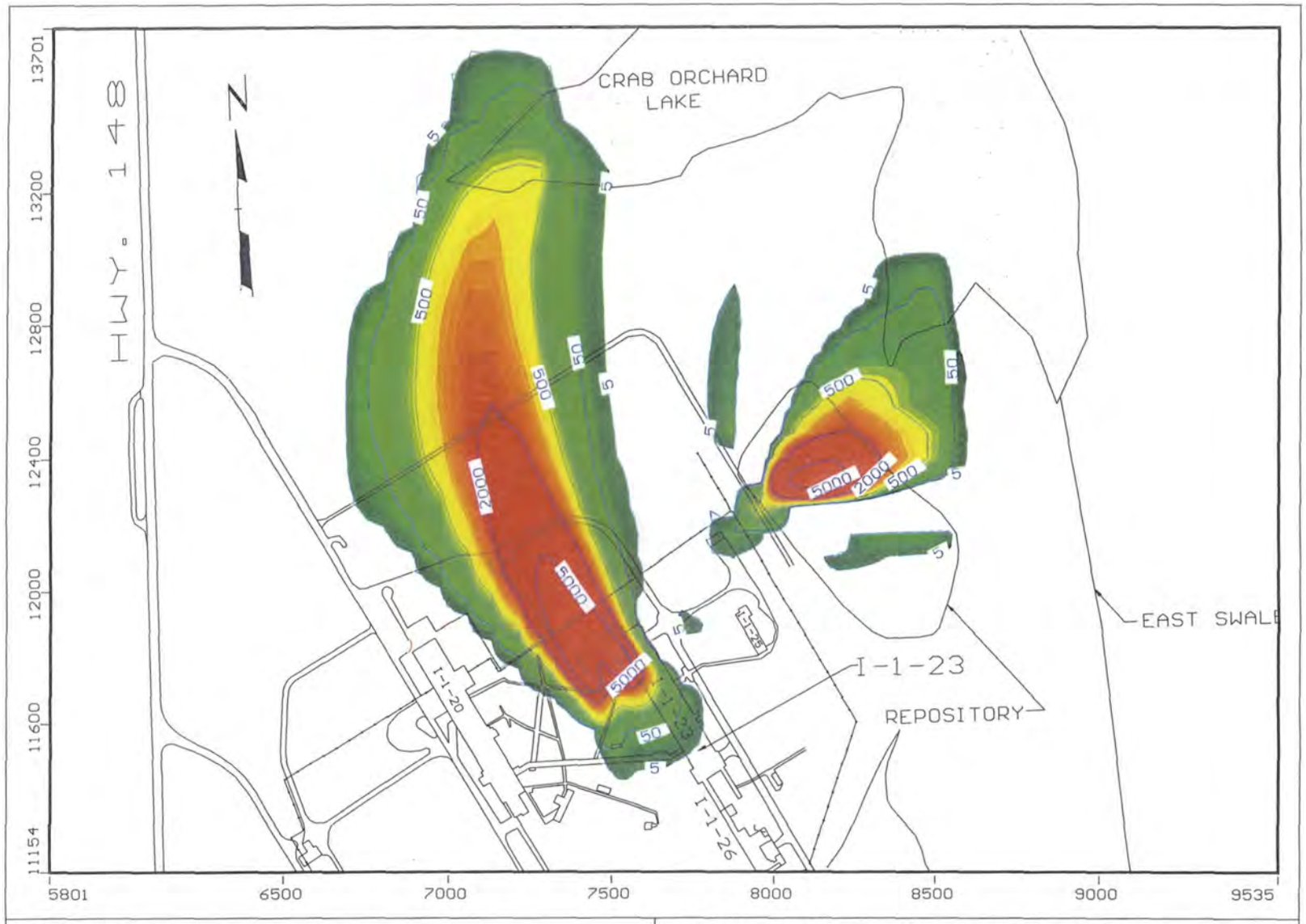
Current Layer: 2



RMT, Inc.
Project: CRAB ORCHARD Crab529b
Description: MPE/SVE 2yr;pump 2+8 yr
Modeller: TCE,ppb t=30 years
9 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995-1999
Waterloo Hydrogeologic, Inc.
NC: 119 NR: 135 NL: 5
Current Layer: 2



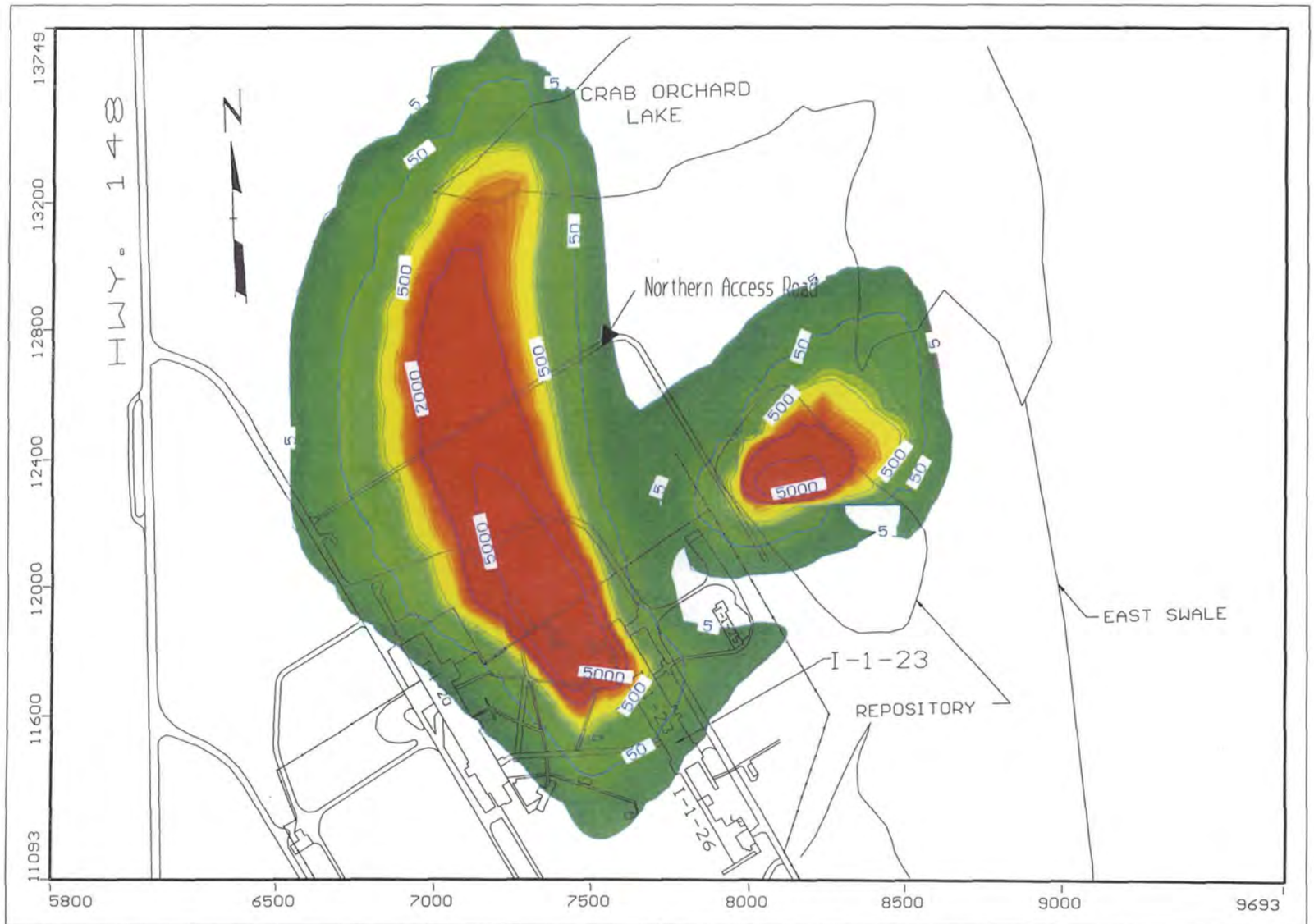
RMT, Inc.
Project: CRAB ORCHARD Crab529b
Description: MPE/SVE 2yr;pump 2+8 yr
Modeller: TCE,ppb t=40 years
9 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 119 NR: 135 NL: 5
Current Layer: 2

Building I-1-23 Area
Case 9

MPE with pneumatic fracturing in Upper Clay. MPE wells, SVE wells, and horizontal groundwater extraction wells in Upper Sand. All operated for 2 years, then shut down. 43% VOC removal from overall source area. No PRB.

Model Run No. 531



RMT, Inc.
Project: CRAB ORCHARD Crab520
Description: Current Conditions Simul.
Modeller: TCE,ppb t=0 yr
22 Aug 01

Visual MODFLOW v.2.8.2, (C) 1995-1999
Waterloo Hydrogeologic, Inc.
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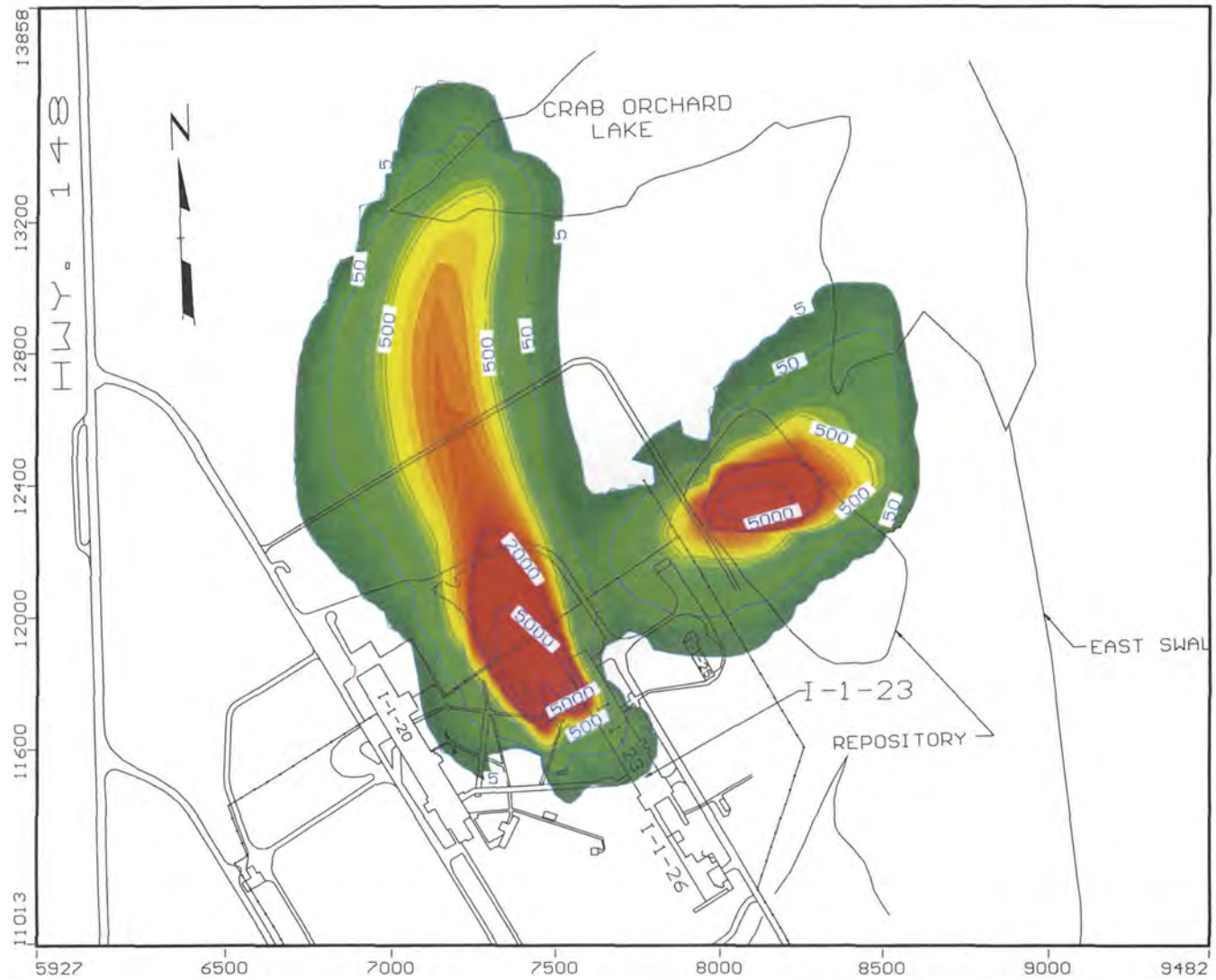
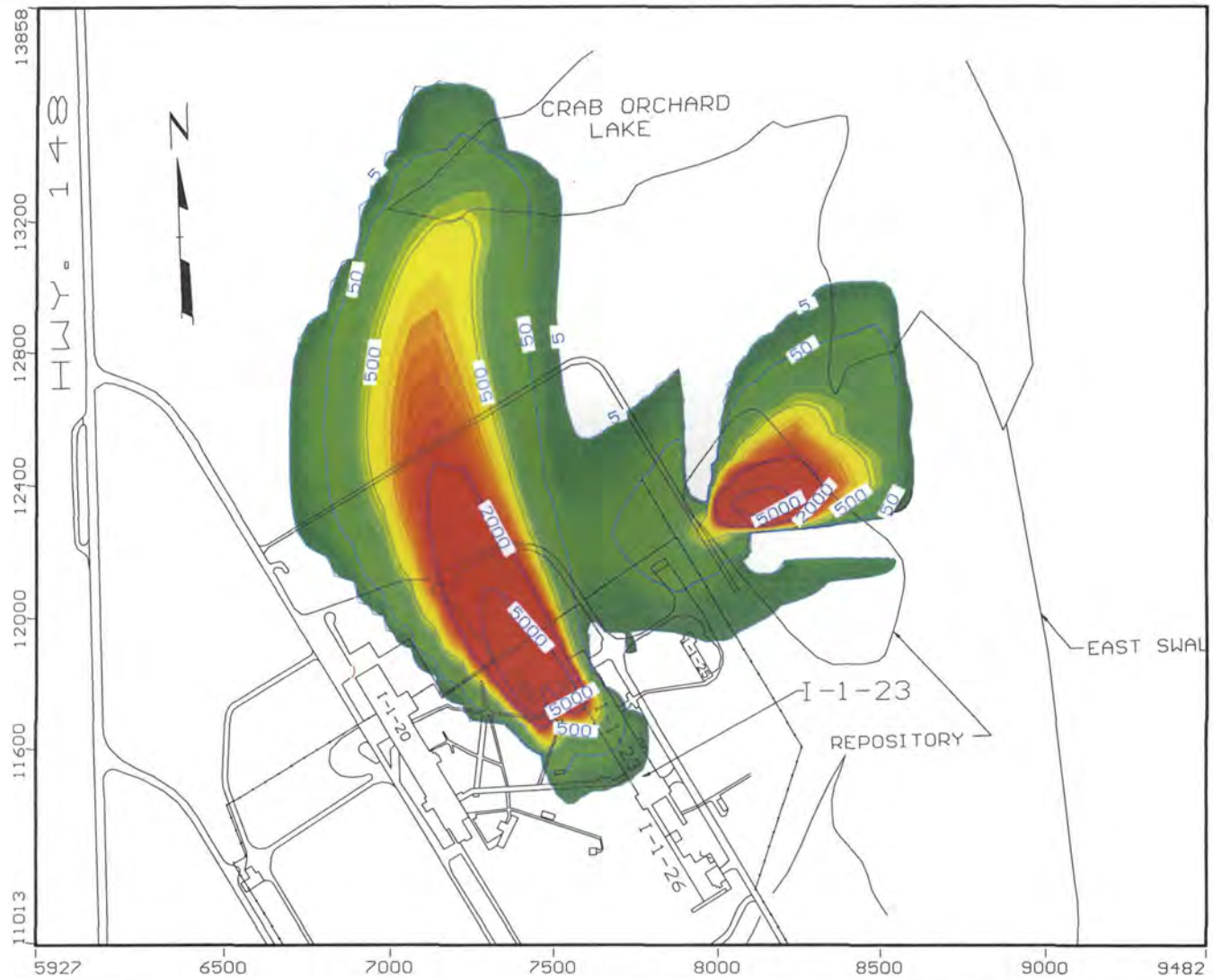
Current Layer: 2



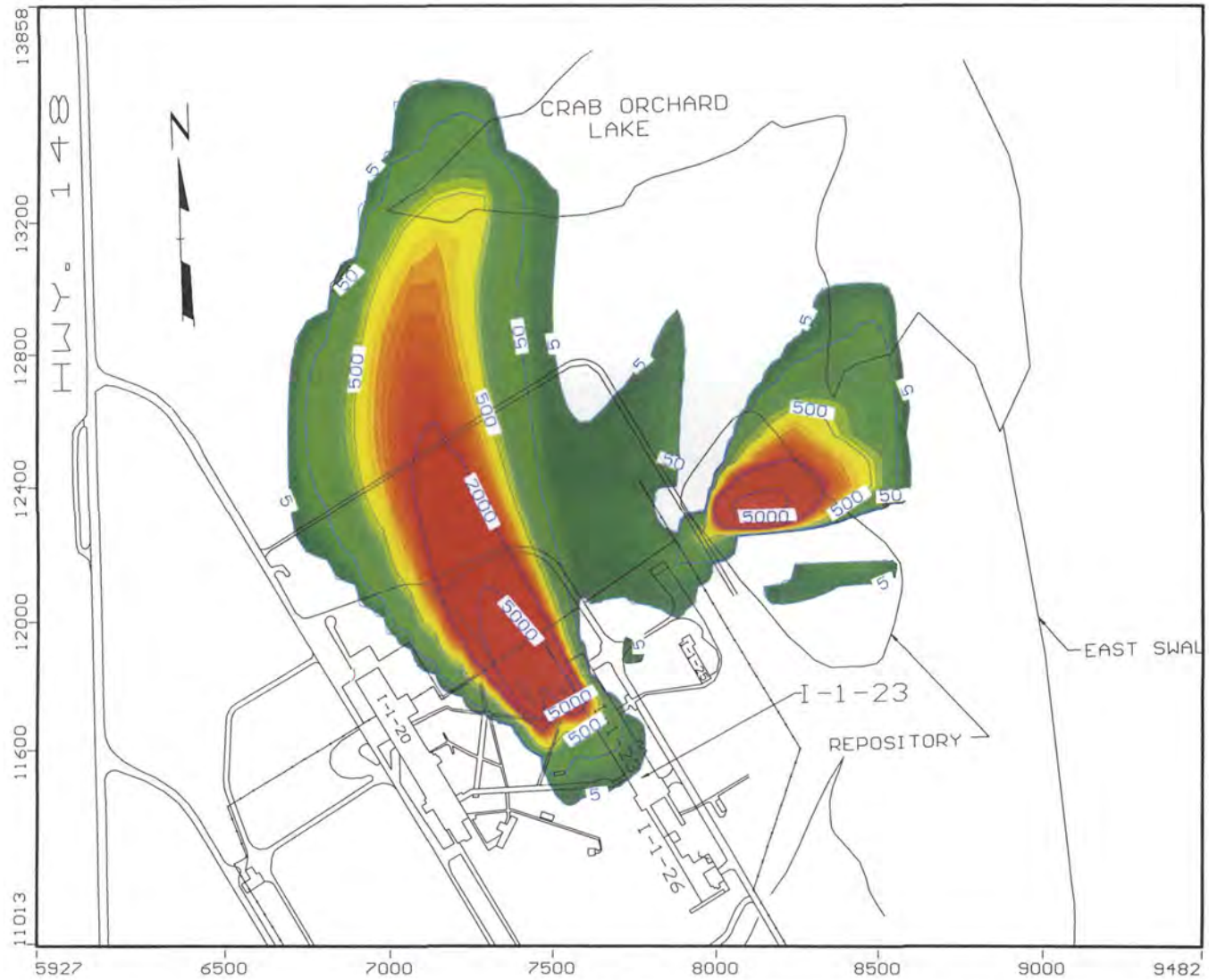
RMT, Inc.
Project: CRAB ORCHARD Crab531
Description: MPE w/Pneu.Fracture,UC,US
Modeller: TCE,ppb t=5 yr
11 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 5
Current Layer: 2



RMT, Inc.
Project: CRAB ORCHARD Crab531
Description: MPE w/Pneu.Fracture,UC,US
Modeller: TCE,ppb t=10 yr
11 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 5
Current Layer: 2



RMT, Inc.
Project: CRAB ORCHARD Crab531
Description: MPE w/Pneu.Fracture,UC,US
Modeller: TCE,ppb t=20 yr
11 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 113 NR: 127 NL: 5
Current Layer: 2

Attachment 2
Proposal from EnviroMetal Technologies for PRB at Building I-1-23 Area

envirometal
technologies
inc.

745 Bridge St. W., Suite 7
Waterloo, Ontario
Canada N2V 2G6
Tel (519) 746-2204
Fax (519) 746-2209

To:	Jack Anderson
Company:	RMT, Inc.
Fax:	608-831-3334
Date:	29 August 2001
From:	**Andrzej Przepiora, Hydrogeologist, Ext. 234**
Email:	**aprzepiora@eti.ca**
Re:	*31617C.88*
Pages:	1 of 15

Dear Jack:

Attached is the requested cost estimate for implementation of the iron PRB technology at the Building I-1-23 Area, Crab Orchard NWR, Marion, IL. Note that we have used an iron unit cost of $450/ton to be consistent with previous estimates we provided for the site, however, the iron cost may be closer to $400/ton delivered to Marion, IL from Chicago. We can supply you with site-specific iron cost quote from an iron supplier, if needed. Please contact us, if you have any questions regarding this proposal.

Regards,

Andrzej Przepiora

Original To Follow: Mail☐ Courier☐ No☑

This transmission contains information that may contain confidential and/or legally privileged. It is intended for use only by the person to whom it is directed. If you have received this in error, please notify us by telephone immediately. Thank you.

enviro**metal**
technologies
inc.

29 August 2001

Jack Anderson
RMT, Inc.
744 Heartland Trail
Madison, WI 53717-1934

Reference: ***In-Situ* Application of the EnviroMetal Process in the Building I-1-23 Area, Crab Orchard NWR, Marion, IL – 31617C.88**

Dear Jack:

Thank you for your interest in using the EnviroMetal Process for remediation of contaminated groundwater in the Building I-1-23 Area, Crab Orchard NWR, Marion, IL. We believe the iron technology has the potential to provide a cost-effective remedy for treatment of the chlorinated VOCs identified in groundwater at the site. Attached are our initial recommendations regarding technology application. We would be happy to visit your company or the client and provide you with an update of our technology, as well as discuss the site in more detail.

Sincerely,

EnviroMetal Technologies Inc.

Andrzej Przepiora, M.Sc.
Hydrogeologist

Stephanie O'Hannesin, M.Sc.
Senior Project Director

Encl.

745 Bridge St. West, Suite 7
Waterloo, Ontario
Canada N2V 2G6
Tel: (519) 746-2204
Fax: (519) 746-2209

enviromental
technologies
inc.

IN-SITU APPLICATION OF THE ENVIROMETAL PROCESS IN THE BUILDING I-1-23 AREA, CRAB ORCHARD NWR, MARION, IL

Prepared For:

RMT, Inc.
744 Heartland Trail
Madison, WI
USA 53717-1934

Prepared By:

EnviroMetal Technologies Inc.
745 Bridge St. West, Suite 7
Waterloo, Ontario
Canada N2V 2G6

ETI Reference: 31617C.88

29 August 2001

1.0 INTRODUCTION

EnviroMetal Technologies Inc. (ETI) is pleased to provide the following preliminary conceptual design and revised cost estimate for the installation of an *in-situ* permeable reactive barrier (PRB) in the Building I-1-23 Area, Crab Orchard NWR, Marion, IL. ETI received preliminary water quality data and hydrogeologic information for the site from RMT on 28 August 2001. From our initial review of the data, we are confident that the EnviroMetal Process (metal enhanced reductive dehalogenation) will degrade the trichloroethene (TCE), cis 1,2-dichloroethene (cDCE) and associated breakdown products present in the site groundwater.

Since 1994, 61 PRBs containing granular iron have been installed to remediate VOCs. There are currently 40 full-scale *in-situ* systems removing VOCs from groundwater, in addition to 21 pilot-scale systems that have been installed to provide "proof of concept" data and more recently to demonstrate innovative construction methods.

ETI is typically retained by site owners, environmental consultants, or government agencies to assist in the design and implementation of PRBs for treatment of VOCs. ETI currently has a staff of five professionals who assist in all phases of design, installation and evaluation of PRBs. Senior staff at ETI have been involved with the technology from the initial development and are amongst the most experienced professionals in the application of PRBs.

2.0 RECOMMENDED APPROACH

ETI's involvement in a project can typically be divided into four phases:

Phase I:	Data Review
Phase II:	Bench-Scale Testing (If Required)
Phase III:	Assistance with Field Design and Implementation
Phase IV:	Performance Monitoring

2.1 Phase I: Data Review

The purpose of this phase is to review available site hydrogeologic, geochemical and geotechnical data as related to the application of the EnviroMetal Process. The concentration

and distribution of organic compounds, inorganic groundwater chemistry and the hydrogeology of the site are examined to determine the feasibility and possible PRB configurations. When considering *in-situ* treatment, particular attention must be given to:

- depth and fluctuations of the water table
- depth to the top and bottom of the contaminated zone
- spatial variation in VOC and inorganic concentrations
- lateral boundaries of the contaminated zone
- flow direction
- groundwater velocity
- hydraulic conductivity
- geotechnical data as they pertain to "constructability" issues

Based on a review of the available data for the site, ETI can work with the project team to identify any data gaps and if necessary assist in the development of a plan for additional data collection. ETI has been involved in the design of numerous PRBs and can provide insight from our experience on these designs.

We encourage that the data review be accompanied by a site visit and meeting in order to obtain additional information regarding site characteristics, possible construction constraints and regulatory requirements. We could also discuss the use of groundwater modeling to facilitate design of the field-scale PRB. A presentation regarding the technology could also be made at this time to the involved parties. We have found that a site visit greatly facilitates project communication and co-ordination. A cost estimate for Phase I is given in Table 1.

2.2 Phase II: Bench-Scale Testing (If Required)

Phase II involves bench-scale testing of the EnviroMetal Process using groundwater from the site and commercially available granular iron material. The bench-scale test typically involves a laboratory column test to establish site-specific VOC degradation rates under flowing conditions. This test enables us to predict system performance and provide data for field design.

The degradation rates determined from the column tests are used to determine the required residence time in the granular iron. Using the residence time and the expected groundwater flow rate, the flow-through thickness of the PRB is determined. The laboratory column test

also includes inorganic sampling of column influent and effluent. This provides information concerning potential mineral precipitation in the reactive material caused by changing redox potential (Eh) and pH conditions. The potential for mineral precipitation must be considered in the field design.

The standard laboratory protocols and measurement methods are designed to provide high quality data at minimal cost. The column is made of Plexiglas™ with an inner diameter of 1.5 inches and a length of either 1.6 ft or 3.2 ft. Groundwater from the site is supplied to the influent end of the column at a constant flow velocity using a laboratory pump. The flow velocity is selected to approximate the groundwater velocity expected in a field-scale PRB. This flow velocity is determined through consultation with the client. VOC concentrations are measured along the column until a steady-state profile is achieved. Eh and pH profiles are measured periodically during the test. Inorganic parameters (major cations, anions, and alkalinity) are monitored to help predict possible mineral precipitation. If necessary, other chemical parameters relevant to a particular site and/or proposed construction method can also be measured.

The water shipped from the site should have characteristics (VOC concentrations and inorganic chemistry) similar to the groundwater expected to enter a field-scale PRB. Shipping instructions are provided by ETI once the project proceeds.

The report issued at the conclusion of the laboratory tests will include:

- results of all chemical analyses
- calculated degradation rates
- summary tables of major results
- graphs showing degradation profiles

Estimated residence time requirements for the field application will also be calculated, based on laboratory results and VOC design influent concentrations and effluent maximum contaminant levels (MCLs).

2.3 Phase III: Assistance with Field Design and Implementation

ETI's typical role in Phase III is to act as a design consultant. That is, the lead consultant would have responsibility for the overall program (completion of design documents, obtaining

construction permits, general construction oversight and co-ordination, implementation of monitoring program, etc.). ETI would assist in these tasks, and bill on a time and materials basis for this work. Particular tasks that involve ETI staff include:

- determination of residence time requirements for VOC treatment
- consultation on system design, in particular, iron PRB dimensions
- consultation on system modeling
- assistance in selecting construction method
- specification/procurement/quality assurance of reactive material
- assistance during field installation
- development of a performance monitoring program

Typically several design scenarios (varying depth, length, treatment levels) are evaluated during the design. ETI has developed a degradation model to simulate the EnviroMetal Process and can utilize this model to predict the PRB performance for various design scenarios.

ETI has several standard specifications for granular iron quality, granular iron handling and construction verification. ETI can either prepare these specification sections or provide the information to the site consultant. ETI can also provide overall assistance with preparing the specification and provide input based on past experience preparing specifications. We have also been involved in construction contractor bid evaluation.

Site construction management is normally handled by engineering or contracting firms (or, your organization if you provide construction services). ETI retains the right to have on-site representation during the installation phase of the project.

Work on subsequent phases of the design and installation will be billed on a time and materials basis. Once the scope of the project is more fully defined, we can provide cost estimates for these activities. On past projects of this size, our costs have been on the order of about $5,000 to $10,000.

ETI has been granted exclusive rights for commercialization of this patented technology by the patent holder, the University of Waterloo. A site license fee of 15 percent of capital construction costs will be charged should full-scale implementation of the technology at the site proceed. The fee is based on the cost of delivered iron to the site and the PRB

construction (i.e. cost for the construction of a continuous wall or funnel and gate system installation, including mobilization and demobilization).

2.4 Phase IV: Performance Monitoring

ETI typically assists with the data interpretation and evaluation of system performance over time. This includes preparation and/or review of compliance monitoring documents for submission to the regulatory agencies involved. As ETI has been involved with the performance assessment of most of the installed PRBs, we can provide a detailed evaluation of the system performance incorporating our experience from other sites.

ETI's involvement in performance monitoring will also be billed on a time and materials basis. Because performance monitoring detail and schedules vary from site to site, cost estimates for this phase can be given as the need arises.

3.0 PRELIMINARY CONCEPTUAL DESIGN FOR A FULL-SCALE PRB

The following provides a preliminary conceptual design for a full-scale iron PRB in the Building I-1-23 Area, Crab Orchard NWR, Marion, IL. The design will focus on the Upper Sand unit at the site. This conceptual design is based on the information received to date. Other design scenarios and configurations can be evaluated in Phase I once more site data is available.

3.1 Location and Configuration

Plume maps and geologic cross sections showing VOC concentrations in the Upper Sand unit were provided by RMT. Based on information received from RMT, the proposed PRB is located about 100 ft north of Building I-1-23 and is about 350 ft in width, with the iron zone placed in the Upper Sand unit. Based on soil borings SB-213 and SB-214, the Upper Sand unit at this location is overlain by the Upper Clay unit (about 25 vertical thickness) and underlain be the Lower Clay unit at a depth of about 45 ft.

There are two basic designs for a PRB, a continuous PRB or a funnel and gate. In a continuous PRB configuration the granular iron is distributed across the entire path of the

contaminated groundwater. In the case of granular iron, the iron has a hydraulic conductivity greater than many aquifers and thus should not significantly alter the natural groundwater flow path or velocity. The continuous PRB has been the most common configuration used to date.

A funnel and gate configuration uses low permeability materials (funnel) to direct groundwater towards a permeable treatment zone (gate). By directing or funneling the groundwater towards a treatment gate the natural groundwater flow velocity may be increased several times. For a funnel and gate system, groundwater flow modeling is required to estimate the velocity through the gates in order to determine the flow-through thickness required. The mass of iron required is generally the same regardless of the configuration since the same contaminant flux must be treated. Funnel and gate designs need to extend beyond the extent of the plume to ensure that all of the contaminated groundwater is captured and treated. The length of a funnel and gate system may be on the order of 1.2 to 2.5 times the plume width depending on the number of gates and the funnel to gate ratio. To ensure that flow beneath the system does not occur, funnel and gate systems must be keyed into a competent underlying low permeable zone.

ETI has assumed that a continuous PRB would be constructed. The advantages and disadvantages of constructing a continuous permeable wall versus a funnel and gate system or alternate configuration could be discussed further during the data review phase (Phase I).

3.2 Granular Iron Requirements

Based on chlorinated ethene degradation rates from our database of bench-scale tests and field sites, a residence time of about 4 days would be required to degrade a maximum concentrations of 52 mg/L for TCE and 9.8 mg/L for cDCE (well 33MWC-07) and associated breakdown products to below US Federal maximum contaminant levels (MCLs). Given the reported groundwater flow velocity of 70 to 110 ft/yr, a 100% granular iron PRB would need to be a maximum of 1.2 ft in thickness to provide sufficient residence time.

If the construction method requires that the treatment zone be larger than 1.2 ft, the iron could be mixed with sand to minimize materials cost. Therefore, for example, a 50% by volume iron and 50% by volume sand mixture in a 2.4 ft wide trench would provide the equivalent 100% iron thickness of 1.2 ft. ETI recommends that the minimum amount of iron in an iron-sand mixture should be 20% by volume.

The total volume of iron required for the 350 ft wide groundwater plume in the Upper Sand unit (average thickness of 20 ft) is (350 ft × 20 ft × 1.2 ft =) 8,400 ft^3. The *in-situ* bulk density of granular iron is approximately 0.075 tons/ft^3. Therefore, a total of 630 tons of granular iron would be required. If the groundwater flow velocity was around 70 ft/yr in areas along the 350 ft length of the proposed PRB, then the iron costs could be reduced.

3.3 Construction Methods

A 1.2 ft in thickness PRB to a depth of about 45 ft could be constructed using either an injection based method such as jetting or an excavation based method such as biopolymer supported trenching. Using a jetting method the upper 20 to 25 ft of subsurface would not need to be excavated. However, given the relative thickness of the PRB two or more parallel rows of injections would be required to emplace sufficient iron. Thus, an excavation using biopolymer may be more cost effective. Due to the limited site geology/geotechnical data provided, it is difficult to determine which construction methods are best suited for the site. Each of the above methods has been used to construct treatment zones containing iron and each has its advantages and disadvantages. For this preliminary cost estimate we have assumed that the PRB would be constructed using excavation with biopolymer. These construction methods and alternate ones can be discussed and more detailed cost estimates developed in Phase I.

Jetting uses high pressures (about 5,000 to 6,000 psi) to jet fine grained iron into the natural aquifer formation. The jetting tool is advanced into the formation to the desired depth. An iron/biodegradable slurry is then injected from nozzles as the tool is withdrawn. If the tool is rotated a columnar iron zone is created. If the tool is not rotated, and has only one or two opposing nozzles, a thin diaphragm treatment wall can be created. Diaphragm walls may be about 3 inches thick near the point of injection, but may be several inches of an iron-aquifer mixture further away. The diameter of injection will depend on several factors, but distances of 2 to 6 ft are expected for columnar walls and diameters of up to 15 ft have been reached for diaphragm walls. Therefore, large treatment zones require several injections. A successful jetting demonstration to a depth of 65 ft occurred in June 1999 at Travis AFB in California and a full-scale application occurred later the same summer in North Carolina.

Installation of a treatment zone of iron using biopolymer slurry is similar to constructing a conventional impermeable slurry wall. The biopolymer used is typically guar based. As the trench is excavated, biopolymer provides stability to the trench walls. Granular iron can then

be placed into the trench through the biopolymer. After some time, the biopolymer breaksdown (i.e. become less viscous) allowing groundwater to flow through the iron treatment zone.

3.4 Preliminary Cost Estimate

The following cost estimate for technology application at the site is presented to provide a degree of insight with respect to the full-scale implementation costs. We emphasize that the costs presented here are based on costs we obtained for construction at other sites, and would need to be refined based on a more complete review of site conditions and quotations for construction costs from qualified contractors.

The costs for constructing a PRB using the biopolymer excavation method are summarized in Table 3. At a delivered unit cost of about $450/ton, the cost of 630 tons of granular iron would be approximately $284,000. Estimated costs for installation of a 350 ft continuous PRB to an average depth of about 45 ft bgs would be approximately $365,000 (assumes a unit cost of $20/ft^2 for bioslurry trenching), which includes mobilization/demobilization costs of $50,000.

The total estimated cost, including site license is $746,000. Other costs which may be incurred including site preparation, utility relocation, soil disposal, site restoration, permitting, construction management, and engineering design and oversight should also be estimated and included in the overall cost.

3.5 Operation and Maintenance Cost

The frequency and amount of groundwater monitoring that will be required is dependent on the site and/or regulatory requirements. Guidance for a monitoring schedule can be found in the ITRC document "Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Chlorinated Solvents 2nd Edition, December 1999" (www.itrcweb.com).

Other than groundwater monitoring, the major factor affecting O&M costs is the possible need for periodic rejuvenation of iron sections affected by mineral precipitates. The iron material itself should last for decades. The precipitates (if significant) will likely form in a zone on the upgradient face of the PRB.

We note that no significant precipitates were observed in cores from a PRB at an Ontario test site four years after it was installed. This PRB performed consistently for over 5 years. There is also no evidence of sliming or plugging in commercial *in-situ* systems operating successfully for over 6 years.

The objective of rejuvenation of the granular iron would be to restore the permeability loss due to precipitates and possibly to remove the precipitate from the iron to restore any lost reactivity. Since it is presumed that the majority of the precipitate formation will occur on the upgradient face of the PRB, rejuvenation methods would likely target the upgradient face. Possible rejuvenation methods include:

- Jetting the PRB with water under high pressure;
- Using ultrasound to break-up the precipitate on the upgradient face; and
- Using a pressure wave hydraulic pulse method to break-up the precipitate.

To date these possible rejuvenation methods have not been needed and only ultrasound has been tested on a limited scale in the field-scale to determine its effectiveness. At this point we can only state that these methods may prove to be successful in rejuvenating a PRB. To be conservative, we recommend that costing models consider implementation of these possible methods on a 10 year interval. Costs for mechanical agitation methods such as jetting or augering are estimated to be in the range of $4 to $6 per square foot.

5.0 SUMMARY

Based on our review of the data you have provided, the *in-situ* iron technology has the potential to provide a technically feasible method for remediation of the VOCs present at the site. The VOCs present at the site have been treated in previous field applications, and the construction depths, etc., are within reasonable limits where the technology can be successfully applied.

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Table 1: Preliminary Cost Estimate for ETI's Involvement, Building I-1-23 Area, Crab Orchard NWR, Marion, IL

Phase		Estimated Cost (US$)
I	Data review	$1,000
	Site Visit and Meeting[a]	$4,000
II	Bench-Scale Testing[b] (if required)	$17,500
III	Assistance with Field Design and Implementation	$5,000 - $10,000
V	Performance Monitoring	Variable

Notes:

[a] Includes travel

[b] Costs of sample collection and shipment are not included.

Table 2: Summary of PRB Design Parameters, Building I-1-23 Area, Crab Orchard NWR, Marion, IL

Parameter	Conceptual Design Value
Dimensions	***Upper Sand Unit***
Plume Width	350 ft
Total Depth	45 ft
Saturated Thickness	20 ft
Hydraulic Parameters	
Maximum Groundwater Velocity	0.30 ft/day
VOC Concentrations	
TCE	52,000 µg/L
cDCE	9,800 µg/L

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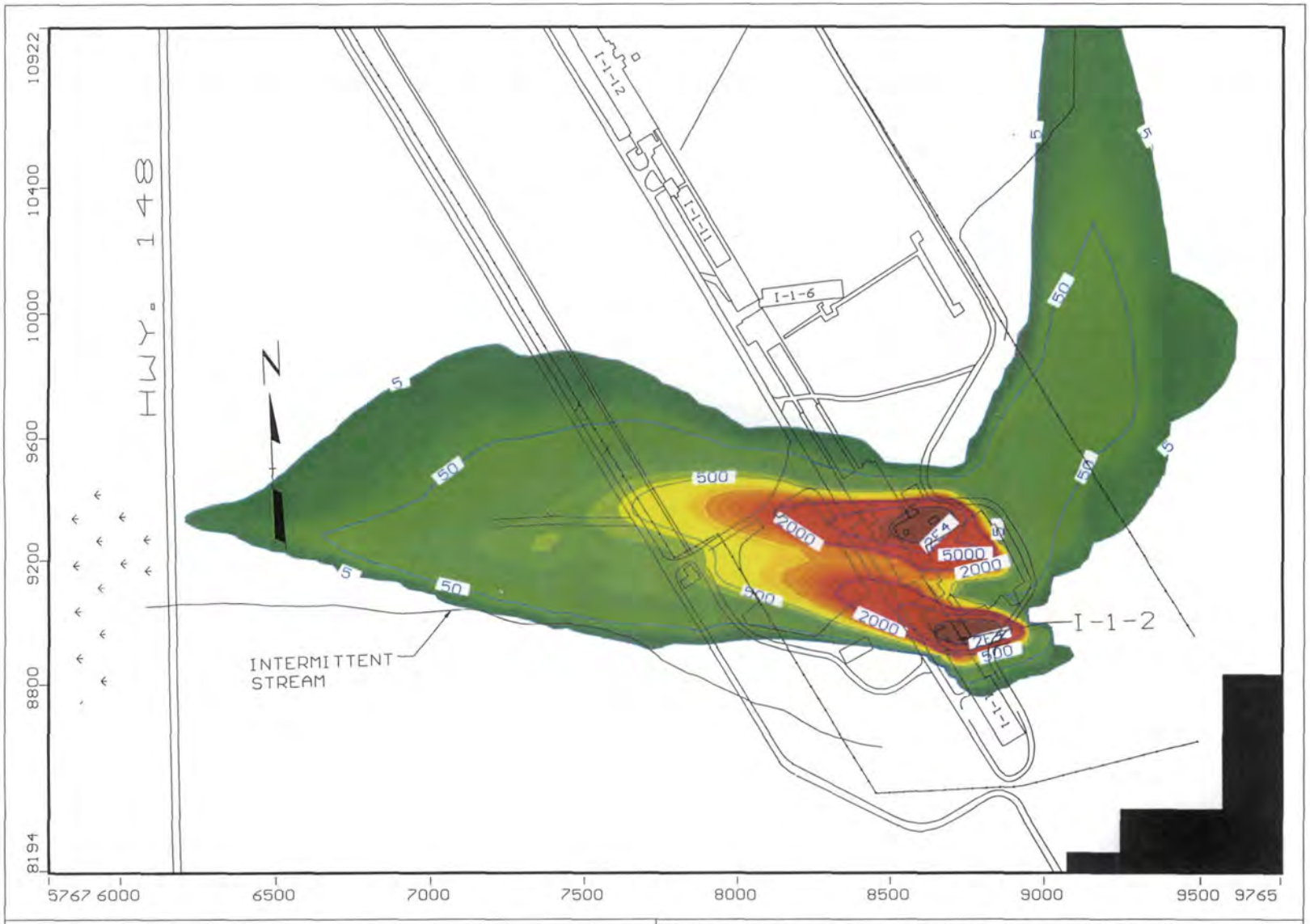
Table 3: Summary of PRB Design, Building I-1-23 Area, Crab Orchard NWR, Marion, IL

PRB Design Parameter	Parameter Value
Length	350 ft
Saturated Thickness	20 ft
Estimated Residence Time	4 days
Iron Flow-Through Thickness	1.2 ft
Volume of Granular Iron	8,400 ft^3
Mass of Granular Iron (@0.075 ton/ft^3)	630 tons
Cost Estimate[a] ($US)	
Mobilization	$50,000
Excavation using Biopolymer	$315,000
Total Construction	**$365,000**
Iron Supply and Delivery (@ $450/ton)	$284,000
Sub Total	**$649,000**
Site License Fee (15%)	$97,000
TOTAL	**$746,000**

Notes:

[a] Based on cost data from other sites. Would need to be refined based on a more complete review of site data and quotation from local construction contractors. Does not include costs for activities such as site preparation, permitting, soil disposal, site construction management, etc.

Attachment 3
Building I-1-2/I-1-3 Area Model Run Figure for Current Conditions Using Refined Model Grid



RMT, Inc.
Project: CRAB ORCHARD Crab523
Description: Current Conditions Simul.
Modeller: TCE,ppb t=0 yr ref grid
7 Sep 01

Visual MODFLOW v.2.8.2, (C) 1995-1999
Waterloo Hydrogeologic, Inc.
NC: 119 NR: 135 NL: 5
Current Layer: 1