

## Performance of soil flushing and groundwater extraction at the United Chrome Superfund site\*

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### Abstract

In 1987, CH2M HILL, under contract with the U.S. EPA, undertook the cleanup of the United Chrome Superfund site in Corvallis, Oregon. Waste disposal practices and leaky plating tanks at this chrome plating facility had resulted in heavy contamination of soil and groundwater by hexavalent chromium. Distinguishing elements of this site remediation project were two infiltration basins to flush contaminated soils, a 23-well groundwater extraction network in low permeability soils, and treatment of the concentrated chromium wastewaters. Remedial actions also included decontamination and demolition of structures, and offsite disposal of 1,100 tons of contaminated soil and debris. The infiltration basins and groundwater extraction and treatment system have been operating since July 1988. This paper presents the data and experience gathered on the system's performance during the 2 years of operation, and points to potential applications at other sites.

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### 1. Background

The United Chrome Products facility is a former industrial hard-chrome electroplating shop located in Corvallis, Oregon. The shop was converted from a 20,000-square-foot World War II airplane maintenance building. Leaking plating tanks and the discharge of rinse water into a "dry well" during its operation between 1956 and 1985 caused the contamination of soil and groundwater underlying the facility. Soil concentrations of over 60,000 mg/kg chromium and groundwater concentrations of over 19,000 mg/l chromium have been measured adjacent to the plating tanks.

Groundwater contamination in the coarse silts underlying the site has spread downgradient to create a plume covering about 2 acres. A confining clay layer at about 18 feet separates the upper zone silts from a deep gravel aquifer. Chromium contamination in this deep aquifer has been measured as high as 600

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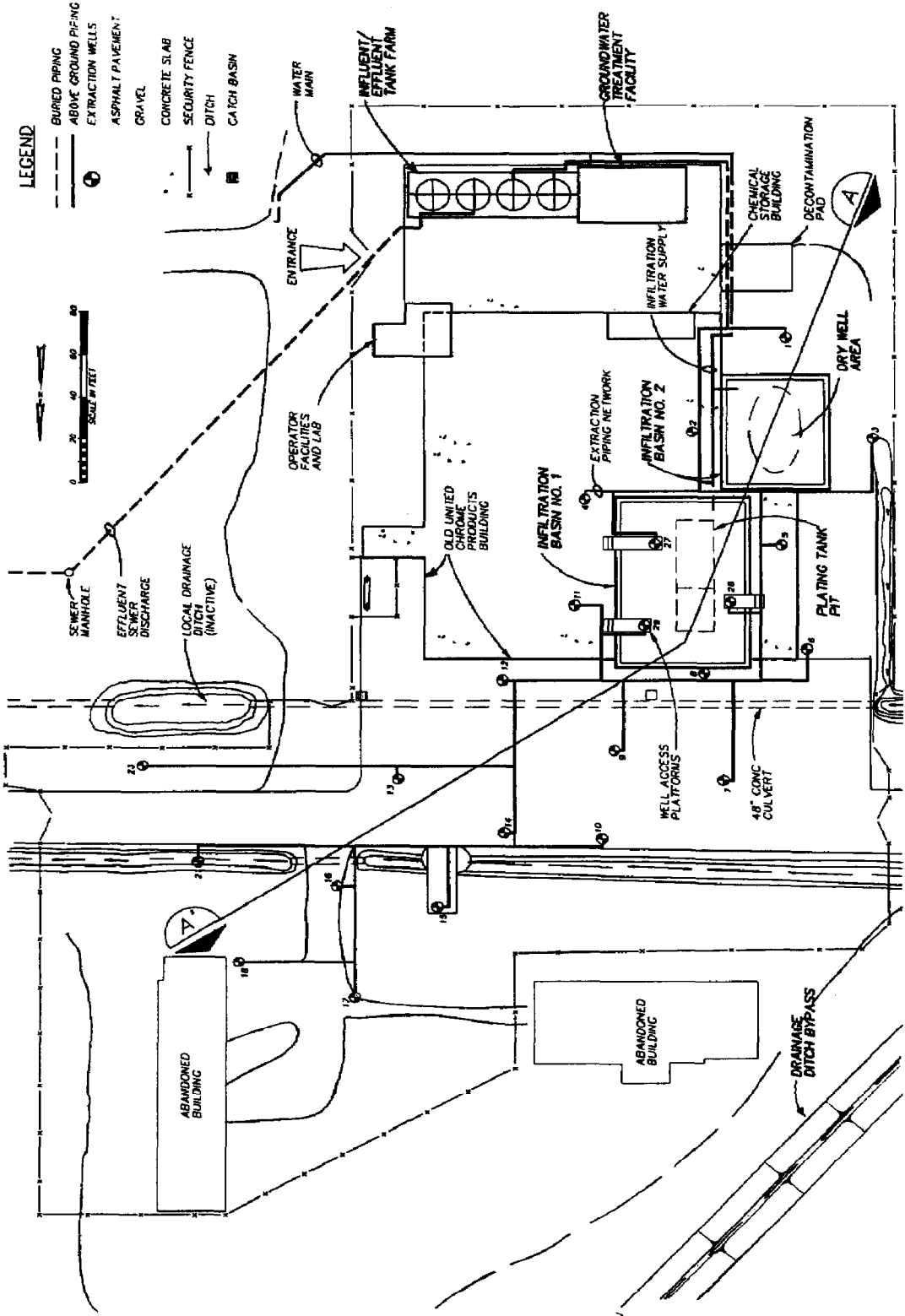


Fig. 1. Current site features.

mg/l, four orders of magnitude above the present drinking water standard of 0.05 mg/l.

## **2. Remedial action**

The United Chrome site was designated by the U.S. EPA as a Superfund site in 1983. Beginning in 1985, CH2M HILL, under contract with the U.S. EPA, undertook the remedial investigation, feasibility study, remedial design, and finally remedial action at the site. Remedial action has proceeded in two phases.

Phase I, the focus of this paper, is directed toward cleanup of the facilities, surface water, soils, and the upper zone groundwater (i.e., the most concentrated sources of chromium contamination) with the objective of protecting the deep aquifer. The cleanup goal for the upper zone groundwater, as established in the Record of Decision (ROD), is 10 mg/l chromium. Phase I cleanup commenced in December 1987 and included:

- Decontamination (high-pressure spray wash) and demolition of the United Chrome building
- Excavation and offsite disposal of about 1,100 tons of heavily contaminated soil (from the dry well and plating tank areas) and contaminated demolition debris
- Installation of 23 shallow groundwater extraction wells
- Construction of two infiltration basins over the dry well and plating tank areas
- Construction of a groundwater treatment facility, including the installation of a packaged chemical reduction and precipitation treatment system for chromium removal
- Rerouting of the local drainage ditch to bypass the site

The infiltration basins and groundwater extraction and treatment systems were constructed and operating by July 1988. The current site features are shown in Fig. 1.

Phase II is directed at deep aquifer characterization and remediation. Remedial action is underway.

## **3. Site conditions**

The site conditions following the completion of Phase I remedial construction activities are described below:

### *3.1 Contaminant characteristics*

Four contaminants — arsenic, barium, chromium, and lead — are present in significant concentrations at the United Chrome site. Although soil concentrations of lead, arsenic, and barium are relatively high, groundwater concen-

trations are very low. It was evident from the data collected on the four contaminants, and their mobility characteristics, that chromium represented the primary migration threat.

In the environment chromium is most commonly found in the trivalent [Cr(III)] or hexavalent [Cr(VI)] form. In general, Cr(III) compounds are cationic and thus readily adsorbed to soils, precipitate as hydroxide at pH above 5, and are relatively insoluble in water, thereby exhibiting a low migration potential in soil [1]. Hexavalent chromium Cr(VI) compounds are anionic (predominantly  $\text{CrO}_4^{2-}$ ), very soluble, and therefore quite mobile in the aqueous environment [2]. Compounds of Cr(VI) are considered more toxic than Cr(III) compounds because they are more soluble, readily pass through biological membranes, and have strong oxidizing power. Hexavalent chromium (VI) is considered a potential carcinogen via chronic inhalation exposure [3]. EPA has established a maximum concentration level (MCL) of 0.05 mg/l chromium (total) as a drinking water standard.

Redox reactions, adsorption/desorption phenomena, and precipitation/dissolution reactions control the transformation and mobility of chromium in an aqueous environment. Chromium (III) and (VI) appear to be interconvertible under natural water conditions. Specifically, Cr(VI) is reduced to Cr(III) by Fe(II), dissolved sulfides, and certain organic compounds, whereas Cr(III) can be oxidized by  $\text{MnO}_2$  [4–6]. Site-specific geochemical studies [7] indicate that there is significant reduction capacity in site soils to reduce Cr(VI) to Cr(III), but the reaction is rate-limited. These studies also indicate that the oxidation potential for converting Cr(III) to Cr(VI) is much smaller (four times) relative to the reduction capacity of site soils.

Preliminary adsorption/desorption tests have been conducted by adding hexavalent chromium to uncontaminated site soil samples [7]. The results indicated that desorption is relatively rapid and reversible. However, extraction tests run on contaminated site soil samples indicate that a significant reserve of Cr(VI) remains in the soil. It has been conjectured that the reserve Cr(VI) may be in the mineral or amorphous phases (e.g.,  $\text{BaCrO}_4$ ), within the soil matrix.

### 3.2 Hydrogeology

A geological cross section of the site is shown in Fig. 2. The upper zone consists of about 18 feet of coarse to fine silt overlying an aquitard. The 2- to 10-foot-thick aquitard separates the deep aquifer from the upper zone. The aquitard consists of a hard, dark grey clay, without obvious voids or fractures, and grades into deep aquifer soils at 22 to 23 feet. The deep aquifer consists of interbedded silty sandy gravel layers. The finer grained zones yield very little water, whereas the silt-free zones appear to have high yields. The lower aquitard is a plastic clay at least 40 feet thick.

Groundwater in the upper zone flows generally to the northeast, but is af-

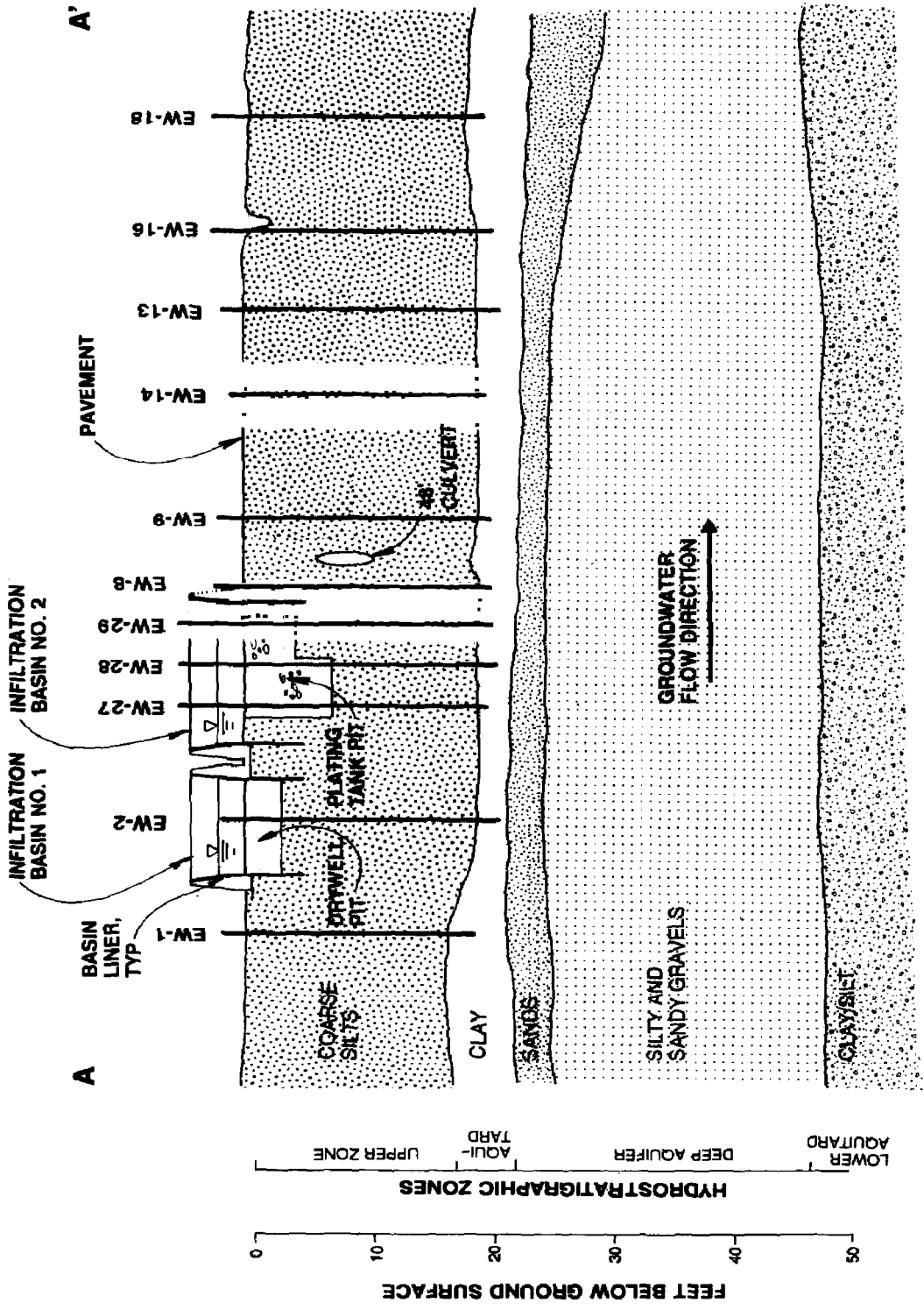


Fig. 2. Geologic schematic of cross section A-A.

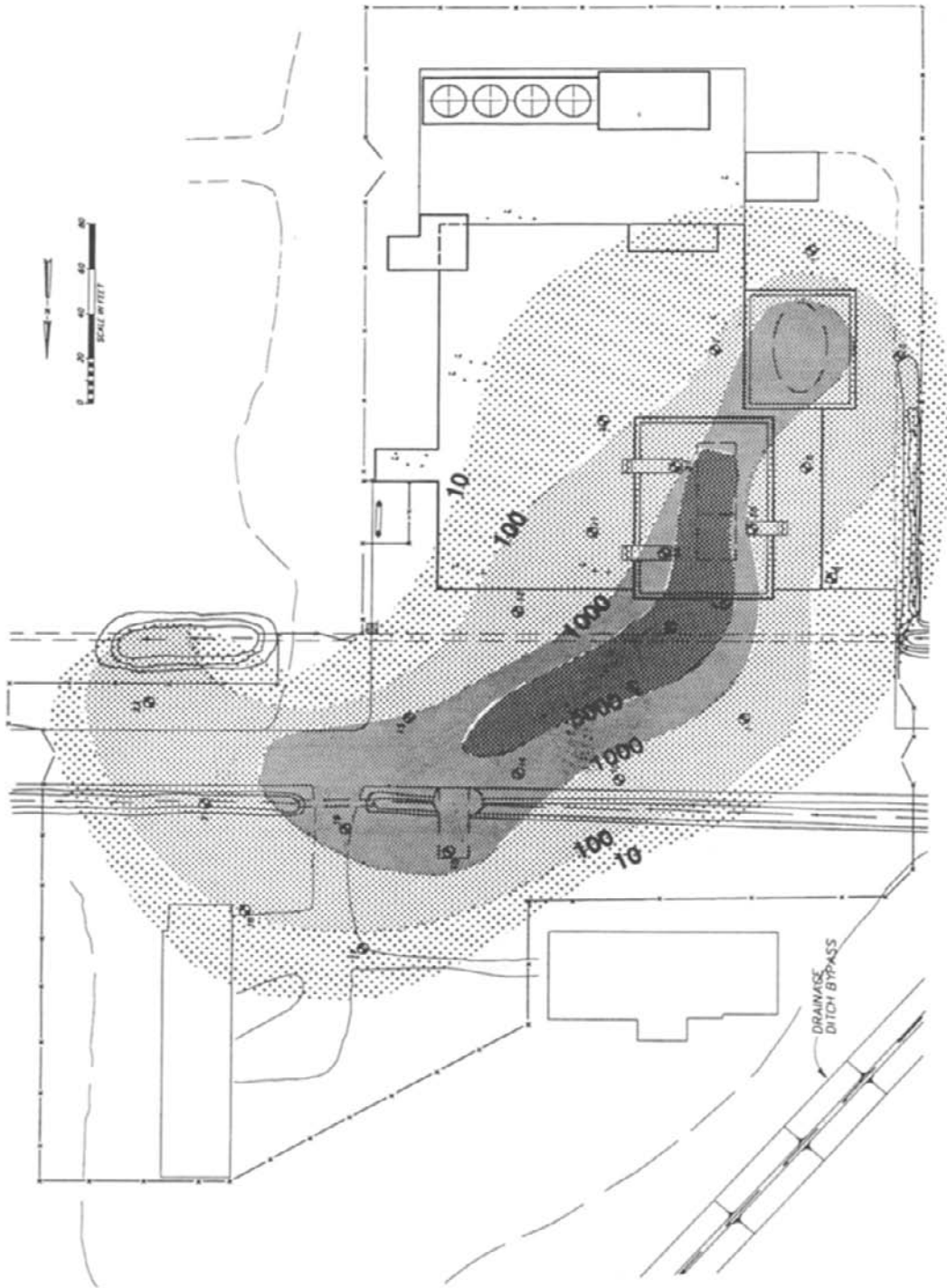


Fig. 3. Cr(VI) Contamination in upper zone groundwater (mg/l), August 1988.

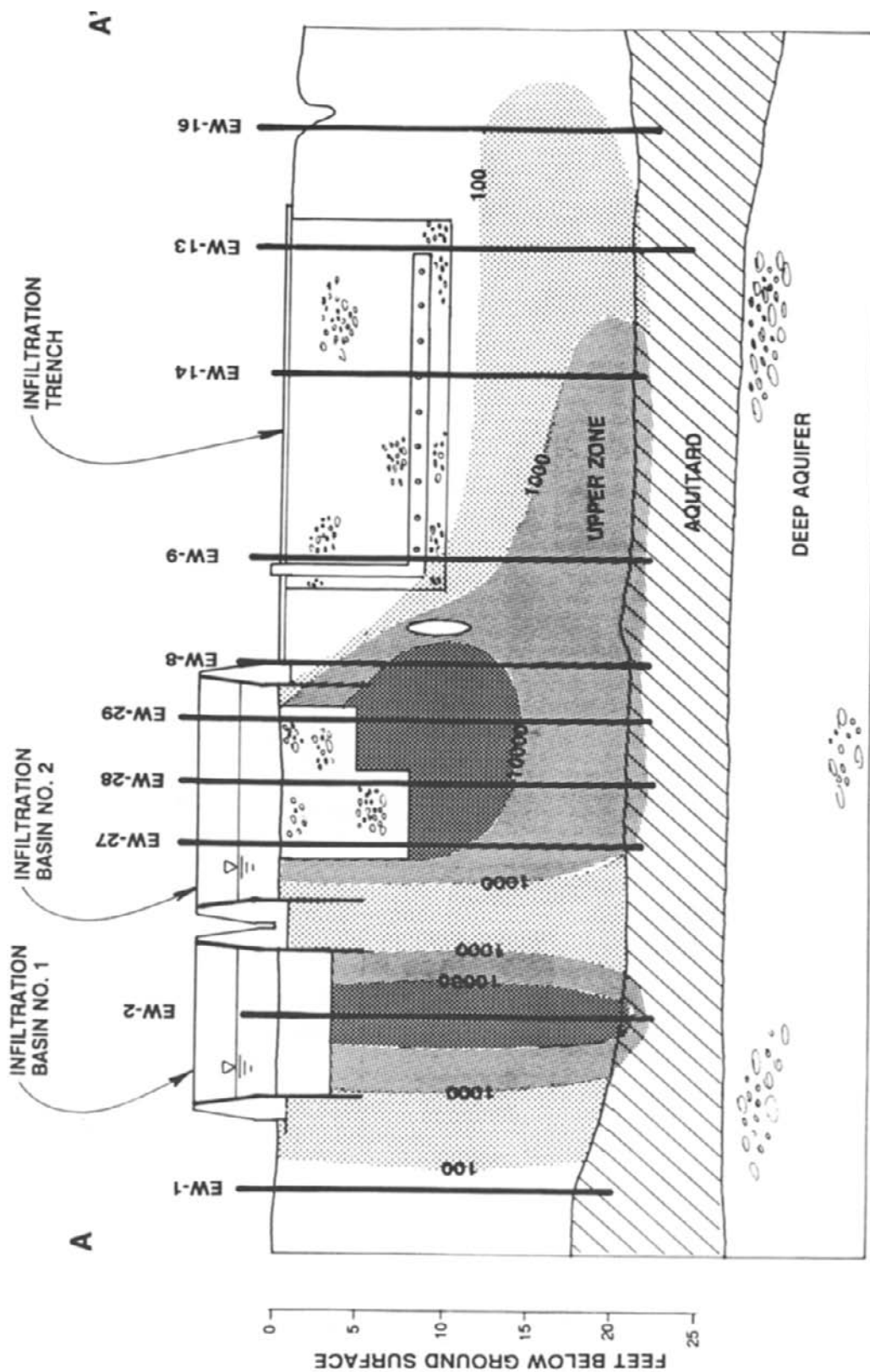


Fig. 4. Vertical distribution of Cr(VI) in soils (mg/kg), April 1988.

ected by local gradients induced by the local ditch and other site features (such as culverts). The estimated hydraulic conductivity of the silts ranges from about 0.5 to 2.5 feet per day. Using an average gradient (across the site), the average linear (advective) velocity ranges from 3 to 30 feet per year. The unconfined water table varies seasonally between the ground surface and 10 feet below ground.

A long-term pumping test conducted in the deep aquifer indicated a local confined condition. However, in a regional setting, this aquifer is described as semiconfined, with recharge supplied from the overlying silts. The general groundwater flow direction in the deep aquifer is to the northeast with a linear (advective) velocity of about 50 feet/year.

### *3.3 Groundwater contamination*

Figure 3 shows Cr(VI) contamination in the upper zone groundwater before extraction began (August 1988). At that time, Cr(VI) concentrations as high as 19,000 mg/l were measured near the plating tanks. The plume had migrated from the dry well and plating tank sources to the northeast with the groundwater. Within the influence of the ditch, the plume pathway abruptly changed to the east, discharging into the ditch under high groundwater conditions. Surface water contamination in this ditch was measured at over 200 mg/l Cr(VI) before the ditch was rerouted around the site.

### *3.4 Soil contamination*

Contaminated soil with concentrations as high as 60,000 mg/l Cr(VI) were excavated from the plating tank and dry well area and disposed of offsite as part of Phase I remedial action. The vertical distribution of Cr(VI) in the remaining soils is shown in Fig. 4. The infiltration basins were strategically placed over the "hot spots" of soil contamination (plating tank excavation pits and dry well). Measured concentrations as high as 16,000 mg/kg Cr(VI) remained in soils adjacent to the plating tanks, and as high as 10,000 mg/l Cr(VI) in the dry well.

The vertical distribution of soil contamination indicates the migration pathway of Cr(VI) released from the dry well and plating tanks. Figure 4 shows that the migration pathway has remained within about 10 feet of the aquitard interface. Factors that tend to limit the plume to this depth include a slight downward vertical gradient, high specific gravity (greater than 1) of the contaminated groundwater, and the point of release was apparently at the base of the plating tank (12 feet below ground surface).

## **4. Operations**

Since startup, the facility has been operated by the City of Corvallis, a potentially responsible party (PRP) for cleanup of the site, with technical sup-



port from CH2M HILL. The operation of the extraction and treatment system started slowly because of the initially high Cr(VI) concentrations and associated treatment plant capacity limitations, and a limited operating schedule. During the first year, operation of the groundwater extraction and treatment system was limited to about 80 hours per month. Since then, however, the operating schedule has been significantly expanded. Over the past year, the extraction system has been operated almost continuously (600 to 700 hours per month) and treatment plant operations have averaged 150 to 200 hours per month. Operation of the infiltration basins has followed a pattern similar to that of the extraction system.

The operating strategy for the groundwater extraction and treatment system, and infiltration basins, is described below.

#### *4.1 Pumping strategy*

The overall pumping objective for the upper zone plume has been to minimize overall cleanup time by extracting groundwater at the highest rate possible while focusing extraction in source ("hot spot") areas, e.g., plating tank and dry well areas. The pumping strategy has been to operate three groups of extraction wells, relatively independently, through pumping and recovery cycles. These well groups are cycled on and off to maximize yields in the most contaminated areas, maintain an inward gradient, and minimize stagnation zones. The well groupings are listed below.

*Basin Wells* are located within and around the two infiltration basins. These wells contained the highest initial Cr(VI) concentrations and have been pumped at maximum yields. When the infiltration basins are operating, these wells can be pumped continuously (i.e., requiring no recovery cycle).

*Axis Wells* are located along the axis (northeast) of the plume, generally within the original 1,000 mg/l Cr(VI) concentration contour (see Fig. 3). They are also pumped at maximum yields, but yield significantly less than the basin wells because of limited recharge. These wells require a significant recovery phase, especially in dry weather.

*Boundary Wells* are located along the plume border and exhibit relatively low Cr(IV) concentrations and low yields. These wells are pumped more moderately to avoid inducing a gradient from the higher Cr(VI) concentration areas to the lower concentration boundary wells. They also require a significant recovery phase.

#### *4.2 Infiltration basins*

City water is discharged to the infiltration basins. A preset operating water level is maintained by a float valve. The infiltration basins are currently being operated continuously.

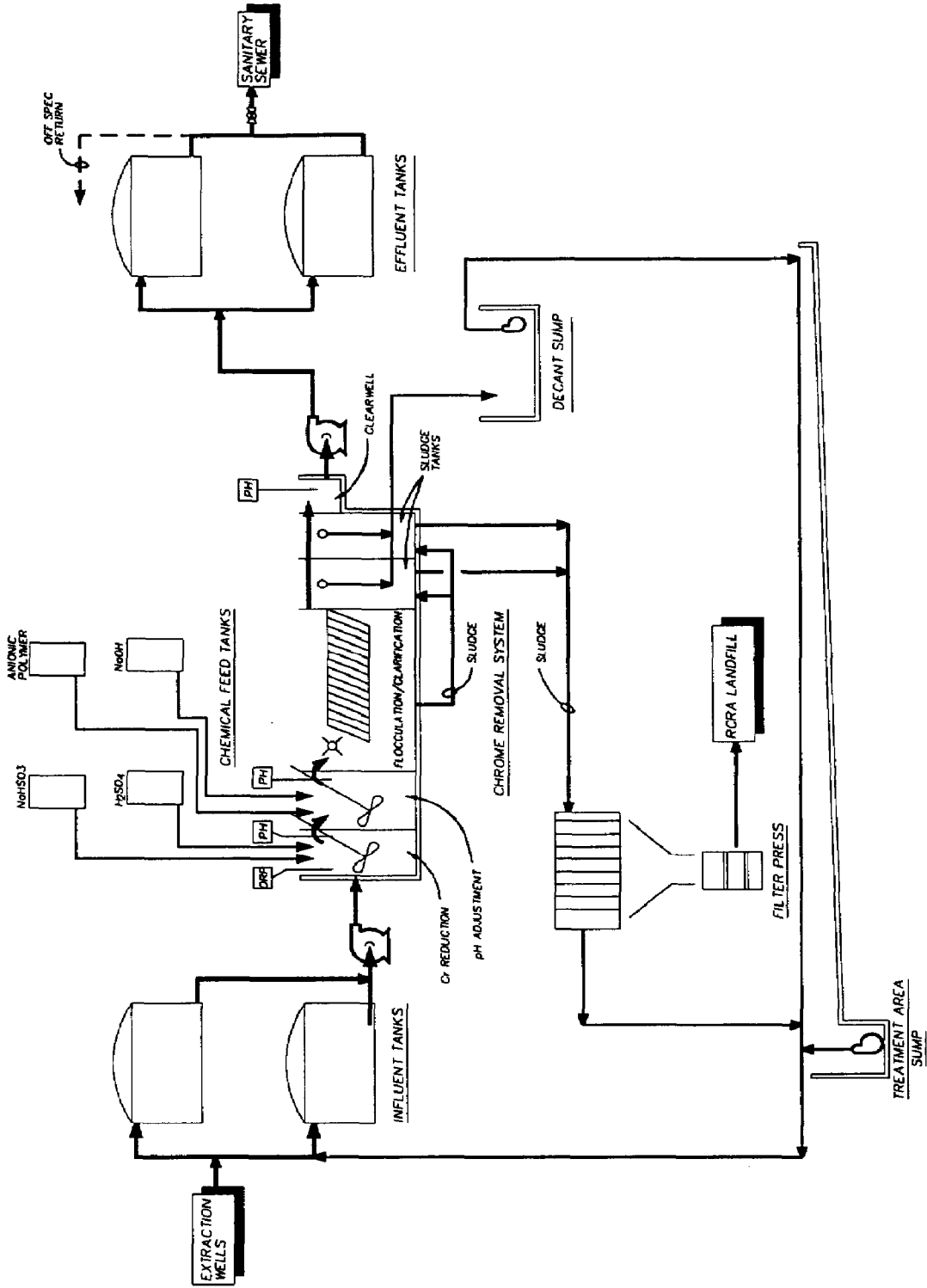


Fig. 5. Process flow diagram, groundwater treatment system.

### 4.3 Groundwater treatment system

A process flow diagram of the groundwater treatment system is shown in Fig. 5. The treatment steps are:

- *Equalization/storage.* Extracted groundwater is accumulated in either of two storage tanks for treatment.
- *Cr(VI) Reduction.* pH is adjusted to 2.3 with sulfuric acid and sodium metabisulfite introduced (as an electron donor) to reduce Cr(VI) to Cr(III).
- *Cr(III) Precipitation.* pH is adjusted to 8.5 with sodium hydroxide to produce a chromium hydroxide precipitate.
- *Flocculation/clarification.* An anionic polymer is added to the influent in a settling tube clarifier, to aid in the flocculation and settling of the chromium hydroxide precipitate.
- *Effluent storage.* Treated flows are accumulated in effluent storage tanks for testing and metered discharge to the municipal wastewater treatment plant.
- *Sludge processing.* Chromium hydroxide sludge is drawn off the bottom of the clarifier, thickened, and dewatered in a plate and frame filter press. Filtrate is returned for treatment.
- *Filter cake disposal.* Chromium hydroxide filter cake failed toxicity characteristic leaching procedure (TCLP) toxicity criteria for chromium, so is landfilled offsite as hazardous waste.

## 5. Performance

### 5.1 General performance data

The original design basis is compared with actual operating conditions in Table 1. General performance data is summarized in Table 2. In general, these data show the groundwater extraction system has met expectations in effectively removing soluble chromium [Cr(VI)] from the upper zone. Average concentrations of the plume have been reduced from 1,923 mg/l to 207 mg/l in the first one and half pore volumes. One pore volume is equal to the volume of the porewater contained in the contaminant plume. This has been estimated to be about 2.6 million gallons.

The infiltration basins have been a key to achieving this progress. Over 65% of the extracted groundwater to date has been supplied by the infiltration basins, all of which has been flushed through the contaminant sources (dry well, plating tank areas).

The groundwater treatment plant has had to perform under very high and widely ranging influent Cr(VI) concentrations (1,923 mg/l to 207 mg/l). These conditions have affected treatment plant throughput, initially limiting the groundwater extraction rates.

### 5.2 Groundwater extraction

The groundwater pumping strategy has been effective in containing the plume by creating a net hydraulic gradient, in most cases, opposite the concentration

TABLE 1

## Design basis and actual operating conditions — United Chrome remedial action

Component	Basis of design	Operating conditions
Infiltration basins	Flush soluble chromium from unsaturated soils in "source" areas (dry well and plating tank areas). Recharge upper zone groundwater system in source area.	Basins have provided unsaturated zone flushing. Flushing rate is lower during winter and higher during summer. Basin use has significantly increased extraction well yields in source areas.
Extraction system	15 extraction wells in upper zone.  Upper zone wells to produce 0.5 gpm (7.5 gpm combined) on an extraction/recovery cycle. Average Cr(VI) concentration from upper zone of 800 mg/l. Operated 24 h/day to produce 11,000 gpd for treatment.	23 extraction wells installed in upper zone, 3 within Infiltration Basin No. 1. Well yields average 0.43 gpm (10 gpm combined).  Average Cr(VI) concentrations initially 1,923 mg/l, now 207 mg/l due to focused extraction in source areas. Operated initially 80 h/month (2,000 gpd average), now operated almost 24 h/day (14,000 gpd average). Now 207 mg/l, as extracted.
Treatment system	10 mg/l cleanup goal in the upper zone. Influent Cr(VI) concentrations of 800 mg/l. 25-gpm average flow rate (11,500 gpd in an 8 h/day plant operation schedule). 1.70 mg/l Cr (total) effluent discharge standard.	Influent Cr(VI) has ranged from 1,923 mg/l to 207 mg/l. Initially 15 gpm, now 40 gpm average flow rate.  Treatment plant has consistently produced effluent within discharge standards.

TABLE 2

Summary of general performance data (August 1988 through June 1990)

Parameter	Data
Groundwater extracted	4,038,000 gallons
Extracted Cr(VI) (concentration)	1,923 to 207 mg/l
Extracted Cr(VI) (mass)	20,200 pounds
Groundwater recharged	2,623,000 gallons
Effluent Cr (total)	3.4 mg/l (average)
Effluent Cr(VI)	1.8 mg/l (average)
Sludge produced	5,400 cubic feet

gradient, thereby causing a net flow toward the center of the plume. The local drainage ditch, since being rerouted around the site, no longer has a hydraulic influence on the plume. The net effect of groundwater extraction to date is shown in the current Cr(VI) plume map in Fig. 6. This figure reflects groundwater contamination after approximately 1.5 pore volumes have been extracted. A comparison with the initial (August 1988) Cr(VI) plume map (see Fig. 3) shows a dramatic reduction in groundwater Cr(VI) concentrations in the source areas (dry well and plating tank areas).

This cleanup pattern can be attributed in large part to the relative yields of each of the extraction wells. Yields between wells have varied dramatically because of local soil characteristics and, more importantly, available recharge. The infiltration basins, which provide groundwater recharge, have had a profound effect on individual well yield.

Since Basin Wells adjacent to the infiltration basins have had significantly higher yields than the Axis or Boundary Wells reductions in groundwater contamination in the high-yielding Basin Wells have been more dramatic than for the other wells. This phenomenon is illustrated by comparing the Cr(VI) concentration plots for selected Basin Wells in Fig. 7 with comparable Axis and Boundary Wells in Fig. 8. These plots show that Basin Wells, with as much as five times the extraction volume of other wells, have a significantly higher Cr(VI) reduction rate over this operating period compared with the Axis and Boundary Wells. Total gallons extracted from each well to date are noted.

The groundwater extraction rate for all extraction wells is compared with the recharge rate through the two infiltration basins in Fig. 9. Over the entire operating period, the infiltration basins have supplied about 65% of the extracted volume. The basins are now being used more aggressively and currently account for 75 to 90% of the extracted volumes during dry summer months.

### 5.3 Soil flushing

The water table during summer months is as low as 10 feet below ground surface. Infiltration water from the basins flushes through the seasonally un-

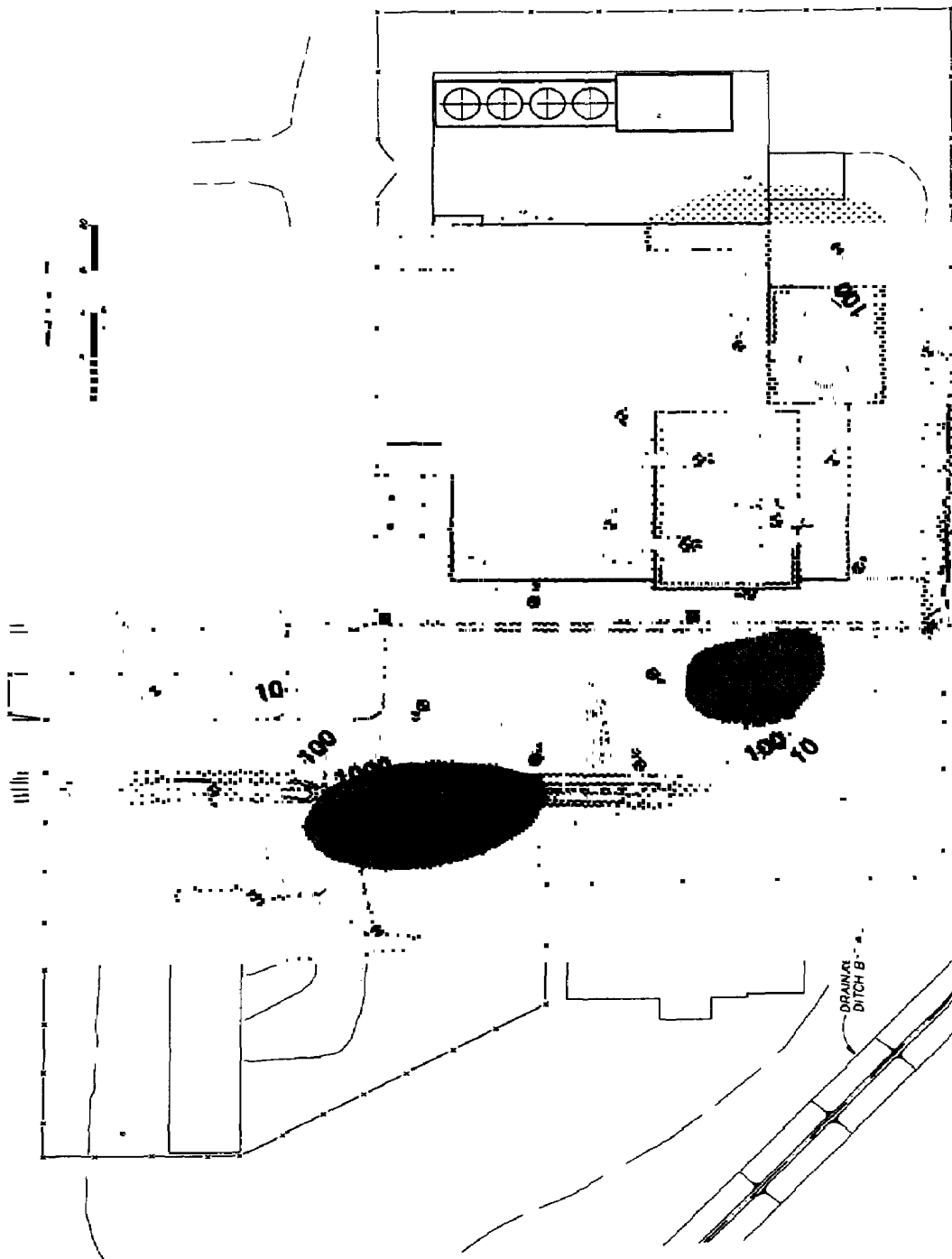


Fig. 6. Cr(VI) Contamination in upper zone groundwater (mg/l), June 1990.

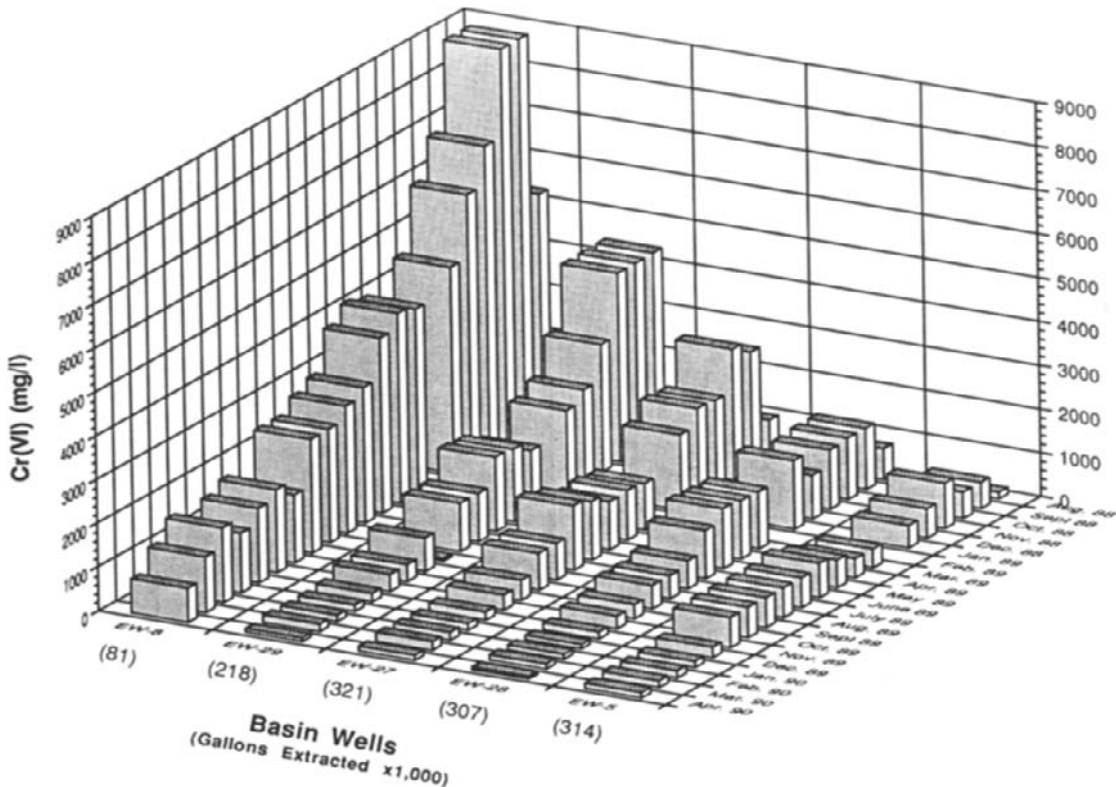


Fig. 7. Cr(VI) Concentrations in basin wells.

saturated zone and builds a slight mound on the depressed water table. The dry weather infiltration rate from the basins is estimated to be 3 to 4 inches per day, based on the peak seasonal infiltration volume averaged for both basins. This represents the flushing rate for contaminated unsaturated soils under the infiltration basins. Although current soils data are not available to characterize the effectiveness of soil cleanup, a soil flushing rate of 10,000 to 15,000 gallons per day (gpd) and progress in groundwater cleanup suggest unsaturated zone soils are being cleaned.

#### 5.4 Groundwater treatment

Although the groundwater treatment plant has had to effectively treat influent that has Cr(VI) concentrations ranging from 1,923 mg/l to 207 mg/l, treatment of influent that has concentrations below 10 mg/l is expected in the final stages of the cleanup.

The effluent discharge standard was initially set at 1.7 mg/l Cr (total) for the first year of operation. After further review, the discharge standard was raised to 6.0 mg/l Cr (total). The treatment plant has performed effectively in reducing chromium to below these discharge standards.

To accommodate the high initial influent loading, the plant throughput had

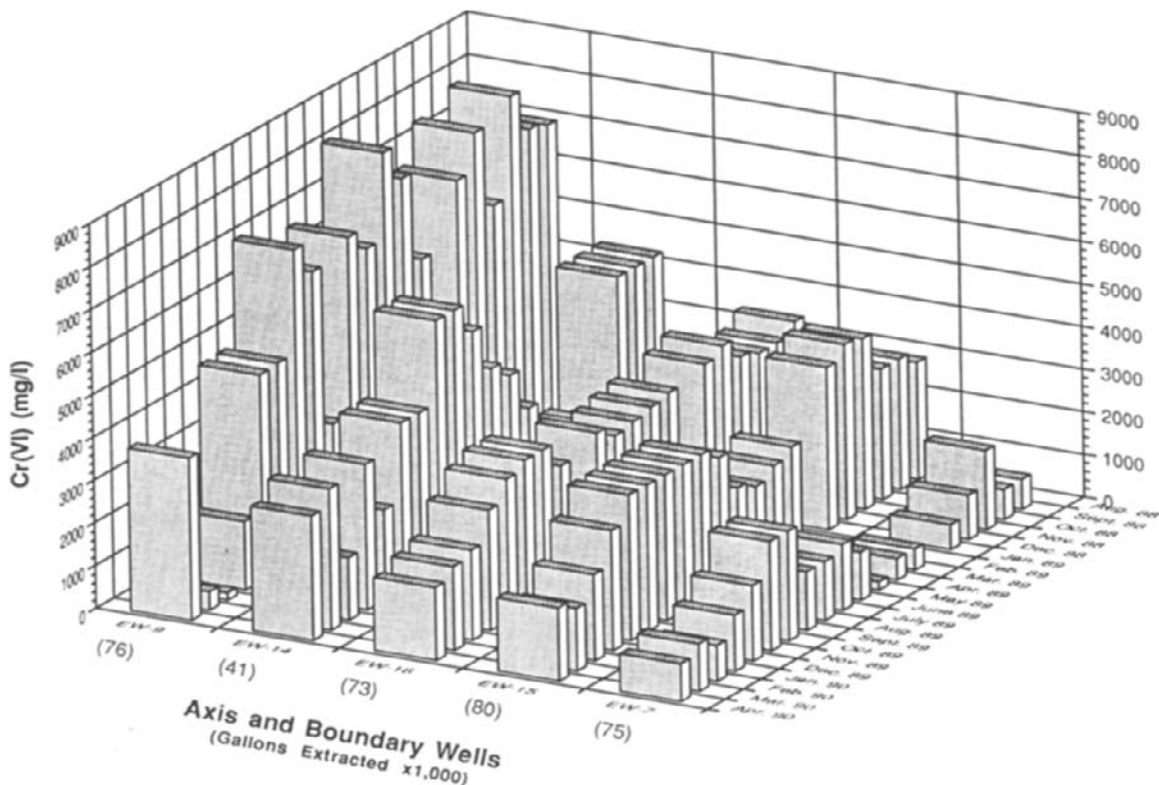


Fig. 8. Cr(VI) Concentration in Axis and Boundary Wells.

to be reduced significantly because of the limited capacity of the sludge dewatering system. Under peak influent loading conditions, plant throughput was reduced to about 15 gallons per minute (gpm). The sludge dewatering system was modified to increase capacity and resulted in an increase in plant throughput to about 30 gpm during the initial loading conditions.

As the influent concentrations have dropped, hydraulics have become the limiting factor in plant throughput capacity. These limitations have ranged from insufficient retention time in the Cr(VI) reduction reactor for complete Cr(VI) reduction to solids carryover in the clarifier, depending on influent conditions. Under current influent conditions, maximum plant throughput is about 42 gpm.

### 5.5 Cleanup trends

As an overview, extracted groundwater Cr(VI) concentrations and cumulative Cr(VI) removed over this operating period are shown in Fig. 10 as a function of total gallons extracted. Over 10 tons of Cr(VI) have been removed to date. On a site average, extracted groundwater concentrations have dropped by about 90%. This rapid rate of cleanup is expected to continue for the first



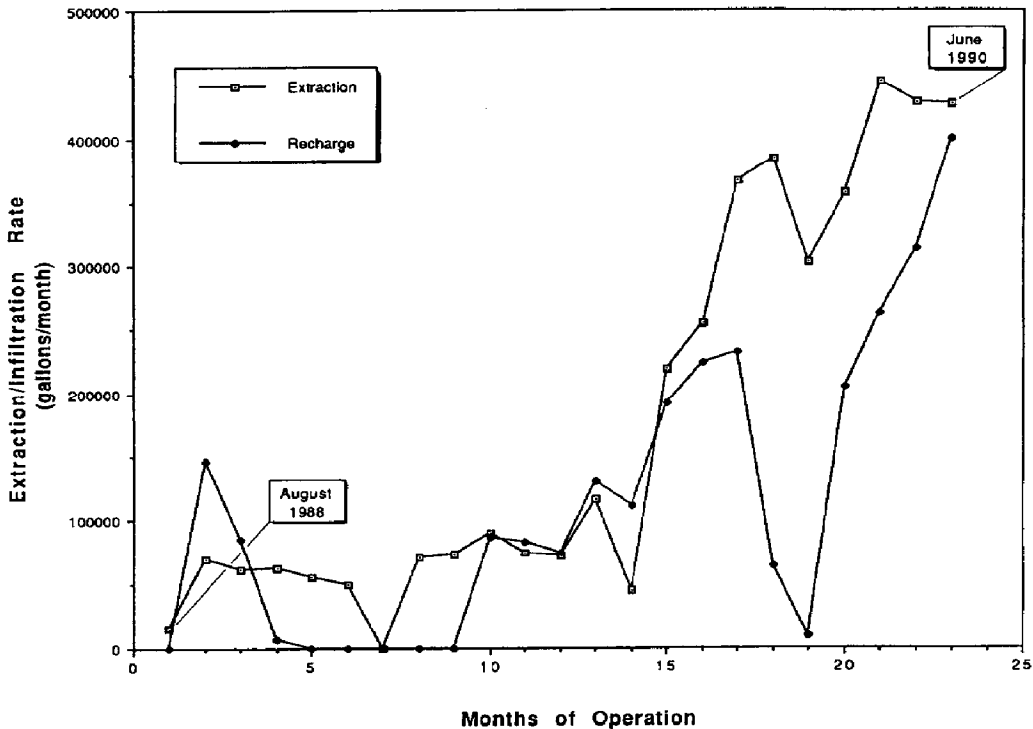


Fig. 9. Extraction and infiltration rates.

few pore volumes (estimated at 2.6 million gallons per pore volume) until the Cr(VI) concentration begins to tail off to some asymptotic level.

Some “tailing” is evident already (see Fig. 10), caused by several factors, including hydraulic isolation, sorption, dissolution of solid phases, and other geochemical processes, and it generally defines the practical limit of pump and treat remediation. For example, finer pores or dead end pores in the soil matrix trap water and contaminants that are only slowly exchanged with the bulk water present in the larger pores. It is the water and the contaminants in the larger pores that are generally mobilized during pumping. Tailing may also result from the gradual release of sorbed or solid phase contaminants into the water. These slow desorption or dissolution releases act in concert with slow contaminant releases from the fine pores, discussed above, to cause tailing [8].

It should be noted that an extracted groundwater concentration does not necessarily represent the equilibrium concentration in the groundwater after extraction ceases. It should be understood that the contaminant cannot be removed faster than it is released into the passing groundwater. When extraction ceases, water-soluble components will continue to be released from residual sources until an equilibrium is reached, generally well above the final extracted concentrations.

Column leach tests have been performed on the contaminated upper zone soils to evaluate the potential effectiveness of pump and treat remediation at

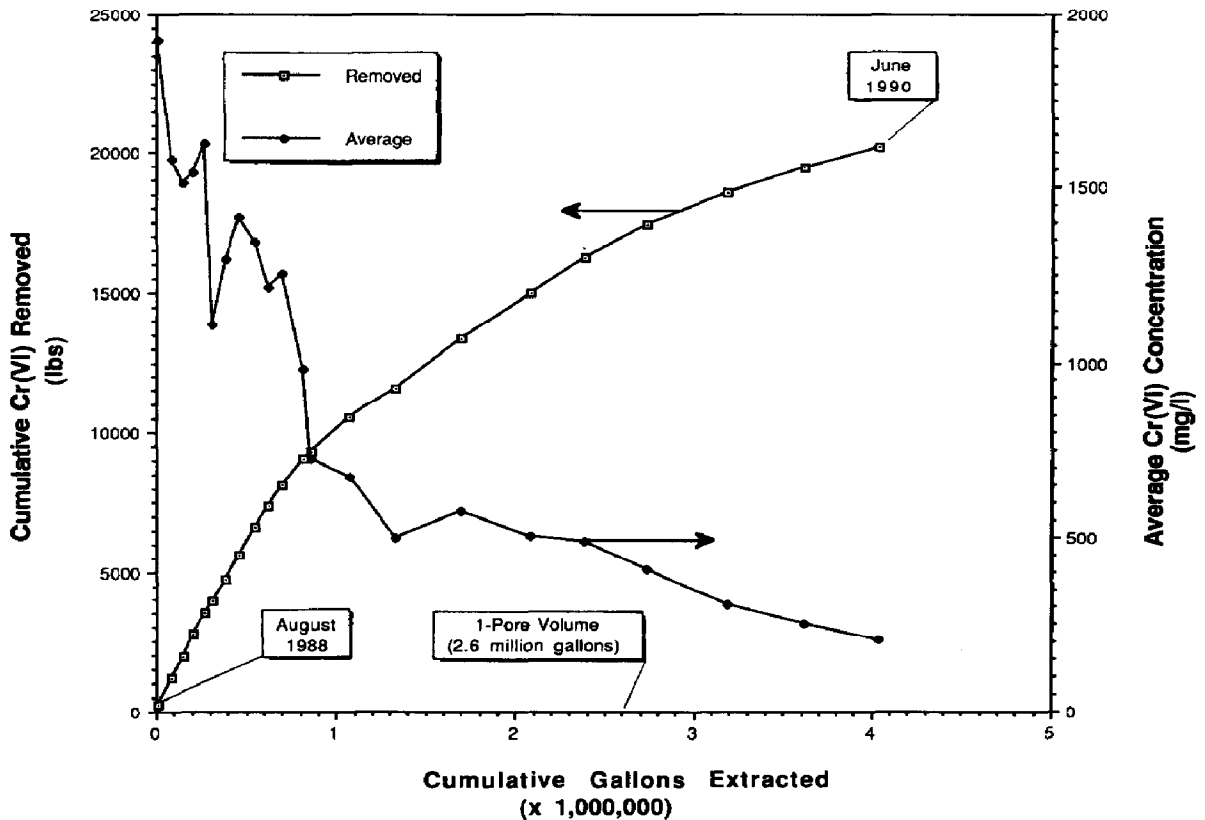


Fig. 10. Extracted Cr(VI) concentrations and cumulative Cr(VI) removed.

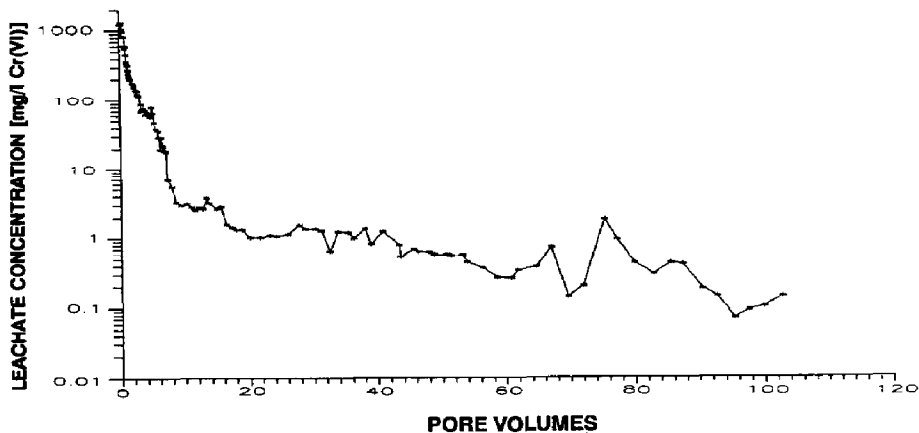


Fig. 11. Column leach test results (source [7]).

the United Chrome site [7]. Results from a column leach test are shown in Fig. 11. Soil was set in a confining cell and leached with groundwater for over 100 pore volumes. This type of test provides an estimate for the minimum cleanup time for the given concentration. The column test ignores effects such

as aquifer heterogeneity and the differential times it takes chromium to migrate along different flow paths to an extraction well. For these reasons, actual site cleanup is expected to proceed slower than column results may indicate.

The column test indicates chromium is removed in two phases. The first phase is relatively rapid, achieving a leachate concentration of 5 mg/l in about 10 pore volumes. The second phase is slower, requiring an additional 95 pore volumes to reach a concentration of 0.1 mg/l. This analysis suggests that 5 mg/l may be the practical limit for remediation of these soils.

A comparison of actual site data (see Fig. 5) to the column test (see Fig. 10) indicates a good correlation over the first 1.5 pore volumes. This is encouraging in that the original goal of 10 mg/l was obtainable in the laboratory.

## **6. Application to other sites**

The following conclusions can be drawn from the experience gained over the past 2 years of operating the United Chrome groundwater extraction and treatment and soil flushing systems:

- Groundwater extraction and treatment of soluble contaminants can be effective in relatively low-permeability soil systems. However, there is a practical limit to cleanup goals, imposed by diminishing returns of “tailing,” and concentration “creep” caused by ongoing desorption or dissolution of residual contaminants after extraction has ceased.
- If remedial action is going to include groundwater extraction, groundwater recharge will significantly increase the rate of cleanup. Groundwater recharge will increase the rate of pore water exchange by not limiting well yield to natural recharge conditions.
- Groundwater extraction can be further enhanced by focusing extraction in source (“hot spot”) areas because these areas will control the time of cleanup. Aggressive groundwater recharge in these source areas will maximize well yields.
- Soil flushing can serve the dual purpose of leaching soluble contaminants from soils in the unsaturated zone while recharging groundwater to the extraction wells. Although specific data on the effectiveness of soil flushing in removing contaminants from the soil is not available, circumstantial evidence indicates that soil flushing is effective. This evidence includes flushing rates of 10,000 to 15,000 gpd through the infiltration basins, and dramatic reductions in Cr(VI) concentrations in extracted groundwater from in and around the infiltration basins.
- The range of influent Cr(VI) concentrations to the groundwater treatment plant can be extreme. The treatment plant must be capable of effectively treating the full range of anticipated concentrations and at rates that allow for continuous extraction within a reasonable operating schedule.

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