In-situ leaching of contaminated soil and ground water

Le lessivage in-situ des sols contaminés par l'eau du sol

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SYNOPSIS: Ground water withdrawal and treatment is commonly used as a method of remediation at Superfund sites in the United States. This paper describes the theoretical basis, laboratory testing, and engineering analyses applied to the extraction and treatment of contaminated ground water, and the flushing of contamination from site soil by ground water extraction, at the Western Processing site in Kent, Washington. The approach described is useful as a guideline for other sites where ground water flushing may be feasible.

INTRODUCTION

Western Processing is a former hazardous waste management facility located south of Seattle, Washington, U.S.A. The facility operated from 1961 to 1982 as a processing, recycling, and transfer point for contaminated materials generated by over 400 public and private organizations. During this period, spills, leakage from impoundments, and sludge disposal caused contamination of an adjacent stream (Mill Creek) and the underlying alluvial aquifer. Rated among the 50 most contaminated sites in the United States under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, or Superfund), Western Processing was one of the first Superfund sites where waste generators and transporters took the lead in allocating financial responsibility, developing a cleanup plan, and accomplishing the cleanup.

The remedial program at Western Processing includes: removal of surficial waste piles, tanks, drums, and other facilities; removal of highly contaminated buried materials; construction of a "hanging" soil-bentonite slurry wall around 66,700 square meters of the most contaminated material; installation of a ground water extraction system; construction of an infiltration system to reinject water and leaching solutions to enhance the removal of soil contamination; construction of a ground water treatment facility; cleanup of a separate plume of organic chemical contaminants located outside the confines of the slurry wall; and surface water and ground water monitoring to evaluate cleanup progress and verify long-term compliance with the cleanup standards. This paper focuses on the design, construction, and operation of the enhanced leaching system which is composed of the slurry wall, well points, and infiltration system.

BACKGROUND

During operation, Western Processing received waste materials consisting of electroplating solutions, pickle liquor, oils, battery acids, steel mill flue dust, spent solvents, paints, and zinc dross from industrial generators. Major contaminants at the site include: volatile organic compounds (VOCs) - chloroform, cis and trans 1,2 dichloroethene, methylene chloride, toluene, and trichloroethane; metals - zinc and cadmium; semi-volatiles - phenol and various phenolic compounds.

By August 1988, some highly contaminated buried materials had been removed, construction of the ground water extraction and infiltration system and treatment facilities was complete, and the slurry wall was about 60 percent complete. Also, the system of ground water monitoring wells and the surface water monitoring points had been established and sampled. The ground water extraction system had been tested and was known to function as designed, but continuous operation of this system and the treatment facilities had not yet begun.

GROUND WATER EXTRACTION SYSTEM

The ground water extraction system (Figure 1) consists of 206 well points, a pumping system to extract and direct ground water to the treatment facilities, a series of infiltration trenches, and the associated piping. Well points were installed to a depth of 9 m using air rotary drilling equipment. The well points are 5 cm in diameter, screened over the lower 1.5 m with 0.5 mm machined slots, and have 2.5 cm diameter riser pipes which can be replaced if they become encrusted with iron deposits. Continuing maintenance of the well points will include periodic acidification to counteract potential iron encrustation. The annulus between the well point casing and the borehole wall is filled with washed sand, graded to act as a filter between the native silty sand soil and the selected screen slot size.

The well points are variably spaced to account for differences in contaminant concentrations in the ground water. They are grouped in 7 cells, and each cell is connected by a common header line. The entire extraction system is designed to allow flexibility in

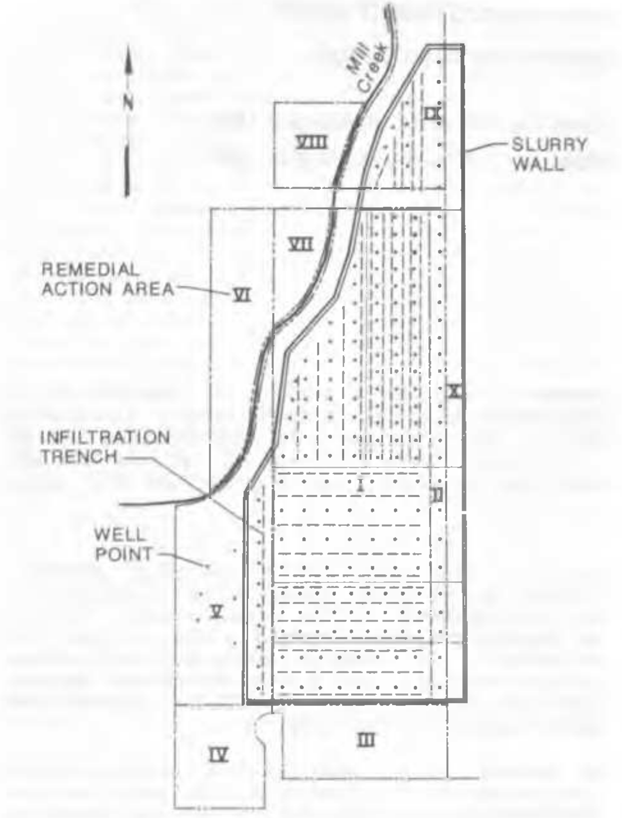


Figure 1. Western Processing Ground Water Extraction System.

operation. The flow rate from each well point is variably adjustable. Thus, portions of the site in which contaminant concentrations decrease rapidly can be isolated from those areas where cleanup is occurring at a slower rate.

An important part of the ground water extraction system is the slurry wall, which encloses all but 6 well points. The slurry wall is installed primarily as a ground water flow control device rather than for contaminant isolation. Although many silty layers of relatively low permeability are present in the upper 12 m, none are continuous across the length and width of the site. Hence, seating the slurry wall in one or more of these layers has limited value in containing the contaminants present on the site. However, the slurry wall will restrict flow from the creek, intercept preferred horizontal seepage paths caused by the strong horizontal anisotropy in the site soil, and direct relatively uncontaminated ground water from below a depth of 12 m through the contaminated zone.

The slurry wall was constructed to a depth of 12 to 13.5 meters below the ground surface using a backhoe fitted with an extended boom. The slurry backfill, with a minimum of 3.6 percent bentonite, is designed to provide a maximum hydraulic conductivity of 10^{-7} cm/sec.

Under steady state conditions, the water balance for the extraction system is:

$$Q_e = Q_p + Q_i + Q_u + Q_{sw}$$

where

Q_e = extraction rate of ground water

Q_p = infiltration rate caused by rainfall

Q_i = induced infiltration rate

Q_u = underflow rate

Q_{sw} = the rate of ground water flow through the slurry wall

This water balance is shown on Figure 2 with the projected ground water flow patterns during pumping.

The ground water extraction rate is planned to vary between 0.006 and 0.013 m^3/sec (100 to 200 U.S. gallons per minute). The initial total pumping rate will be 0.006 m^3/sec, or approximately 3×10^{-5} m^3/sec per well point. The treatment facility is capable of handling a hydraulic loading of slightly more than 0.013 m^3/sec, but is limited by contaminant mass loading capability during the initial stages of the cleanup. As the concentration of contaminants in the ground water decreases during the cleanup, the total extraction system pumping rate will be incrementally increased to accel-

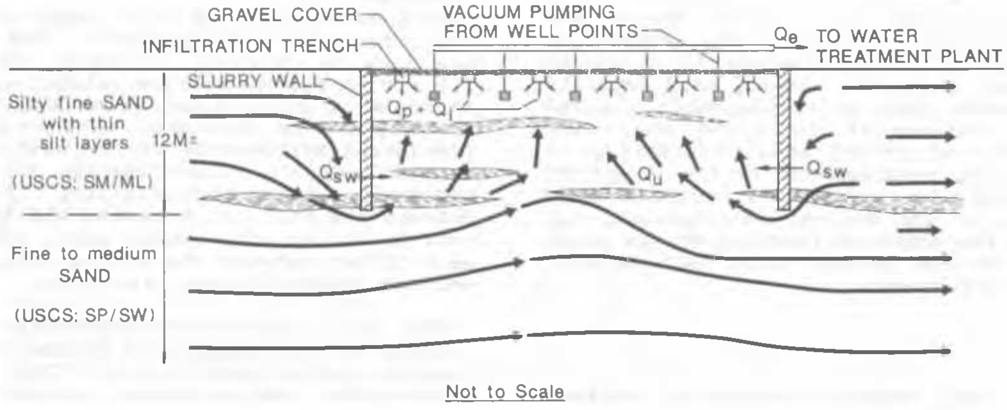


Figure 2. Ground Water Extraction System Schematic.

erate the cleanup. The average drawdowns across the site during steady state conditions are expected to average 0.3 to 0.6 m. Drawdowns at each well point are expected to vary between 1 and 2 m.

At a total pumping rate of 0.006 m^3/sec, the water balance is as follows:

Q_e = 0.006 m^3/sec Q_p = 0.001 m^3/sec

Q_i = 0.003 m^3/sec Q_u = 0.002 m^3/sec

Q_{sw} = 0.001 m^3/sec

Q_p is not dependent on Q_e, but Q_i, Q_u, and Q_{sw} will vary with the drawdowns resulting from Q_e.

The volume of ground water extracted will be accounted for in terms of pore volumes. A pore volume is defined as the amount of water contained in the saturated soil within the confines of the slurry wall. For this project, the site area is 66,700 m^2, the saturated depth is 10.5 m and the porosity is estimated to be 0.30, resulting in a pore volume of about 210,000 m^3 of ground water. At an extraction rate of 0.006 m^3/sec, 0.9 pore volumes of ground water are removed each year.

THEORETICAL BASIS FOR CONTAMINANT FLUSHING

The potential for contaminant flushing was evaluated using both an analytical method that could be performed with a hand-held calculator and computer modeling using a finite element representation of the ground water system.

The analytical method is based on the well known "single cell" model represented by the following equation:

$$C_t = C_o\, e^{[\ln(\frac{R-1}{R})]T}$$

where

C_t = concentration at time T

C_o = initial concentration

e = expotential constant = 2.718

R = retardation coefficient

T = time in pore volumes

The retardation coefficient, defined as the ratio of the ground water flow velocity to the velocity of contaminant movement is the key to the above equation. Higher retardation factors indicate slower contaminant flow.

TABLE I
ESTIMATED CONTAMINANT REDUCTION
SINGLE CELL ANALYTICAL MODEL

		C_t/C_{Co} after 1,2,5, and 10 PV			
Contaminant	R	1PV	2PV	5PV	10PV
Chloroform	2.49	0.60	0.36	0.08	0.01
Methylene Chloride	2.00	0.50	0.25	0.03	0.001
Toluene	15.1	0.93	0.87	0.71	0.50
Trans 1,2 Dichloroethylene	7.19	0.86	0.74	0.47	0.22
Trichloroethylene	5.46	0.82	0.67	0.36	0.13
Phenol	1.38	0.28	0.08	0.001	0
Cadmium	49.0	0.98	0.96	0.90	0.81
Lead	35,800	1.00	1.00	1.00	1.00
Zinc	73.0	0.99	0.97	0.93	0.87

NOTE: R = retardation coefficient, PV = pore volume

Table 1 summarizes the retardation coefficient and ratio of remaining concentration to initial concentration for various organic and metals contaminants estimated using the single cell analytical method. This indicated that removal of volatile organics by ground water flushing would be relatively effective, while removal of metals would be more difficult.

Detailed evaluation of the metals, as well as the organic chemicals, was performed using a two-dimensional finite element computer model, which accounted for boundary conditions and variability of soil conditions, contaminant concentrations and pumping rate. Computer model results, shown on Figure 3, suggest somewhat faster removal of metals than the analytical method, but ground water flushing for metals removal could nevertheless be a slow process.

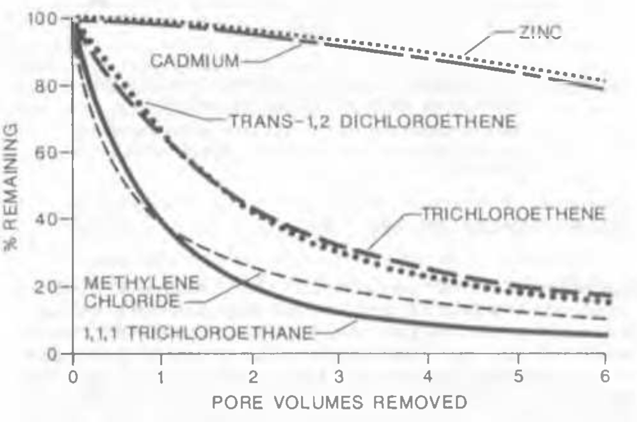


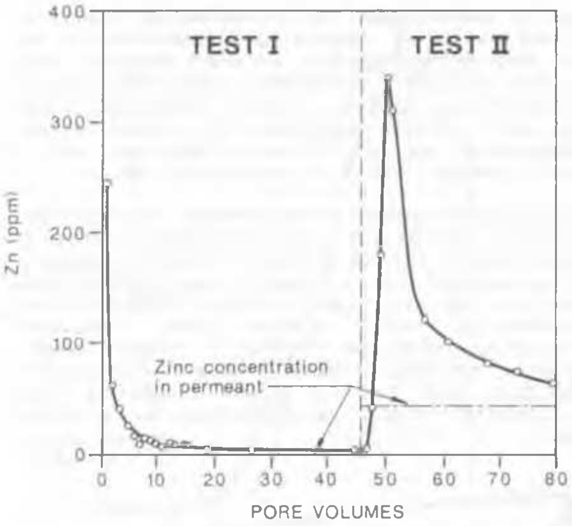
Figure 3. Contaminant Reduction Curves from Numerical Modeling.

Because relative solubility is the most important factor in the movement of metals in ground water, methods for increasing the solubility of metals in the ground water system were studied. The laboratory testing described below provided additional data for evaluation of the potential for metals removal by this form of "enhanced" ground water flushing.

LABORATORY STUDIES

Column leach tests were performed using soil and ground water samples obtained from the site. Figure 4 shows the results from one of the tests. The first part of the test (up to 45 pore volumes) was performed using water collected from a depth of about 15 m below the site surface. Previous monitoring indicated water at this depth to be relatively uncontaminated, although low concentrations of some metals and organic chemicals were present. The second part of the test consisted of applying water collected from the 3 to 10 m depth zone, which was known to contain relatively high concentrations of metals and organic chemicals and have a somewhat lower pH.

These tests indicated a relatively rapid decrease in concentration of contaminants in the leachate during the "clean water" phase of the test. After about 8 to 12 pore volumes, the



NOTE: Test I performed using relatively clean ground water from depth of 50 feet as permeant.

Test II performed using relatively contaminated ground water from 10-35 foot depth zone as permeant.

Figure 4. Column Leach Test - Zinc.

concentration of metals in the leachate stabilized at a small fraction of the initial value. Switching to relatively contaminated water resulted in an immediate significant increase in the concentration of the contaminants in the leachate, followed by a decreasing trend of contaminant concentration similar to that observed using relatively clean water. In this test, leachate contaminant concentrations appeared to asymptotically approach the concentration of contaminants in the contaminated water, as would be expected. The different chemical properties of the relatively contaminated water apparently caused mobilization of some contamination remaining in the soil after permeation with the relatively clean water.

These tests indicated that flushing with clean water from beneath the slurry wall had a high potential for achieving stable ground water contaminant concentrations at a small fraction of the original concentration within an economically feasible time period. However, additional chemical modification of the ground water to mobilize additional amounts of metals contaminants from the soil also appeared to be of value.

As a part of a separate contract, samples of site soil(s) were tested with various acidifying and chelating chemicals (SAIC, 1985). The results of these tests (Table 2) suggest that EDTA, a strong chelating agent, is very effective in mobilizing metals for removal by ground water flushing. Sodium citrate is also effective, although somewhat less so than EDTA. Further study indicated that sodium citrate provides the most cost-effective balance between enhanced metals mobilization and cost.

TABLE II
LABORATORY LEACHING TEST RESULTS

	Percent Removal				
Leaching Agent	Cd	Cr	Cu	Ni	Pb
EDTA	114	24	62	14	106
Hydroxylamine Hydrochloride	86	32	43	20	80
Sodium Citrate	77	24	48	14.5	65
Pyrophosphate	5.4	9.6	29	2.9	9.7

NOTE: from SAIC 1985

INITIAL CONTAMINANT CONDITIONS

At this time, ground water extraction has begun on a limited basis to test extraction system treatment facility performance; hence, comparisons of actual performance with predicted performance are not available. However, Table 3 summarizes the initial contaminant conditions as indicated by monitoring completed as of August 1988.

TABLE III
PRE-PUMPING CONTAMINANT CONCENTRATIONS IN GROUND WATER

Contaminant	Well Points	Mill Creek	Average of Shallow Monitoring Wells in Area I
Chloroform	NA	3.8 (1,280)(d)	2,135
Methylene Chloride	5-498,000(a)	86 (11,000)(e)	46,700
Trans 1,2 Dichloroethylene	10- 13,700	21 (11,600)(e)	18,000
Toluene		ND(b) (17,500)(e)	2,300
Trichloroethylene	100-273,000	20 (21,900)	28,000
Phenol		2.7 (2,560)	72,350
Cadmium	6- 959	7 (1.1)	2,100
Chromium	NA(c)	ND (210)	4,250
Copper	NA	10 (12)	1,450
Lead	NA	ND (3.2)	365
Zinc	2-120,000	600 (47)	140,000

NOTE:
(a) All concentrations reported in parts per billion (ppb).
(b) ND = not detected.
(c) NA = data not available as of August 1988.
(d) Values in parentheses are fresh water chronic water quality criteria (some are hardness dependent) representing approximate cleanup goals.
(e) acute criterion - chronic criterion not available.

CONCLUSIONS

The large number of contaminants, wide variability in contaminant concentrations and patterns, and highly variable subsurface stratigraphy at Western Processing necessitate a remediation program requiring design flexibility and innovation. Ground water flushing is a cost-effective method for achieving the cleanup goals at this site, along with other more conventional measures such as contaminated soil removal. The probable effectiveness of remediation of organic chemical contamination was indicated theoretically by both analytical evaluation and computer modeling. The theoretical basis for metals removal from the soil was less clear, but laboratory testing suggests probable success. At this time, ground water extraction is expected to be necessary for 5 to 7 years, although certain contaminants will undoubtedly respond more rapidly.

REFERENCES

SAIC, (1985), Interim Report, Treatment of Soils Contaminated With Heavy Metals. Science Application International, Corporation, report dated September 30, 1985.