HAZARDOUS SITE CONTROL DIVISION

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VOLUME II
APPENDIXES

FEASIBILITY
STUDY FOR
SUBSURFACE CLEANUP

WESTERN PROCESSING
KENT, WASHINGTON

EPA 37.0L16.2

March 6, 1985

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PREFACE

This volume of the Western Processing Subsurface Cleanup Feasibility Study contains Appendixes A through G. Volume I contains Chapters 1 through 7, and an Executive Summary is bound separately.

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APPENDIX A

PRP REMEDIAL ACTION PLAN

This appendix is divided into two parts. Part I, the PRP Remedial Action Plan Development Process, describes the alternative evaluation criteria and process that led to the selection of the PRP remedial action plan included in this feasibility study as example alternative 4. Part II provides background information on the analyses of contaminant concentrations and the evaluation of contaminant excavation and groundwater extraction effectiveness performed as part of PRP remedial action plan development process.

PART I

PRP REMEDIAL ACTION PLAN DEVELOPMENT PROCESS

INTRODUCTION

The PRP remedial action plan for the Western Processing site was developed by the consulting engineering firms of Landau Associates and Dames & Moore. The plan is based on these consultants' understanding of the distribution of contamination at the site, the surface water hydrology and biology, the groundwater hydrology, the geology and soil conditions, and the prevailing and likely future land and water uses in the site vicinity.

Using contamination data obtained from the federal and state governments and from a review of historical site operations to form this understanding, the consultants examined alternative programs and technologies for subsurface cleanup. The basic aspect of the consultants' understanding of onsite and site vicinity conditions are outlined in Table 1.

ALTERNATIVES EVALUATION CRITERIA AND PROCESS

The following sections described the alternatives review and evaluation process and explain how the PRP plan was developed. The alternative evaluation process followed by the consultants included the following steps:

1. Potential alternative cleanup schemes and technologies were identified and evaluated (some sequentially, others concurrently.)

TABLE 1

CONDITIONS AT AND IN THE VICINITY OF WESTERN PROCESSING[1]

	Condition	Interpretation
I.	Contamination Distribution In Soil	Computer run analyses of contaminant depth profiles provided evidence of significant contamination in the deepest samples from many onsite borings and a pattern of increasing concentrations of individual contaminants with depth in many borings. The largest quantities of heavy metals appear to be present in the northern half of the site, with larger quantities of organics present in the southern half of the site.
II.	Contamination Distribution In Groundwater	In general, organics concentrations are higher in groundwater beneath the site

[1]Based primarily on EPA data (EPA 1983).

		than in soil beneath the site. The reverse is generally true for metals.
III.	Subsurface Soil and Geological Conditions	Subsurface soil at the site exhibits highly varying permeabilities, ranging from the low permeabilities of clay and silt to the relatively high permeabilities of the granular soil. No continuous low permeability layer is known to be present beneath the site at shallow to moderate depths (15 to 100 feet); a low permeability layer is known to be present to the east and south of the Western Processing site at a depth of between 150 to 200 feet and is inferred to be present beneath the site.
IV.	Groundwater Hydrology	Groundwater mounding is present at the site. Regional groundwater flow is to the west and north at a rate of about 100 feet per year. The region is characterized by a two aquifer system; a lower, artesian aquifer and an upper, water table aquifer. The piezometric surface of the lower aquifer is substantially higher than that of the upper aquifer at the eastern margin of the Kent Valley; this condition is inferred to extend to the Western Processing site area. Groundwater flow in the vicinity of the Western Processing site is primarily to the west-northwest. Mill Creek is normally a discharge point for groundwater in the immediate vicinity of the site; during periods of high flow, the creek probably discharges to the groundwater system.
V.	Surface Water Hydrology	Mill Creek flows vary widely but are probably less than about 10 cfs in the summer. EPA measurements in May 1982 indicated that the creek flow increased by about 10 percent from groundwater contribution in the reach adjacent to the site.
VI.	Surface and Groundwater Use	The rivers and tributary streams in the Kent Valley support spawning runs of

anadromous trout and salmon species. The Green River is used for recreational fishing; it is also a discharge point for treated industrial waste water.

Drinking and agricultural water supplies are drawn from the lower, artesian aquifer. The City of Kent has installed three new wells into the lower aquifer approximately 1 1/4 miles upgradient from the Western Processing site. The planned future pumping from these wells is not expected to cause drawdown in the lower aquifer beneath the site; therefore, the pumping would not draw contaminants in the upper aquifer into the lower aquifer.

The upper aquifer is not presently known to be used as either a public or private water supply in the site vicinity; it is not likely to be used for water supply in the future because of the abundance of cleaner water in the lower aquifer and from other sources. Multiple non-point sources of contamination are present in the Kent Valley and are contributing to the degradation of water quality in the upper aquifer.

VII. Land Use

The Kent Valley in the Western Processing site area has changed from an agricultural to a commercial/light industrial area over the past 20 years. This use is projected to continue for the foreseeable future.

2. Alternative technologies under each scheme were evaluated and compared in terms of the following screening criteria:

   a. technical feasibility

   b. previous use

   c. reliability

   d. potential for public acceptance

   e. future productive site use

   f. installation time

   g. future liability for PRPs

3. The most favorable alternative cleanup scheme that resulted from the screening process was evaluated in terms of its capability to eliminate the potential for harm at identified receptors. Because the upper aquifer in the site vicinity is not used as a source of municipal or private water supply for human or other uses, and is not likely to be useable for human consumption without treatment, the receptors of concern were identified as Mill Creek and the Green River. Because these two receptors are not sources of water for human consumption, the consultants focused on the potential for harm to aquatic organisms as the measure of impact. Freshwater aquatic water quality criteria were identified for comparison to projected and predicted contaminant levels at the receptors. Two-dimensional contaminant transport modeling was performed to evaluate contaminant concentrations at the Green River following completion of the cleanup scheme. A "no action" scheme was also modeled for comparison.

The computer modeling indicated that the most favorable alternative scheme would reduce contaminant concentrations to acceptable levels in Mill Creek and the Green River; the most favorable alternative was therefore adopted as the PRP remedial action plan. Refinements to the plan were subsequently made following review by the PRPs and during the development of design specifications for the plan.

POTENTIAL CLEANUP SCHEMES

Following the consultants' review of available hydrological and hydrogeological information on the Kent Valley and the EPA report "Investigation of Soil and Water Contamination at Western Processing, King County, Washington, September to November, 1982" (EPA 1983), potential cleanup schemes were identified. As indicated below, the general categories of potential cleanup schemes consisted of containment or removal of the contaminated material, although only the removal option was considered for Mill Creek.

1. Containment - surrounding the contaminated onsite materials and soil with an impermeable barrier or chemically stabilizing the contaminated materials.

2. Removal - removal of contaminated onsite materials and soil by excavation or other means, removal and treatment of contaminated groundwater.

3. Mill Creek cleanup - removal of contaminated sediments.

ALTERNATIVES ANALYSIS

For each of the potential cleanup schemes there were several alternative technologies that could be employed to provide the identified type of cleanup. A list of these alternatives is provided in Table 2.

The alternative technologies evaluated for each potential cleanup scheme and the major advantages and disadvantages of each alternative are described in the following subsections. An evaluation of the alternatives in terms of the previously identified screening criteria is provided in Table 3.

Table 3
EVALUATION SUMMARY
POTENTIAL CLEANUP SCHEMES AND ALTERNATIVE TECHNOLOGIES
WESTERN PROCESSING SITE

	Technical Feasibility	Previous Use	Reliability	Installation Time	Potential for Public Acceptance	Future Site Use	Liability for PRPs
A. Containment							
1. Impermeable cap and cutoff wall	Not feasible at Western Processing because of lack of continuous impermeable stratum	Cutoff walls and impermeable caps have had widespread application and demonstrated success in reducing or eliminating ground and surface water flow into and out of a site	High contaminant concentrations and pH range could reduce long-term effectiveness of cutoff wall	Could be installed in less than one year	Evaluated to be low because all contaminated material remains on-site, with potential for eventual escape if cutoff wall fails	Site would remain hazardous waste disposal site and not be available for future use	Site would require maintenance and monitoring for at least 30 years as required under RCRA. Long-term potential for liability associated with cover degeneration and cutoff wall failure
2. RCRA landfill	Feasible	Demonstrated technology	Assumed to have reasonable reliability	May require more than one year to install	Evaluated to be low because all contaminated material remains on site; public distrust of landfill technology	Site would remain a RCRA hazardous waste site and not be available for future use	Site would require maintenance and monitoring for at least 30 years as required by RCRA. Long-term liability associated with necessity to repair and/or replace liners

Table 3
(continued)

	Technical Feasibility	Previous Use	Reliability	Installation Time	Potential for Public Acceptance	Future Site Use	Liability for PRPs
3. Stabilization	Questionable feasibility, given range of contamination chemistry and concentrations and pH range	Not previously used at site with comparable chemical complexity	If successful stabilization product is identified through testing, would be considered to have good long-term reliability	Likely to require more than one year to install	Evaluated to be low because site remains a hazardous waste site under RCRA	Site would remain a RCRA hazardous waste site and not be available for future use	Site would require maintenance and monitoring for at least 30 years under RCRA. Lowest potential long-term liability from a technical standpoint of the containment alternatives
B. Removal							
1. Excavation of contaminated material and soil to a specific concentration level	Feasible; extensive dewatering and large volume water treatment required for probable concentration cutoff levels	Extensive previous use	High reliability in terms of source removal; does not address contaminant in groundwater beneath site	Could be accomplished in less than one year	High potential for public acceptance, provided that the cutoff level selected reduces receptor impacts to nonharmful levels	Unrestricted future use	Potential long-term liability because groundwater contamination is not addressed

Table 3
(continued)

	Technical Feasibility	Previous Use	Reliability	Installation Time	Potential for Public Acceptance	Future Site Use	Liability for PRPs
2. Excavation of fill and hot spots; cutoff wall; groundwater pumping	Technically feasible	Each component previously used; limited use of all three in combination	Because alternative removes all mobile contaminants, long-term reliability is good	Can be installed in one year, with groundwater removal for several additional years	Good, because receptor impacts reduced to nonharmful levels	Site available for some future productive uses	No long-term liability for site maintenance or systems failures
C. Mill Creek Cleanup							
1. Sediment removal only	Technically feasible; simplest cleanup alternative	Commonly used for contaminant removal	Combined with the onsite cleanup plan, sediment removal will allow Mill Creek water quality to recover	Of the three alternatives, sediment removal only requires the shortest installation time	Should be acceptable to the public	NA	Because the contamination is removed, no long-term liability is associated with this alternative
2. Sediment removal with creek liner	Feasible	Not as commonly used as sediment removal	Liner could deteriorate with time	Requires more time for installation than removal only, but less time than creek diversion	Should be acceptable	NA	Potential requirement for liner maintenance activities

Table 3
(continued)

	Technical Feasibility	Previous Use	Reliability	Installation Time	Potential for Public Acceptance	Future Site Use	Liability for PRPs
3. Creek diversion	Feasible but more difficult than sediment removal only	Not as commonly used as sediment removal	Reliable	Would require longer to install than other two alternatives. Long potential delays associated with need to obtain property or easements for new creek bed	Should be acceptable, with the possible exception of landowners on whose property the new creek bed would be constructed	NA	No long-term liability

Containment Scheme

As identified in Table 2, three containment technologies -- enclosing the contaminated materials in place so that future contaminant releases are prevented -- were evaluated: (1) enclosing the site with a cutoff wall and copaivering the site with an impervious cap, (2) confining the contaminated materials within a RCRA landfill, and (3) chemically solidifying the contaminated materials.

Impervious Cap with Cutoff Wall

To completely enclose the contaminated materials by means of an impervious cap and cutoff wall, a low permeability soil or rock layer must be present continuously beneath the site to be enclosed. When such a low permeability layer or stratum is present, the cutoff wall can be tied in to this stratum, thereby forming a subsurface "vault." With the cutoff wall and an impermeable cap in place, neither surface water nor surrounding groundwater will flow into and through the contaminated materials. With no water flow through the site, mobile contaminants in the soil and contaminants in the groundwater beneath the site would have no means of offsite transport except by diffusion (a slow process that is very minor relative to groundwater flow).

Cutoff walls have been used extensively to stop the flow of groundwater into excavation sites, to divert groundwater flow around a site, and to prevent migration of water or liquid wastes through dikes or out of impoundments. More recently they have been used at hazardous waste sites to divert groundwater flow around a site and/or to prevent the migration of leachate from a contaminated site. Thus, the technology is well demonstrated in terms of its capability to block the flow of water or certain liquid waste materials. However, the long term effectiveness of a cutoff wall to block groundwater flow and prevent the migration of contaminants at hazardous waste or Superfund sites has not been demonstrated. Materials evaluated for the cutoff wall included sheet piling, concrete, cement/bentonite, soil/bentonite, asphalt, and a synthetic membrane.

The use of impervious caps or covers to reduce or eliminate rainfall infiltration is a proven, reliable technology. An asphaltic concrete cover was contemplated under this scheme.

Although this type of scheme is feasible in concept, it was rejected for the Western Processing site because the data supplied by EPA in their 1983 report did not confirm the presence of a continuous low permeability layer at a reasonable depth beneath the site. With no such layer to serve as the bottom of the vault, this scheme was not viable for the Western Processing site.

In addition to the above consideration, the consultants were concerned about the long term reliability of the cutoff wall, given the nature of the chemical contamination and pH conditions beneath the site. No previous use of a cutoff wall at a site with a similar large number of contaminants (both metals and organics) and high contaminant

concentrations, plus both low and high pH conditions, was identified. There was considerable doubt regarding whether, over the long term, any type of cutoff wall could maintain the desired level of impermeability (at least $1x10^{-7}$ cm/sec.) while continuously exposed to these conditions.

Because the contaminated materials would remain onsite, this alternative would be regulated as a RCRA disposal site. Therefore, productive future use of the land would be precluded.

Onsite RCRA Landfill

At the same time the impervious cap/cutoff wall scheme was being investigated, the consultants also were evaluating the possibility of enclosing the contaminated materials in an onsite landfill designed to RCRA specifications (40 CFR 264). Use of this technology would involve excavating the contaminated material and soil and stockpiling them on the site; this would be followed by the construction of a clay base, a synthetic liner, and a leachate collection system. The contaminated material would then be placed in the lined excavation. An impervious cap consisting of a clay base, synthetic liner, drainage layer, and topsoil layer would then be constructed over the top of the contaminated material. The contaminated material would, by this means, be completely enclosed and isolated from contact by surface water or groundwater. Excess moisture present in the contaminated material when placed in the lined excavation would slowly migrate to the bottom of the landfill and be collected in the leachate collection system. No contaminant migration from the site would occur.

Because the landfill design selected was that mandated under RCRA, the landfill technology was deemed to be a technically feasible, previously used, and reliable alternative for use at the Western Processing Site. Technical difficulties that would have to be addressed included the necessity of constructing the landfill in stages, so that the excavated contaminated material could be stockpiled onsite before being replaced in the lined excavation. Because the bottom of the landfill would need to be above the seasonal high groundwater table, which is close to the land surface, much of the landfill would have to be constructed as an above-ground mound.

Like the encapsulation alternative, the RCRA landfill alternative would leave the site as a permanent hazardous waste disposal facility, eliminating productive future use of the site. As such, the site would also remain a potential long-term liability to the PRPs.

Stabilization

Under this alternative, onsite contaminated material would be excavated, mixed with a material that would immobilize (stabilize) the contaminants, and replaced in the excavation. The site would then be capped with an asphaltic concrete cover. Portland cement, asphalt-based lime, fly ash, gypsum, and polymer stabilization agents were evaluated.

This alternative, like the other containment alternatives, had the advantage of eliminating the risks and costs associated with transporting

and disposing of the contaminated material at an offsite hazardous waste facility. Under some stabilization methods, the cost of stabilization was considerably less than the cost of offsite transportation and disposal on the basis of vendor cost estimates. However, stabilization was rejected for the following reasons:

1. Only one of the stabilization methods, cement, had been demonstrated at a site with the chemical complexity of the Western Processing site. This stabilization method can be very costly. The time required to develop and test suitable formulae for other potential stabilizers would be lengthy, with no guarantee that a successful product--one with a high probability of long-term effective operation--could be developed.

2. While some of the stabilization methods (e.g., lime and fly ash) were relatively inexpensive, compared to the cost of offsite transportation and disposal, others were more expensive. The less expensive methods were evaluated to have a lower probability of effective, long-term binding of all of the chemical contaminants at the Western Processing site.

3. Where chemical stabilization has been or is proposed for use at other hazardous waste sites around the country, the EPA is requiring that the sites be considered RCRA landfills. Thus, the stabilization alternative would involve all of the components and costs of the RCRA landfill alternative plus the difficulties, uncertainties, and cost of chemical stabilization. Although these two technologies combined would result in a state-of-the-art containment scheme with a high probability of successfully containing contaminants on the site over the long term, the site would still be left as a hazardous waste disposal site and hence not available for productive use. As such, the site would be a long-term potential liability for the PRPs.

Removal Schemes

Two types of removal schemes were evaluated for the Western Processing site: excavation of contaminated soil to depths defined by a selected contaminant concentration "cutoff" level, and excavation of probable buried waste locations combined with a program to remove contaminated groundwater and flush mobile contaminants from unexcavated soil. Removal schemes are normally focused on removing a specified amount of the contaminants present at a site. A decision regarding how much needs to be removed is made on the basis of regulatory requirements or guidelines and the potential for harm to humans and the environment. Normally the contaminated material is taken to a hazardous waste facility for disposal by landfilling.

At the Western Processing site, the EPA's onsite data indicated that contaminants had migrated to at least 30 feet below ground surface. A number of individual contaminant concentrations showed a pattern of increase with depth in onsite borings, suggesting that high concentrations could be expected in soil below 15 feet. However, any excavation at the site deeper than 8 to 10 feet below the ground surface during the drier summer season would encounter groundwater. During the wet winter season, groundwater

would be encountered at shallower depths. Excavating to depths below the groundwater table would require dewatering of the excavations and consequently slower construction techniques. Most significantly, the groundwater that would have to be removed to dewater the excavations would be contaminated and would have to be either treated prior to discharge or transported to a hazardous waste facility.

Analysis of the data developed by EPA on the distribution of contaminants in surface and subsurface soils had indicated that there was no clear pattern of contaminant distribution on which to base a removal scheme, other than that the majority of metals contaminants were in the soil while the majority of organics were in the groundwater.

Excavation to Contaminant Cutoff Level

The contaminant cutoff scheme initially evaluated for the Western Processing site focused on levels of metals in the soil. The consultants evaluated removal schemes that involved excavation to two cutoff levels: 5000 ppm and 2000 ppm of total priority pollutant metals. The following table shows the amount of contaminated material that would need to be excavated, and the maximum depth of the excavation, for these contaminant cutoff levels:

Total Priority Pollutant Contaminant Level (ppm)	Volume of Excavation (cu.yds)	Maximum Depth of Excavation
5,000	105,000	11 feet
2,000	145,000	13 feet

As can be seen, these alternatives would involve the removal of very large quantities of material that would subsequently have to be shipped to a hazardous waste facility for disposal. Moreover, the excavations would extend below the groundwater table. Thus, large quantities of water would have to be pumped (and subsequently treated or shipped to a hazardous waste facility) in order to dewater the excavations.

Furthermore, the contaminant cutoff levels were chosen somewhat arbitrarily--there are no guidelines that specify acceptable residual contamination levels for Superfund sites. At the time, the Washington Department of Ecology's policy for cleanup of soil contamination was to clean a site to levels no higher than 10 times the water quality criterion for the contaminant in question, or to a background level established by measuring soil samples that were representative of the site area. Despite the large quantities and depths that would be involved in the previously cited options, none would have satisfied the DOE policy.

Excavation of Waste Materials Combined with a Pumping/Flushing Scheme

At the same time that the depth/concentration questions were being evaluated, pumping and treatment of contaminated groundwater were also being evaluated. Because most of the organics (by mass) were present in the groundwater, according to EPA's data, no program of soil removal alone would remove these contaminants from the site. Therefore, groundwater pumping was deemed necessary to remove the organics from beneath the site.

Groundwater removal can be accomplished by three general methods: gravity collection (drains), vacuum pumping (well point system), or positive displacement (individual wells with submerged pumps). Which method or combination of methods is appropriate for a particular site depends on the objectives for the installation and performance of the system. For the Western Processing site, the following objectives are applicable to the groundwater removal system.

a. The method selected should, in conjunction with other components of the cleanup plan, minimize the quantity of groundwater pumped.

b. It should be reliable and easily serviceable.

c. It should be flexible and adaptable.

d. It should allow groundwater samples to be collected conveniently.

e. It should be cost-effective to install and maintain.

Gravity collection satisfies several of these objectives, but would be unable to withdraw contaminated groundwater below a depth of about 15 feet. Gravity collection would, however, be effective in eliminating the groundwater mound present at the site.

A well point system satisfies all of the above objectives. It would be particularly effective in minimizing the quantity of groundwater pumped. Such a system is adaptable, reliable, and conveniently serviceable. The system can be designed so that individual well points can be sampled at various locations on the site. Because of the large number of well points that would be installed, clogging or other failure of a few of the well points would not adversely affect the performance of the system. The ease of installation and low individual cost allow uncomplicated and inexpensive replacement if necessary.

The well point system would be particularly useful for identifying the effectiveness of the pumping in all areas of the site. Individual well points or sections of the system could be closed off to allow selective recovery from specific portions of the site if necessary to optimize the recovery of contamination remaining after soil removal.

Deeper wells with submerged pumps also satisfy most of the above criteria, but less effectively than the well point system. Because of the cost of an individual well installation and the greater drawdown afforded by each individual well, the number of wells installed would be considerably less than for the well point system; the deep well system would, therefore, be less flexible and adaptable. The failure of an individual deep well would have a greater impact on the overall performance of the system, and the cost of service and replacement would be greater than for the well point system.

As the consultants considered the technical aspects of groundwater removal as well as the infeasibility of excavating enough soil from the site to remove the majority of contamination in the soil, they realized that they could also use the groundwater removal system to remove mobile contaminants from the soil by a soil flushing process. This involves removing the

contaminated groundwater from beneath the site and then drawing cleaner water from outside the site through the contaminated soil. As this cleaner water passes through the soil, it will remove the mobile contaminants that had been leached by infiltrating rainwater from the surface or from buried wastes and had subsequently become physically or chemically bound to the soil particles. This soil flushing process would partially reverse the mechanism which conveyed the contaminants to their present location within the soil profile.

To maximize the depth of contaminated soil through which the cleaner water would be drawn, the consultants determined that construction of a "hanging" cutoff wall would be useful. Unlike the cutoff wall contemplated under the containment scheme, this cutoff wall would be constructed only to a depth equal to or slightly greater than the depth at which contaminants were still found in relatively high concentrations. Because the contaminated groundwater would be withdrawn from beneath the site in a relatively short period of time, the cutoff wall would not be subjected to the same degree of chemical attack that was of concern to the containment scheme. Further, the wall would only need to maintain a very low permeability for the duration of the limited pumping/flushing period.

In the absence of definitive data on the depths to which high concentrations of contaminants occur on the site, a depth of 40 feet was selected for the hanging cutoff wall. While there is evidence suggesting that the high concentrations decrease between 25 and 30 feet below the ground surface, a 40-foot depth was chosen to be conservative.

The decision to use a groundwater removal system to also remove mobile contaminants from contaminated soil at the site made the well point system the definitely preferable alternative for groundwater removal. In addition, the consultants determined that, for the reverse leaching scheme to work at the Western Processing site, very high concentrations of contaminants and all buried wastes would have to be removed. This is because any contamination that had entered the subsurface by a means other than leaching would not be amenable to removal by the reverse leaching or soil flushing process. Thus, an excavation plan that would complement the groundwater pumping/soil flushing plan was developed concurrently.

This excavation plan involves the excavation of all fill areas on the site to the original ground contours prior to the first use of the site as an anti-aircraft artillery (AAA) installation. Aerial photographs of the site over the years from 1946 to 1982 showed continuous excavation and filling operations. It was reasoned that fill areas, whether natural depressions or excavations, would be the most likely location of buried materials. The excavation plan also included removal of "hot spots"--areas of significantly higher contaminant concentrations--identified on the basis of EPA's data.

Mill Creek Cleanup

Measures to clean up Mill Creek were deemed appropriate due to relatively high concentrations of contaminants in sediments in the creek adjacent to and downstream of the Western Processing site. Three cleanup alternatives were evaluated: sediment removal only, sediment removal in conjunction with placement of a synthetic bottom liner, and sediment removal associated with

permanent creek diversion. All three alternatives involve diversion of the creek, although diversion in the first two alternatives is temporary. Mill Creek cleanup is essentially independent of the technologies for onsite contaminant containment or removal; it was thus evaluated separately.

Sediment removal only was selected because of its cost effectiveness and relative ease and feasibility of construction. It can be accomplished independently of the onsite work. Because this method requires temporary diversion of Mill Creek, it is best implemented during the summer to minimize the need to divert high flows and handle precipitation into and runoff from the cleanup area. Permits to divert the flow and cross private and public property with the diversion pipeline would be necessary for this as well as the other alternatives.

Addition of a liner after sediment removal would reduce the amount of residual contamination entering Mill Creek via groundwater. However, after the onsite remedial activities are implemented, the transport of contamination to the creek by groundwater will be significantly reduced. Therefore, only a small amount of residual contamination would enter Mill Creek, if unlined; this contamination would remain in the groundwater if a liner is placed in the creek. For these reasons, placement of the liner is not deemed appropriate.

Permanent creek diversion (rerouting) could potentially eliminate residual contamination entering the creek. However, the reasons for rejecting the liner alternative are the same as for rejecting the permanent diversion alternative. Additionally, permanent diversion would require obtaining easements or rights-of-way or acquisitions of property; it might also interfere with the City of Kent's plans to modify the Mill Creek system to improve storm water drainage in the Kent Valley. While it would obviously be desirable to coordinate permanent diversion of the creek with the drainage system improvements, plans for the latter have not been developed and will not be until after implementation of the remedial action plan. Thus, permanent diversion during cleanup is unwise from a long-range planning standpoint as well as being unwarranted technically.

PART II - BACKGROUND INFORMATION ON STUDIES PERFORMED AS PART OF THE PRP REMEDIAL ACTION PLAN DEVELOPMENT PROCESS

The studies described in the following sections were based on contaminent data developed by the USEPA and published in May 1983 in the two part document entitled "Investigation of Soil and Water Contamination at Western Processing, King County, Washington." Subsequent investigations conducted by USEPA have produced additional contaminant data; these data are not reflected in the following discussions. In addition, at the time these studies were performed, the degree of influence exerted by Mill Creek on local groundwater flow patterns was not known; subsequent ongoing studies are refining the results of the effectiveness analyses performed to evaluate the PRP plan to take into account this new information regarding Mill Creek's effect on local groundwater flow.

The studies described in this part are the following:

1. The method of calculating onsite average contaminant concentrations in soil and groundwater.

2. The contaminant ranking procedure.

3. Post-excavation soil concentrations.

4. Flushing program effectiveness evaluation.

ONSITE AVERAGE CONTAMINANT CONCENTRATIONS

Need for Average Concentrations

The data for soil and groundwater contaminant concentrations at the Western Processing site reported in the USEPA May 1983 report reflect large quantitative variations among different samples. These are demonstrated in highly skewed frequency distributions of concentrations for most of the measured contaminants. Analyses based only on maximum concentrations would not reflect this distribution of con-

taminant concentrations; some measure of typical concentrations at the site for both soil and groundwater contaminants was desirable in order to supplement the analyses based on maximum concentrations alone.

The variation of contaminant concentrations in samples from different onsite locations diminishes in importance with increasing distance from the site. A variety of physical and chemical processes act to "average" the disparate concentrations, reducing the variability characteristic of individual measured concentrations. A calculation of onsite average concentrations may be used as a first approximation of this phenomenon. Moreover, information on the average concentrations by contaminant in soil and groundwater provides data helpful for selecting appropriate parameters for groundwater modeling for use in evaluating the effectiveness of a remedial action. Such modeling still may account for the geographic variability in contaminant concentrations across the site. However, parameter values determined using the data for onsite average concentrations incorporate site conditions (e.g., soil types) and thereby supplement parameters derived from theory alone and improve modeling predictions.

General Approach

A weighting factor approach, with the sum of the weights equal to one, was used to calculate a single average concentration from the multiple onsite sample values for each contaminant.[1] Considerations of geographic proximity and past activities and uses of the site led to the development of two different sets of weights. The first was based on a geometric partitioning of the site into contiguous areas surrounding each available sampling location. The values at a sampling location were assumed to be representative of the area defined around it, and the appropriate weight therefore became the proportional site area included in the partitioned cell surrounding the sample location. This method accounted for the assumed proximity relationship (nearby locations should have more similar pollutant concentrations than distant locations, on average); however, the partitioned cells often included only a

[1] The average value of contamination C is calculated by the formula $C_{ave.} = {}_iW_iC_i$, where W_i is the weight for well number i and C_i is the concentration of contaminant C at well number i.

part of an area of significant site use (e.g., surface impoundment) or included multiple site uses, and therefore do not reflect appropriately the influence of site history.

A second approach used information on past site activities and uses to derive a set of weights. Rather than assigning a single (area-derived) weight to each sampling location directly, the site history approach focused on identifying distinct subareas of the site used for surface impoundments, waste piles, tanks, or other significant uses. A set of one or more sampling locations deemed representative of each subarea was identified, based on the correspondence of site history for the subarea and sampling locations. The proportional area of each site-history derived cell was then allocated equally to each of the representative sampling locations. For example, the reaction pond area constituted approximately 6.95 percent of the total site area. Wells 10, 14, and 16 were deemed representative of this impoundment area; each was allocated a weight equal to one-third of the reaction pond's proportional area, or 0.0695 divided by 3 equals 0.0232. A single sampling location could be representative of more than one site use subarea; in such cases, the final weight assigned to that sampling location was the sum of its partial weights.

In most instances, the set of representative sampling locations consisted of adjacent or nearby wells, preserving the assumed proximity relationship even though assigning weights somewhat differently. In a few cases, however, no nearby wells represented similar site used; in these cases, the representative sampling locations used were from more distant portions of the site. Given the available sampling locations, both site history and proximity relationships could not be preserved in all cases.

The weights resulting from these two approaches showed considerable differences. However, the onsite average concentrations calculated for each contaminant using these two sets of weights are generally similar, differing most significantly for a few contaminants detected only at low concentrations or at only a few locations. The calculated average contaminant concentrations, along with maximum concentrations, are listed in Table A-1.

TABLE A-1

MAXIMUM AND AVERAGE CONTAMINANT CONCENTRATIONS IN ONSITE SOIL[a]

Contaminant	Maximum Concentration[b]		Average Concentration[b]		
	Surface Soil[c]	Subsurface Soil	Geometric[d]	Site History[d]	Percent Difference[e]
Al	4,700	19,500	3,263	3,353	2.8
Cr	5,300	7,600	594.26	438.90	26.1
Ba	150	180	36.37	34.49	5.2
Co	16	12.4	0.57	0.44	22.8
Cu	890	5,700	332.93	294.25	11.6
Fe	18,900	13,400	4,373	4,198	4.0
Ni	740	1,900	94.11	63.94	32.1
Mn	2,900	2,800	368.32	255.18	30.7
Zn	81,000	40,500	2,578	2,043	20.8
B	170	240	60.68	69.88	15.2
V	140	76	2.40	1.99	17.1
Ag	6.1	1.4	0.01	0.01	0
As	38	102	3.28	1.98	39.6
Sb	98	130	8.59	3.02	64.8
Se	1	30.5	0.83	0.31	62.7
Tl	0	1.5	0.01	0.01	0
Hg	0.14	0.36	0.01	0.01	0
Sn	19	10	0.81	0.38	53.1
Cd	420	402	34.72	20.21	41.8
Pb	31,000	141,000	5,451	2,729	49.9
CN	15	179	11.16	6.37	42.9

(a) For all contaminants present at quantifiable levels.

(b) Values in ppm.

(c) The following contaminants, with maximum concentrations indicated, were found only in surface soils:

Pentachlorophenol	17,000
di-N-butyl phthalate	2,600
di-N-octyl phthalate	29,000
benzo-B-fluoranthene	200,000
benzo-K-fluoroanthene	130,000

(d) These data are based on 103 onsite subsurface samples excluding 7 samples at Wells 13 and 14 offsite.

(e) The percent difference in the two site average values is calculated as the absolute value of: $\frac{\text{Geometric} - \text{Site History}}{\text{Geometric}}$

TABLE A-1, continued

Contaminant	Maximum Concentration[f]		Average Concentration[f]		
	Surface Soil[c]	Subsurface Soil	Geometric[d]	Site History[d]	Percent Difference[e]
2,4-Dichlorophenol	0	7,900	208.60	164.39	21.2
2,4-Dimethylphenol	11,000	10,000	218.15	168.67	22.7
Phenol	19,000	65,000	1652	1210	26.8
Aldrin	0	2,860	6.08	9.58	57.6
Dieldrin	145	3,340	7.10	11.19	57.6
4,4-DDT	0	129	2.92	4.12	41.1
4,4-DDD	0	100	0.77	0.84	9.1
Heptachlor	0	2,960	6.23	9.82	57.6
Lindane	34	11.8	0.09	0.10	11.1
PCB-1242		1,780	79.03	50.51	36.1
PCB-1254	137	407	4.33	1.89	56.4
PCB-1248	3,300	19,600	341.27	292.32	14.3
PCB-1260	2,046	1,710	38.13	33.25	12.8
PCB-1016	2,030	3,160	50.32	42.31	15.9
Acenaphthene	0	8,700	75.86	116.75	53.9
Hexachloroethane	5,090,000	1,800	19.17	8.35	56.4
1,2-Dichlorobenzene	0	565,000	13,007	10,780	17.1
Fluoranthene	2,200	7,700	155.75	165.88	6.5
Naphthalene	234,000	13,000	226.52	196.88	13.1
Bis-2 (ethyl hexyl) phthalathe	6,200,000	410,000	12,238	4,635	62.1
Benzylbutylphthalate	860,000	9,100	79.35	122.12	53.9
Benzo(a)-anthracene	884,000	4,000	47.84	35.28	26.3
Chrysene	1,210,000	2,500	29.90	22.05	26.3
Anthracene	0	1,600	19.14	14.11	26.3
Flourene	8,600,000	16,900	147.37	226.80	53.9
Phenanthrene	20,000,000	62,400	719.80	954.30	32.6
Pyrene	16,000,000	11,000	184.42	212.89	15.4

(f) Values in ppb.

TABLE A-1, continued

Contaminant	Maximum Concentration[f] Surface Soil[c]	Maximum Concentration[f] Subsurface Soil	Average Concentration[f] Geometric[d]	Average Concentration[f] Site History[d]	Percent Difference[e]
Benzene	0	199.5	1.53	1.67	9.2
1,1,1-Trichloroethane	0	174,000	2,870	2,411	16.0
1,1-Dichloroethane	0	17.3	0.13	0.14	7.7
Chloroform	0	18,000	143.25	155.81	8.8
Trans-1,2-Dichloroethene	0	34	0.99	0.51	48.5
Ethylbenzene	13	37,000	523.87	570.13	8.8
Methylene chloride	130	49,000	1,486	1,435	3.4
Florotrichloromethane	25	73	3.21	1.90	40.8
Tetrachloroethene	99	72,000	1,196	976.28	18.4
Toluene	0	394,000	6,437	6,817	5.9
Trichloroethene	37	580,000	19,267	17,853	7.3

Available Data

The locations of available data for soil and groundwater contaminant concentrations in the upper zone differ slightly. For EPA Wells 27 and 28, which are immediately adjacent to the western boundary of the site, groundwater data are available but no soil values were reported.[2] These wells, because of their location near the site boundary, provided useful data for calculating onsite groundwater concentrations. Therefore, the weights for soil and groundwater averages are slightly different, reflecting the inclusion of EPA Wells 27 and 28 in the latter case only. A total of four distinct sets of weights--using geometric and site history approaches for both soil and groundwater data--were derived.

Data from more distant offsite wells, including Wells 13 and 19 which provide the only offsite soils information included in the data base of this study, were not used in the calculation of onsite average concentrations for the upper zone.

[2]EPA's May 1983 report, "Investigation of Soil and Water Contamination at Western Processing, King County, Washington," shows that a total of 5 soil samples were taken (see Part I, Table 2, p. 15) at Wells 27 and 28. However, no data were reported for these soil samples.

Limited groundwater data were available for several deeper zones at approximately 30 to 150 feet below ground surface. Five onsite wells (1, 11, 17, 22, and 25) provided information for the 30-foot zone; the 50- and 130-foot zones were each characterized by three offsite wells from the set of four Wells 31 through 34. A set of weightings for each of these deeper groundwater zones was derived using a geometric partitioning approach. No comparable data for deeper soil contaminant concentrations were available; except for Well 17, the deepest soil samples were for 15 feet below ground surface.

Weightings Used in Calculating Average Concentrations

Soil Average Concentrations. Each onsite well provided soil contaminant data for a series of sampling depths. For the purpose of calculating onsite averages of contaminant concentrations in soil, this depth profile information was not preserved. The concentrations within each well were averaged and then multiplied by the appropriate weight; the sum of these values was then used to represent the onsite average concentration.[3] Sixty-eight contaminants (51 priority pollutants, 8 nonpriority pollutant inorganics, 9 nonpriority pollutant organics) were quantified in the data base for this study at concentrations above detection limits in onsite subsurface soils.

The same weights can be used to calculate average soil concentrations before and after the soil removal phase of remedial actions onsite, thus providing one measure of the effectiveness of surface cleanup and soil removal.

Figure A-1 shows the partitioning of the site used to derive a set of geometric weights for calculating soil averages. Table A-2 lists both the geometric and site history weights by well location. A comparison of the two sets of weights in Table A-2 shows that there are significant differences in the weights derived by the two approaches.

Groundwater Average Concentrations. Onsite groundwater average concentrations were calculated for the upper zone, using the data from the

[3]The limitations of available data with depth are accepted in performing this calculation; no attempt was made to project contaminant concentrations for depths below the sample locations. Thus, the calculation provides an "upper-zone" average concentration in soils.

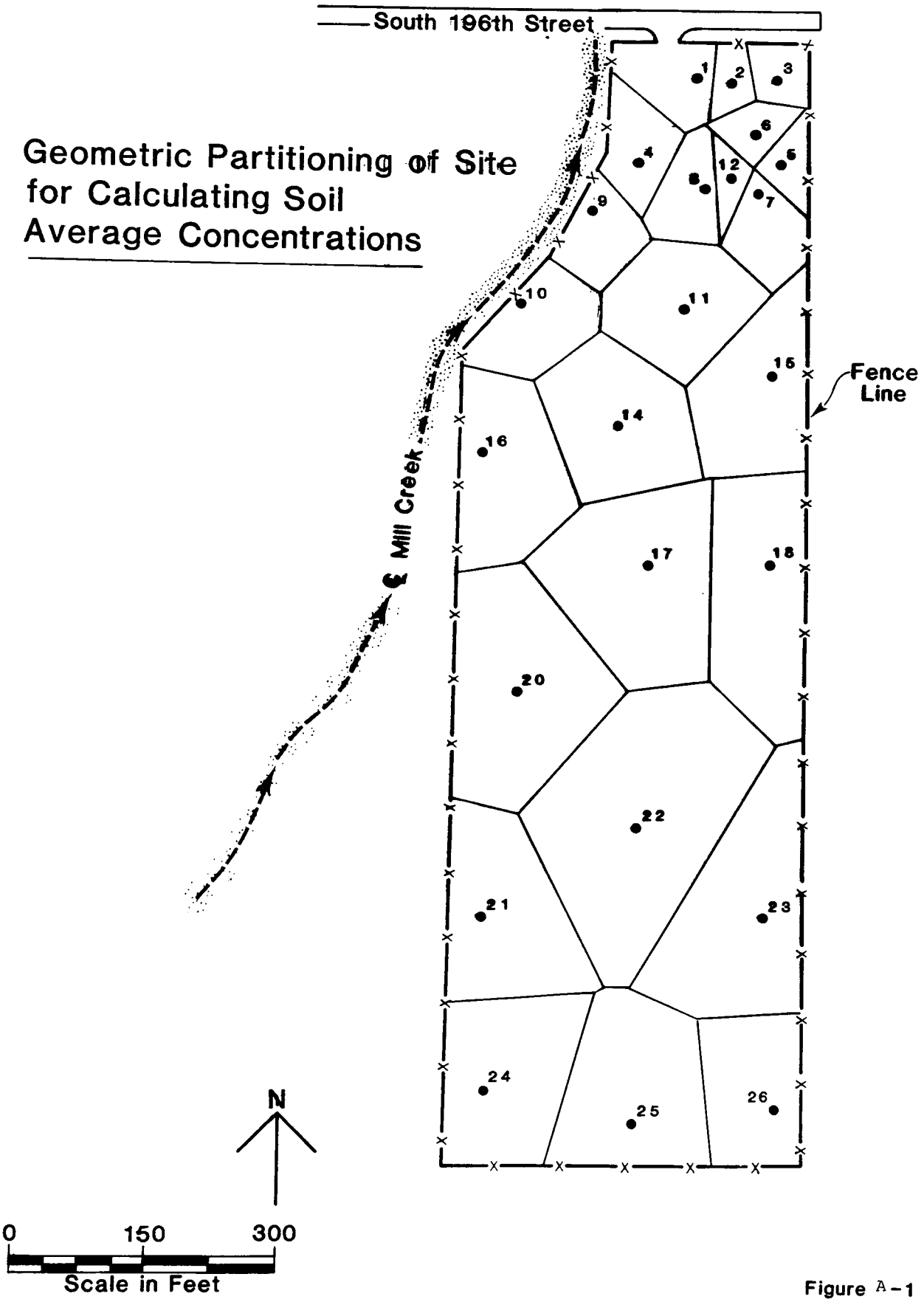

South 196th Street
Geometric Partitioning of Site for Calculating Soil Average Concentrations
Mill Creek
Fence Line
1
2
3
4
5
6
7
8
9
10
11
12
14
15
16
17
18
20
21
22
23
24
25
26
N
0
150
300
Scale in Feet

Figure A-1

TABLE A-2

WEIGHTINGS FOR CALCULATING ONSITE SOIL AVERAGES
(SUBSURFACE)

Well	Weightings	
	Geometry	Site History
1	0.0195	0.0549
2	0.0076	0.0169
3	0.0074	0.0134
4	0.0201	0.0549
5	0.0065	0.0134
6	0.0085	0.0134
7	0.0178	0.0169
8	0.0187	0.0549
9	0.0167	0.0230
10	0.0272	0.0232
11	0.0436	0.0671
12	0.0054	0.0169
13(a)	--	--
14	0.0532	0.0232
15	0.0473	0.0392
16	0.0513	0.0232
17	0.0769	0.0838
18	0.0653	0.1180
19(a)	--	--
20	0.0851	0.0499
21	0.0598	0.0441
22	0.1282	0.0441
23	0.0759	0.0441
24	0.0569	0.0241
25	0.0612	0.0883
26	0.0399	0.0491
27(b)	--	--
28(b)	--	--
Sum of weights	1.00	1.00

(a)Wells 13 and 19 are offsite (as are Wells 29 and 30) and do not contribute to the calculation of onsite averages.
(b)No soils data were reported for Wells 27 and 28.

uppermost screened interval in each of the wells. Since the data for only a single sample within each well were used, no averaging of values within the well was necessary. Each value was multiplied by the appropriate weight; the sum of these contributions over the site represents the (upper zone) average groundwater concentration. A total of 46 priority pollutants, 8 nonpriority pollutant inorganics, and 10 nonpriority pollutants organics were quantified at concentrations above detection limits in the groundwater data.

Figure A-2 shows the partitioning of the site used to derive a set of geometric weights for calculating upper zone groundwater averages. This is identified to Figure A-1 for soils, except in the vicinity of Wells 27 and 28, located on the western boundary of the site. Table A-3 lists both the geometric and site history weights, again illustrating that significant differences in weights result from the two approaches to calculating onsite averages.

For deeper groundwater zones at approximately 30, 50, and 130 feet below ground surface, only a geometric partitioning assignment of weights was used since the available data were quite limited. Table A-4 identifies the wells and weights used for these three deeper zones to calculate average concentrations. All of the data used in calculating groundwater average concentrations for the deeper zones (50- and 130-foot) represent offsite sampling locations.

CONTAMINANT RANKING

Although 46 EPA priority pollutants[4] were encountered in the groundwater, including known and suspected carcinogens, there is a wide range of contaminant concentrations and toxicities. Because of this toxicity range and the large number of contaminants encountered, a classification system was established to identify which contaminants would be analyzed in detail. This "priority ranking" was determined using a subjective analysis that included the following considerations, listed in order of decreasing importance:

[4]All 13 EPA priority pollutant metals and 33 of the EPA priority pollutant compounds were found in quantifiable concentrations in groundwater.

1. Diminution factor, which is the average concentration of the contaminant in the groundwater in the upper zones of onsite monitoring wells divided by either the human health criterion or the aquatic criterion for that contaminant, whichever is lower. The resulting factor indicates the ratio by which the contaminant must be diluted or otherwise attenuated to meet the criterion. Assuming all other issues related to contaminants are equal, contaminants with the highest diminution factors are of greatest concern.

2. Average concentration of the contaminant in the onsite groundwater.

3. Comparison of concentrations in the onsite groundwater with background concentrations at receptors.

4. The number of wells in which the contamination was found.

5. Whether there is a water quality criterion for the specific contaminant or only for a related compound or element.

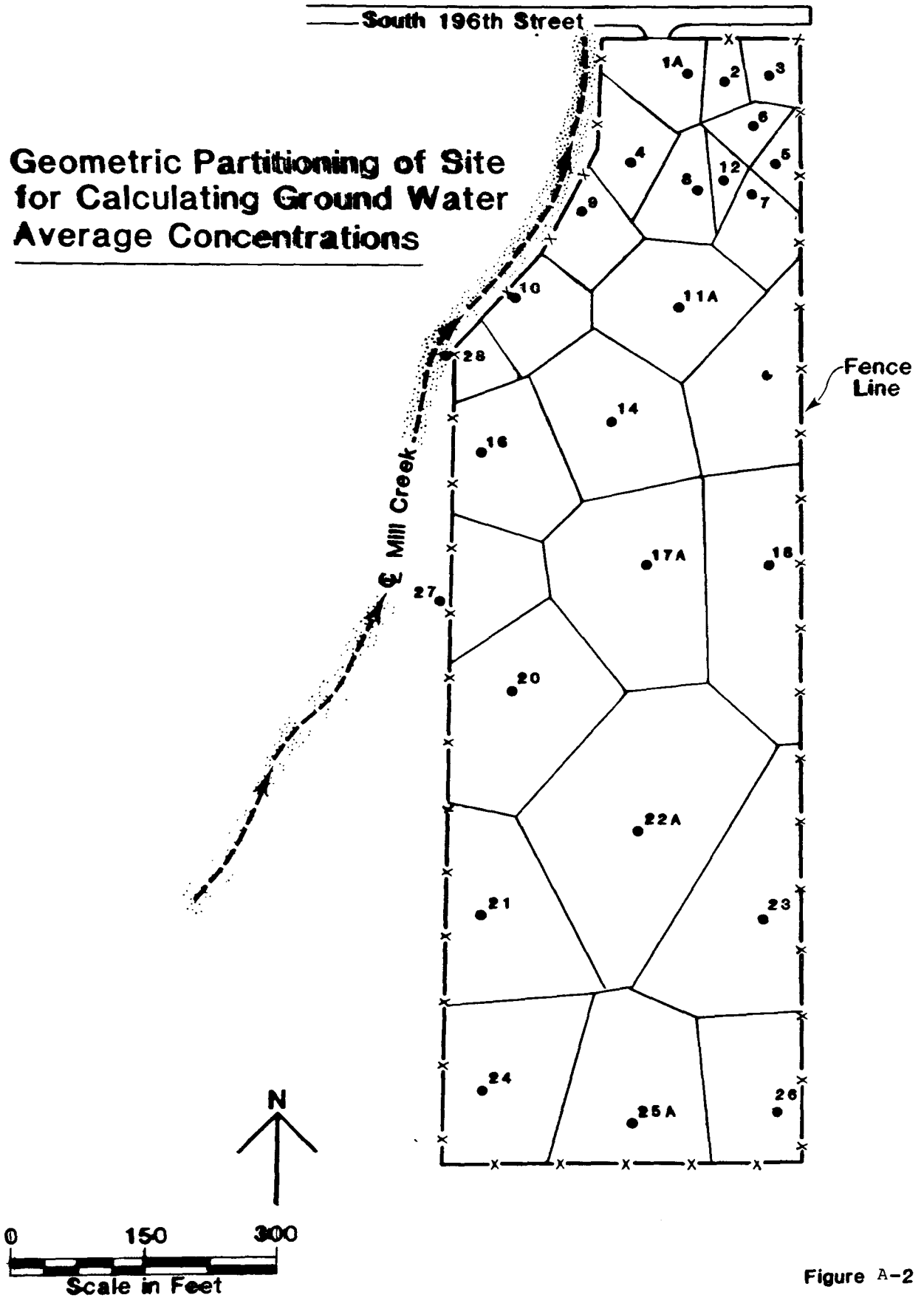

Geometric Partitioning of Site for Calculating Ground Water Average Concentrations
South 196th Street
Fence Line
℄ Mill Creek
1A
2
3
4
5
6
7
8
9
10
11A
12
14
16
17A
18
20
22A
21
23
24
25A
26
27
28
N
0
150
300
Scale in Feet

Figure A-2

TABLE A-3

WEIGHTINGS FOR CALCULATING ONSITE UPPER ZONE GROUNDWATER AVERAGES

Well	Weightings	
	Geometry	Site History
1A	0.0195	0.0549
2	0.0076	0.0169
3	0.0074	0.0134
4	0.0201	0.0549
5	0.0065	0.0134
6	0.0085	0.0134
7	0.0178	0.0169
8	0.0187	0.0549
9	0.0167	0.0230
10	0.0221	0.0174
11A	0.0436	0.0671
12	0.0054	0.0169
13(a)	--	--
14	0.0532	0.0173
15	0.0473	0.0392
16	0.0399	0.0174
17A	0.0750	0.0793
18	0.0653	0.1180
19(a)	--	--
20	0.0700	0.0455
21	0.0598	0.0441
22A	0.1282	0.0441
23	0.0759	0.0441
24	0.0569	0.0241
25A	0.0612	0.0840
26	0.0399	0.0491
27	0.0261	0.0134
28	0.0074	0.0173
Sum of weights	1.00	1.00

(a)Wells 13 and 19 are offsite (as are Wells 29 and 30) and do not contribute to the calculation of onsite averages.

TABLE A-4

WEIGHTINGS FOR CALCULATING ONSITE
DEEPER ZONE GROUNDWATER AVERAGES CONCENTRATIONS[a]

	Wells	Weightings
30-foot zone	1B	0.0843
	11B	0.2014
	17B	0.2567
	22B	0.2766
	25B	0.1810
Sum of Weights		1.00
50-foot zone	31B	0.1732
	33A	0.1250
	34B	0.7018
Sum of Weights		1.00
130-foot zone	31A	0.0756
	32B	0.2108
	34A	0.7136
Sum of Weights		1.00

(a) Data based on site geometry.

As a result of this analysis, three categories of contaminants were established: Priority Levels 1, 2, and 3. Detailed analyses of contaminant concentrations and migration were conducted for contaminants of greatest concern, i.e., those in Priority Levels 1 and 2.

Priority Level 1 contaminants were considered to be of greatest concern and were thus subjected to the most rigorous analyses throughout studies. Priority Level 2 includes contaminants that are of potential concern, but that appear to represent less of a threat than those in Level 1. Priority Level 3 contaminants are those not expected to significantly affect potential receptors and were not subjected to detailed analyses. Because the diminution factors for Priority Level 3 contaminants are relatively low, it is expected that the remedial measures adopted for Priority Level 1 and 2 contaminants will also be effective for Priority Level 3 contaminants. Table A-5 lists the priority levels, average concentrations, water quality criteria, and diminution factors for all EPA priority pollutant metals and organics in the shallow groundwater.

In addition, several contaminants not on the priority pollutant list were measured in the groundwater. The following eight non-priority pollutant metals were measured in the groundwater:

aluminum	barium	cobalt
iron	manganese	boron
vanadium	tin	

Since aluminum was found at such high concentrations in the groundwater and could be a human health concern, it was included in the groundwater contaminant ranking. Average concentrations for barium, vanadium, and tin were below the level of concern. There are no established criteria for cobalt or boron; therefore, a detailed analysis was not made for them. The concentrations of iron and manganese were greater than drinking water standards, but since these standards are based on aesthetic considerations rather than human health or aquatic toxicity, these metals also were not analyzed in detail.

TABLE A-5

GROUND WATER CONTAMINANT RANKING[a]

	Human Health Criteria[b]	Freshwater Aquatic Criteria[c] Existing	Freshwater Aquatic Criteria[c] Proposed[d]	Average Concentration in Ground Water On Site[e]	Diminution Factor (GW Avg./ Strictest Existing WQ Criteria)	Priority Level	Comment
Metals							
Cadmium	10	0.012	2	2,100	1.8×10^5	1	--
Aluminum[f]	200 (WHO-aesthetics[g])	1[h]		71,564	7.2×10^4	2	Priority Level 2 due to widespread occurrence on site
	5,000 (NAS 7-day health advisory)				1.4×10^1	2	Priority Level 2 due to widespread occurrence on site
Hexavalent chromium	50	0.29	7.2	4,251	1.5×10^4	2	Priority Level 2 since trivalent form more likely
Arsenic	0.0022	40	72	14.7	6.4×10^3	2	Priority Level 2 since soil concentration only slightly greater than background
Zinc	5,000 (taste)	47		139,732	3.0×10^3	1	--
Nickel	13.4	56		15,471	1.2×10^3	1	--
Lead	50	0.75	1.0	366	4.9×10^2	2	--
Copper	1,000 (taste)	5.6	5.8	1,467	2.6×10^2	2	--
Trivalent chromium	170,000	44	42	4,251	1.0×10^2	2	--
Silver	50	0.12		1.54	1.3×10^1	3	--
Beryllium	0.0068	5.3		0.04	5.9×10^0	3	--
Mercury	0.144	0.2	0.2[i]	0.36	2.5×10^0	2	Priority Level 2 due to presence in Green River
Antimony	146	1,600		1.45	9.9×10^{-3}	3	--
Selenium	10	35		(none in upper zone)		3	--
Thallium	13	20		(none on site)		3	--

(a) All concentrations expressed in parts per billion.
(b) For carcinogens, the concentrations shown represent a risk level of 10^{-6}.
(c) For criteria varying with hardness, a value of 50 mg/l as $CaCO_3$ is assumed.
(d) Proposed revisions to water quality criteria, February 7, 1984 (49 Fed. Reg. 4551).
(e) Weighted average for upper aquifer calculated based on previous use of the site.
(f) EPA has issued no water quality criteria for aluminum (see 45 Fed. Reg. 79318, November 25, 1980); the values shown here are other proposed or derived criteria.
(g) WHO = World Health Organization. See 48 Fed. Reg. 45514, October 5, 1983 where EPA gives an advance notice of proposed rule making for National Revised Primary Drinking Water Regulations.
(h) Derived from review of literature. Assumes factor of safety of 100 over bioassay results.
(i) May not protect some salmonids from chronic toxicity. Also, applies to divalent mercury, not methyl mercury.

TABLE A-5, Continued

	Human Health Criteria[b]	Freshwater Aquatic Criteria[c] Existing	Proposed[d]	Average Concentration in Ground Water On Site[e]	Diminution Factor (GW Avg./ Strictest Existing WQ Criteria)	Priority Level	Comment
Organics (continued)							
2,4,6-Trichlorophenol	1.2	970		118	9.8×10^{1}	3	--
Chloromethane	0.19	11,000		14.27	7.5×10^{1}	3	--
Vinyl chloride	2	no standard		31.70	1.6×10^{1}	3	--
2,4-Dichlorophenol	0.3 (taste)	70		3.81	1.3×10^{1}	3	--
Pentachlorophenol	30 (taste)	3.2		18.76	5.9×10^{0}	3	--
1,1,2-Trichloroethane	0.6	9,400		2.47	4.1×10^{0}	3	--
1,1,1-Trichloroethane	18,400	18,000		18,904	1.1×10^{0}	2	High concentration only at Well 1
4-Nitrophenol	13.4 (strictest nitrophenol class)	150 (algae)	230	125	9.3×10^{0}	3	--
2,4-Dimethylphenol	400 (taste)	2,120		179	4.5×10^{-1}	3	--
Toluene	14,300	17,500		2,324	1.6×10^{-1}	2	Moderate concentration at several wells
1,2-Dichlorobenzene	400	763		6.27	1.6×10^{-2}	3	--
Isophorone	5,200	117,000		9.34	1.8×10^{-3}	3	--
Ethyl benzene	1,400	32,000		0.43	3.1×10^{-4}	3	--
Heptachlor epoxide	0.000278 (heptachlor)	0.0038 (heptachlor)		(none found on site)	--	3	--
BIS-2 (EM) Phthalate	15,000 (di-)	3		(none found on site)	--	3	--
Carbon tetrachloride	0.40	35,200		(none found on site)	--	3	--
Acenaphthylene (PAH)	0.0028	no standard (300 salt water)		(none found on site)	--	3	--

TABLE A-5, Continued

	Human Health Criteria[b]	Freshwater Aquatic Criteria[c] Existing	Freshwater Aquatic Criteria[c] Proposed[d]	Average Concentration In Ground Water On Site[e]	Diminution Factor (GW Avg./ Strictest Existing WQ Criteria)	Priority Level	Comment
Organics							
Trans-1,2-Dichloroethene	0.33[j] (1,1-dichloro)	11,600		17,963	5.4×10^5	2	High concentration only at Well 2
Methylene chloride	0.19	11,000		46,682	2.5×10^5	1	--
Chloroform	0.19	1,240		2,135	1.1×10^4	1	--
Trichloroethene	2.7	21,900 (behavioral)		27,859	1.0×10^4	1	--
1,1-Dichloroethane	0.94[k] (for 1,2 DCE)	20,000		1,484	1.6×10^3	3	High concentration only at Well 1
Dieldrin	0.000071	0.0019		0.06	8.5×10^2	3	Quantifiable concentration only at Well 28
Aldrin	0.000074	3		0.06	8.1×10^2	3	Quantifiable concentration only at Well 28
1,2-Dichloroethane	0.94	20,000		627	6.7×10^2	3	Quantifiable concentration only at Well 15
Fluorotrichloromethane	0.19	11,000		72.96	3.8×10^2	3	Quantifiable concentration only at Well 17
Benzene	0.66	5,300		199	3.0×10^2	2	--
1,1-Dichloroethene	0.033	11,600		8.47	2.5×10^2	3	--
Phenol	300 (taste)	2,560		72,350	2.4×10^2	2	--
Heptachlor	0.000278	0.0038		0.06	2.2×10^2	3	--
Cyanide	200	3.5	4.2	689	2.0×10^2	3	--
Tetrachloroethene	0.8	840		92	1.2×10^2	3	--
2-Nitrophenol	13.4 (strictest nitrophenol class)	150 (algae) 230		17,428	1.3×10^3	3	High concentration only at Well 2

(j) No criterion available; criteria listed is for a related compound. Trans-1-2 dichloroethene is reported to be noncarcinogenic and much less toxic than 1-1-DCE.

(k) No criteria available, criterion listed is for a related compound. A conservative criterion is probably 10 times that shown.

The following 10 organic contaminants, which are not on the priority pollutant list, were measured in the groundwater:

acetone	benzoic acid	benzyl alcohol
2-butanone	2-hexanone	2 methyl phenol
4 methyl phenol	styrene	2,4,5 trichlotophenol
o-xylene		

Because there are no established water quality criteria for these compounds, a detailed analysis was not conducted for them. Because these compounds are closely associated, both chemically and physically, with priority pollutant compounds measured at the site, the cleanup of priority pollutants is expected to affect these non-priority pollutants in a similar manner.

POST EXCAVATION CONTAMINANT CONCENTRATIONS

Surficial soils/fill will be removed from the entire site to a depth equal to elevation 22 above mean sea level; subsurface fill materials will be excavated from locations identified by the analysis of historical site development and use. Figure A-3 indicates by location the approximate depth of excavation.

The maximum concentrations of contaminants in subsurface soil on the Western Processing site, both before and after excavation, are shown in Table A-6. The maximum surface soil concentrations are also shown for comparison. Soil removal will substantially reduce the maximum concentrations of inorganic contaminants in subsurface soil; for example, cadmium will be reduced by 76 percent, nickel by 83 percent, and zinc by 92 percent. The organic contaminants, which often were detected and quantified in only a few of the soil samples, reflect a contrasting pattern. Many of the maximum organic concentrations were found at significant depths, that is, below the levels to be excavated. In these cases, the maximum concentrations will not be reduced at all. For those organics found only at a few locations higher in the soil depth profile, all quantified concentrations will be removed and the resulting maximum post-excavation concentration will be 0 (detection limit), or 100 percent reduction. Thus, the resulting post-excavation pattern for organics is strongly bimodal, yielding either nearly 0 or nearly 100 percent reduction in maximum concentration.

Proposed Site Excavation Plan

Note:

Elevations shown are in feet above Mean Sea Level and represent the approximate bottom of excavation in that area of the site.

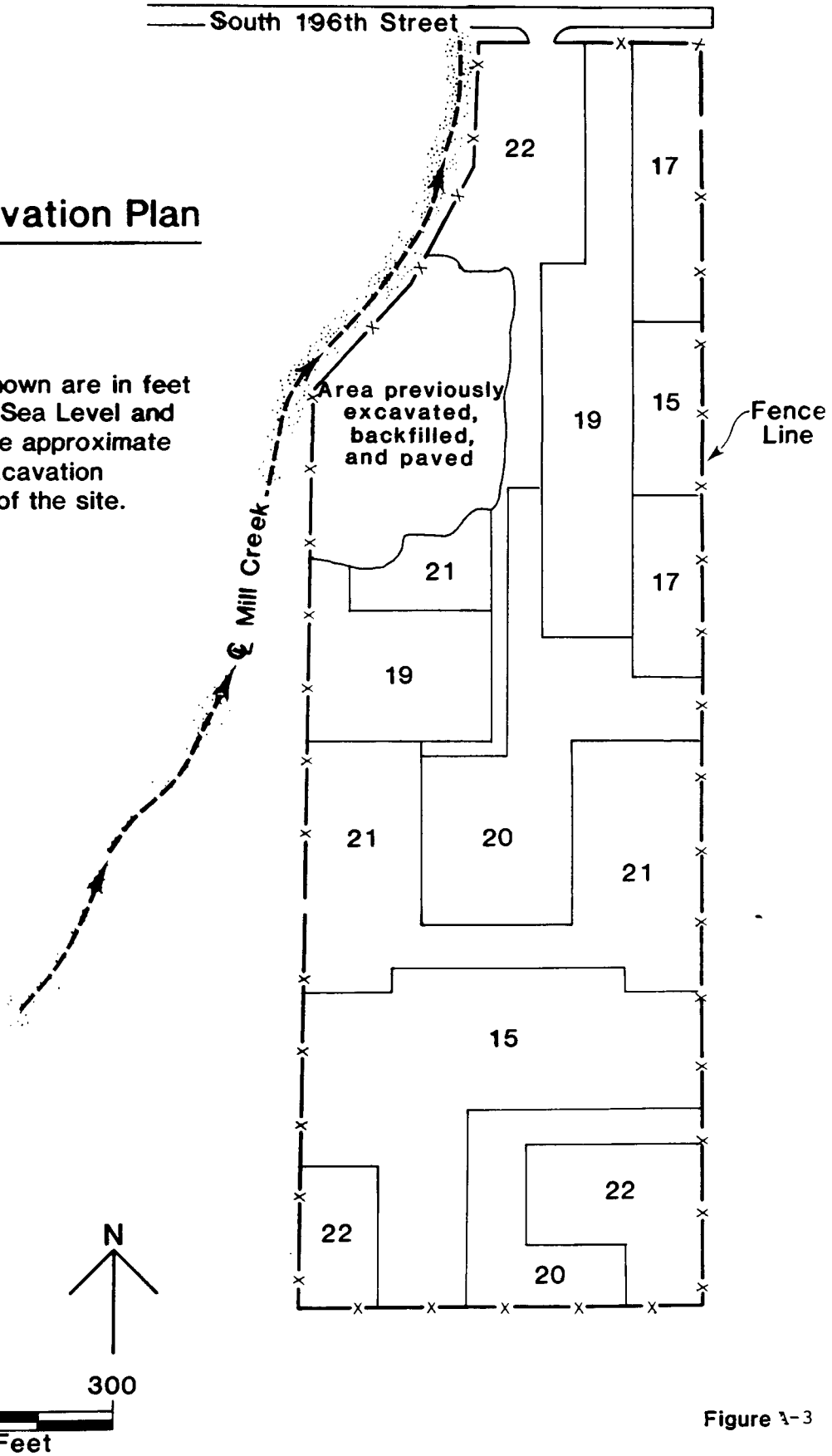


Figure 1-3

TABLE A-6

COMPARISON OF PRE- AND POST-EXCAVATION SOIL CONTAMINANT CONCENTRATIONS BASED ON MAXIMUM CONCENTRATION

Contaminant	Surface Samples (in ppm)[a]	Subsurface Samples[b,c]		
		Pre-excavation	Post-excavation	Percent Reduction
Al	4,700	19,500	6,200	68.21
Cr	5,300	7,600	1,300	82.89
Ba	150	180	84	53.33
Co	16	12.4	0	100.00
Cu	890	5,700	1,240	78.25
Fe	18,900	13,400	10,500	21.64
Ni	740	1,900	320	83.16
Mn	2,900	2,800	1,400	50.00
Zn	81,000	40,500	3,100	92.35
B	170	240	170	29.17
V	140	76	0	100.00
Ao	6.1	1.4	1.4	0.00
As	38	102	6.8	93.33
Sb	98	130	3.4	97.38
Se	1	30.5	0	100.00
Tl	0	1.5	1.5	0.00
Hg	0.14	0.36	0.36	0.00
Sn	19	10	3.2	68.00
Cd	420	402	98	75.62
Pb	31,000	141,000	5,200	96.31
CN	15	179	22	87.71

(a) The following contaminants, with maximum concentrations indicated, were found only in surface soils:

pentachlorophenol	17,000 ppb
di-N-butyl phthalate	2,600 ppb
di-N-octyl phthalate	29,000 ppb
benzo-B-fluoranthene	200,000 ppb
benzo-K-fluoroanthene	130,000 ppb

The excavation plan would include removal of surface soil (1 foot) over the entire site.

(b) Data shown are for 103 onsite subsurface soil sampling locations (excluding offsite Wells 13 and 19).

(c) Values in ppm.

TABLE A-6, Continued

Contaminant	Surface Samples (in ppm)(a)	Subsurface Samples(b,d) Pre-excavation	Post-excavation	Percent Reduction
2,4-Dichlorophenol	0	7.900	7,900	0.00
2,4-Dimethylphenol	11,000	10,000	10,000	0.00
Phenol	19,000	65,000	65,000	0.00
Aldrin	0	2,860	0	100.00
Dieldrin	145	3,340	0	100.00
4,4-DDT	0	129	129	0.00
4,4-DDD	0	100	0	100.00
Heptachlor	0	2,960	0	100.00
Lindane	34	11.8	0	100.00
PCB-1242		1,780	810	54.49
PCB-1254	137	407	0	100.00
PCB-1248	3,300	19,600	1,510	92.30
PCB-1260	2,046	1,710	111	93.51
PCB-1016	2,030	3,160	0	100.00
Acenaphthene	0	8,700	8,700	0.00
Hexachloroethane	5,090,000	1,800	1,800	0.00
1,2-Dichlorobenzene	0	565,000	0	100.00
Fluoranthene	2,200	7,700	7,300	5.19
Naphthalene	234,000	13,000	13,000	0.00
Bis (2-ethyl hexyl) phthalate	6,200,000	410,000	31,000	92.44
Benzylbutylphthalate	860,000	9,100	9,100	0.00
Benzo(a)-anthracene	884,000	4,000	0	100.00
Chrysene	1,210,000	2,500	0	100.00
Anthracene	0	1,600	0	100.00
Fluorene	8,600,000	16,900	16,900	0.00
Phenanthrene	20,000,000	62,400	62,400	0.00
Pyrene	16,000,000	11,000	11,000	0.00

(d) Values in ppb.

TABLE A-6, Continued

Contaminant	Surface Samples (in ppm)(a)	Subsurface Samples(b,d) Pre-excavation	Post-excavation	Percent Reduction
Benzene	0	199.5	199.5	0.00
1,1,1-Trichloroethane	0	174,000	16,000	90.80
1,1-Dichloroethane	0	17.3	17.3	0.00
Chloroform	0	18,000	18,000	0.00
Trans-1,2-Dichloroethene	0	34	34	0.00
Ethylbenzene	13	37,000	37,000	0.00
Methylene chloride	130	49,000	49,000	0.00
Fluorotrichloromethane	25	73	59	19.18
Tetrachloroethene	99	72,000	1,300	98.19
Toluene	0	394,000	394,000	0.00
Trichloroethene	37	580,000	558,000	3.79

The effectiveness of the excavation plan in reducing contaminant concentrations was also evaluated using average onsite soil concentrations. The pre- and post-excavation comparisons of average soil contaminant concentrations are shown in Table A-7 (geometric averages) and Table A-8 (site history averages). The pattern of results in these two tables is very similar; the two approaches to calculating average concentrations yield consistent estimates of the percent reduction in onsite soil contamination. Average inorganic contaminant concentrations will be substantially reduced. The percent reduction for cadmium will be 79 or 88 percent, for nickel 75 or 84 percent, and for zinc 78 or 84 percent; the analysis based on site history generally shows marginally smaller reductions in average contaminant concentrations. The results for organic contaminants are similar to those based on maximum concentrations. In most cases, the reduction in the average soil concentration of an organic contaminant will be either minimal or nearly total; that is, the percent reduction achieved by excavation will be near 0 percent or near 100 percent. This is a consequence of the distribution of organic contaminants in onsite soils, a distribution markedly different than for inorganic contaminants.

FLUSHING PROGRAM EFFECTIVENESS

The concept of reverse flushing that is incorporated in the PRP groundwater extraction component, and the analytical and computer modeling methods used to evaluate the effectiveness of this component, are discussed in this section. The relative value of flushing to the PRP plan is dependent on the implementation of other components of the plan, particularly the excavation and diversion barrier components.

Flushing Concepts

The PRP groundwater extraction component includes a "reverse flushing" concept for removing contaminants from groundwater and subsurface soil, including contaminants remaining after completion of the soil excavation program.

The design of the flushing procedure to be used at the site has assumed that a 40-foot deep diversion barrier (referred to hereinafter as a "cutoff wall") will be installed around the entire site. This

TABLE A-7

COMPARISON OF PRE- AND POST-EXCAVATION SOIL CONTAMINANT CONCENTRATIONS BASED ON GEOMETRIC AVERAGE CONCENTRATIONS

Contaminant	Pre-excavation[a]	Post-excavation[a,b]	Percent Reduction
Al	3,263	1,602	50.90
Cr	594.26	88.13	85.17
Ba	36.37	12.42	65.86
Co	0.57	0	100.00
Cu	332.93	46.03	86.17
Fe	4,373	2,126	51.38
Ni	94.11	15.38	83.66
Mn	368.32	67.58	81.65
Zn	2,578	420.20	83.70
B	60.68	31.52	48.06
V	2.40	0	100.00
Ao	0.01	0.01	0.00
As	3.28	0.79	75.91
Sb	8.59	0.03	99.65
Se	0.83	0	100.00
Tl	0.01	0.01	0.00
Hg	0.01	0.01	0.00
Sn	0.81	0.03	96.30
Cd	34.72	4.02	88.42
Pb	5,451	107.25	98.03
CN	11.16	1.59	85.75

(a) Values in ppm.
(b) The calculation of post-excavation average concentrations assumed clean backfill soils had zero concentrations of all contaminants.

TABLE A-7 (Continued)

Contaminant	Pre-excavation[c]	Post-excavation[b,c]	Percent Reduction
2,4-Dichlorophenol	208.60	91.39	56.19
2,4-Dimethylphenol	218.15	218.15	0.00
Phenol	1,652	1,641	0.67
Aldrin	6.08	0	100.00
Dieldrin	7.10	0	100.00
4,4-DDT	2.92	2.63	9.93
4,4-DDD	0.77	0	100.00
Heptachlor	6.23	0	100.00
Lindane	0.09	0	100.00
PCB-1242	79.03	20.49	74.07
PCB-1254	4.33	0	100.00
PCB-1248	341.27	14.83	95.65
PCB-1260	38.13	2.26	94.07
PCB-1016	50.32	0	100.00
Acenaphthene	75.86	75.86	0.00
Hexachloroethane	19.15	19.15	0.00
1,2-Dichlorobenzene	13,007	0	100.00
Fluoranthene	155.75	63.66	59.13
Naphthalene	226.52	226.52	0.00
Bis (2-ethyl hexyl) phthalate	12,238	1,386	88.67
Benzylbutylphthalate	79.35	79.35	0.00
Benzo(a) anthracene	47.84	0	100.00
Chrysene	29.90	0	100.00
Anthracene	19.14	0	100.00
Fluorene	147.37	147.37	0.00
Phenanthrene	719.80	636.08	11.63
Pyrene	184.42	95.92	47.99
Benzene	1.53	1.53	0.00
1,1,1-Trichloroethane	2,870	126.34	95.60
1,1-Dichloroethane	0.13	0.13	0.00
Chloroform	143.25	143.25	0.00
Trans-1, 2-Dichloroethene	0.99	0.71	28.28
Ethylbenzene	523.87	521.98	0.36
Methylene chloride	1,486	670.96	54.85
Fluorotrichloromethane	3.21	1.79	44.24
Tetrachloroethene	1,196	51.62	95.68
Toluene	6,437	5,378	16.45
Trichloroethene	19,267	7,282	62.20

(c) Values in ppb.

TABLE A-8

COMPARISON OF PRE- AND POST-EXCAVATION SOIL CONTAMINANT CONCENTRATIONS BASED ON SITE HISTORY AVERAGE CONCENTRATIONS

Contaminant	Pre-excavation[a]	Post-excavation[a,b]	Percent Reduction
Al	3,353	1,947	41.93
Cr	438.90	98.38	77.58
Ba	34.49	16.81	51.26
Co	0.44	0	100.00
Cu	294.25	59.05	79.93
Fe	4,198	2,572	38.73
Ni	63.94	15.88	75.16
Mn	255.18	72.62	71.54
Zn	2,043	440.13	78.46
B	69.88	41.67	40.37
V	1.99	0	100.00
Ag	0.01	0.01	0.00
As	1.98	0.76	61.62
Sb	3.02	0.02	99.34
Se	0.31	0	100.00
Tl	0.01	0.01	0.00
Hg	0.01	0.01	0.00
Sn	0.38	0.03	92.11
Cd	20.21	4.23	79.07
Pb	2,729	82.57	96.97
CN	6.37	2.31	63.74

(a) Values in ppm.
(b) The calculation of post-excavation average concentrations assumed clean backfill soils had zero concentrations of all contaminants.

TABLE A-8 (Continued)

Contaminant	Pre-excavation[c]	Post-excavation[b,c]	Percent Reduction
2,4-Dichlorophenol	164.39	77.95	52.58
2,4-Dimethylphenol	168.67	168.67	0.00
Phenol	1,210	1,204	0.50
Aldrin	9.58	0	100.00
Dieldrin	11.19	0	100.00
4,4-DDT	4.12	3.80	7.77
4,4-DDD	0.84	0	100.00
Heptachlor	9.82	0	100.00
Lindane	0.10	0	100.00
PCB-1242	50.51	11.91	76.42
PCB-1254	1.89	0	100.00
PCB-1248	292.32	18.15	93.79
PCB-1260	33.25	3.27	90.17
PCB-1016	42.31	0	100.00
Acenaphthene	116.75	116.75	0.00
Hexachloroethane	8.35	8.35	0.00
1,2-Dichlorobenzene	10,780	0	100.00
Fluoranthene	165.88	97.97	40.94
Naphthalene	196.88	196.88	0.00
Bis (2-ethyl hexyl) phthalate	4,635	853.62	81.58
Benzylbutylphthalate	122.12	122.12	0.00
Benzo(a) anthracene	35.28	0	100.00
Chrysene	22.05	0	100.00
Anthracene	14.11	0	100.00
Fluorene	226.80	226.80	0.00
Phenanthrene	954.30	892.56	6.47
Pyrene	212.89	147.62	30.66
Benzene	1.67	1.67	0.00
1,1,1-Trichloroethane	2,411	137.84	94.28
1,1-Dichloroethane	0.14	0.14	0.00
Chloroform	155.81	155.81	0.00
Trans-1, 2-Dichloroethene	0.51	0.30	41.18
Ethylbenzene	570.13	569.40	0.13
Methylene chloride	1,435	672.31	53.15
Fluorotrichloromethane	1.90	0.82	56.84
Tetrachloroethene	976.28	30.17	96.91
Toluene	6,817	5,862	14.01
Trichloroethene	17,853	7,921	55.63

(c) Values in ppb.

cutoff wall, which will not be keyed into a continuous, low-permeability stratum, will inhibit the horizontal migration of residual contamination in the onsite soil and groundwater. Therefore, contaminant migration beneath will occur vertically in contrast to the normally dominant horizontal routes. The cutoff wall will also isolate the remaining contaminated groundwater and soil from the surround-ing shallow groundwater flow. Thus, installation of the cutoff wall would significantly reduce the rate of migration of remaining contamination, even without flushing (groundwater extraction).

The excavation program will have little effect on the existing levels of contamination in groundwater beneath the site. Unless additional remedial measures are implemented, this contaminated groundwater would eventually escape into the upper aquifer by moving vertically downward under the bottom of the cutoff wall, and into the existing groundwater flow. The vertical migration route requires more time than the existing groundwater flow for contaminants to leave the site. Thus, without flushing, contaminant migration with a cutoff wall in place would result in the release of lower concentrations of contaminants but over a longer time period as compared to the present site conditions.

During groundwater extraction, the contaminated groundwater pumped from within the cutoff wall will be replaced by relatively uncontaminated groundwater from outside and below the cutoff wall. Because the contamination in the groundwater and soil is in general equilibrium, "flushing" the soil with less contaminated groundwater pumped from outside the cutoff wall will establish a new equilibrium by "leaching" contaminants from the soil. Thus, the net effect of the pumping will be to flush the mobile contaminants from the soil with groundwater and pump the contaminated groundwater to a treatment facility to remove contaminants prior to approved discharge.

The groundwater extraction program will not remove all of the contamination remaining after the surface cleanup and onsite soil excavation for two main reasons. First, the mechanisms by which the contamination in groundwater and soil establish equilibrium are probably only partially reversible for most contaminants. In addition,

these mechanisms, which include adsorption and chemical reactions, are probably hysteretic and/or non-linear. Thus, adsorption and desorption are not simple "reversing" mechanisms. Second, the release and migration of contaminants are time dependent. The proposed groundwater extraction program will not continue long enough to have a significant effect on the concentrations of contaminants of low mobility.

A general evaluation of the effectiveness of the groundwater extraction/flushing operation can be made by comparing the current rate of infiltration with the rate of water withdrawal during pumping. About 6 inches of precipitation per year is estimated to infiltrate through the site surface. This value is slightly higher than the regional infiltration rate because of higher infiltration through the bare soil of the site. This higher infiltration rate at the site is documented by the groundwater mound beneath and in the vicinity of the site.

Assuming a rate of 6 inches per year and a site area of 13 acres, the total average yearly infiltration is approximately 2 million gallons. At the pumping rate of 1 million gallons per week included in the PRP plan, the ratio of groundwater withdrawal rate to the current rate of infiltration will be 52:2. Thus, the "reverse" flow rate during each year of pumping will be equivalent to about 26 years of the normal infiltration rate.

Groundwater Flow Model

A two-dimensional finite-element groundwater flow model was used to assist in assessing the effectiveness of the proposed flushing program. The model used, acronymed FPM, is part of the six-model Golder Groundwater Package (Golder Associates, 1983). The FPM program is based on mathematical equations by Bredehoeft and Pinder (1973) that are valid for general three-dimensional, variable-density groundwater flow. However, the FPM program is written for two-dimensional flow in a vertical planar or axi-symmetric section. It is capable of performing both steady state and transient analyses. The solutions to the basic equations are approximated by a Galerkin optimization procedure.

The limitations and assumptions on which the solution of the general flow equations are based are as follows:

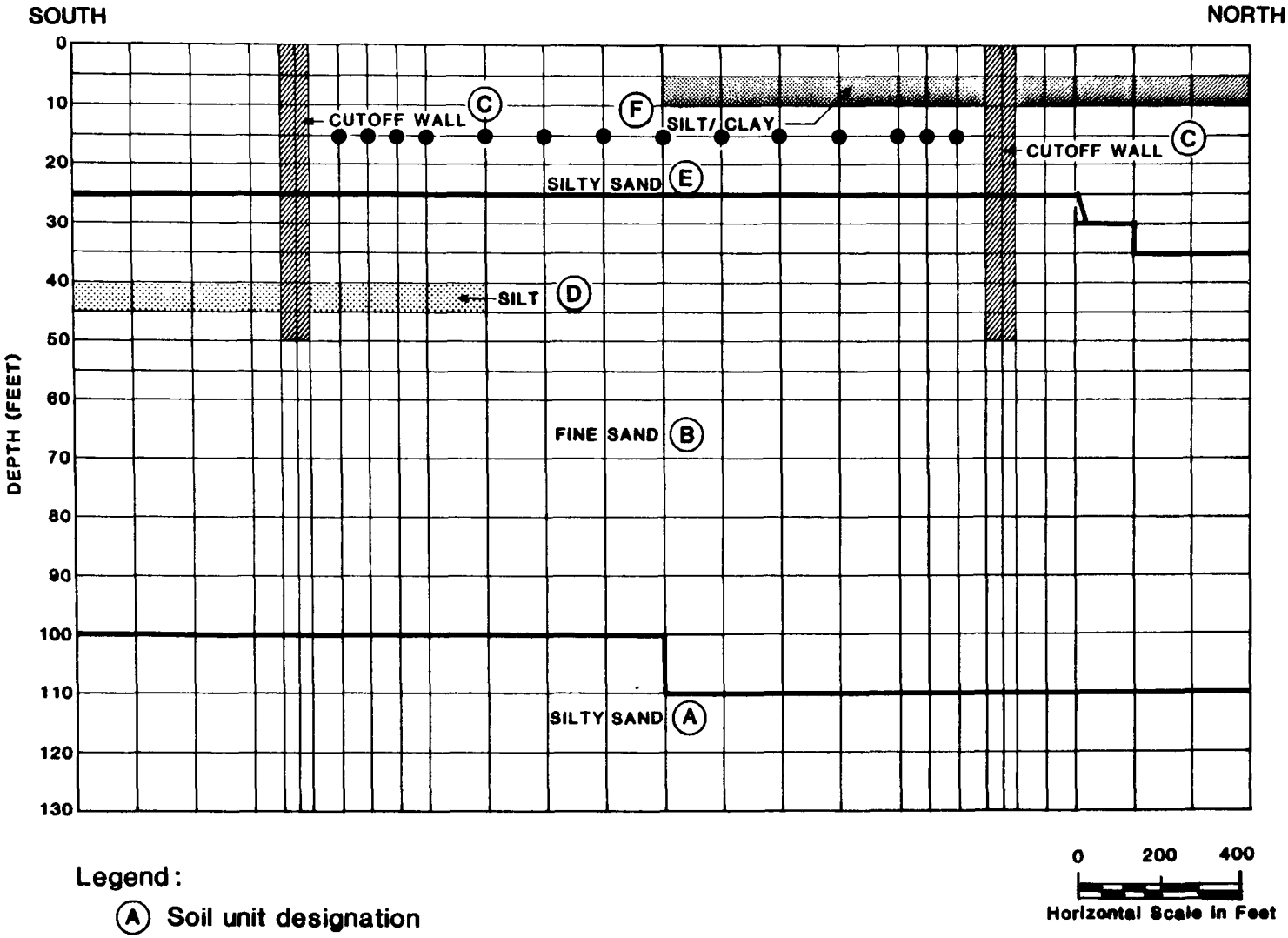
1. Darcy's Law is valid.
2. The solid skeleton of the aquifer deforms linearly and elastically.
3. The groundwater obeys a linear equation of state.
4. The aquifer properties are independent of pressure and salinity changes.
5. Groundwater flow due to gradients of salinity, temperature, or electric potential is negligible.

The finite-element mesh used for the analysis of the effectiveness of flushing was developed using subsurface information from several shallow borings drilled on and immediately adjacent to the Western Processing site by the Environmental Protection Agency (EPA). The mesh is shown on Figure A-4.

Use of the model is predicated on the identification and quantification of several boundary conditions. The driving forces for groundwater flow within the mesh are the regional groundwater gradient, estimated to be parallel to the ground surface with a slope of approximately 1.25 feet per 1,000 feet, and the quantity of water pumped from within the cutoff wall in the proposed flushing program. The quantity pumped, 1 million gallons per week, was assumed to be pumped or removed from the mesh nodes indicated on Figure A-4.

Physical Properties

The aquifer properties requiring definition for use of the model are hydraulic conductivity, storativity and/or specific yield, and porosity. The hydraulic conductivity of the five different soil types and the cutoff wall used in the flushing model were estimated using empirical relationships based on grain size interpreted from the written soil descriptions in the EPA exploration logs. No laboratory or field test data were available to corroborate these estimates at the time the modeling was accomplished. Table A-9 summarizes the values of hydraulic conductivity and the values for other key variables used in the model. Artesian conditions were not modeled for the analysis of the flushing



Legend:

(A) Soil unit designation

● Nodes at which pumping occurs

Finite Element Grid for the Flushing Model

Figure A-4

TABLE A-9

FLUSHING MODEL PHYSICAL PARAMETERS

Parameter	Soil Unit[a] A	B	C	D	E	F
Effective porosity	0.25	0.27	0.35	0.35	0.30	0.35
Horizontal hydraulic conductivity (cm/sec)	3.5×10^{-3}	1×10^{-2}	1×10^{-7}	3.5×10^{-4}	5×10^{-3}	2×10^{-3}
Vertical hydraulic conductivity (cm/sec)	3.5×10^{-4}	1×10^{-3}	1×10^{-7}	3.5×10^{-5}	5×10^{-4}	2×10^{-4}
Longitudinal dispersivity (ft)	40	50	1	30	40	10
Transverse dispersivity (ft)	8	10	1	6	8	2
Density (grams/cc)	1.60	1.51	1.58	1.31	1.44	1.27
Percent organic carbon	1	1	3	2	1	3

(a) See Figure A-4 for soil unit designations.

program, so an estimate of the value or values of storativity for the different soil types is not required. However, a value for specific yield, sometimes referred to as drainable porosity, is required for the evaluation of non-pressured groundwater. A specific yield value of 0.10 was used for each of the six soil types (including the cutoff wall).

The porosities of the soil units modeled were estimated from an evaluation of the degree of saturation, moisture content, and dry density of numerous soil samples obtained from reports describing borings drilled in the vicinity of the Western Processing site. The borings used were drilled for numerous other projects and purposes in the site vicinity; they were not drilled during the EPA investigation. A summary of this analysis is shown on Figure A-5. The effective porosities used for the various soil types (listed in Table A-9) were assumed to be two-thirds of the total porosities estimated as described above.

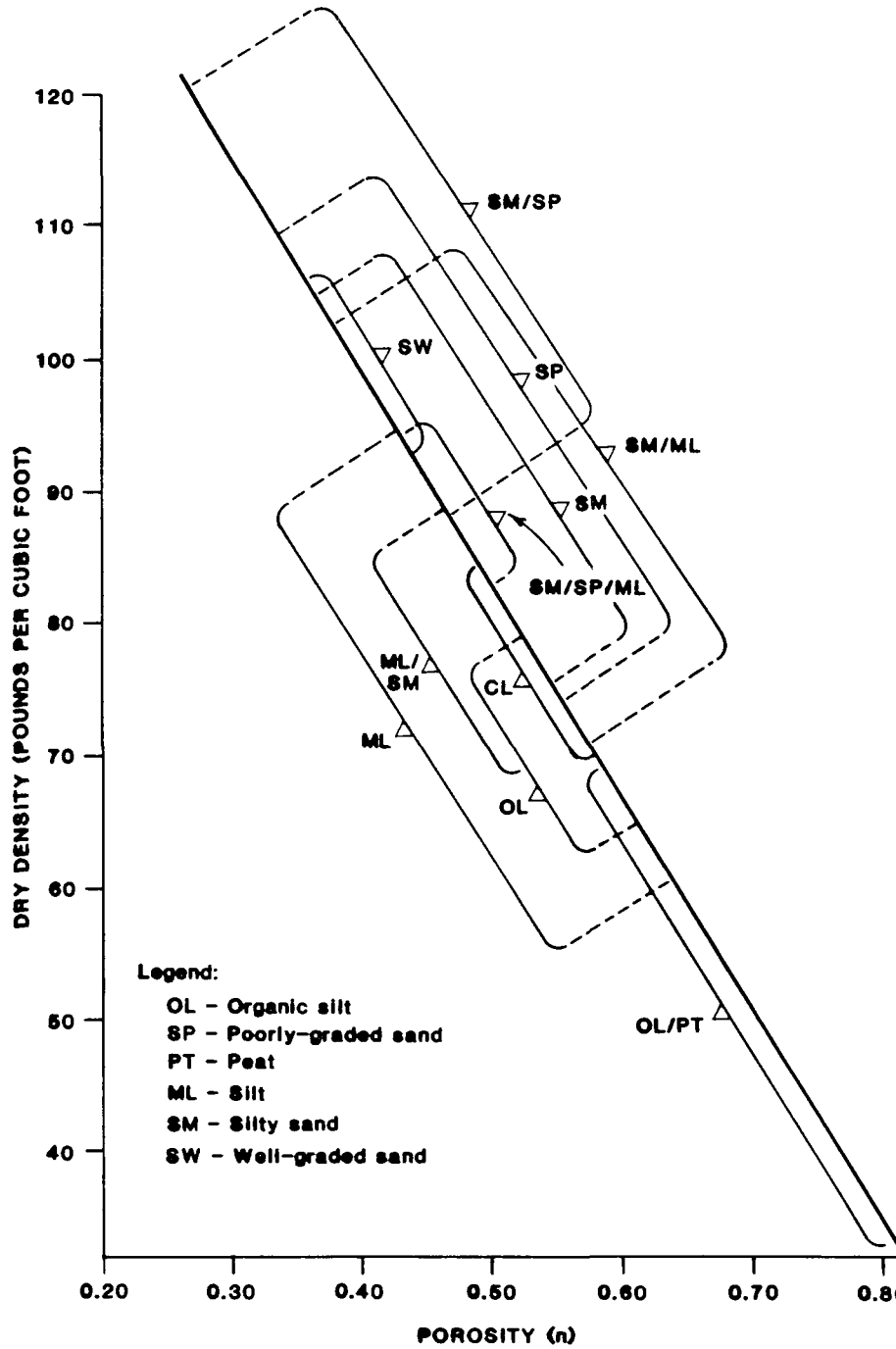
The FPM program is capable of considering hydrologic factors such as precipitation and evapotranspiration. The net effect of average annual precipitation, runoff, and evapotranspiration was incorporated into the model using a net inflow of 4.5 inches per year for infiltration outside of the cutoff wall. Inside the cutoff wall, recharge due to the planned disposal of storm runoff from the site surface through an onsite infiltration system was calculated to be 35 inches per year (90 percent of the annual average precipitation) and used as model input.

Contaminant Transport-Solute Model

The solute transport model used, acronymed SOLTR, is also a primary component of the Golder Groundwater Package. It is capable of estimating a steady state or transient solution of solute concentrations based on chemical properties specific to the contaminant being analyzed and on boundary conditions established by the results of hydraulic modeling. A solution to the groundwater flow model is required as input to the solute transport model. Since the model is capable of analyzing the distribution of only a single contaminant at one time, the interaction between different contaminants was not modeled.

In SOLTR, contaminant movement is modeled as the combination of advection (the bulk movement of the contaminant with flowing groundwater) and hydrodynamic dispersion (the movement of the contaminant in response to concentration gradients). The model is written so that diffusion can be incorporated into the latter term, although diffusion is generally not significant. For the analysis of contaminant movement from the Western Processing site, diffusion was not considered. An important feature of the solute transport model is that it is capable of considering the effects of (1) physical retardation, or (2) chemical or biological decay, also a form of retardation. The "loss" of contamination by chemical or biological decay was not considered in the analysis of the Western Processing situation; however, physical retardation is a very important aspect in the estimation of contaminant movement.

Retardation. Physical retardation is assumed to be a linear relationship and is defined as the ratio of the rate of movement of ground-



Porosity Ranges for Near-Surface Soils

Figure A-5

water to the rate of movement of the contaminant. Physical retardation occurs primarily as a result of chemical reactions between the contaminant and the aquifer soil matrix, and adsorption-desorption activity between the contaminant and the aquifer matrix. The general mathematical formulation of retardation is as follows:

$$R_d = 1 + \frac{}{n} Kd$$

Where:

R_d = retardation coefficient or factor

K_d = partition coefficient

= soil mass density (grams/cc)

n = soil effective porosity

As indicated by this relationship, the retardation of an individual contaminant in a particular type of soil is directly related to a value referred to as the partition coefficient. This coefficient is a measure of the affinity of the particular contaminant for a particular soil. However, the determination of this coefficient is relatively difficult.

Partition Coefficients: Metals

Several factors are important when considering the partitioning of metals in the soil-groundwater medium. The element's combination with other ions, and thus its movement, is largely dependent upon the pH, quantity of clay and organic matter, and the oxidation-reduction status of the soil. In general, when the pH of the soil is greater than approximately 6.5, most heavy metals are bound to the soil and are not readily "available" to the groundwater. Availability also decreases with increasing cation exchange capacity (CEC, the total exchangeable cations that each soil unit can hold by adsorption) of the soil. CEC increases as the organic and clay content of the soil increase. Aluminum, iron, and manganese hydroxides also play an important role in combining with trace metals and decreasing their mobility. In addition, a well-aerated soil will generally decrease mobility of trace metals by decreasing the metals' solubilities as a result of increasing the oxidation state.

EPA measurements at Western Processing show that the pH of the groundwater varies widely, from 4.6 to 13, indicating that the availability of the metals to the groundwater, and the form of the cations, varies significantly from one area to another. The pH of the soil plays a key role in the leachability of the metals. By decreasing the pH in areas of alkaline groundwater, the metals concentrations in the groundwater will significantly increase, although the amount of increase is dependent upon the specific metal and the mechanisms by which it is bound in the soil.

The CECs have not been established specifically for soil units on the site. However, the CEC for a silt loam and a gravelly loam sand in King County is reported to vary between 6.0 and 36.6 milliequivalents (meq)/100 gm (U.S. Department of Agriculture, 1973). These values apply to near-surface soil which is high in organic matter due to tillage; the CEC for soil at depth is probably lower. By totaling the average meq/100 gm for each cation reported in the EPA's analysis of soil samples from the site (see Table A-10), a value of 34.5 meq/100 gm is obtained. This is near the upper end of the expected range of CEC for the soil (6.0 to 36.6 meq/100 gm), but does not include other significant cations (calcium, sodium, potassium, and magnesium) that are probably present. Therefore, it is a conservative total of cations that are available for adsorption to exchange sites. Because the total cation pool exceeds the expected CEC of the soil, precipitation by various anions (e.g., sulfate, phosphate, and nitrate), adsorption by hydroxides, and/or chelation by organic compounds must also be important mechanisms for binding metals contaminants at the Western Processing site.

To assess the availability of the various cations, critical limiting factors for availability must be evaluated for each cation separately. To determine which cations are most important to evaluate, several factors were used to assess relative potential environmental impact. The most important of these are: (1) a ratio of the average groundwater concentration of the element (weighted on the basis of site history) and the lowest freshwater criterion for each of the priority pollutant metals, and (2) a ratio of the average soil concentrations at

the site after soil excavation and the recommended maximum residual soil concentrations based on current literature (EPA 1983) and experience. The results of the ranking are presented in Table A-11.

TABLE A-10

EXCHANGEABLE CATIONS

Metal	Average g/g in Onsite Soil After Fill Removal	Cations in meq/100 gm
Al^{3+}	1,947	21.65
Cr^{3+}	98.4	0.57
Cu^{2+}	59.1	0.18
Fe^{2+}(a)	2,572	9.21
Ni^{2+}	15.9	0.05
Mn^{2+}(a)	72.6	0.26
Zn^{2+}	440.1	1.35
B^{3+}	41.7	1.16
Pb^{2+}	82.6	0.08
Total		34.5

(a) Reduced valence state of Fe and Mn used (assumes anaerobic conditions).

TABLE A-11

RELATIVE RANKING OF METALS

Rank	Metal	Method A(a)	Metal	Method B(b)
1	Cd	1.2×10^5	Zn	2.55
2	As	4.6×10^3	Pb	1.02
3	Zn	1.9×10^3	Cu	0.62
4	Ni	6.1×10^2	Cd	0.44
5	Pb	1.6×10^2	Ni	0.37
6	Cu	1.3×10^2		

(a) Ranking established based on the following ratio:
Average concentration in groundwater/water quality criterion

(b) Ranking established based on the following ratio:

$$\frac{\text{Average concentration in soil after soil excavation}}{\text{Suggested maximum for concentration in soil}}$$

With the exception of arsenic, both ranking systems used had the same five elements in the five highest ranks, although the order of these elements differed between the two systems. Arsenic concentrations in the soil are generally low and arsenic ranks low relative to the recommended maximum soil concentration (ratio = 0.003). Thus, although arsenic was present in a few groundwater samples from the Western Processing site at elevated levels, the levels in the soil indicate that the long-term potential for arsenic contamination is not significant.

Zinc and lead are the only metals whose concentrations would be greater than the suggested maximums for soil to be left at closure of a waste site (EPA 1983). For these and the metals below the maximum suggested concentrations, some form of immobilization is necessary to minimize or prevent environmental contamination off site.

Lead concentrations will be the most difficult to decrease in the soil. Lead strongly adsorbs to the soil when present as a cation and, depending on the anions present, could remain in the soil as insoluble sulfates, phosphates, or carbonates. Hydrous iron oxides and hydrous aluminum oxides also will strongly bind lead (the selection sequence for hydrous iron oxides has been found to be: Pb> Cu> Zn> Ni> Cd [Nriagu 1980]; aluminum hydrous oxide adsorbs metals in a slightly different sequence: Cu> Pb> Zn> Ni> Cd, with lead being only slightly less closely held than copper).

Lead is found in groundwater at the Western Processing site at elevated levels as deep as 130 feet, indicating that it has probably been in the soil for an appreciable length of time. The movement of lead may also have been aided by burial of lead-laden material or by the occurrence of acidic conditions.

Cadmium and nickel are bound much less strongly than lead by soil adsorption and hydrous oxides. The quantities of cadmium and nickel remaining after flushing are expected to be associated mostly with precipitated metals (e.g., cadmium carbonate, cadmium phosphate, and/or cadmium sulfide) rather than that adsorbed to the soil. The low concentrations of cadmium and nickel in the deep wells (130 feet) indicate that the cadmium and nickel have not migrated far through the groundwater.

For those remaining trace metals of concern (copper and zinc), the extent of removal by flushing will vary based on the same considerations of chemical precipitation as lead, cadmium, and nickel, with the strength of adsorption to the soil intermediate between the relatively strong adsorption of lead and the relatively weak adsorption of cadmium and nickel.

Aluminum occurs at elevated levels throughout the groundwater at the site. Because the aluminum values reported for the soils were not determined using a total acid digestion of the soil, the total amount of aluminum in the soils cannot be assessed. Based on the groundwater data, aluminum is present at depths as great as 130 feet, indicating that leaching of aluminum has been occurring for many years. At a pH of from 4 to 10, aluminum is not readily available to the groundwater, but is instead bound in the form of hydrous oxides. These hydrous oxides will adsorb metals from the groundwater, thus greatly increasing the potential for metal fixing. As aluminum is flushed from the groundwater system, additional metals could be released as the aluminum hydroxides solubilize. However, since the hydrous oxides are soluble only at the extreme ends of the pH range, aluminum should be strongly bound in the neutral pH range expected during flushing. An exception would be if large amounts of fluoride are present. Because fluoride was not analyzed by the EPA, it is not known whether enough fluoride is present to affect the aluminum solubility.

Overall, if the pH of the soil and groundwater at the site equilabrates to a pH of 6.5 or greater, the trace metals of most concern (Cu, Ni, Pb, Cd, and Zn) that remain after flushing will form hydroxides and will not be available to the groundwater. Large quantities of sulfates, carbonates, or phosphates could keep the metals fixed in the soil.

The above discussion provides a background on the mechanisms that control the partitioning of metals between groundwater and soil. To estimate the retardation of individual metals migrating in groundwater, it is necessary to quantify these mechanisms.

No method could be found in the literature to adequately address the inherent variation in partition coefficient for a specific metal in

relation to soil type, environmental conditions (particularly pH), and the presence of other contaminants. For this reason, the partition coefficients for metals were estimated using available data for onsite measurements of contamination in both the soil and groundwater. A significant effort was expended in attempting to identify the form and variation in the partition coefficients over the wide range of physical and environmental conditions and concentrations existing at the site. Multivariate regression analyses were attempted using various environmental parameters as covariants. With few exceptions, these efforts did not provide usable relationships. As a result, the partition coefficients for metals were established on the basis of the ratio of the average concentration of a contaminant in the soil to that in the shallow groundwater. As indicated in Table A-12, the partition coefficients for metals are all larger than 1. For comparison, Table A-12 also lists partition coefficients for organics determined in the same manner, although these were not used in the analyses. In the case of lead, the coefficient is over 7,000. Partition coefficients of 10 or more generally indicate a contaminant with very low mobility in an aqueous environment.

Partition Coefficients: Organics

Organic compounds may have many different fates in the soil and groundwater environment: (1) they may be adsorbed to the soil, (2) they may be leached through the groundwater, (3) they may volatilize and be lost to the atmosphere, (4) they may be broken down by organisms, and (5) they may undergo chemical reactions with other materials.

Volatilization of the compounds to the atmosphere would be extremely limited at the site because most of the volatile contamination is present well below the ground surface. The breakdown of chemicals by organisms would also be severely limited without flushing, since there would be toxic quantities of trace metals and solvents remaining in the soil. For example, microbial metabolism of organic chemicals can be inhibited by values of 0.5 mg/l of copper or 5.0 mg/l of zinc in the groundwater (Matthess 1982). Without flushing, the concentrations of these metals would be expected to be much greater than these values.

TABLE A-12

PARTITION COEFFICIENTS BASED ON CONCENTRATION RATIOS

Contaminant	Average Concentrations (ppm)[a]		Partition Coefficient[b]
	Shallow Wells	Soil Samples	
Cadmium	2.1	20.2	10
Zinc	139.7	2,043	15
Nickel	15.5	63.9	4
Chromium	4.25	439	103
Arsenic	0.014	1.98	141
Lead	0.36	2,729	7,456
Copper	1.47	294	201
Mercury	0.00036	0.010	28
Aluminum	71.6	3,350	47
Methylene chloride	46.7	1.4	0.030
Chloroform	2.14	0.16	0.075
Trichloroethene	27.9	17.9	0.64
Trans-1,2-dichloroethene	18.0	0.0005	0
Benzene	0.20	0.0017	0.008
Phenol	72.4	1.2	0.02
1,1,1-Trichloroethane	18.9	2.4	0.13
Toluene	2.32	6.8	2.9

(a) Weighted on basis of site history.
(b) Partition coefficient calculated as follows:

$$\frac{\text{concentration in soil}}{\text{concentration in shallow wells}}$$

The organic chemicals will probably undergo various chemical reactions during the period of time they remain in the soil, with the specific reactions dependent primarily upon the pH and the presence of other chemical species. Chemical degradation has been shown to occur slowly in sterile anaerobic soils for phenol and its chlorinated derivatives such as 2,4,6-trichlorophenol and pentachlorophenol (EPA 1983). However, the reactions and degradations that might occur at the site are not possible to predict since such a wide range of chemical environments is present.

The tendency for an organic compound to partition between water and soil solids can be estimated using solubility relationships. The more soluble a chemical, the greater tendency it will have to be in the water phase. However, partitioning is also directly related to the organic carbon content in the soil; the higher the organic carbon content, the more an organic compound will be bound by the soil solids.

To estimate the degree that an organic compound is adsorbed to soil, the partition coefficient, K_d, can be determined by the following relationship (Conway 1982):

$$K_d = \frac{K_{oc}}{100} \times (\% \text{ Organic Carbon})$$

where:

K_d = partition coefficient (amount adsorbed by the soil [oven-dry basis] divided by the amount of the chemical in the water [units of grams/cubic centimeter])

K_{oc} = soil adsorption coefficient

K_{oc} constants for various organic chemicals can be obtained indirectly by estimation from known values for water solubility (S). The octanol-water ratio (K_{ow}) can also be used, but since K_{ow} is a more difficult value to determine and since a direct relationship between K_{oc} and solubility (S) in water has been demonstrated (Chiou 1977), solubility values were used to assess K_{oc}. The following regression equation was used to estimate K_{oc} (Conway 1982):

$$\log K_{oc} = 3.64 - 0.55 (\log S)$$

where:

S = solubility in water (ppm at 25° C)

Using this relationship to obtain K_{oc}, K_d was calculated for the Priority Level 1 and 2 organic. A listing of the partition coefficients using percent carbon as a variable is shown in Table A-13. The compounds most readily available to the groundwater are those with the lowest partition coefficients.

Retardation Coefficients

Using the physical properties of the soil units listed in Table A-9, the partition coefficients for metals listed in Table A-12, and the partition coefficients for organics listed in Table A-13, the retardation coefficients for use in the flushing model were estimated using the previously described relationship. These are summarized in Table A-14.

TABLE A-13

PARTITION COEFFICIENTS FOR ORGANICS (SOLUBILITY METHOD)

Organic Chemical	Partition Coefficient[a] 1%C	2%C	3%C
Phenol	0.08	0.16	0.24
Methylene chloride	0.21	0.42	0.63
1,2-dichloroethane	0.30	0.60	0.90
Chloroform	0.31	0.62	0.93
1,1-Dichloroethane	0.38	0.76	1.14
1,1,1-Trichloroethane	0.43	0.86	1.29
Benzene	0.85	1.70	2.55
Trichloroethene	0.93	1.86	2.79
2,4,6-Trichlorophenol	1.10	2.20	3.30
Trans-1,2-dichloroethene	1.29	2.58	3.87
Toluene	1.38	2.76	4.14
Pentachlorophenol	10.2	20.4	30.6

(a) The partition coefficient is based on solubility and is a function of percent organic carbon in the soil (%C).

TABLE A-14

RETARDATION COEFFICIENTS FOR THE FLUSHING MODEL

Contaminant	Retardation Coefficient by Soil Unit[a] A	B	C	D	E	F
Cadmium[b]	64.9	56.9	46.0	38.5	49.0	37.3
Zinc[b]	96.9	84.9	68.5	57.1	73.0	55.5
Nickel[b]	26.6	23.4	19.0	16.0	20.2	15.5
Chromium[b]	659.	577.	465.	386.	495.	375.
Arsenic[b]	896.	784.	631.	525.	673.	509.
Lead[b]	55,600.	41,700.	33,600.	27,900.	35,800.	27,100.
Copper[b]	1,280	1,120	906.	753.	966.	731.
Mercury[b]	180	158	127.	106.	135.	103.
Aluminum[b]	301	264	213.	177.	227.	172.
Methylene Chloride	2.34	2.17	3.79	2.57	2.00	3.25
Chloroform	2.98	2.73	5.23	3.36	2.49	4.41
Trichloroethene	6.94	6.20	13.5	7.92	5.46	11.1
Trans-1,2-dichloroethene	9.24	8.21	18.4	10.7	7.19	15.1
Benzene	6.41	5.75	12.5	7.36	5.08	10.3
Phenol	1.51	1.45	2.08	1.60	1.38	1.87
1,1,1-Trichloroethane	3.75	3.40	6.85	4.25	3.06	5.72
Toluene[b]	19.7	17.4	14.2	12.0	15.1	11.6

(a) See Figure A-4 for soil unit designation.
(b) Based on partition coefficient from onsite measurements.

The retardation coefficients for organic compounds were also determined using partition coefficients estimated from the water and soil concentrations reported by EPA for organic compounds found at the site. Retardation coefficients determined by both methods (for organics) and by site data (for metals) are summarized in Table A-15 for comparison purposes. Overall, those based on the soil and water data from the site are lower than the values based on solubility relationships for organic contaminants. The lower values could be due to (1) the loss of the volatile compounds from the soil during sampling and handling, and/or (2) lower laboratory recovery rates from the soil matrix analyses in comparison to rates associated with water sample analyses. (These types of losses do not occur as easily when sampling and analyzing for trace metals.)

TABLE A-15

TYPICAL RETARDATION COEFFICIENTS

Substance	Retardation Coefficient[a] From Onsite Measurements	Retardation Coefficient[a] Based on Solubility
Cadmium	49	--
Zinc	73	--
Nickel	20	--
Chromium	500	--
Arsenic	678	
Lead	36,000	--
Copper	1,000	--
Mercury	135	
Aluminum	225	--
Methylene chloride	1.2	2.0
Chloroform	1.4	2.5
Trichloroethene	4.1	5.5
Trans-1,2-dichloroethene	1.0	7.2
Benzene	1.0	5.1
Phenol	1.1	1.4
1,1,1-Trichloroethane	1.6	3.1
Toluene	15.0	7.6

(a) Retardation coefficients vary with soil type. Typical values listed in this table are for a silty sand assuming an effective porosity (n) = 0.30, a bulk dry density ( ) = 1.44 grams per cubic centimeter, and (for organics based on solubility) an organic carbon content in the soil of 1 percent.

Dispersion. Hydrodynamic dispersion is a combination of diffusion and the physical spreading of a contaminant by mixing within the pore spaces

of the aquifer matrix. Diffusion is strictly a function of the difference in concentration between two points, whereas the physical mixing occurs in response to the velocity of groundwater flow as well as concentration gradients. Dispersion is strongest in the direction of groundwater flow, but also occurs in the direction normal (perpendicular) to groundwater flow. This so called transverse dispersion is less than that in the primary direction of flow, referred to as longitudinal dispersion.

Dispersion is described by dispersion coefficients, which are required input parameters to the SOLTR model. Neglecting diffusion, the value of the coefficients of longitudinal and transverse dispersion are equal to the groundwater flow velocity multiplied by the longitudinal and transverse dispersivity, the units of which are length. Dispersivity values are dependent on the type of aquifer material and are difficult to estimate. For the analysis of contaminant movement from the Western Processing site, the values for dispersivity and therefore the dispersion coefficient were estimated on the basis of published information for an investigation of contaminant migration in soil similar to that at the site (Perlmutter and Lieber 1970). The values used in the flushing model are listed in Table A-9. Although it is believed that the values used are reasonable, substantiation of their accuracy would require additional data, analyses, and possibly field testing.

Initial Contaminant Concentrations. The initial concentrations of contaminants used in the analysis of the effectiveness of the proposed flushing operation were established using the chemical data developed by the EPA during the initial site investigation. Estimates of contamination levels were for depth intervals below the site ground surface inside the site fence line, as previously described. For the purpose of the analysis of flushing effectiveness, the average concentration at the 10-foot depth was assumed to apply to the depth zone from the water table to a depth of 25 feet, and the average concentrations for the 30-, 50-, and 130-foot depths were assumed to apply between 25 and 45 feet, 45 and 80 feet, and below 80 feet, respectively.

Results

The higher partition coefficients of the metal contaminants indicate that they would not be likely to move rapidly from the Western Processing site to distant receptors. Conversely, the generally low retardation characteristic of the various organic contaminants suggests that relatively rapid movement of these contaminants in groundwater can be expected. Although the lower retardation factors suggest that the organic contaminants, particularly the volatile organics, will move in groundwater more rapidly than the metals, they also indicate that the flushing operation will be more rapid and effective for organics than for metals.

The flushing model indicates that most of the residual Priority Level 1 and 2 organic contaminants remaining after excavation are reduced by at least 85 percent assuring 5 years of flushing, whereas the reduction of remaining metal contaminants is generally below 50 percent of post-excavation levels.

Table A-16 provides a summary of the contamination concentration averages, partition/retardation coefficients, water quality criteria, and diminution factors previously discussed. It also provides the calculated pre- and post-excavation mass for each Priority Level 1 and 2 contaminant, and the post-flushing (post groundwater extraction) contaminant mass that would be achieved by the PRP plan.

Line 11 on Table A-16 lists the total mass in pounds for each contaminant in the groundwater. This total mass was obtained by summing the weights of the contaminant in each depth zone to 200 feet. The depth zones used were: 10 to 25 feet, 25 to 45 feet, 45 to 80 feet, and 80 to 200 feet. The concentrations used for each depth zone are listed in Lines 1, 3, 4, and 5, respectively. The total contaminant mass for each zone was obtained by using the following equation:

TABLE A-16

CONTAMINANT CONCENTRATIONS AND EFFECT OF PRP
EXCAVATION AND GROUNDWATER EXTRACTION PROGRAMS

Parameter No. and Description	Cd	Al	Cr+6[a]	As	Zn	Ni	Pb	Cu	Cr+3[a]	Ag	Be	Hg
AVG. CONTAM. CONCENTRATION[b]												
1 SH, Shallow GW (ppb)	2,100	71,564	4,251	14	139,732	15,471	366	1,467	4,251	1.54	0.04	0.36
2 SH, Soil (ppb)	20,210	3,353,000	438,900	1,980	2,043,000	63,940	2,729,000	294,250	438,900	10	0.00	10
3 Geom., 30-ft GW (ppb)	1,011	101,662	366	13	124,928	14,795	275	787	336	0.00	0.00	13
4 Geom., 50-ft GW (ppb)	0.41	29,530	29	20	190	10	76	101	29	0.00	0.00	0.13
5 Geom., 130-ft GW (ppb)	6.28	19,579	27	57	279	64	57	79	27	0.00	0.00	0.00
PARTITION/RETARDATION												
6 Ratio Conc. Soil/GW	9.6	46.9	103.2	139.7	14.6	4.1	7,456.3	200.6	103.2	6.5	0.00	27.8
7 Partition Coefficient (K_d)	10	47	103	140	15	4	7,456	201	103	6.5	0.00	28
8 Retardation Factor (R_D)	49	225	494	678	73	20	36,000	966	495	31	0.00	135
QUALITY/DIMINUTION												
9 Water Quality Criteria (ppb)	0.012	1	0.29	0.0022	47	13.4	0.75	5.6	44	0.12	0.007	0.14
10 Diminution Factor	175,000.00	72,000	15,000	6,400	3,000	1,200	490	260	97	13	5.9	2.54
PRE-EXCAVATION MASS												
11 Mass in GW (lbs)	483	59,700	688	73	42,640	4,930	189	469	688	2.12	0.005	2.50
12 Mass in Soil (lbs)	11,660	1,930,000	253,000	1,140	1,180,000	36,900	1,570,000	170,000	253,000	5.77	0.00	5.77
13 Total Mass (lbs)	12,143	1,989,700	253,688	1,213	1,222,640	41,830	1,570,189	170,469	253,688	7.89	0.005	8.27
POST-EXCAVATION MASS												
14 Mass in GW (lbs)	483	59,700	688	73	42,640	4,930	189	469	688	2.12	0.005	2.50
15 Mass in Soil (lbs)	2,440	1,120,000	56,700	438	254,170	9,170	47,570	34,100	56,700	5.77	0.00	5.77
16 Total Mass (lbs)	2,923	1,180,700	57,388	511	296,810	14,100	47,759	34,569	57,388	7.89	0.005	8.27
POST-FLUSHING MASS												
17 Mass in GW (lbs)	362	57,320	688	73	34,111	2,610	189	469	688	1.27	0.00	2.4
18 Mass in Soil (lbs)	1,830	1,075,000	56,700	438	203,000	4,860	47,570	34,100	56,700	3.46	0.00	5.48
19 Total Mass (lbs)	2,192	1,132,320	57,388	511	237,111	7,470	47,759	34,569	57,388	4.73	0.00	7.88

(a) The data reported by EPA on Cr concentrations are represented in both Cr^{+6} and Cr^{+3} columns. EPA (1983) stated that samples containing chromium were checked for hexavalent chrome, but none was found. Therefore the CR^{+3} is probably more appropriate for evaluating the Western Processing site.

(b) SH = site history based; geom. = geometric-based.

TABLE A-16 (continued)

Parameter No. and Description	Trans-1,2-Dichloro-ethene	Methylene Chloride	Chloro-form	Trichloro-ethene	1,1-Dichloro-ethane	Dieldrin	Aldrin	1,2-Di-chloro-ethane	Fluro-trichloro-methane	Benzene	1,1-Di-chloro-ethene	Phenol
AVG. CONTAM. CONCENTRATION[b]												
1 SH, Shallow GW (ppb)	17,963	46,682	2,135	27,859	1,484	0.06	0.06	627	72.96	199	8.471	72,350
2 SH, Soil (ppb)	0.51	1,435	156	17,853	0.14	11.19	9.58	0.00	1.90	1.67	0.00	1,210
3 Geom., 30-ft GW (ppb)	157	50,660	2,193	7,740	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,547.6
4 Geom., 50-ft GW (ppb)	0.00	0.00	0.00	49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
5 Geom., 130-ft GW (ppb)	21	19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
PARTITION/RETARDATION												
6 Ratio Conc. Soil/GW	0.000028	0.030	0.075	0.64	0.00009	186.5	160.0	0.00	0.026	0.008	0.00	0.0
7 Partition Coefficient (K_d)	1.29	0.21	0.31	0.93	0.38	350	330	0.30	0.93	0.85	1.60	0.0
8 Retardation Factor (R_D)	7.2	2.0	2.5	5.5	2.8	1,700	1,600	2.4	5.5	5.1	8.7	1.3
QUALITY/DIMINUTION												
9 Water Quality Criteria (ppb)	0.033	0.19	0.19	2.7	0.94	0.000071	0.000074	0.94	0.19	0.66	0.033	300
10 Diminution Factor	544,000	246,000	11,000	10,000	1,600	845	811	667	384	302	257	241
PRE-EXCAVATION MASS												
11 Mass in GW (lbs)	2,530	15,780	697	5,280	205	0.008	0.008	86	10	28	1.20	10,270
12 Mass in Soil (lbs)	0.29	828	90	10,300	0.08	6.50	5.50	0.00	1.1	0.96	0.00	698
13 Total Mass (lbs)	2,530	16,608	787	15,580	205.08	6.508	5.508	86	11.1	28.96	1.20	10,968
POST-EXCAVATION MASS												
14 Mass in GW (lbs)	2,530	15,780	697	5,280	205	0.008	0.008	86	10	28	1.20	10,270
15 Mass in Soil (lbs)	0.17	388	90	4,530	0.00	0.00	0.00	0.00	0.47	0.96	0.00	695
16 Total Mass (lbs)	2,530.17	16,168	787	9,812	205	0.008	0.008	86	0.47	28.96	1.20	10,965
POST-FLUSHING MASS												
17 Mass in GW (lbs)	304	1,420	35	845	12	0.008	0.008	4.30	0.00	2.80	0.22	308
18 Mass in Soil (lbs)	0.02	35	4.5	725	0.005	0.00	0.00	0.00	0.00	0.096	0.00	21
19 Total Mass (lbs)	304.02	1,455	39.5	1,510	12.005	0.008	0.008	4.30	0.00	2.896	0.22	329

TABLE A-16 (continued)

Parameter No. and Description	Heptachlor	Cyanide	Tetra-chloro-ethene	2-Nitro-phenol	2,4,6-Tri-chloro-phenol	Chloro-methane	Vinyl chloride	2,4-Di-chloro phenol	Penta-chloro-phenol	1,1,2-Tri-chloro-ethane	1,1,2-Tri-chloro-ethane	Toluene
AVG. CONTAM. CONCENTRATION[b]												
1 SH, Shallow GW (ppb)	0.06	689	92.43	17,428	118	14.27	31.7	3.81	18.76	2.47	18,904	2,324
2 SH, Soil (ppb)	9.82	6,370	976	0.00	0.00	0.00	0.00	164.39	0.00	0.00	2,400	6,800
3 Geom., 30-ft GW (ppb)	0.00	17	0.00	77	0.00	0.00	0.00	0.00	0.00	0.00	1,047	332
4 Geom., 50-ft GW (ppb)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5 Geom., 130-ft GW (ppb)	0.32	742	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PARTITION/RETARDATION												
6 Ratio Conc. Soil/GW	164.0	9.2	10.6	0.00	0.00	0.00	0.00	43.1	0.00	0.00	0.127	2.93
7 Partition Coefficient (K_d)	300	9.2	3.0	0.21	1.10	0.36	0.93	0.42	10.20	2.37	0.43	1.38
8 Retardation Factor (R_D)	1,400	45.0	15.0	2.00	6.29	2.70	5.50	3.00	50.00	12.4	3.07	7.63
QUALITY/DIMINUTION												
9 Water Quality Criteria (ppb)	0.000278	3.5	0.8	13.4	1.2	0.19	2	0.3	3.2	0.6	18,000	14,300
10 Diminution Factor	216	197	116	1,300	98	75	16	13	5.9	4.1	1.1	0.16
PRE-EXCAVATION MASS												
11 Mass in GW (lbs)	0.008	916	12.8	2,420	16	2	4.4	0.53	2.6	0.34	2,790	382
12 Mass in Soil (lbs)	5.70	3,680	563	0.00	0.00	0.00	0.00	95	0.00	0.00	1,390	3,930
13 Total Mass (lbs)	5.708	4,596	575.8	2,420	16	2	4.4	95.53	2.6	0.34	4,180	4,312
POST-EXCAVATION MASS												
14 Mass in GW (lbs)	0.008	916	12.8	2,420	16	2	4.4	0.53	2.6	0.34	2,790	382
15 Mass in Soil (lbs)	0.00	1,330	17	0.00	0.00	0.00	0.00	45	0.00	0.00	83	3,380
16 Total Mass (lbs)	0.008	2,246	29.8	2,420	16	2	4.4	45.53	2.6	0.34	2,873	3,762
POST-FLUSHING MASS												
17 Mass in GW (lbs)	0.008	640	4.1	48	1.92	0.10	0.00	0.03	1.82	0.00	112	150
18 Mass in Soil (lbs)	0.00	930	17	0.00	0.00	0.0	0.00	2.70	0.00	0.00	3.3	1,350
19 Total Mass (lbs)	0.008	1,570	21.1	48	1.92	0.10	0.00	2.73	1.82	0.00	115.3	1,500

Groundwater contaminant mass for Zone A (lbs)	=	area of site (421,250 ft^2)	X	zone thickness (ft)	X	soil porosity (0.35)	X
		weight of water (62.4 lb/ft^3)	X	average containment concentration in Zone A (ppb) x 10^{-9}			

The total contaminant mass in the soil for each contaminant is listed in Line 12 on Table A-16. These data were calculated using the following equation:

Soil contaminant mass (lbs)	=	area of site (421,250 ft^2)	X	average depth of soil sampled (13.7 ft)	X
		weight of soil (100 lb/ft^3)	X	soil average site history concentration (Line 2, ppb) x 10^{-9}	

Line 13, the sum of Lines 11 and 12, represents the total contaminant mass for each contaminant at the site. All contaminant mass calculations are based on concentration values as reported by EPA (EPA 1983), and therefore do not adjust for the sensitivity of laboratory analytical methods or other factors. To the extent they are included in the reported values, normal background concentrations are included in the mass calculations.

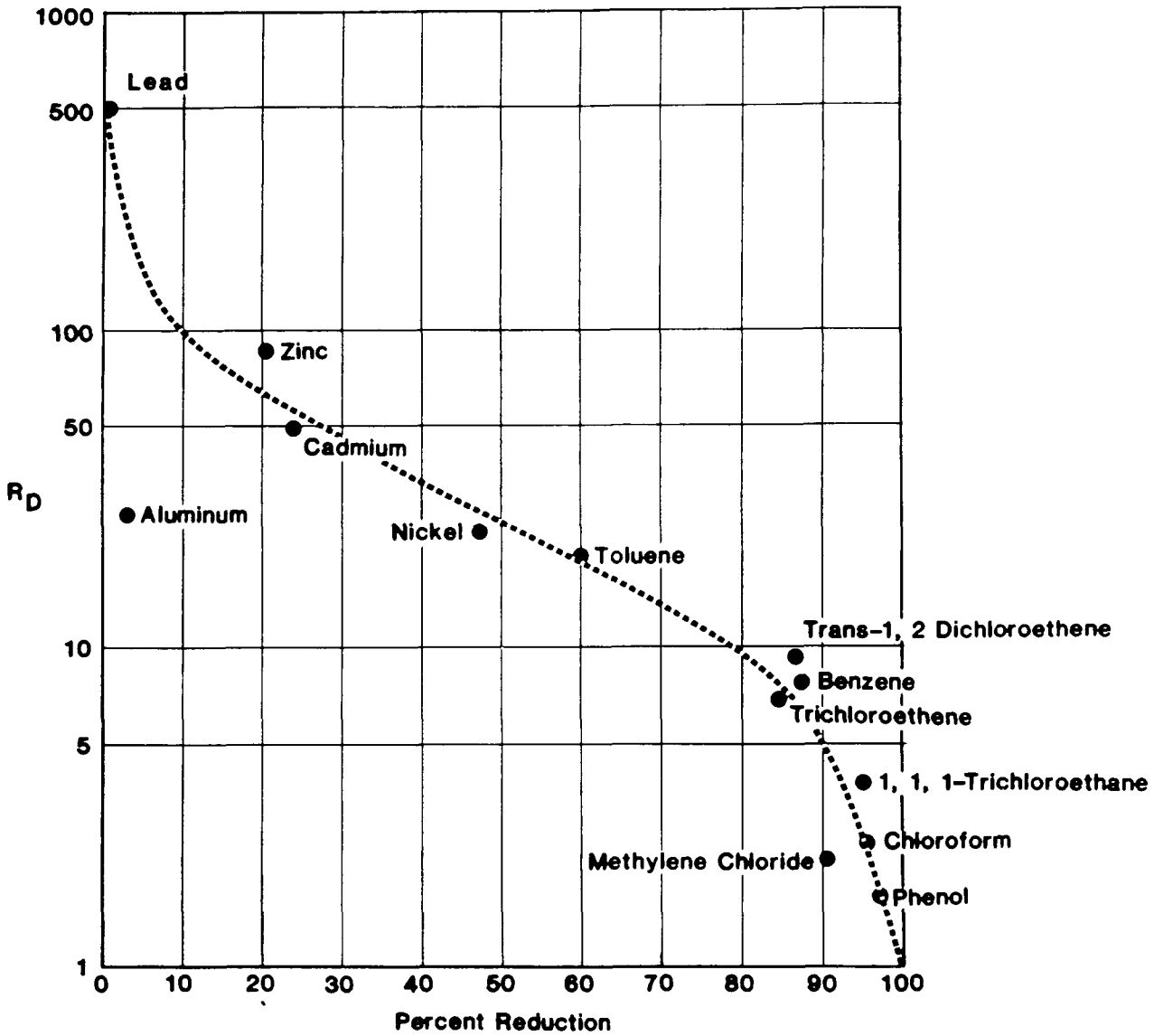
Line 14 is the total mass of contaminants in the groundwater after planned subsurface excavation and material removal. The values in Line 14 are equivalent to those in Line 11, since the mass of contaminant in the groundwater will not be changed significantly by the excavation program.

As previously discussed, excavation of fill will substantially reduce the amount of contamination on site; however, not all of the contamination will be removed. To calculate the mass remaining in the soil after excavation, the fraction of each contaminant remaining was multiplied by Line 12, the pre-excavation mass. The results are listed on Line 15. The total mass of each contaminant remaining on site after excavation was calculated by adding Lines 14 and 15 for each contaminant. These values are listed on Line 16.

Line 17, the mass remaining in the groundwater, was obtained by multiplying Line 14, the mass of contaminants in the groundwater after excavation, by the fraction of each contaminant not removed with flushing. The fraction of contaminant not removed with flushing is dependent upon the retardation factor (R_D, Line 8) and was obtained as follows: (1) using the contaminant reduction curve presented on Figure A-6, the percent of contaminant reduction was determined for each contaminant based on its retardation factor (expressed as a decimal), and (2) the value obtained in (1) was subtracted from 1.0.

Line 18, the mass remaining in soil, was similarly calculated: Line 15, the post-excavation mass in soil, was multiplied by the fraction of each contaminant not removed with flushing.

The total mass of contaminants remaining after flushing, Line 19, was calculated by adding Lines 17 and 18.



Notes: (1) R_D = Soil retardation coefficient
(2) Reductions shown are based on concentrations remaining in soil after proposed flushing

Summary of Contaminant Reduction

Figure A-5

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Appendix B: Summary of Applicable Regulations

APPENDIX B
SUMMARY OF APPLICABLE REGULATIONS

This appendix summarizes regulations of Federal, state, regional, and local agencies that would apply to the potential remedial action alternatives for cleanup at the Western Processing site. Chapter 6 of this feasibility study describes how these regulations apply to each of the specific alternatives. Standards for contaminant levels that are referred to in this section, but which are not included in this section, are contained in Chapter 2. This appendix contains a summary of the following regulations:

Federal

Resource Conservation and Recovery Act, 40CFR Parts 260 to 264

National Pollutant Discharge Elimination System (NPDES), 40 CFR Part 122

National Emissions Standards for Hazardous Pollutants, 40 CFR Part 61

EPA Groundwater Protection Strategy

Implementation of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, 40 CFR 4

Intergovernmental Review of Environmental Protection Agency Programs and Activities, 40 CFR Part 129

Statement of Procedures on Floodplain Management and Wetlands Protection 40 CFR 6, Appendix A

National Environmental Policy Act (NEPA)

Effluent Guidelines and Standards, CFR 40 Subchapter N Part 400

Hazardous Materials Regulations, 49 CFR Parts 170 to 179

State

National Pollutant Discharge Elimination System (NPDES) Permit Program, Chapter 173-220 WAC

Water Quality Standards of the State of Washington, Chapter 173-201 WAC

Hydraulics Permit, Chapter 220-110 WAC

State Flood Control Permit, Chapter 508-60 WAC

Washington Industrial Safety and Health Act

Washington State Department of Ecology (WDOE) Final Cleanup Policy, July 10, 1984

Dangerous Waste Regulations, Chapter 173-303 WAC

Washington State Implementation Plan, Puget Sound Air Pollution Control Agency (PSAPCA)

Regional

Industrial Waste Discharge Permit and Discharge Limitations, Metro

Regulation I and Regulation II of the Puget Sound Air Pollution Control Agency

Local

City of Kent Ordinances, Regulations, and Permit Approvals

FEDERAL

RESOURCE CONSERVATION AND RECOVERY ACT, 40 CFR, PARTS 260 TO 264

CERCLA specifically requires (in Section 104(c)(3)(B)) that hazardous substances from removal actions be disposed at facilities in compliance with Subtitle C of the Solid Waste Disposal Act and which are acceptable to the President (EPA). CERCLA makes no statement, however, on requirements of other environmental laws when the selected CERCLA remedy is not a removal. To address this issue, EPA has formulated a policy that requires examination of CERCLA remedies (both removal and nonremoval) in light of applicable and relevant standards of other environmental laws. Recognizing that RCRA is often the most relevant of the other laws in remedial actions, EPA has issued guidance that at least one RCRA-compliant alternative be considered in CERCLA feasibility studies.

There are four major technical requirements under RCRA which are pivotal in the following analyses of selected CERCLA remedial measures. Those requirements are:

- Closure performance standard (as specified in 40 CFR 264.111)

- o Groundwater protection standard (as specified in 40 CFR 264.92)
- o Point of compliance (as specified in 40 CFR 264.95)
- o Design requirements
  - Landfills (as specified in 40 CFR 264.301)

The regulatory language and technical implications for each requirement are as follows.

CLOSURE PERFORMANCE STANDARD

40 CFR 264.111 states:

> The owner or operator must close the facility in a manner that:
> (a) Minimizes the need for further maintenance, and
> (b) Controls, minimizes or eliminates, to the extent necessary to prevent threats to human health and the environment, post-closure escape of hazardous waste, hazardous waste constituents, leachate, contaminated rainfall, or waste decomposition products to the ground or surface waters or to the atmosphere.

These requirements clearly preclude any closure of a regulated facility which leaves waste in the ground without a durable, engineered barrier or containment system. Further, agency interpretation concludes that in cases of landfills (or soils where hazardous contaminants are present) an engineered cap must be part of that system. Additional guidance has also been issued "that such a cap must have at least a synthetic layer, a drainage layer, and a vegetative support layer. (Notwithstanding the much more loosely stated requirement of 40 CFR 264.310(a)(5) which states the cap must have a permeability less than or equal to any bottom liner or natural subsoils present.) All these layers together must be specified, sized, and sloped to minimize short- and long-term maintenance.

Alternatively, one can meet the closure performance standard by removing all hazardous waste and waste constituents from the facility. Historically, EPA has interpreted this removal to be complete when contaminant levels reach "background" for the area in question.

The fact that 264.11 is noted as a performance standard also implies that if, for any reason, the cap or other closure system fails, noncompliance is automatic. A remedy would be required to return to RCRA compliance.

GROUNDWATER PROTECTION STANDARD AND POINT OF COMPLIANCE

40 CFR 264.92 states:

> The owner or operator must comply with conditions specified in the facility permit that are designed to ensure that hazardous constituents under § 264.93 entering the groundwater from a regulated unit do not exceed the concentration limits under § 264.94 in the uppermost aquifer underlying the waste management area beyond the point of compliance under § 264.95 during the compliance period under § 264.96. The Regional Administrator will establish this groundwater protection standard in the facility permit when hazardous constituents have entered the groundwater from a regulated unit.

Sections 264.93 through 264.96 which are cited above read as follows:

> § 264.93 Hazardous constituents.
>
> (a) The Regional Administrator will specify in the facility permit the hazardous constituents to which the groundwater protection standard of § 264.92 applies. Hazardous constituents are constituents identified in Appendix VIII of Part 261 of this chapter that have been detected in groundwater in the uppermost aquifer underlying a regulated unit and that are reasonably expected to be in or derived from waste contained in a regulated unit, unless the Regional Administrator has excluded them under paragraph (b) of this section.
>
> (b) The Regional Administrator will exclude an Appendix VIII constituent from the list of hazardous constituents specified in the facility permit if he finds that the constituent is not capable of posing a substantial present or potential hazard to human health or the environment. In deciding whether to grant an exemption, the Regional Administrator will consider the following:
>
> (1) Potential adverse effects on groundwater quality, considering:
>
> (i) The physical and chemical characteristics of the water in the regulated unit, including its potential for migration;
>
> (ii) The hydrogeological characteristics of the facility and surrounding land;
>
> (iii) The quantity of groundwater and the direction of groundwater flow;
>
> (iv) The proximity and withdrawal rates of groundwater users;

(v) The current and future uses of groundwater in the area;

(vi) The existing quality of groundwater, including other sources of contamination and their cumulative impact on the groundwater quality;

(vii) The potential for health risks caused by human exposure to waste constituents;

(viii) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents;

(ix) The persistence and permanence of the potential adverse effects; and

(2) Potential adverse effects on hydraulically-connected surface water quality, considering:

(i) The volume and physical and chemical characteristics of the waste in the regulated unit;

(ii) The hydrogeological characteristics of the facility and surrounding land;

(iii) The quantity and quality of groundwater, and the direction of groundwater flow;

(iv) The patterns of rainfall in the region;

(v) The proximity of the regulated unit to surface waters;

(vi) The current and future uses of surface waters in the area and any water quality standards established for those surface waters;

(vii) The existing quality of surface water, including other sources of contamination and the cumulative impact on surface-water quality;

(viii) The potential for health risks caused by human exposure to waste constituents;

(ix) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents; and

(x) The persistence and permanence of the potential adverse effects.

(c) In making any determination under paragraph (b) of this section about the use of groundwater in the area around the facility, the Regional Administrator will consider any identification of underground sources of drinking water and exempted aquifers made under § 144.8 of this chapter.

§ 264.94 Concentration limits.

(a) The Regional Administrator will specify in the facility permit concentrations limits in the groundwater for hazardous constituents established under § 264.93. The concentration of a hazardous constituent:

(1) Must not exceed the background level of the constituent in the groundwater at the time that limit is specified in the permit; or

(2) For any of the constituents listed in Table B-1, must not exceed the respective value given in that Table if the background level of the constituent is below the value given in Table B-1; or

Table B-1
MAXIMUM CONCENTRATION OF CONSTITUENTS
FOR GROUNDWATER PROTECTION

Constituent	Maximum Concentration (milligram/liter)
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Selenium	0.01
Silver	0.05
Endrin (1,2,3,4,10, 10-hexachloro-1,7-epoxy-1,4,41,5,6,7,8,9a-octahydro-1, 4-endo, endo-5,8-dimethano naphthalene)	0.0002
Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer)	0.004
Methoxychlor (1,1,1-Trichloro-2,2-bis (p-methoxyphenylethane)	0.1
Toxaphene ($C_{10}H_{10}Cl_6$, Technical chlorinated camphene, 67-69 percent chlorine)	0.005
2,4-D (2,4-Dichlorophenoxyacetic acid)	0.1
2,4,5-TP Silvex (2,4,5-Trichlorophenox propionic acid)	0.01

(3) Must not exceed an alternate limit established by the Regional Administrator under paragraph (b) of this section.

(b) The Regional Administrator will establish an alternate concentration limit for a hazardous constituent if he finds that the constituent will not pose a substantial present or potential hazard to human health or the environment as long as the alternate concentration limit is not exceeded. In establishing alternate concentration limits, the Regional Administrator will consider the following factors:

(1) Potential adverse effects on groundwater quality, considering:

(i) The physical and chemical characteristics of the waste in the regulated unit, including its potential for migration;

(ii) The hydrogeological characteristics of the facility and surrounding land;

(iii) The quantity of groundwater and the direction of groundwater flow;

(iv) The proximity and withdrawal rates of groundwater users;

(v) The current and future uses of groundwater in the area;

(vi) The existing quality of groundwater, including other sources of contamination and their cumulative impact on the groundwater quality;

(vii) The potential for health risks caused by human exposure to waste constituents;

(viii) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents;

(ix) The persistence and permanence of the potential adverse effects; and

(2) Potential adverse effects on hydraulically-connected surface-water quality, considering:

(i) The volume and physical and chemical characteristics of the waste in the regulated unit;

(ii) The hydrogeological characteristics of the facility and surrounding land;

(iii) The quantity and quality of groundwater, and the direction of groundwater flow;

(iv) The patterns of rainfall in the region;

(v) The proximity of the regulated unit to surface waters;

(vi) The current and future uses of surface waters in the area and any water quality standards established for those surface waters;

(vii) The existing quality of surface water, including other sources of contamination and the cumulative impact on surface water quality;

(viii) The potential for health risks caused by human exposure to waste constituents;

(ix) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents; and

(x) The persistence and permanence of the potential adverse effects.

(c) In making any determination under paragraph (b) of this section about the use of groundwater in the area around the facility the Regional Administrator will consider any identification of underground sources of drinking water and exempted aquifers made under § 144.8 of this chapter.

§ 264.95 Point of compliance.

(a) The Regional Administrator will specify in the facility permit the point of compliance at which the groundwater protection standard of § 264.92 applies and at which monitoring must be conducted. The point of compliance is a vertical surface located at the hydraulically downgradient limit of the waste management area that extends down into the uppermost aquifer underlying the regulated units.

(b) The waste management area is the limit projected in the horizontal plane of the area on which waste will be placed during the active life of a regulated unit.

(1) The waste management area includes horizontal space taken up by any liner, dike, or other barrier designed to contain waste in a regulated unit.

(2) If the facility contains more than one regulated unit, the waste management area is described by an imaginary line circumscribing the several regulated units.

§ 264.96 Compliance period.

(a) The Regional Administrator will specify in the facility permit the compliance period during which the groundwater protection standard of § 264.92 applies. The compliance period is the number of years equal to the active life of the waste management area (including any waste management activity prior to permitting, and the closure period.)

(b) The compliance period begins when the owner or operator initiates a compliance monitoring program meeting the requirements of § 264.99.

(c) If the owner or operator is engaged in a corrective action program at the end of the compliance period specified in paragraph (a) of this section, the compliance period is extended until the owner or operator can demonstrate that the groundwater protection standard of § 264.92 has not been exceeded for a period of three consecutive years.

In short, Sections 264.92 through 264.96 require that the owner or operator of a RCRA-regulated facility not contaminate groundwater at the point of compliance beyond concentration limits set by the Regional Administrator. (Usually, background determines the limits.) Further, the owner or operator must prove that he is meeting the established concentration limits by instituting a groundwater monitoring

program at the "point of compliance." A point of compliance is really a perimeter around a waste management unit or units (grouped together). This perimeter extends downward vertically into the groundwater body and monitoring must take place here. If established concentration limits are exceeded at this point of compliance, corrective action must be initiated.

These RCRA requirements are analogous to the CERCLA issue of "How clean is clean?"

DESIGN REQUIREMENTS--LANDFILLS

40 CFR 264.301 states:

> (a) A landfill (except for an existing portion of a landfill) must have:
> (1) A liner that is designed, constructed, and installed to prevent any migration of wastes out of the landfill to the adjacent subsurface soil or groundwater or surface water at anytime during the active life (including the closure period) of the landfill. The liner must be constructed of materials that prevent wastes from passing into the liner during the active life of the facility. The liner must be:
> (i) Constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients (including static head and external hydrogeologic forces), physical contact with the waste or leachate to which they are exposed, climatic conditions, the stress of installation, and the stress of daily operation;
> (ii) Placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift; and
> (iii) Installed to cover all surrounding earth likely to be in contact with the waste or leachate; and
> (2) A leachate collection and removal system immediately above the liner that is designed, constructed, maintained, and operated to collect and remove leachate from the landfill. The Regional Administrator will specify design and operating conditions in the permit to ensure that the leachate depth over the liner does not exceed 30 cm (one foot). The leachate collection and removal system must be:
> (i) Constructed of materials that are:

(A) Chemically resistant to the waste managed in the landfill and the leachate expected to be generated; and

(B) Of sufficient strength and thickness to prevent collapse under the pressures exerted by overlying wastes, waste cover materials, and by any equipment used at the landfill; and

(ii) Designed and operated to function without clogging through the scheduled closure of the landfill.

(b) The owner or operator will be exempted from the requirements of paragraph (a) of this section if the Regional Administrator finds, based on a demonstration by the owner or operator, that alternative design and operating practices, together with location characteristics, will prevent the migration of any hazardous constituents (see § 264.93) into the groundwater or surface water at any future time. In deciding whether to grant an exemption, the Regional Administrator will consider:

(1) The nature and quantity of the wastes;

(2) The proposed alternate design and operation;

(3) The hydrogeologic setting of the facility, including the attenuative capacity and thickness of the liners and soils present between the landfill and groundwater or surface water; and

(4) All other factors which would influence the quality and mobility of the leachate produced and the potential for it to migrate to groundwater or surface water.

(c) The owner or operator must design, construct, operate, and maintain a run-on control system capable of preventing flow onto the active portion of the landfill during peak discharge from at least a 25-year storm.

(d) The owner or operator must design, construct, operate, and maintain a run-off management system to collect and control at least the water volume resulting from a 24-hour, 25-year storm.

(e) Collection and holding facilities (e.g., tanks or basins) associated with run-on and run-off control systems must be emptied or otherwise managed expeditiously after storms to maintain design capacity of the system.

(f) If the landfill contains any particulate matter which may be subject to wind dispersal, the owner or operator must cover or otherwise manage the landfill to control wind dispersal.

(g) The Regional Administrator will specify in the permit all design and operating practices that are necessary to ensure that the requirements of this section are satisfied.

The obvious intent of the above regulations is that new hazardous waste landfills be lined and have a leachate collection system. However the parenthetical statement in paragraph (a) "except for an existing portion of a landfill" is key to many CERCLA actions. This statement was included in the regulations is because it was recognized that unearthing large volumes of already buried hazardous waste might present more undesirable effects than securing it (to the largest degree possible) in place. Thus RCRA does allow for leaving buried hazardous waste in place without meeting the above-cited design standards. It should be noted, however, that the other technical standards of RCRA must be adequately addressed and that if the material is unearthed for the purpose of being land disposed the design standards do apply. Additionally, if the material is unearthed for treatment or another form of disposal the pertinent RCRA regulations apply fully for that treatment or disposal.

In studying the RCRA implications for each alternative it must be remembered that RCRA was not formulated with remedial actions in mind; consequently some interpretations of applicability (or nonapplicability) are open to debate. The basis for the interpretations presented here are taken largely from the memorandum titled: "CERCLA Compliance With the Requirements of Other Environmental Statutes" issued by Lee M. Thomas, U.S. EPA Assistant Administrator.

Note 1: In all cases where hazardous wastes are being transported away from the Western Processing site for treatment or disposal all the current RCRA regulations (for generation, transportation, and disposal) and the requirements of the 1984 Amendments to the Solid Waste Disposal Act must be considered. Further, DOT regulations as appropriate are applicable.

The 1984 amendments have significant requirements for land disposal facilities that become effective at 6 and 12 months (and several later) from the date of enactment. The amendments were signed in November of 1984.

Note 2: In the case where a remedial action is undertaken by the EPA, that agency must assume generator responsibility. In the case where a remedial action is undertaken by the PRP's, that group (or a representative of that group) must assume generator responsibility.

Note 3: The U.S. EPA has published guidance documents for design and installation of caps for hazardous waste landfills. This guidance is substantially more specific than the general regulatory

requirements and is not at all performance oriented. Deviations in cap design from published guidance might well meet the regulatory performance standard but put EPA in the position of justifying doing something other than it recommends in its own guidance.

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES), 40 CFR PART 122

Discharge of treated water from the site into Mill Creek will require an NPDES permit. The NPDES permit program establishes effluent guidelines and standards of pretreatment for new and existing sources. Compliance with the NPDES permit constitutes compliance with Sections 301, 302, 306, 307, 318, 403, and 405 of the Clean Water Act (CWA) except for any toxic effluent standards and prohibitions imposed under Section 307 CWA. Table 2-1 (Chapter 2) shows the toxic pollutant effluent standards and water quality criteria adopted under CWA Section 304 as set forth in 40 CFR part 129 and in the Federal Register, November 28, 1980.

The Washington State Department of Ecology (WDOE) has been authorized to administer the NPDES program. The state is required to conduct the program in accordance with the Federal NPDES program but is not precluded from adopting or enforcing requirements which are more stringent or more extensive. The State-adopted NPDES program is discussed in this appendix.

NATIONAL EMISSIONS STANDARDS FOR HAZARDOUS POLLUTANTS, 40 CFR PART 61

The provisions of this part apply to the owner or operator of any stationary air emissions source for which a standard is prescribed under this part. This part establishes emission standards for asbestos, beryllium, mercury, and vinyl chloride. Owners and operators of facilities which emit these pollutants are prohibited from operating any new source in violation of these standards. They are required to submit to the EPA technical information including calculations of emissions estimates and provide facilities for testing emissions following construction of the source.

EPA GROUNDWATER PROTECTION STRATEGY

The Groundwater Protection Strategy (GWPS) has been developed by EPA to increase state and Federal capability for coping with groundwater problems and to improve the coherence and consistency of EPA programs dealing with groundwater. The objective of the GWPS that is most likely to affect remedial action at the Western Processing site is the adoption of guidelines which would define appropriate

protection strategies for different classes of aquifers. The three classes of aquifers are:

> Class I, Special Groundwaters--those which are highly vulnerable to contamination and are characterized as either irreplaceable sources of drinking water or ecologically vital.
>
> Class II, Current and Potential Sources of Drinking Water--all other groundwaters that are currently used or potentially available for drinking water.
>
> Class III, Groundwater not a potential source of drinking water and of limited beneficial use--groundwaters that are saline or otherwise contaminated beyond reasonable use as drinking water or other beneficial purposes. In addition, the groundwater must not be connected to Class I or Class II groundwater or to surface water in a way that would allow contaminants to migrate to these waters and potentially cause adverse effects on human health or the environment.

Under this ruling, the degree of cleanup and/or protection of groundwater resources to be achieved is generally keyed to the classification of the affected or potentially affected aquifer. Cleanups at sites which lie over Class I, Special Groundwaters, will be to drinking water standards or background levels, as appropriate. In unusual cases, cleanup to a less stringent level may be considered if the alternative would not:

- Preclude fund-balancing
- Be technically infeasible
- Cause unacceptable environmental impacts
- Constitute a final cleanup but rather an interim measure
- Create overriding public health concerns at an enforcement site

For remedial actions at sites over current or potential sources of drinking water (Class II groundwaters), the goal of CERCLA cleanups is drinking water quality and background levels, as appropriate, with allowance for modifications based upon the factors cited above. The exemptions are applied less stringently for potential sources of drinking water (Class II) as compared to current sources of drinking water (Class I).

For CERCLA sites located over groundwaters which are not considered potential sources of drinking water (Class III groundwaters), CERCLA remedial actions will generally not involve groundwater cleanup. The priority of these sites for remedial action implementation is low, in the absence of other hazards to human health and the environment (e.g., surface water contamination, fire, or explosion).

Groundwater at the Western Processing site is classified as Class II. Based on this policy, the cleanup goal for the site would be drinking water quality or background levels.

IMPLEMENTATION OF THE UNIFORM RELOCATION ASSISTANCE AND REAL PROPERTY ACQUISITION POLICIES ACT OF 1970, 40 CFR 4

This part applies to EPA projects and to EPA-assisted projects which cause the displacement of persons or the acquisition of real property. It may be necessary to acquire property off the Western Processing site for construction of the wells, cap, or treatment plant, or to remove offsite contaminants. If EPA acquires offsite property, it is required to provide the current owner with just compensation disregarding any decrease or increase in the value of the property caused by the project. The compensation must be based on the fair market value of the property and it cannot be less than the approved appraised value of the property.

INTERGOVERNMENTAL REVIEW OF ENVIRONMENTAL PROTECTION AGENCY PROGRAMS AND ACTIVITIES, 40 CFR PART 29

These regulations implement Executive Order 12372. The stated purpose of the regulations is:

> To foster an intergovernmental partnership and a strengthened Federalism by relying on state processes and on state, areawide, regional, and local coordination for review of proposed federal financial assistance and direct federal development.

The regulations authorize adoption by the states of a process to review and coordinate proposed federal developments. If a state adopts such a process, EPA is required, to the extent permitted by law, to:

- Use the state process to determine official views of state and local elected officials.
- Communicate with state and local elected officials as early in a program planning cycle as is reasonably feasible to explain specific plans and actions

- o Make efforts to accommodate state and local elected officials' concerns with proposed federal financial assistance and direct federal development

In addition to communication with the state agency, the EPA is required, to the extent practicable, to consult with and seek advice from all other substantially affected federal departments and agencies in an effort to assure full coordination between such agencies and EPA.

At this time, an intergovernmental review process for the Western Processing site cleanup has not been adopted. If site cleanup is funded with federal or state funds or through a cooperative agreement, then an intergovernmental review process will be established by the state. The review process will be established by the State Office of Planning and Community Affairs.

STATEMENT OF PROCEDURES ON FLOODPLAIN MANAGEMENT AND WETLANDS PROTECTION 40 CFR 6, APPENDIX A

Executive Order 11988, entitled "Floodplain Management" and dated May 24, 1977, requires federal agencies to evaluate the potential effects of actions it may take in a floodplain. The purpose is to avoid wherever possible adversely impacting floodplains, and to ensure that its planning programs and budget requests reflect consideration of flood hazards and floodplain management. Executive Order 11990, entitled "Protection of Wetlands" and dated May 24, 1977, requires federal agencies to take action to avoid adversely impacting wetlands wherever possible, to minimize wetlands destruction, to preserve the values of wetlands, and to prescribe procedures to implement the policies and procedures of this Executive Order.

In order to determine whether an action will be located in or affect a floodplain or wetlands, the agency must use the Federal Insurance Administration maps showing flood hazard boundaries. The majority of the Western Processing site is not designated as a flood hazard area. Areas designated as flood hazard areas are along the Mill Creek channel and the drainage ditches along the eastern and southern edges of the property.

The site does not include wetlands designated by the Fish and Wildlife Service.

To the extent that the remedial actions require acquiring land or constructing improvements in the designated flood hazard areas, the regulations require that the agency incorporate floodplain management goals and wetlands protection considerations into its planning, regulatory, and decision-

making processes. It shall also promote the preservation and restoration of floodplains so that their natural and beneficial values can be realized. To the extent possible EPA shall:

1. Reduce the hazard and risk of flood loss and, wherever it is possible, avoid direct or indirect adverse impact on floodplains

2. Where there is no practical alternative to locating in a floodplain, minimize the impact of floods on human safety, health, and welfare, as well as the natural environment

3. Restore and preserve natural and beneficial values served by floodplains

4. Require the construction of EPA structures and facilities to be in accordance with the standards and criteria of the regulations promulgated pursuant to the National Flood Insurance Program

NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)

Superfund-financed remedial actions are generally exempt from NEPA requirements to prepare an environmental impact statement (EIS). This is based on numerous court decisions that found that the agency carries out the functional equivalent of a NEPA review in its permitting and regulatory activities. Under this exemption, the EPA is not obligated to comply with formal EIS procedures if two criteria are met. The first criterion is that the authorizing statute (i.e., CERCLA) must provide substantive and procedural standards to ensure full and adequate consideration of environmental issues and alternatives. The second criterion is that the public must be afforded an opportunity for participation in the evaluation of environmental factors and alternatives prior to arriving at a final decision.

Performance of the following steps is expected to ensure that fund-financed remedial actions meet these criteria and achieve functional equivalency with EIS requirements:

1. The process for determining the appropriate extent of remedy required by CERCLA section 105(3) and described in Section 300.68 of the NCP must be followed. To meet the first criterion of NEPA functional equivalency, this process embodies the necessary and appropriate investigation and analysis of environmental factors as they specifically relate to a Superfund site and alternatives that are being considered to correct the situation.

2. To meet the second criterion, a meaningful opportunity for public comment on environmental issues must be provided prior to the final selection of a remedial alternative. To meet this requirement, EPA regions must allow both the opportunity and adequate time for the public to review draft feasibility studies. This should be accomplished as part of the community relations program that is required at all Superfund response sites.

EFFLUENT GUIDELINES AND STANDARDS: 40 CFR SUBCHAPTER N PART 403

These regulations prescribe effluent limitations guidelines for existing sources, standards of performance for new sources, and pretreatment standards for new and existing sources pursuant to the Clean Water Act. The regulations apply specifically to: (1) pollutants from non-domestic sources covered by pretreatment standards which are discharged into publicly-owned treatment works (POTWs), and (2) any new or existing source subject to pretreatment standards.

Water discharged from the Western Processing site into the Metro sewer system would be subject to the pretreatment standards and therefore must also comply with the effluent guidelines and standards established under this section. Metro has been given the authority and has established effluent standards which comply with 40 CFR Part 400. These are discussed in this appendix under "Regional."

HAZARDOUS MATERIALS REGULATIONS: 49 CFR PARTS 170 TO 179

These regulations are administered by the U.S. Department of Transportation.

All interstate transport of hazardous materials must be conducted according to the provisions of 49 CFR Parts 170 to 179. These regulations apply to the transport of hazardous materials via all carriers (e.g., air, motor vehicle, rail) and to the packaging and reporting procedures required. Intrastate transport via motor vehicle is regulated by WDOE's Dangerous Waste Regulations, WAC 173-303. Transport of hazardous wastes from the Western Processing site to Arlington, Oregon, or any other regulated offsite disposal facility outside Washington state would be regulated under the federal regulations. The Washington State Utilities and Transportation Commission and the Washington State Patrol follow the federal regulations and the WDOE regulations in controlling the transportation of hazardous materials.

STATE

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) PERMIT PROGRAM, CHAPTER 173-220 WAC

WDOE is authorized to administer the NPDES permit program as set forth in the Federal Water Pollution Control Act based on the authority granted to WDOE by RCW 90.48, Water Pollution Control. The purpose of the permit program is to regulate the discharge of pollutants, wastes, or other substances from point sources into navigable water. Discharge of treated groundwater into Mill Creek or the Green River will require an NPDES permit.

Chapter 173-200 WAC does not establish effluent limitations or water quality standards. The regulation does, however, require that the effluent standards set forth in the FWPCA are met where applicable. On this subject, Chapter 173-220 states the following:

> WAC 173-220-130 Effluent limitations, water quality standards, and other requirements for permits.
>
> (1) Any permit issued by the department shall apply and insure compliance with all of the following, whenever applicable:
>
> (a) Effluent limitations under Sections 301, 302, 306, and 307 of the FWPCA. The effluent limitations shall not be less stringent than those based upon the treatment facility design efficiency contained in approved engineering plans and reports or approved revisions thereto. The effluent limits shall reflect any seasonal variation in industrial loading.
>
> (b) Any more stringent limitation, including those:
>
> (i) Necessary to meet water quality standards, treatment standards or schedules of compliance established pursuant to any state law or regulation under authority preserved to the state by Section 510 of the FWPCA; or
>
> (ii) Necessary to meet any federal law or regulation other than the FWPCA or regulations thereunder; or
>
> (iii) Required to implement any applicable water quality standards; such

limitations to include any legally applicable requirements necessary to implement total maximum daily loads established pursuant to section 303(d) and incorporated in the continuing planning process approved under section 303(e) of the FWPCA and any regulations and guidelines issued pursuant thereto;

(iv) Necessary to prevent or control pollutant discharges from plant site runoff, spillage or leaks, sludge or waste disposal, or raw material storage;

(v) Necessary to provide all known, available and reasonable methods of treatment

(c) Any more stringent legal applicable requirements necessary to comply with a plan approved pursuant to section 208(b) of the FWPCA; and

(d) Prior to promulgation by the administrator of applicable effluent standards and limitations pursuant to sections 301, 302, 306, and 307 of the FWPCA, such conditions as the department determines are necessary to carry out the provisions of the FWPCA

(2) In any case where an issued permit applies the effluent standards and limitations described in subparagraph (a) of paragraph (1) of this section, the department shall make a finding that any discharge authorized by the permit will not violate applicable water quality standards.

(3) In the application of effluent standards and limitations, water quality standards and other legally applicable requirements pursuant to paragraphs (1) and (2) hereof, each issued permit shall specify average and maximum daily quantitative (in terms of weight) or other such appropriate limitations for the level of pollutants and the authorized discharge.

Chapter 173.220 requires that any person proposing a discharge of pollutants into navigable waters submit an NPDES permit to the WDOE. Based on this initial submission, the WDOE will make a tentative determination to issue or deny the permit. If the tentative determination is to issue the permit, proposed effluent limitations will be established at that time.

In order to establish effluent limits, the WDOE uses the toxic pollutant effluent standards (40 CFR Part 129) and the Water Quality Criteria (Federal Register, November 28, 1980) for 64 toxic pollutants. For those pollutants contained in a proposed discharge that are not identified in the above sources, WDOE would research other published data to determine effluent limits.

WATER QUALITY STANDARDS FOR WATERS OF THE STATE OF WASHINGTON, CHAPTER 173-201 WAC

The purpose of this regulation is to establish surface water quality standards and classifications for surface waters of the state pursuant to the provisions of Chapter 90.48 RCW. Mill Creek is in the water quality criteria Class A (excellent). Waters in this class are characterized as follows:

WAC 173-201-045 general water use and criteria classes

Class A (excellent)

(a) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (domestic, industrial, agricultural)

(ii) Stock watering

(iii) Fish and shellfish:

Salmonid migration, rearing, spawning, and harvesting

Other fish migration, rearing, spawning, and harvesting

Clam, oyster, and mussel rearing, spawning, and harvesting

Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting

(iv) Wildlife habitat

(v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment)

(vi) Commerce and navigation

(c) Water quality criteria

(i) Fecal coliform organisms

Freshwater--Fecal coliform organisms shall not exceed a geometric mean value of 100 organisms/100 mL, with not more than 10 percent of samples exceeding 200 organisms/100 mL

(ii) Dissolved oxygen

Freshwater--Dissolved oxygen shall exceed 8.0 mg/L

(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection

(iv) Temperature shall not exceed 18.0 degrees C (freshwater) due to human activities. Temperature increases shall not, at any time, exceed $t=28/(T+7)$ (freshwater).

When natural conditions exceed 18.0 degrees C (freshwater) no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3 degrees C.

For purposes hereof, "t" represents the permissive temperature change across the dilution zone; and "T" represents the highest existing temperature in this water classification outside of any dilution zone.

Provided that temperature increase resulting from nonpoint source activities shall not exceed 2.8 degrees C, and the maximum water temperature shall not exceed 18.3 degrees C (freshwater).

(v) pH shall be within the range of 6.5 to 8.5 (freshwater) or 7.0 to 8.5 (marine water) with a man-caused variation within a range of less than 0.5 units.

(vi) Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those of public

health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.

(vii) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

Generally, waste discharge permits issued pursuant to the NPDES program are conditioned to authorize discharges which meet the water quality standards for a particular stream classification. This is consistent with the antidegradation policy of the state as guided by Chapter 90.48 RCW. However, WAC 173-201-035(8) states:

(d) Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria.

(e) The criteria and special conditions established in WAC 173-201-045 through 173-201-085 may be modified for a specific water body on a short-term basis when necessary to accommodate essential activities, respond to emergencies, or to otherwise protect the public interest. Such modification shall be issued in writing by the director or his designee subject to such terms and conditions as he may prescribe.

(f) In no case, will any degradation of water quality be allowed if this degradation interferes with or becomes injurious to existing water uses and causes long-term and irreparable harm to the environment.

Section (d) above states that if the existing water quality is lower than the water quality expected based on the stream class, then the discharge need only be as good as the existing water quality in the stream. Also a permit modification can be requested to temporarily violate the otherwise applicable standards. However, as stated in (f) above, water quality degradation is not allowed if it has an adverse effect on existing water uses or causes long-term damage to the environment. WAC 173-201-035 (12) states that deleterions concentrations of toxic or other nonradioactive materials shall be determined by WDOE in consideration of the Quality Criteria for Water published by EPA 1976 and as revised.

HYDRAULICS PERMIT, CHAPTER 220-110 WAC

A hydraulics permit issued by the Washington State Department of Fisheries is required for projects that would use, divert, obstruct, or change the natural flow or bed of any river or stream as authorized under RCW 75.20.100. Projects in Mill Creek that might be proposed as part of the remedial actions are dredging, temporary diversion, and/or construction of outfall structures to the creek. The following regulations of Chapter 220-110 WAC would be used to evaluate and place conditions on the hydraulics permit:

WAC 220-110-080. CHANNEL CHANGE--TEMPORARY AND PERMANENT. The following technical provisions may apply to channel change--temporary and permanent projects:

(1) Permanent new channels shall be similar in length, width, depth, gradient, and meander configuration as the old channel.

(2) The new channel shall provide fish habitat similar to that which previously existed in the old channel.

(3) During construction, the new channel shall be isolated from the flowing stream by plugs at the upstream and downstream ends of the new channel.

(4) Diversion of flow into a new channel shall be accomplished by: (a) First removing the downstream plug; (b) removing the upstream plug; and (c) closing the upstream end of the old channel.

(5) Filling of the old channel shall begin from the upstream closure and the fill material compacted. Water discharging from the fill shall not adversely impact fish life.

(6) Before water is diverted into a permanent new channel, the banks shall be armored to prevent erosion.

(7) The angle of the structure used to divert the water into the new channel shall allow a smooth transition of water flow.

(8) After completion of the permanent new channel and filling of the old channel, all unprotected banks shall be revegetated or otherwise protected to prevent erosion.

(9) The applicant shall have fish capture and transportation equipment ready and on the job site. Captured fish shall be immediately and safely transferred to free flowing water.

WAC 220-110-130. DREDGING. The following technical provisions may apply to dredging projects:

(1) Dredging shall not be conducted in fish spawning areas.

(2) During the dredging of a lake or pond, a boom or similar device shall be installed to contain floatable materials.

(3) Dredged bed materials shall be disposed of at Department of Natural Resources open water disposal sites or upland sites approved by the Department.

(4) Dredging shall be conducted with dredge types that cause the lowest mortality on fish life.

(5) Dredging shall stop when distressed or dead fish are observed in the work area. The Department shall be notified immediately.

(6) If a hydraulic dredge is used, it shall be operated with the intake on or below the surface of the material being removed. Reverse purging of the intake line shall be held to a minimum.

(7) If a dragline or clamshell is used, it shall be operated to minimize turbidity. During excavation, each pass with the clamshell or dragline bucket shall be complete. Dredged material shall not be stockpiled in the water.

(8) Upon completion of the dredging the watercourse bed shall not contain pits, potholes, or large depressions.

WAC 220-110-170. OUTFALL STRUCTURES. The following technical provisions may apply to outfall structure projects:

(1) The outfall structure shall be designed and constructed to prevent the entry of fish.

(2) The watercourse bank and bed at the point of discharge shall be armored to prevent scouring.

(3) Excavation for placement of the structure or armoring materials shall be isolated from the wetted perimeter.

(4) Alteration or disturbance of banks or bank vegetation shall be held to a minimum, and all disturbed areas shall be revegetated or otherwise protected from erosion.

(5) Structures containing concrete or wood preservatives shall be cured prior to water encroachment.

These regulations are intended to protect aquatic life and habitat. They are technical provisions that may be applied to a project before permit approval is granted. However, they are not required and are subject to interpretation by the Department of Fisheries and the Department of Game.

STATE FLOOD CONTROL ZONE PERMIT, CHAPTER 508-60 WAC

Compliance with this regulation is required by WDOE but the completed permit is submitted to the City of Kent. A flood control zone permit is required for projects which include the following:

> Construction, operation and maintenance of any works, structures and improvements, private or public, to be created or built or to be reconstructed or modified upon the banks or in or over the channel or over and across the flood plain or floodway of any stream or body of water within an established flood control zone.

This permit would apply to the construction of an outfall into Mill Creek and to the construction of any facilities in the designated flood control zone. Facilities that might be constructed at the Western Processing site are a groundwater treatment plant and a landfill. These facilities would be described in a flood control zone permit and submitted to the City of Kent. The City determines whether the structure lies within the flood control zone, which is the 100-year flood plain. For those facilities that lie in the flood control zone, special measures are required in order to protect structures against flood damage.

Based on the Flood Insurance Study for the City of Kent, Federal Emergency Management Agency, 1980, the majority of the site is outside the 100-year flood plain. Mill Creek and the drainage ditches along the eastern and southern side of the property have associated floodways that may be considered to be flood control zones. If these are considered flood control zones, then flood protection measures may be required of structures in these areas.

WASHINGTON INDUSTRIAL SAFETY AND HEALTH ACT

Health standards applicable to hazardous waste site activity are contained in Chapter 296-24 WAC, General Safety and Health Standards, and Chapter 296-62, General Occupational Health Standards. These regulations require the following:

- An accident prevention program or site safety plan must be prepared before site activity begins (WAC 296-24-040).
- A hazard evaluation of the site should identify known and potential hazards from gases, chemicals, and other materials, and the safety plan should instruct workers on safe practices and emergency actions following accidental exposure [WAC 296-24-040(iv)].
- Training programs to improve the skill and competency of the workers should be completed before work is commenced (WAC 296-24-02).
- Workers are required to use personal protective equipment, eye and face protection, and should be instructed in the safe use of respirators for routine and emergency use (WAC 296-07501, -07801, -07115).
- Deluge showers and eye wash fountains are required to be available for emergency operations (WAC 296-62-130).
- Operational procedures, training, and signage must be implemented, and medical surveillance provided for areas where any of the 14 identified carcinogens are present (WAC 296-62-073).
- Personnel requirements and general precautions for operations in confined areas must be established (WAC 296-62-145).
- Operational procedures must be established to ensure that the permissible exposure limits are not exceeded for various substances (WAC 296-62-07005, -0721, -07347, -07517, -080).

These regulations are enforced by WISHA inspectors. The Federal Occupational Safety and Health Administration (OSHA) regulations have been incorporated into and are enforced through WISHA regulations. OSHA regulations would not apply to site activities except possibly to the work of any federal employees.

WASHINGTON DEPARTMENT OF ECOLOGY (WDOE) FINAL CLEANUP POLICY, JULY 10, 1984

See Chapter 2 for a discussion of the WDOE cleanup policy.

DANGEROUS WASTE REGULATIONS, CHAPTER 173-303 WAC

The Dangerous Waste Regulations were prepared under the authority of the Hazardous Waste Disposal Act, Chapter 70.105 RCW, which authorized WDOE to develop standards for "dangerous waste" (DW) and "extremely hazardous waste" (EHW). The general purpose of the Dangerous Waste Regulations is to: (1) operate a state program for controlling DW and EHW, (2) to provide a means of defining and designating DW and EHW, (3) to establish a system for tracking DW and EHW shipments, (4) to develop standards for proper treatment, storage, and disposal of DW and EHW, (5) and to allow issuance of permits to facilities that treat, store, and dispose of DW and EHW.

For the purpose of this discussion, the wastes at Western Processing are assumed to be EHW. The main technical requirements of Chapter 173-303 WAC for such wastes that could apply to remedial actions at the Western Processing site are:

- Transportation Manifest, WAC 173-303-180
- Groundwater Protection, WAC 173-303-645
- Closure and Post Closure, WAC 173-303-610
- Design and Operation of Landfills, WAC 173-303-665

Transportation Manifest, WAC 173-303-180

This regulation requires that a manifest be prepared for the transport of dangerous waste to a disposal facility. The manifest required is the EPA Form 8700-22 as described in the Uniform Manifest Appendix of 40 CFR part 262.

Groundwater Protection, WAC 173-303-645

This section of the dangerous waste regulations applies to the operation of landfills. It establishes groundwater concentration limits for 14 contaminants and describes required groundwater monitoring.

The owner and operator of a landfill or waste storage facility must comply with conditions specified in the facility permit that are designed to ensure that dangerous constituents entering the groundwater from a regulated unit do not exceed the concentration limits under WAC 173-303-180(5) (see Table B-2).

Table B-2
MAXIMUM CONCENTRATION OF CONSTITUENTS FOR GROUNDWATER PROTECTION

Constituent	Maximum Concentration (in milligrams per liter)
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Selenium	0.01
Silver	0.05
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP Silvex	0.01

Note: These are the same as the concentrations identified in 40 CFR Part 264.94

These concentration limits cannot be exceeded in the uppermost aquifer underlying the waste management area beyond the point of compliance established by WDOE. WDOE will specify in the facility permit concentration limits for dangerous constituents in the groundwater. The owner or operator must monitor the groundwater to determine whether regulated units are in compliance with the groundwater protection standard.

Landfills, WAC 173-303-665

These regulations apply to owners and operators of facilities that dispose dangerous wastes in landfills. The regulations prohibit the disposal of EHW in landfills in Washington State other than at the Hanford Landfill (not yet constructed). This could be interpreted as precluding the construction of a landfill at Western Processing for the disposal of EHW. The regulations require that a landfill for DW be double lined and contain a lechate detection system and include groundwater monitoring.

Closure and Post Closure WAC 173-303-610

If wastes are allowed to remain on site in an approved landfill then the facility would have to be closed according to WAC 173-303-610. The owner or operator is required to close the facility in a manner that:

A) Minimizes the need for further maintenance;

B) Controls, minimizes, or eliminates (to the extent necessary to prevent threats to human health and the environment) post-closure escape of dangerous waste, dangerous waste constituents, leachate, contaminated rainfall, or waste decomposition products to the ground, surface water, ground water, or the atmosphere; and

C) Returns the land to the appearance and use of surrounding land areas to the degree possible given the nature of the previous dangerous waste activity.

The closure standards can also be met by removing contaminants from the site. This removal must be done such that the levels of dangerous waste or dangerous waste constituents or residues do not exceed background levels [WAC 173-303-6102(b)(i)].

REGIONAL

INDUSTRIAL WASTE DISCHARGE PERMIT AND DISCHARGE LIMITATIONS, METRO

Metro is authorized under Chapters 90.48.165 RCW, 35.58.180 RCW, and 35.58.200 to establish standards for pretreatment and to require approval of industrial waste discharge permits prior to discharge of industrial waste into the Metro sewer system. Based on this authority and Public Laws 92-500 and 92-217 (Clean Water Act), which require that Metro discharge achieve certain standards, Metro has adopted Resolution No. 3374 "Regarding the control and disposal of industrial waste into the Metropolitan Sewerage System." Based on this resolution, all persons who discharge industrial wastes into the sewer system must obtain a waste discharge permit. Resolution 3374 and amendments to it identify the following prohibited discharges:

3-01. Prohibited Substances

No person shall discharge any of the following prohibited substances directly or indirectly into any public sewer, private sewer, or side sewer tributary to the Metropolitan Sewerage System:

3-01.01 - Flammable or Explosive Materials

Any liquids, solids or gases which by reason of their nature or quantity are, or may be, sufficient either alone or by interaction with other substances to cause fire or explosion or be injurious in any other way to the POTW or to the operation of the POTW. Prohibited materials include, but are not limited to, gasoline, kerosene, naphtha, benzene, toluene, xylene, ethers, alcohols, ketones, aldehydes, peroxides, chlorates, perchlorates, bromates, carbides, hydrides and sulfides and any other substances which the City and the State or EPA have notified the User are a fire hazard or a hazard to the system.

3-01.02. Substances Which Can Cause Obstruction or Interference

Any solid or viscous substances in quantities, either by itself or in combination with other wastes, which are capable of obstruction of flow or of interfering with the operation or performance of sewer works or treatment facilities, including, but not limited to, the following: ashes, cinders, sand, mud, straw, grass clippings, shavings, metal, glass, tar asphalt, plastics, cloth, wood, and chemical residues.

3-01.03. Odorous Substances

Any noxious or malodorous gas or substance which either by itself or by interaction with other wastes, is capable of creating a public nuisance or hazard to life or of preventing entry by authorized personnel to pump stations and other sewerage facilities.

3-01.04. Toxic Vapor

Any gas or substance which either by itself or by interaction with other wastes can produce a toxic vapor. These substances include, but are not limited to, chlorinated hydrocarbons, hydrogen sulfide, sulfur dioxide, and cyanide compounds.

3-01.05. Corrosive Substances

Any gas or substance which either by itself or by interaction with other waste may cause corrosive structural damage to sewer works or treatment facilities, but in no case waters with a pH lower than 5.5.

3-01.06. Excessive Waste

Wastes at a flow rate and/or pollutant discharge rate which are excessive over relatively short time periods

so that there is a treatment process upset and subsequent loss of treatment efficiency.

3-01.07. High Temperature

Heat in amounts which will inhibit biological activity in treatment plant facilities resulting in an interference in the treatment process and specifically including heat in such quantities that the temperature at the treatment works influent exceeds 40 degrees C (104 degrees F) or the temperature exceeds 65 degrees C (150 degrees F) at the point of discharge from the industrial source of public sewers and/or the Metropolitan Sewerage System.

The following restricted substances can be discharged only in the quantities shown or lesser amounts:

4-01. Restricted Substances

No person shall discharge wastes containing restricted substances directly or indirectly into any public sewer, private sewer, or side sewer tributary to the Metropolitan Sewerage System, in excess of limitations specified by conditions of the waste discharge permit or published by the Executive Director or in excess of limitations specified by conditions of the waste discharge permit or published by the Executive Director or in excess of other Metro, state or federal standards.

Discharge limitations established by local public agencies which are more stringent than a National Pretreatment Standard or Metro's limitations shown below will apply to those industrial users within the jurisdiction of that public agency. All other users will comply with the following limitations expressed as milligrams per liter.

Arsenic	1 mg/L
Cadmium*	3 mg/L
Chromium	6 mg/L
Copper	3 mg/L
Lead*	3 mg/L
Mercury	0.1 mg/L
Nickel	6 mg/L
Silver	1 mg/L
Zinc	5 mg/L
Cyanide	2 mg/L

*Metro is considering changing the standard for cadmium to 1.2 milligrams per liter and the standard for lead to 0.6 milligram per liter.

An industrial discharge permit issued in June 1982 currently authorizes a discharge from the Western Processing site of 140,000 gallons per day. This discharge has not been carried out because water treatment facilities which would provide pretreatment of the discharge have not been installed.

REGULATION I AND REGULATION II OF THE PUGET SOUND AIR POLLUTION CONTROL AGENCY

The Puget Sound Air Pollution Control Agency (PSAPCA) as authorized by the Washington Clean Air Act, RCW 70.94, regulates the emission of air contaminants in King, Snohomish, and Pierce Counties except for emissions caused by vehicles, pulp and paper industries, and aluminum smelters. WDOE is authorized to regulate these sources.

PSAPCA requires all non-exempt air contaminant sources to be registered with the agency under Regulation I, Section 5.03. New emissions sources are approved and registered with the agency through submission of a notice of construction and application for approval. All sources registered with the agency are subject to annual or periodic reports discussing their emissions.

Components of the alternative remedial actions that may be considered new sources include air stripping storage piles, air stripping equipment, and other stationary equipment that emits contaminants. For those sources requiring prior approval by PSAPCA, the application for approval must include a description of air emissions control equipment. A source test demonstrating the effectiveness of emission control devices in attaining PSAPCA air emissions standards may be required.

PSAPCA has adopted ambient air quality standards for suspended particulates, lead, carbon monoxide, ozone, nitrogen dioxide, and sulfur dioxide. Emissions standards are established for sulfur dioxide and particulates. Other emissions fall under the general provision of Regulation I, Section 9.11 which states:

> It shall be unlawful for any person to cause or allow the emission of any air contaminant in sufficient quantities and of characteristics and duration as is, or is likely to be, injurious to human health, plant or animal life, or property or which unreasonably interferes with enjoyment of life and property.

New sources which do not require approval prior to construction are regulated under the general provision stated above. All potential sources are required to employ the best

available control technology in order to comply with PSAPCA emissions standards. Compliance with these standards is monitored through spot surveillance of potential sources and by investigation of complaints regarding emissions.

LOCAL

CITY OF KENT ORDINANCES, REGULATIONS, AND PERMIT APPROVALS

Engineering Department

The following permits and regulations of the Kent Engineering Department could apply to remedial actions at the Western Processing site:

- Grade and fill permit
- Temporary erosion control requirements
- Stormwater ordinance No. 2130
- Side sewer permit
- Street use and street cut permit

The grade and fill permit application requires a description of site work including a calculation of the volume of material moved and drawings showing current and proposed elevations. The standards used in evaluating the grade and fill permit are those stated in Chapter 70 of the Uniform Building Code.

A temporary drainage and erosion control plan must be submitted with the grade and fill permit. The City of Kent requires that the plan satisfy the requirements of the King County Storm Drainage Control Requirements and Guidelines. These requirements describe methods for erosion control and control of offsite transport of silt. Since these guidelines are not designed to regulate the release of contaminated silt or surface water, the regulations are generally less restrictive than the measures that the remedial actions are expected to include.

Storm drainage ordinance No. 2130 requires submittal of a storm drainage plan with any grade and fill permit. The stormwater ordinance requires that storm drainage plans for new development include retention and/or detention facilities that will maintain surface water discharge rates at or below the preconstruction design storm peak discharge. A variance from this requirement can be granted if it can be shown that there is sufficient capacity in downstream facilities to handle additional stormwater runoff.

Connection to the City sewer line requires approval of a sewer use permit. Approval of this permit is based primarily on the City's calculation of the capacity of the sewer to handle an additional discharge. A temporary sewer use

permit was granted in winter 1984-1985 for the initial removal actions which limited the discharge to 140,000 gpd. This was based on the capacity of the City system and the Metro interceptor.

A street use and street cut permit was also granted for activities during initial removal. The purpose of this permit is to provide a fund for street repair following potentially damaging construction activity. Permit approval requires posting a bond to cover these estimated costs.

Planning and Building Departments

The following permits and regulations of the Kent Planning and Building Departments could apply to remedial actions at the site:

- Special use permit
- Water Quality and Hazard Area Development (Chapter 15.08.270 Kent City Zoning Code)
- Building permits

Construction of a solid waste landfill or a water treatment plant would require a special use permit since neither of these uses is allowed outright in the manufacturing zone which is the zoning designation of the site. The approval process for granting a special use permit includes a public hearing with the decision to grant or deny the permit being made by the hearing examiner and city council. The hearing examiner uses the following criteria to make a decision to grant or deny a special use permit:

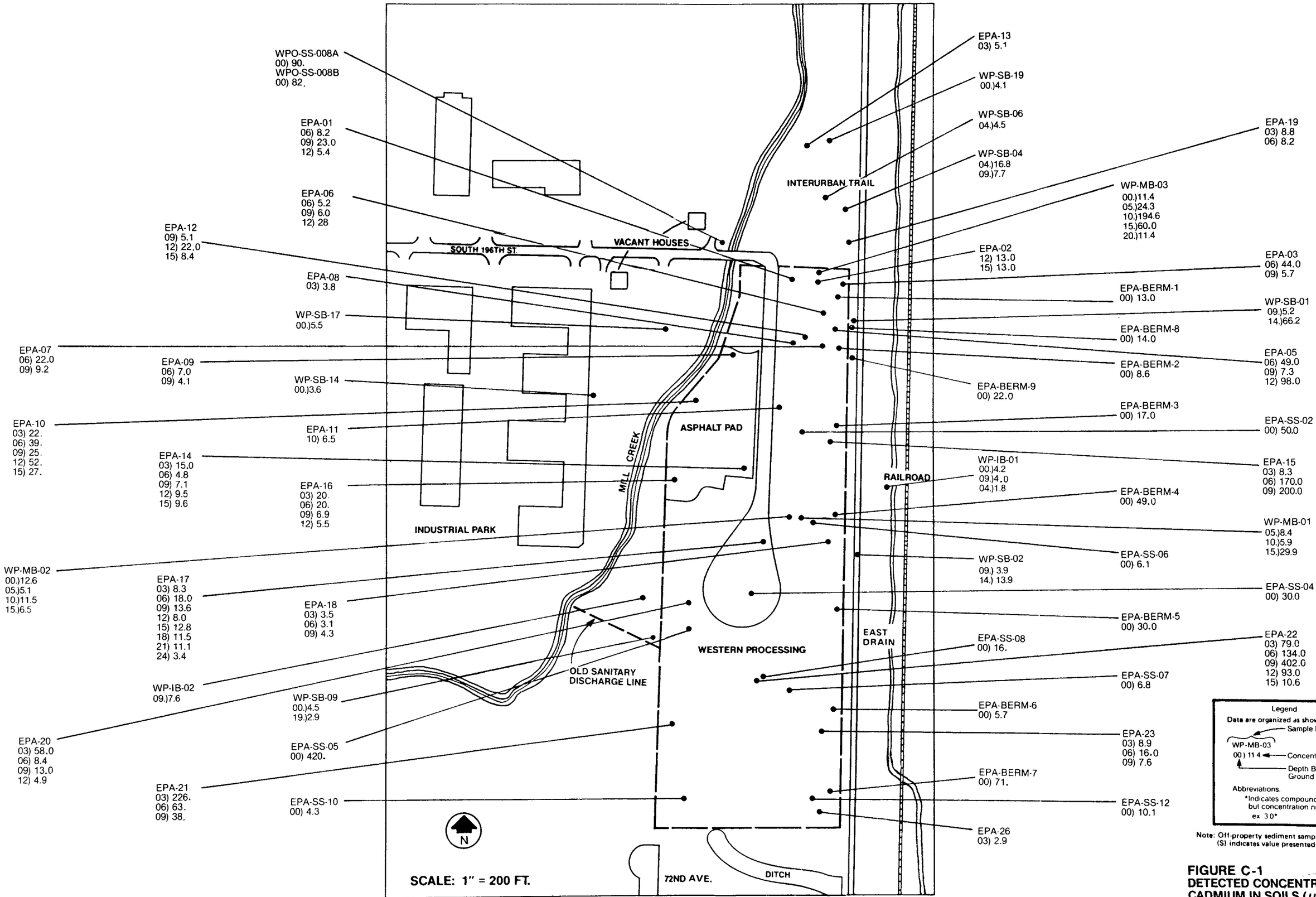
- The proposed use will not be detrimental to other uses legally existing or permitted in the zoning district.
- Adequate buffering devices such as fencing, landscaping, or topographic characteristics protect adjacent properties from adverse effects of the proposed use.
- The size of the site is adequate for the proposed use.

Under the Water Quality and Hazardous Area Development Ordinance, impervious surfaces (buildings, parking lots, etc.) are required to be at least 50 feet away from the ordinary high water mark of a major creek which has been relocated (Mill Creek is considered a major creek). The City requires that all such relocation actions are done in accordance with the recommendations of the Washington State Departments of

Fisheries and Game as prescribed during approval of a hydraulics permit (see discussion of state regulations in this appendix).

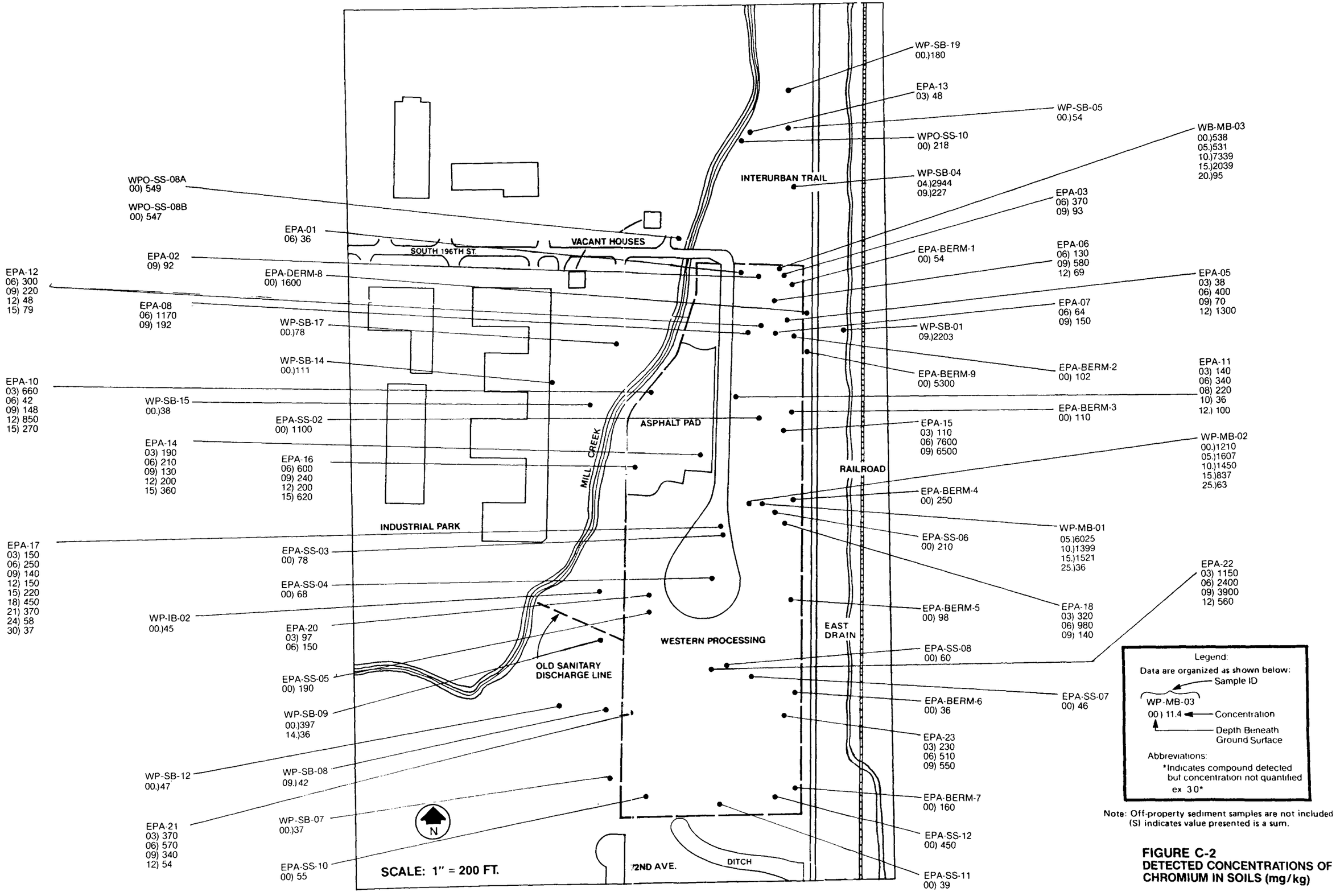
Construction permits that would be required to construct a landfill or groundwater treatment facility are a building permit, plumbing permit, and mechanical permit. An electrical permit is also required by the City but is reviewed by the state.

Appendix C: Detected Indicator Compounds in Soils and Groundwater



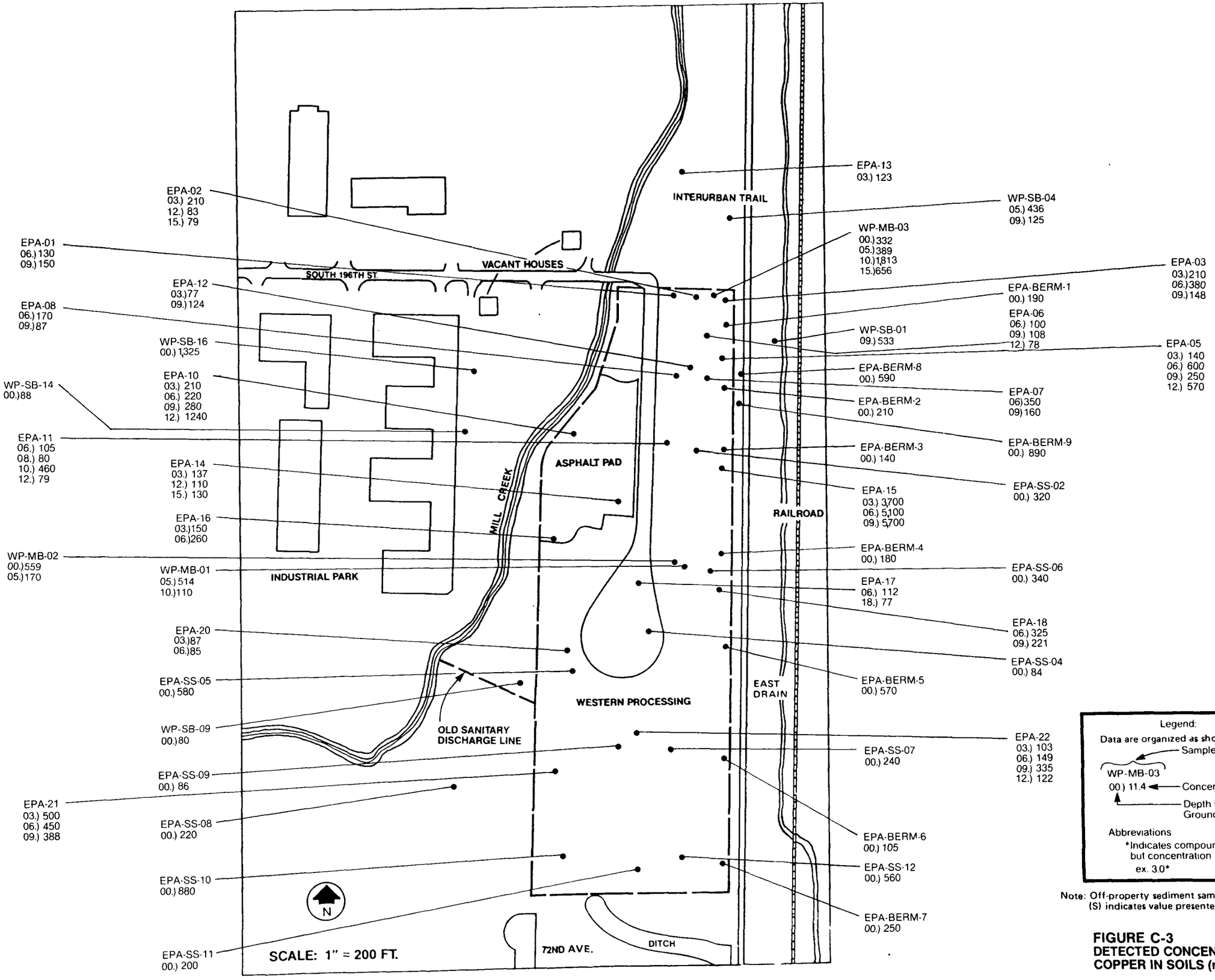
Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-1
DETECTED CONCENTRATIONS OF CADMIUM IN SOILS (μg/kg)



Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-2
DETECTED CONCENTRATIONS OF CHROMIUM IN SOILS (mg/kg)

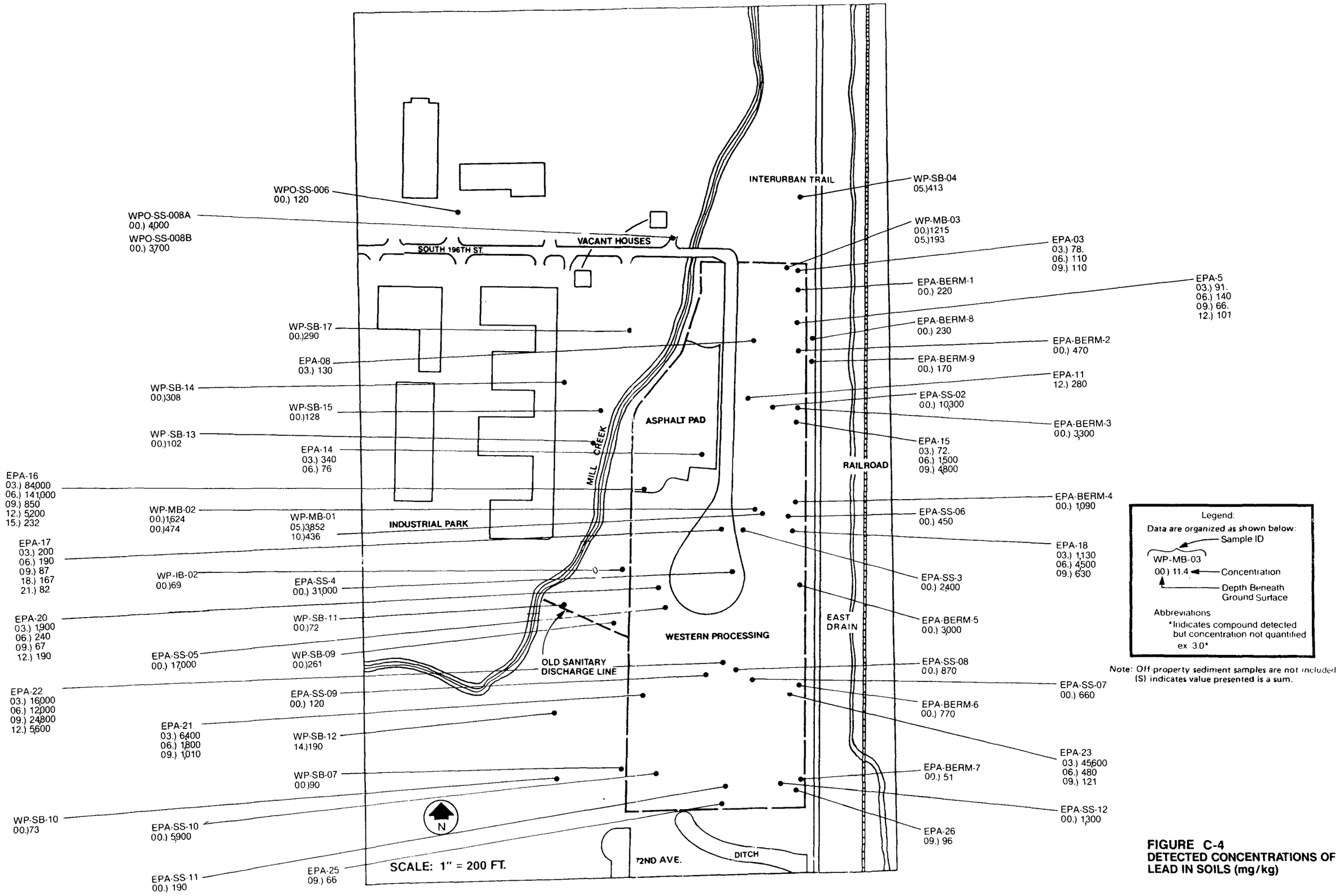


Legend:
Data are organized as shown below:
Sample ID
WP-MB-03
00.) 11.4 ← Concentration
Depth Beneath Ground Surface

Abbreviations
*Indicates compound detected but concentration not quantified
ex. 3.0*

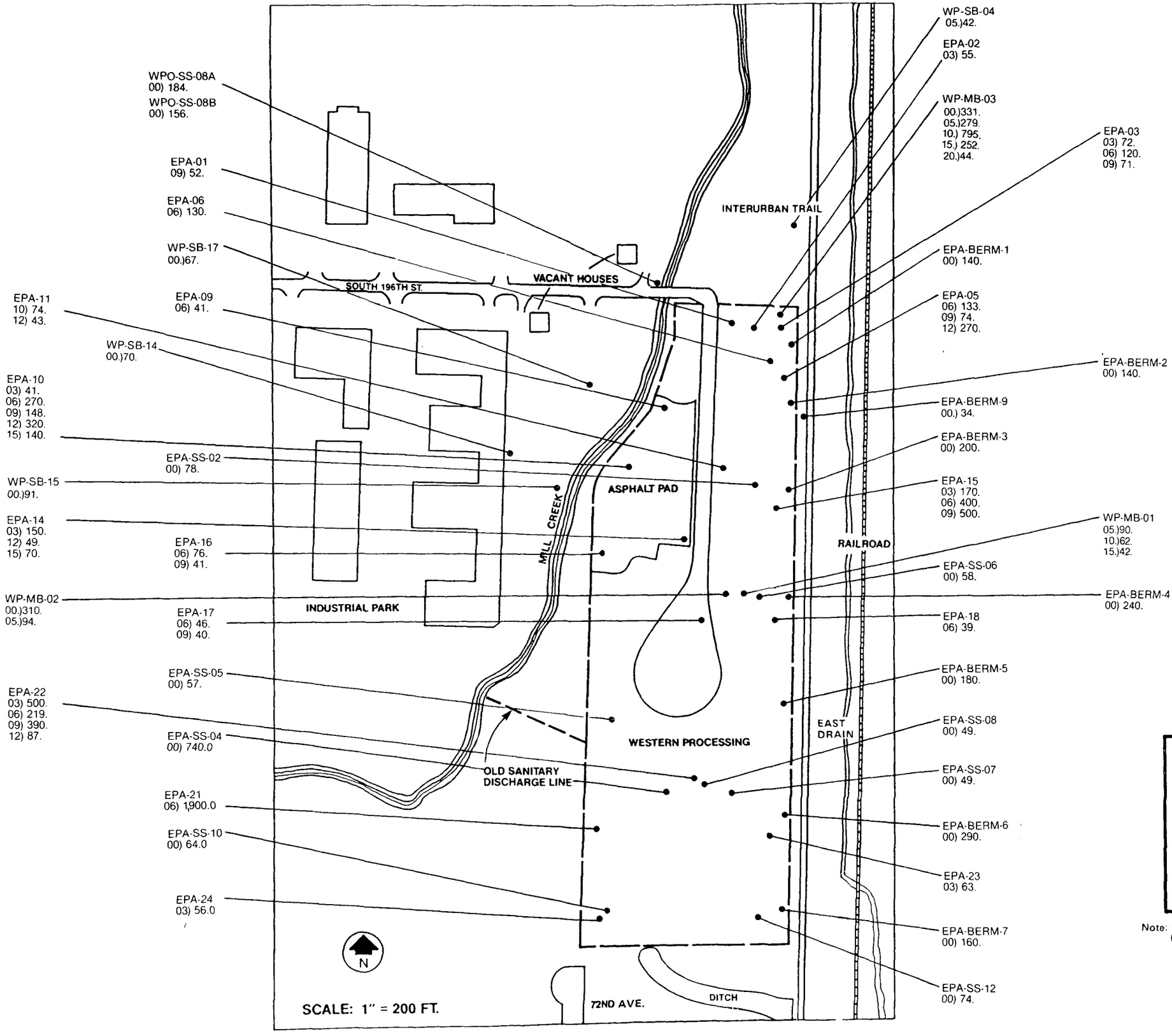
Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-3
DETECTED CONCENTRATIONS OF COPPER IN SOILS (mg/kg)



Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-4
DETECTED CONCENTRATIONS OF LEAD IN SOILS (mg/kg)

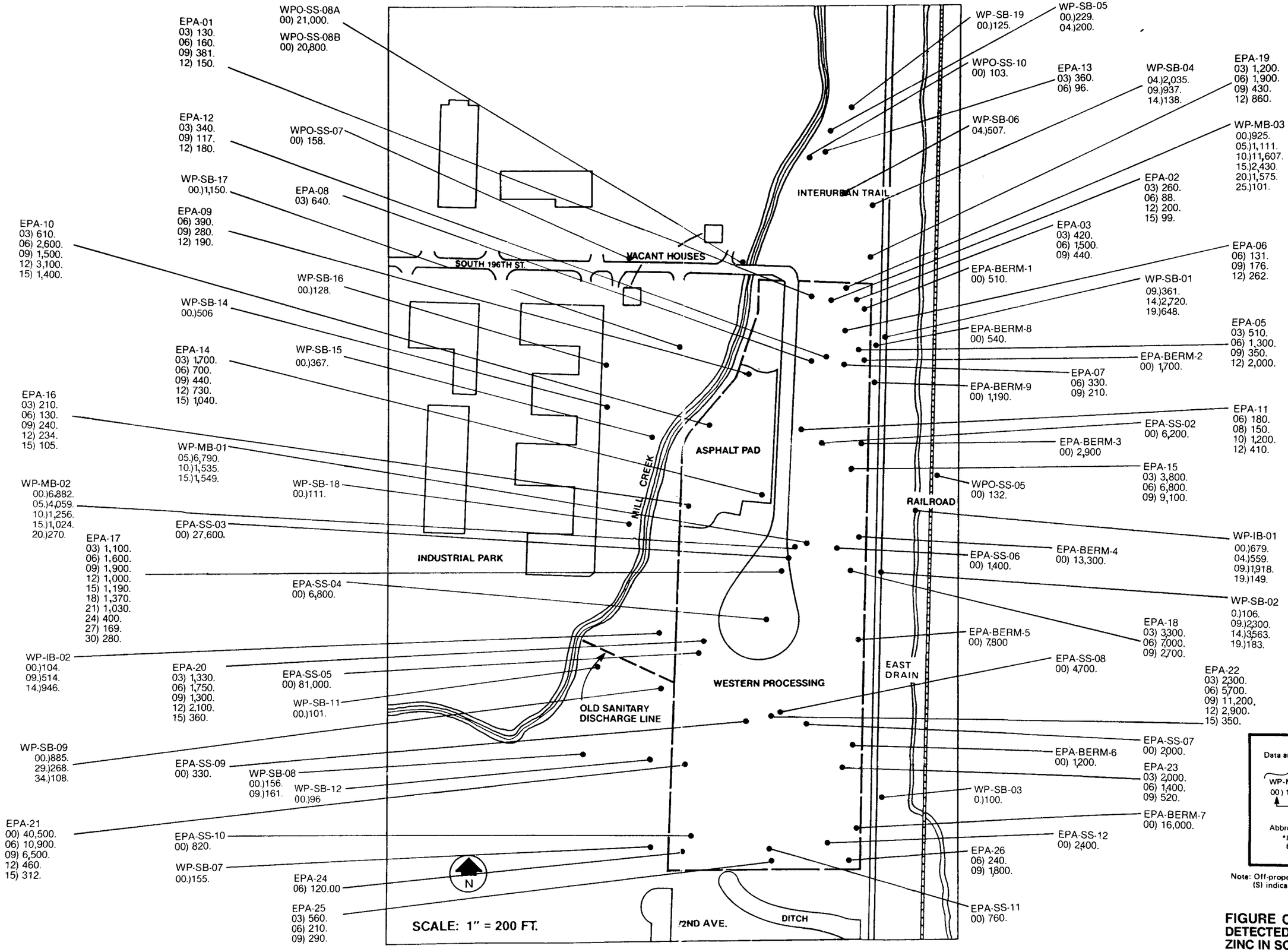


Legend:
Data are organized as shown below:
Sample ID
WP-MB-03
00) 11 4 ← Concentration
Depth Beneath Ground Surface

Abbreviations.
*Indicates compound detected but concentration not quantified
ex 30*

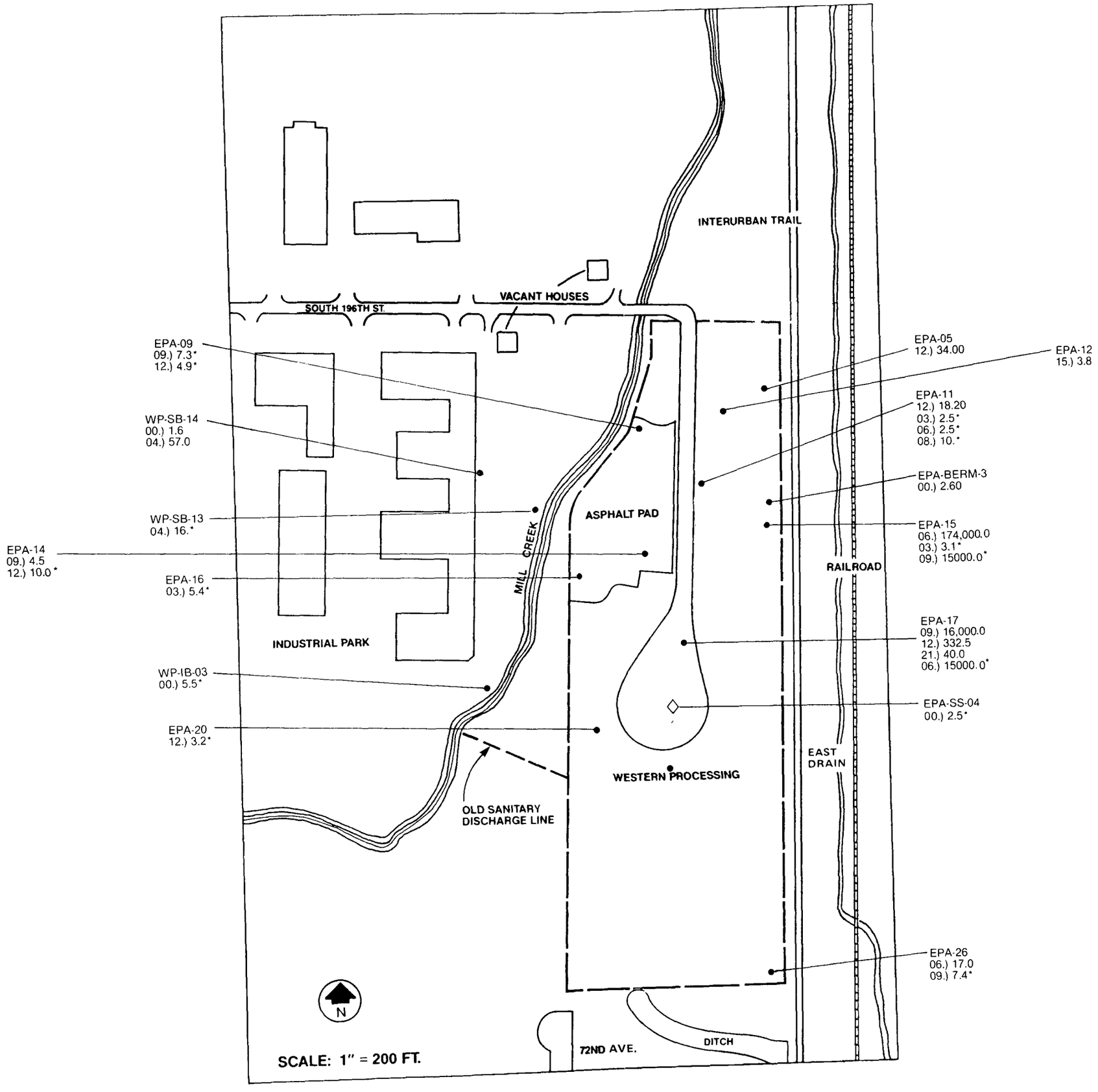
Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-5
DETECTED CONCENTRATIONS OF NICKEL IN SOILS (mg/kg)



Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-6
DETECTED CONCENTRATIONS OF ZINC IN SOILS (mg/kg)

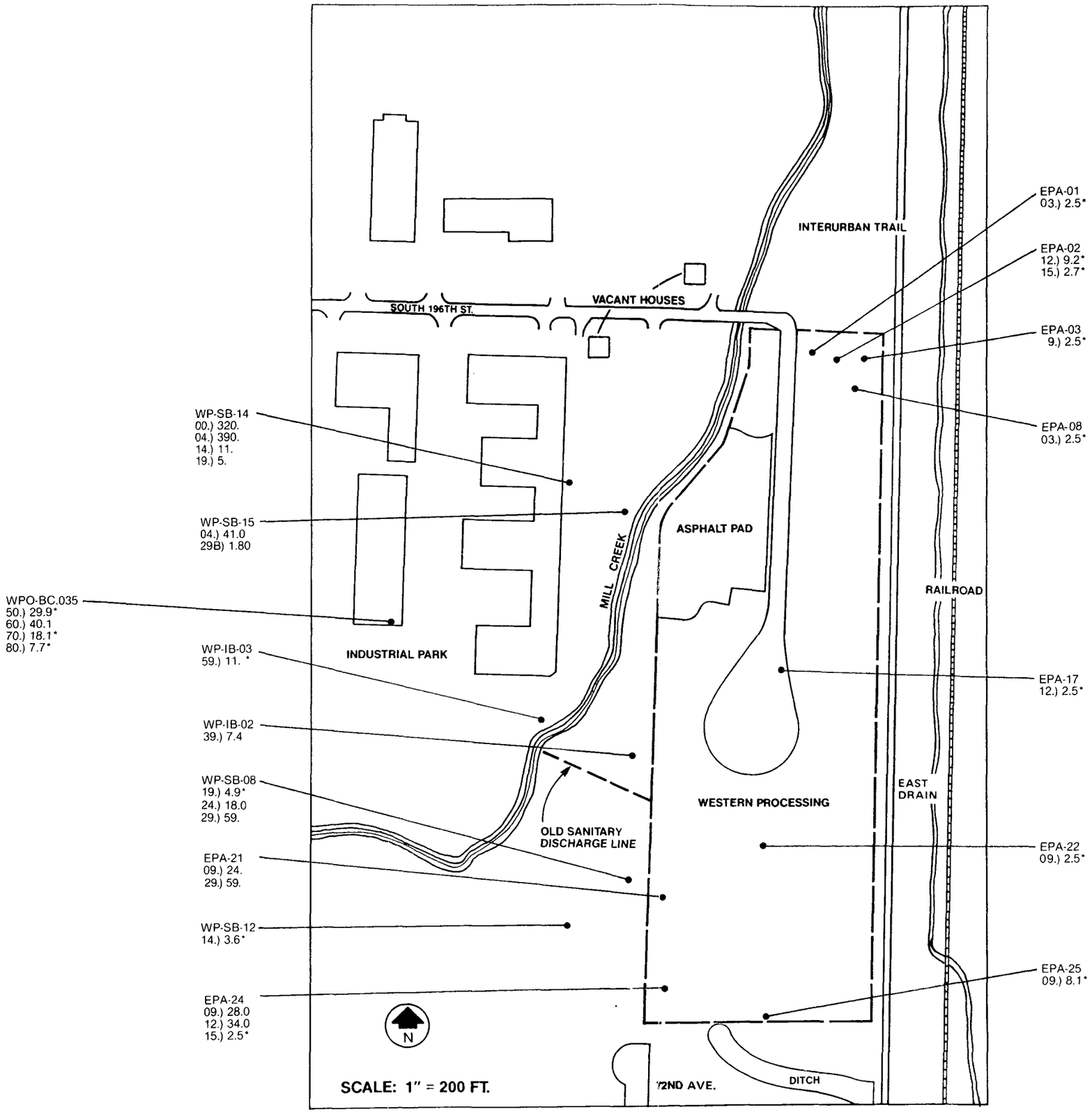


Legend.
Data are organized as shown below:
Sample ID
WP-MB-03
00) 11.4 ← Concentration
Depth Beneath Ground Surface

Abbreviations:
*Indicates compound detected but concentration not quantified
ex. 30*

Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-7
DETECTED CONCENTRATIONS OF 1, 1, 1 — TRICHLOROETHANE IN SOILS (μg/kg)



Legend.

Data are organized as shown below:

WP-MB-03
00) 11.4

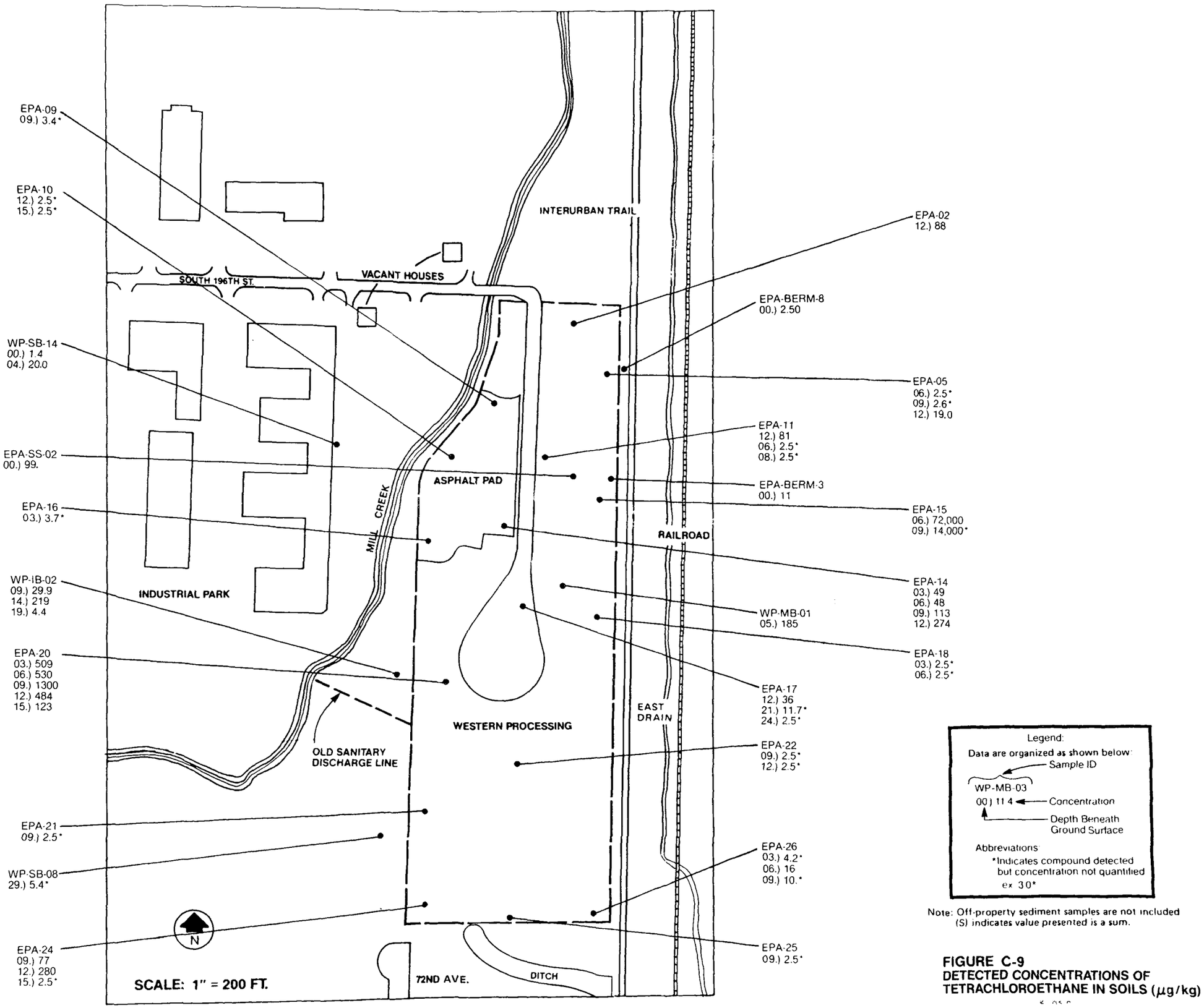
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations.

Indicates compound detected but concentration not quantified ex. 3.0

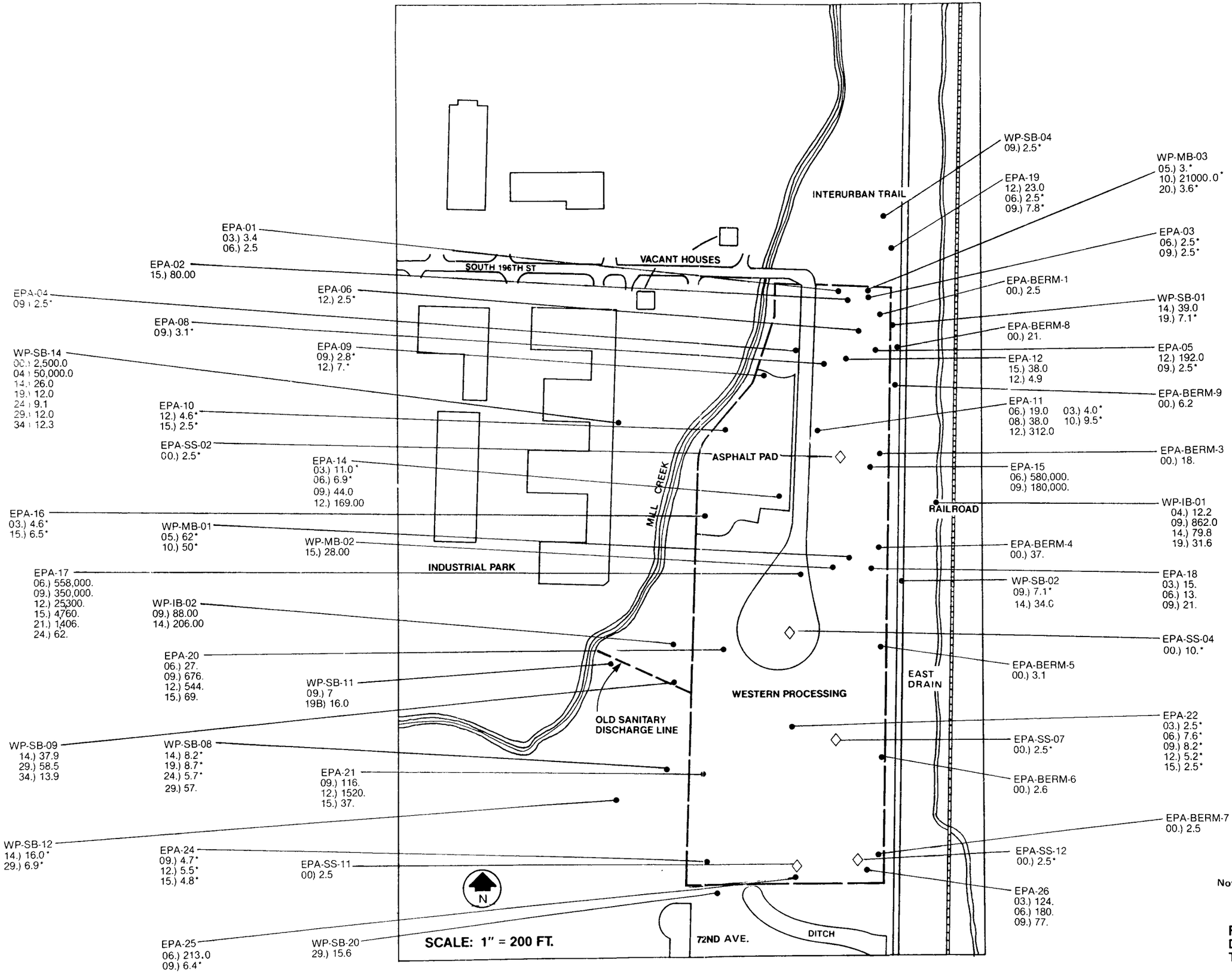
Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-8
DETECTED CONCENTRATIONS OF TRANS — 1, 2, DICHLOROETHENE IN SOILS (ug/kg)



Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-9
DETECTED CONCENTRATIONS OF TETRACHLOROETHANE IN SOILS (μg/kg)



Legend:

Data are organized as shown below:

WP-MB-03
00.) 11.4

- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations.

*Indicates compound detected but concentration not quantified
ex. 3.0*

Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-10
DETECTED CONCENTRATIONS OF TRICHLOROETHENE IN SOILS (μg/kg)

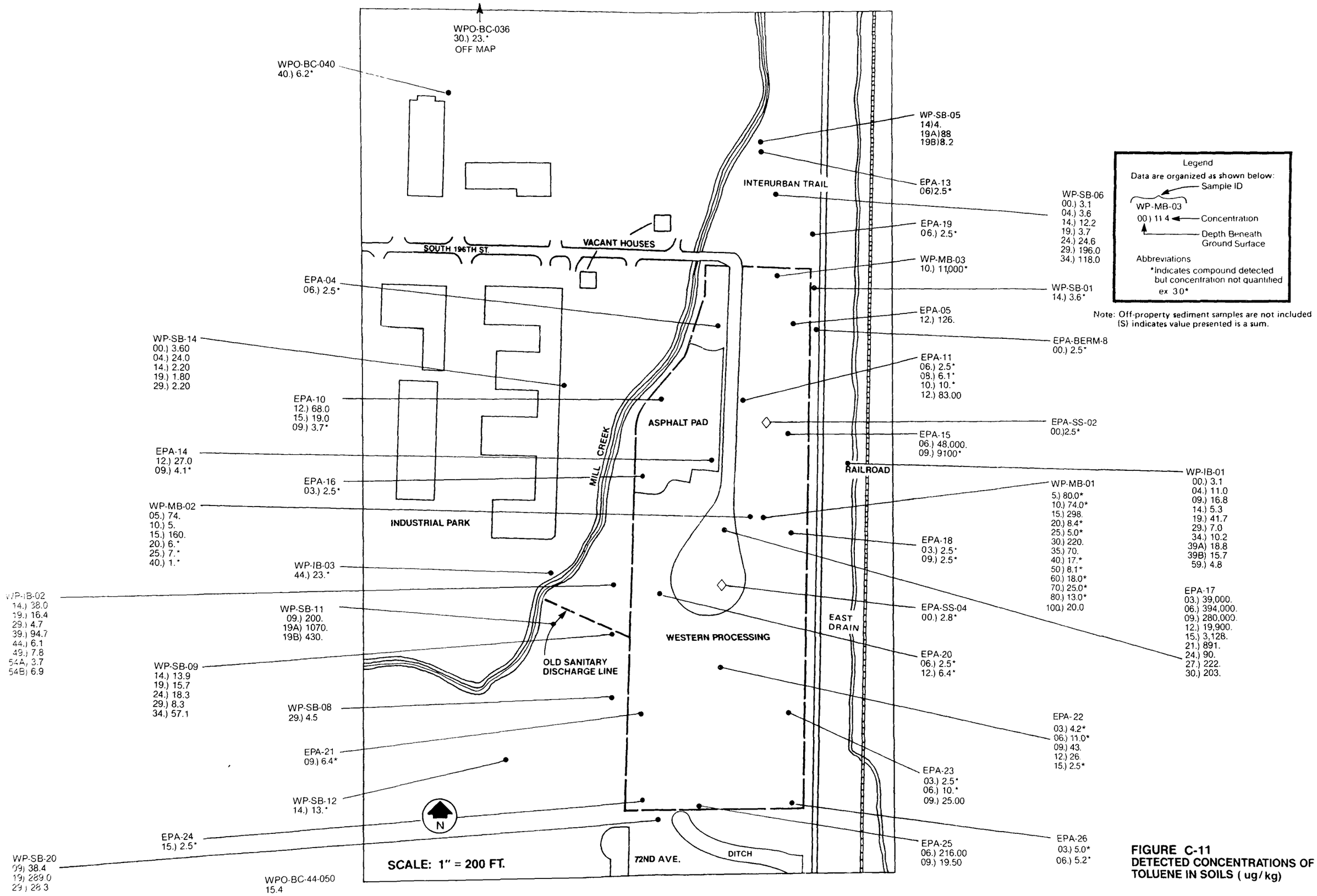
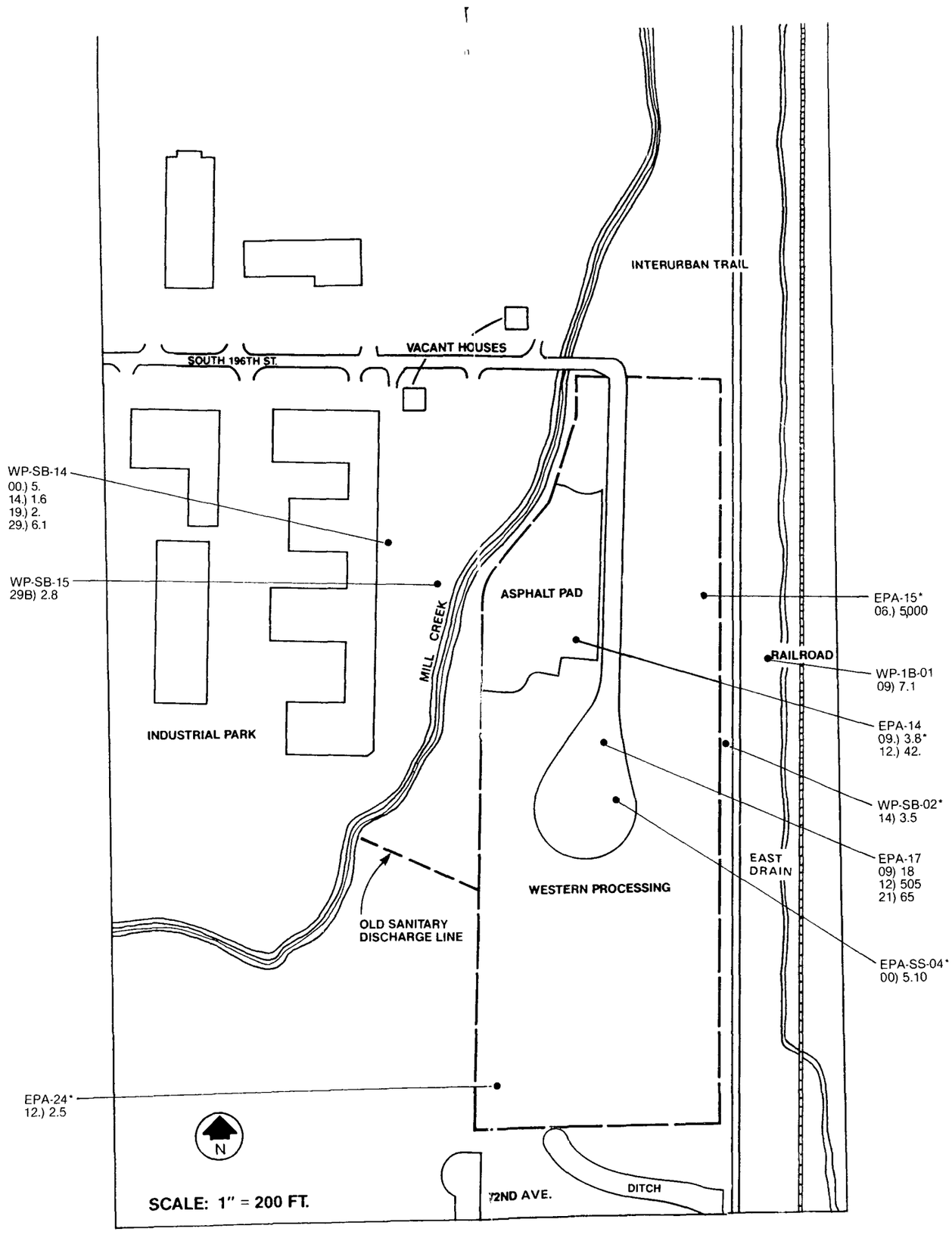


FIGURE C-11
DETECTED CONCENTRATIONS OF TOLUENE IN SOILS (ug/kg)



Legend

Data are organized as shown below.

WP-MB-03
00.) 11.4

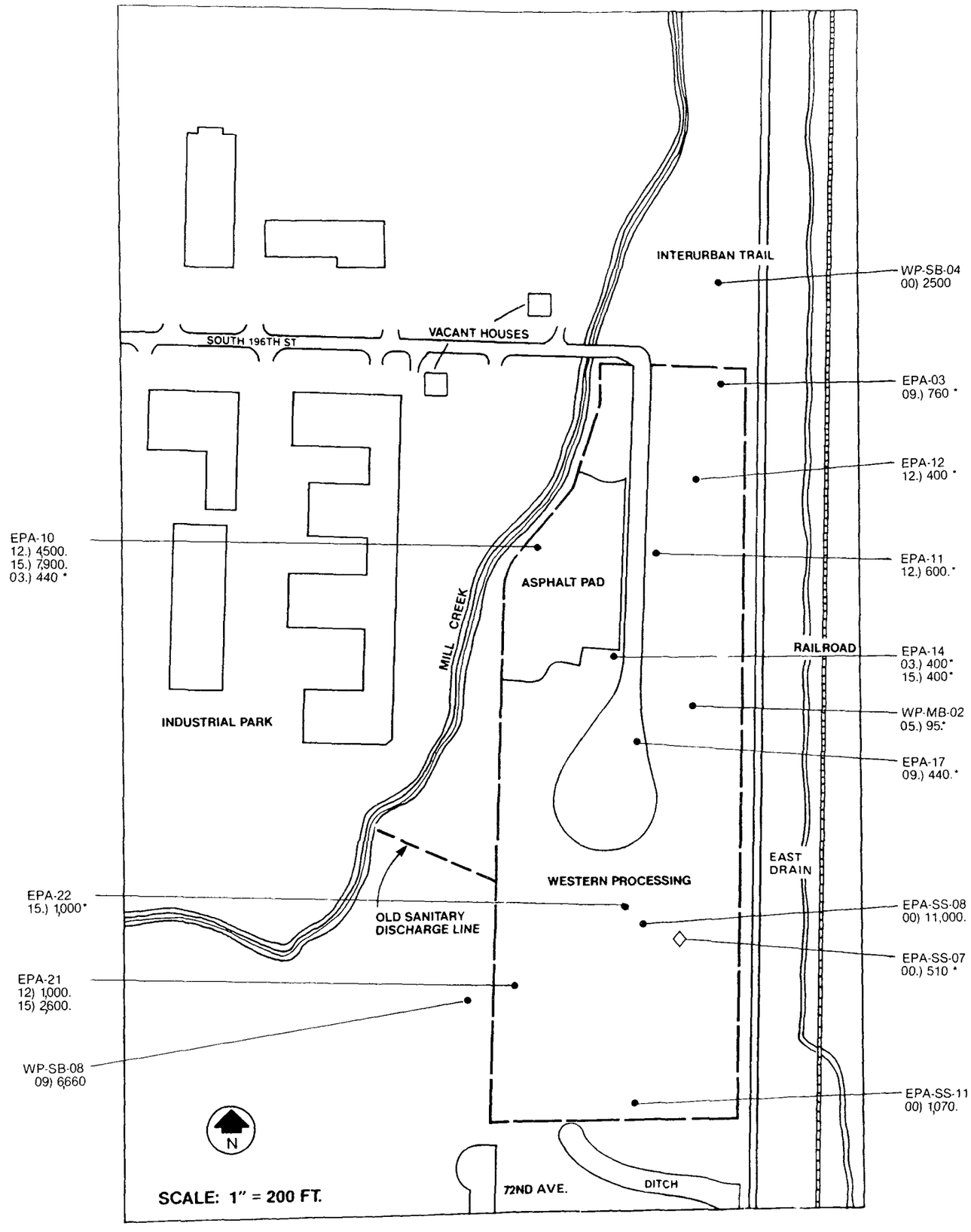
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations.

*Indicates compound detected but concentration not quantified
ex. 3.0*

Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-12
DETECTED CONCENTRATIONS OF CHLOROFORM IN SOILS (ug/kg)



Legend.

Data are organized as shown below:

WP-MB-03
00) 11.4

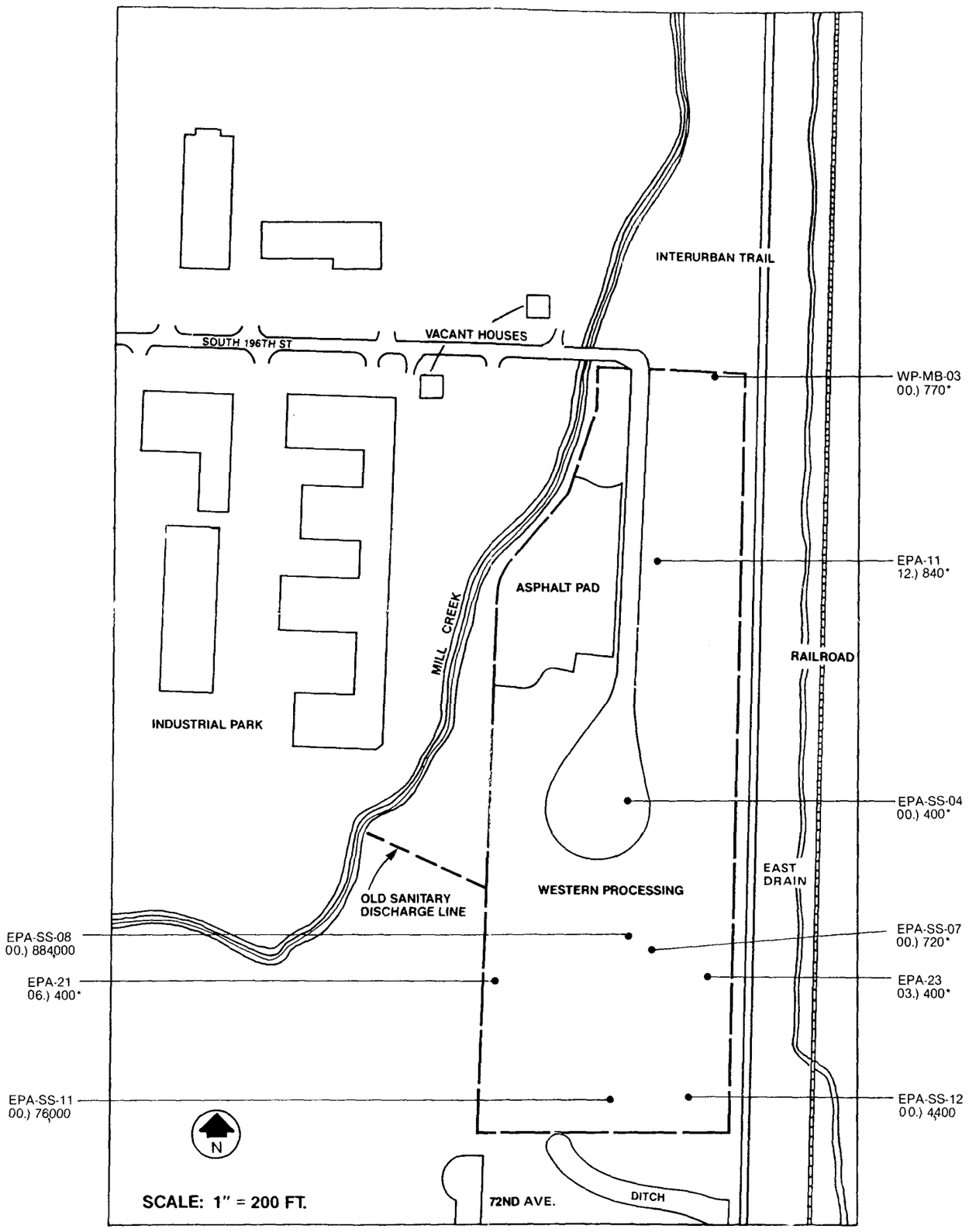
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations.

Indicates compound detected but concentration not quantified ex 3.0

Note: Off-property sediment samples are not included (S) indicates value presented is a sum.

FIGURE C-13
DETECTED CONCENTRATIONS OF 2,4 — DIMETHYLPHENOL IN SOILS (μg/kg)

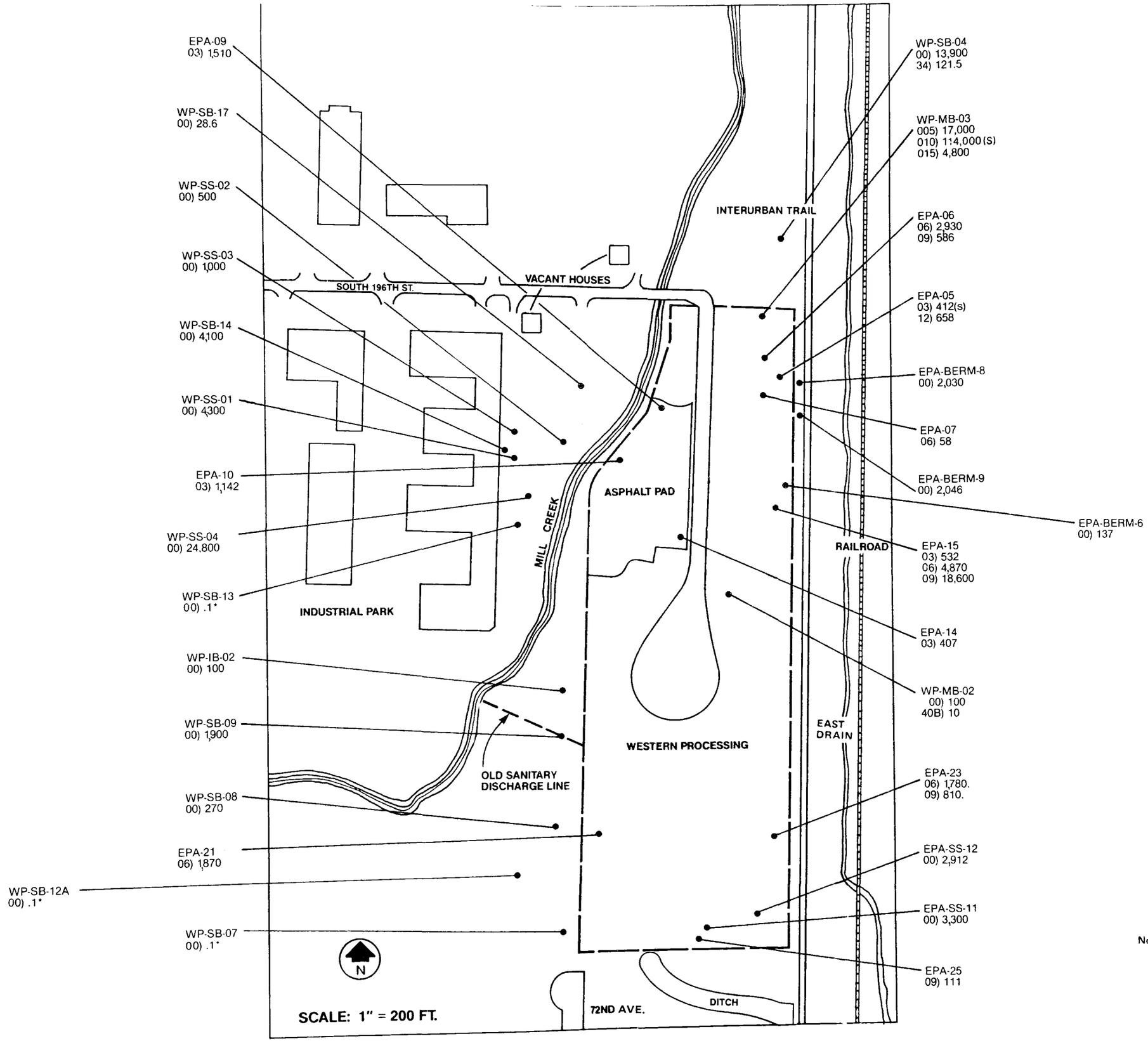


Legend.
Data are organized as shown below:
Sample ID
WP-MB-03
00) 11.4 ← Concentration
Depth Beneath Ground Surface

Abbreviations:
*Indicates compound detected but concentration not quantified
ex 30*

Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-14
DETECTED CONCENTRATIONS OF BENZO (A) ANTHRACENE IN SOILS (μg/kg)



Legend

Data are organized as shown below:

WP-MB-03
00) 11.4

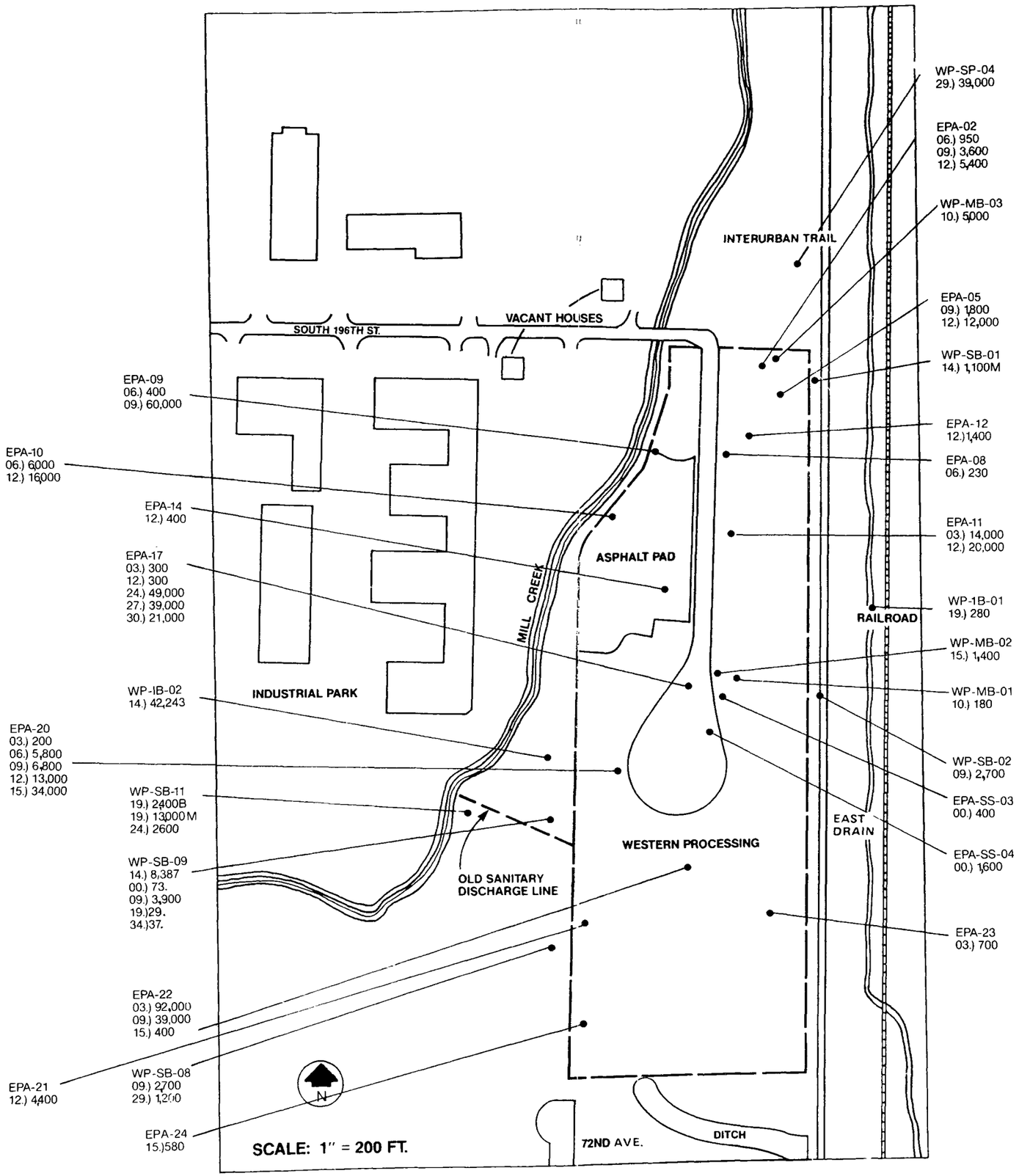
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations.

*Indicates compound detected but concentration not quantified
ex 3.0*

Note: Off-property sediment samples are not included
(S) indicates value presented is a sum.

FIGURE C-15
DETECTED CONCENTRATIONS OF TOTAL PCB'S IN SOILS (μg/kg)



Legend

Data are organized as shown below:

WP-MB-03
00) 11.4

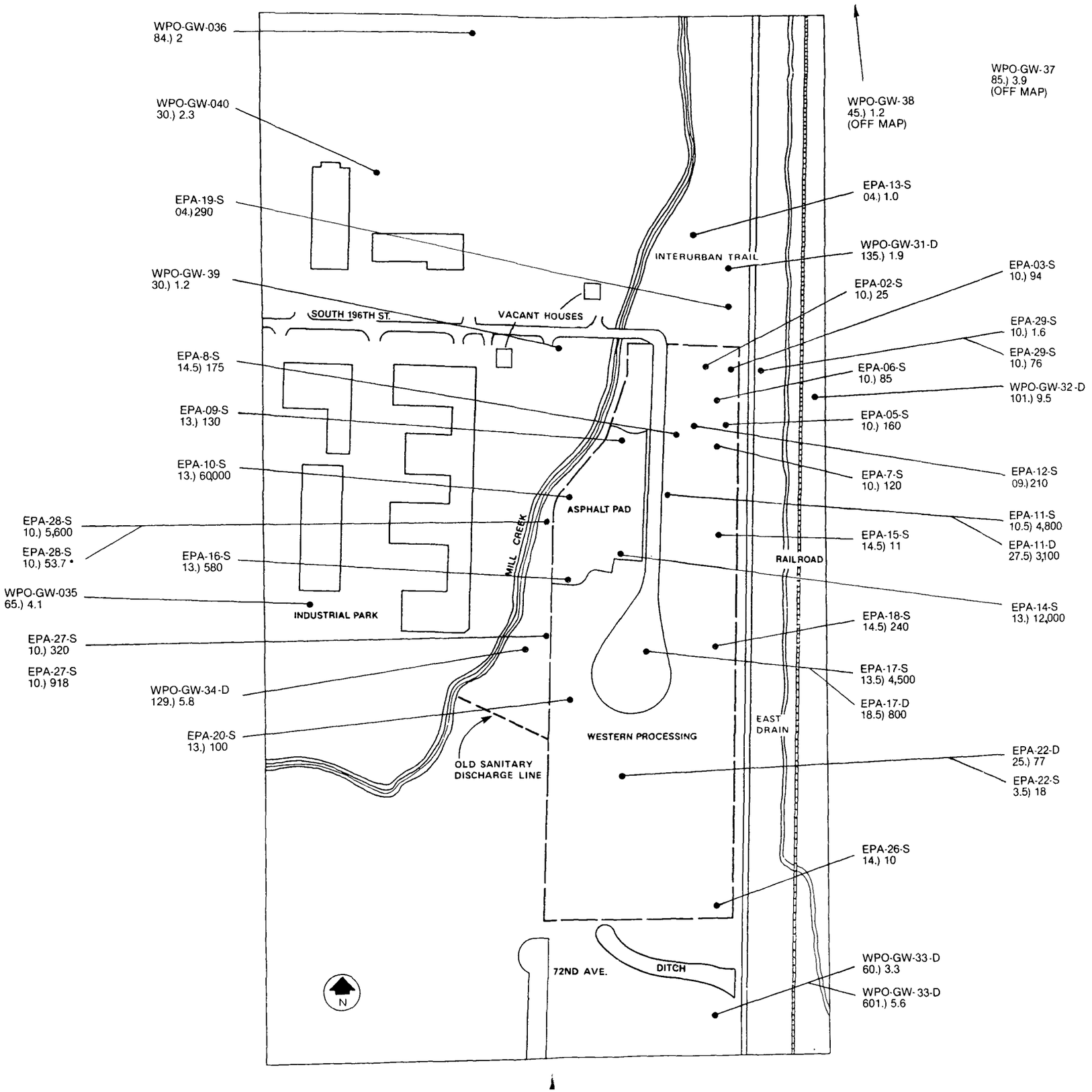
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations.

*Indicates compound detected but concentration not quantified
ex. 3.0*

Note: Off-property sediment samples are not include (S) indicates value presented is a sum.

FIGURE C-16
DETECTED CONCENTRATIONS OF OXAZOLIDONE IN SOILS (μg/kg)



Legend

Data are organized as shown below:

Sample ID

WP-MB-03

00.) 11 4 ← Concentration

Depth Beneath Ground Surface

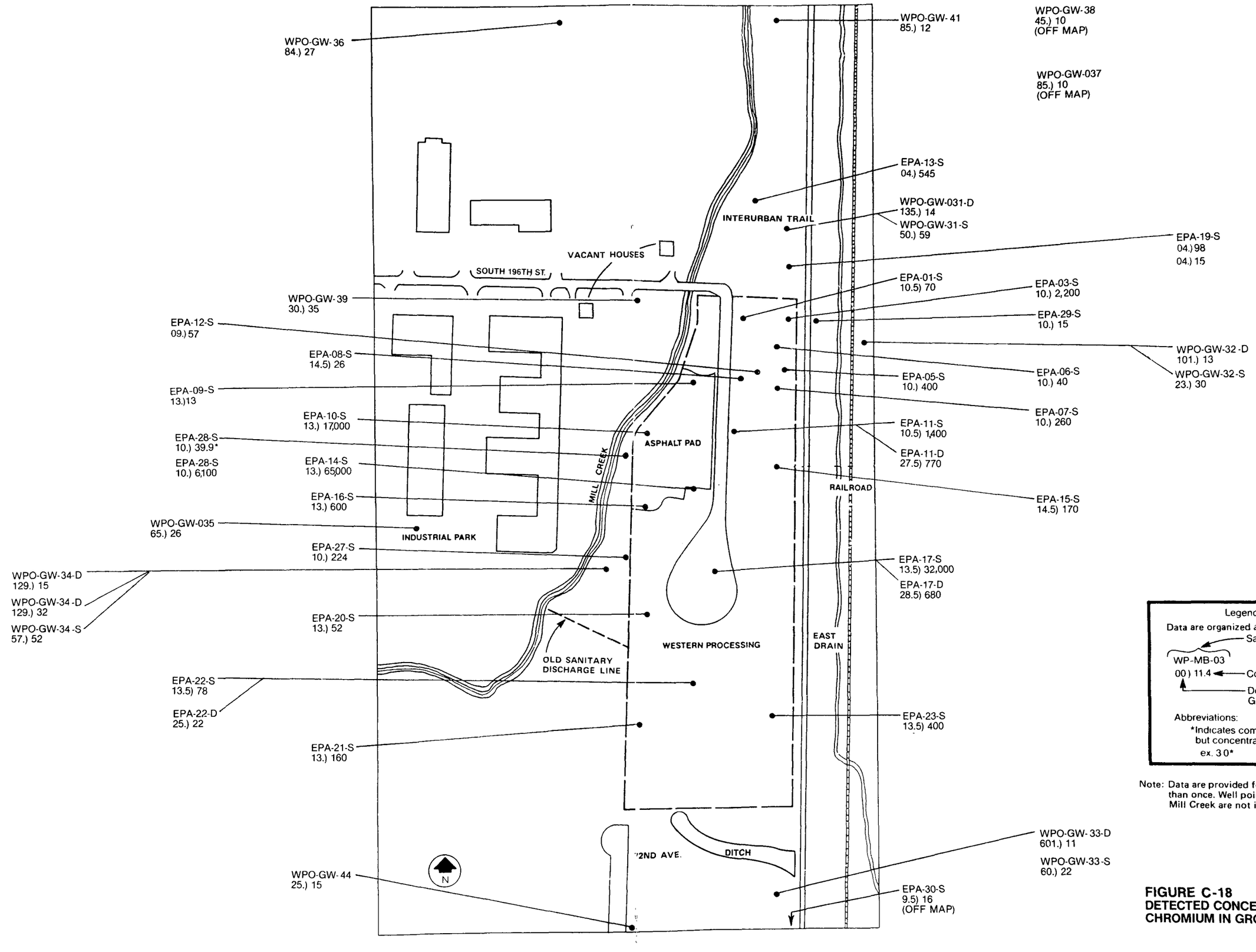
Abbreviations.

*Indicates compound detected but concentration not quantified

ex 3.0*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-17
DETECTED CONCENTRATIONS OF CADMIUM IN GROUNDWATER (µg/L)

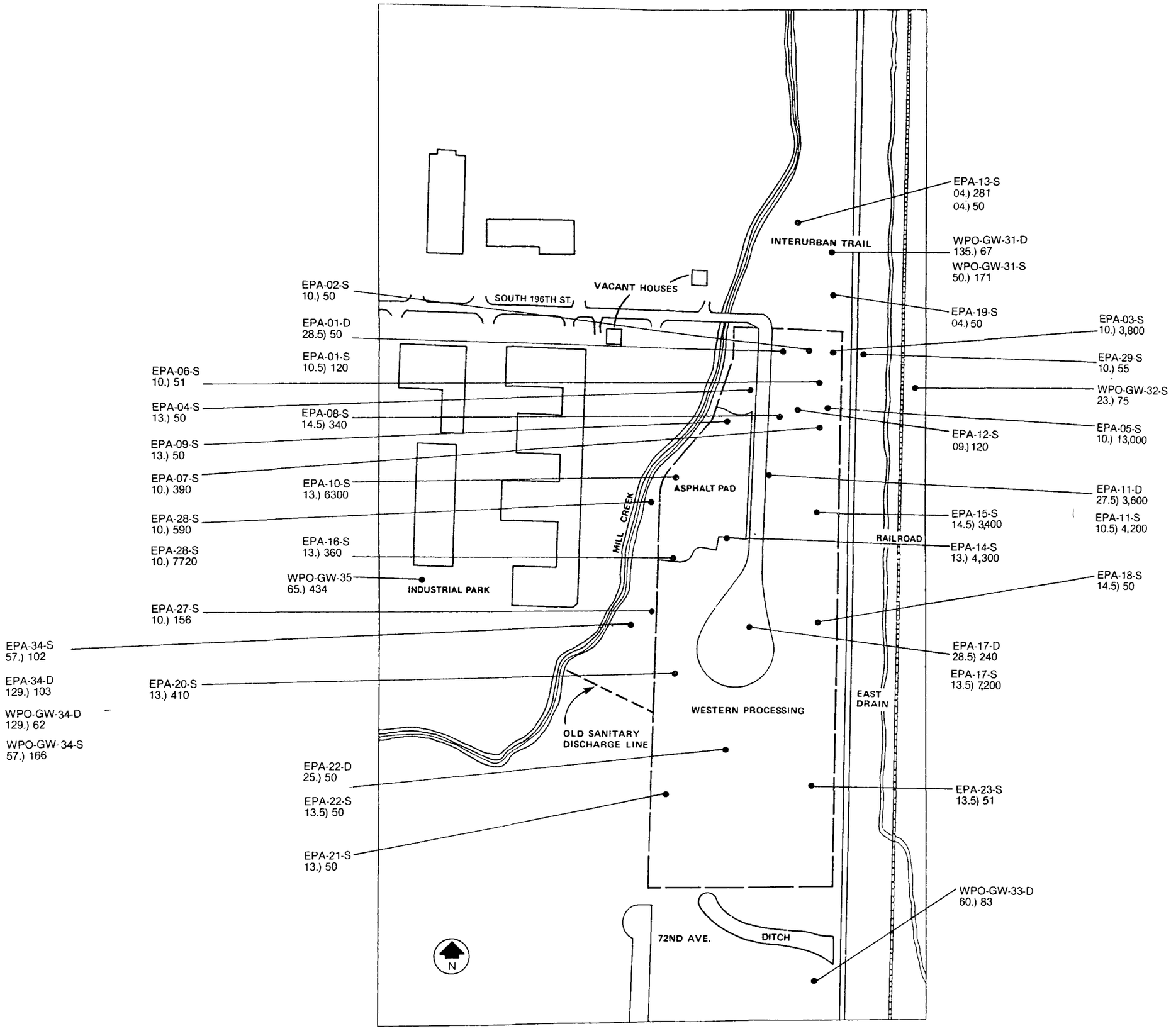


Legend:
Data are organized as shown below:
Sample ID
WP-MB-03
00) 11.4 ← Concentration
Depth Beneath Ground Surface

Abbreviations:
*Indicates compound detected but concentration not quantified
ex. 30*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-18
DETECTED CONCENTRATIONS OF CHROMIUM IN GROUNDWATER (µg/L)



Legend:

Data are organized as shown below:

Sample ID

WP-MB-03

00.) 11.4 ← Concentration

Depth Beneath Ground Surface

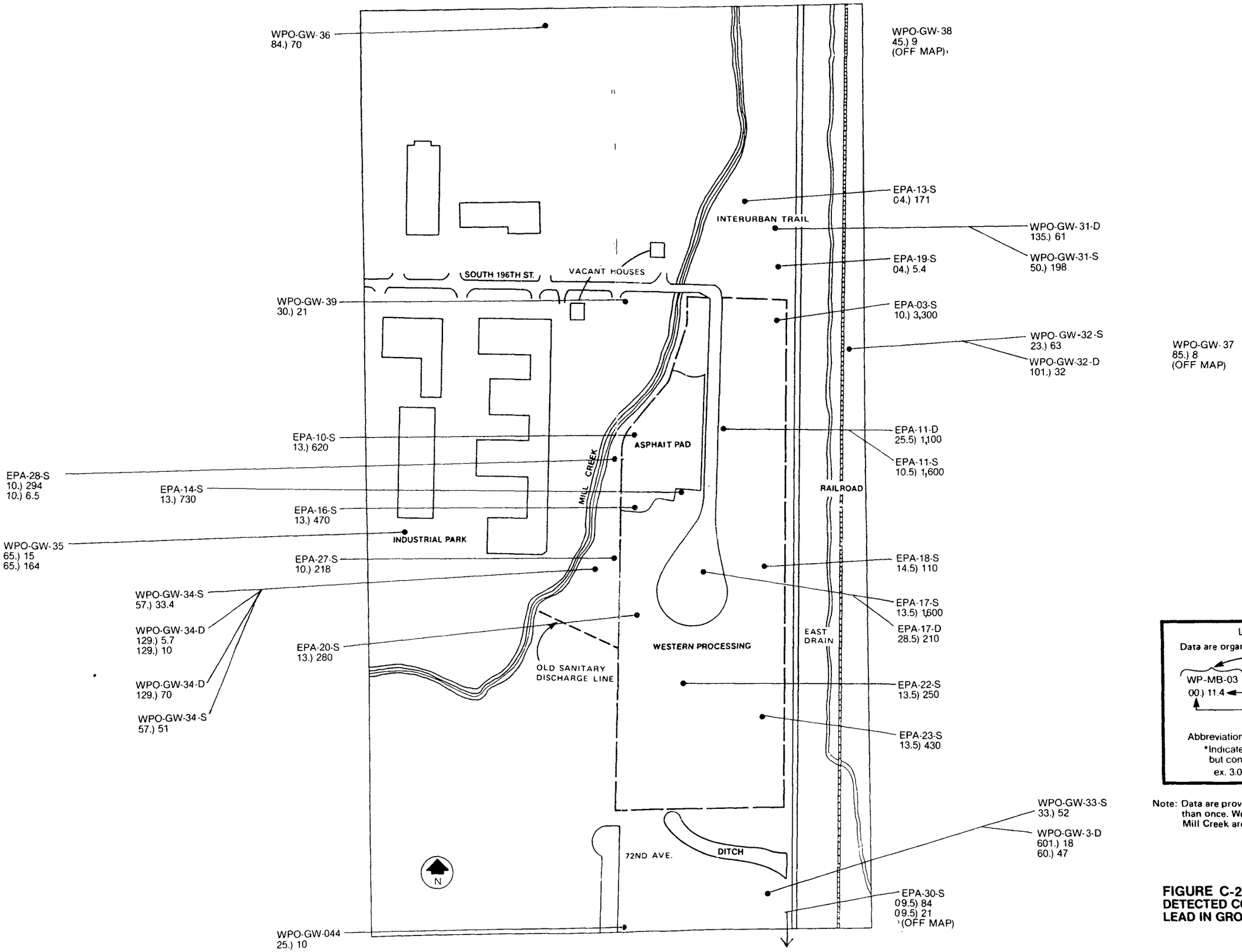
Abbreviations:

*Indicates compound detected but concentration not quantified

ex. 30*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-19
DETECTED CONCENTRATIONS OF COPPER IN GROUNDWATER (µg/L)

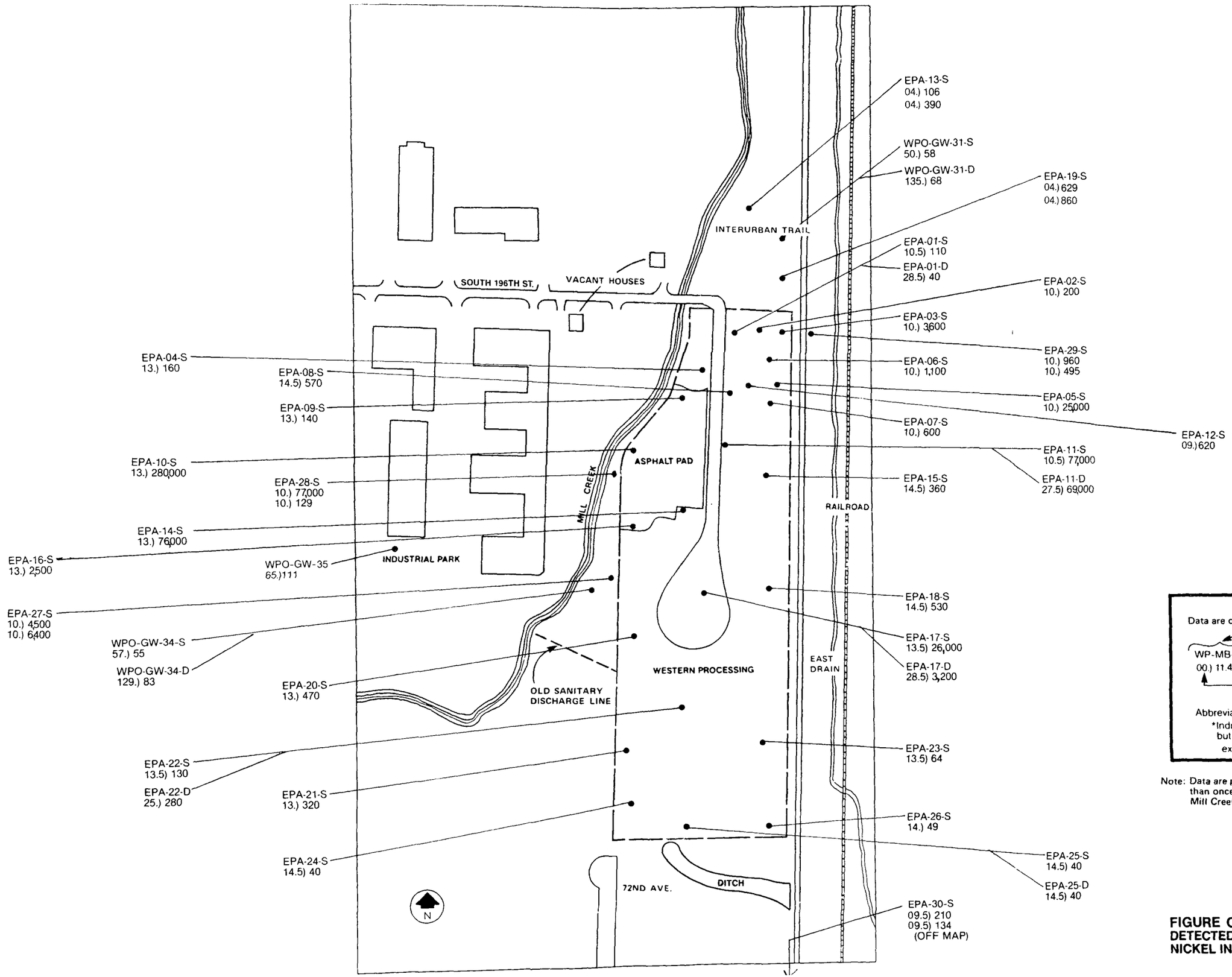


Legend:
Data are organized as shown below:
Sample ID
WP-MB-03
00.) 11.4 ← Concentration
Depth Beneath Ground Surface

Abbreviations.
*Indicates compound detected but concentration not quantified
ex. 3.0*

Note: Data are provided for wells sampled mor than once. Well point samples taken in Mill Creek are not included.

FIGURE C-20
DETECTED CONCENTRATIONS OF LEAD IN GROUNDWATER (µg/L)



Legend:

Data are organized as shown below:

WP-MB-03
00.) 11.4

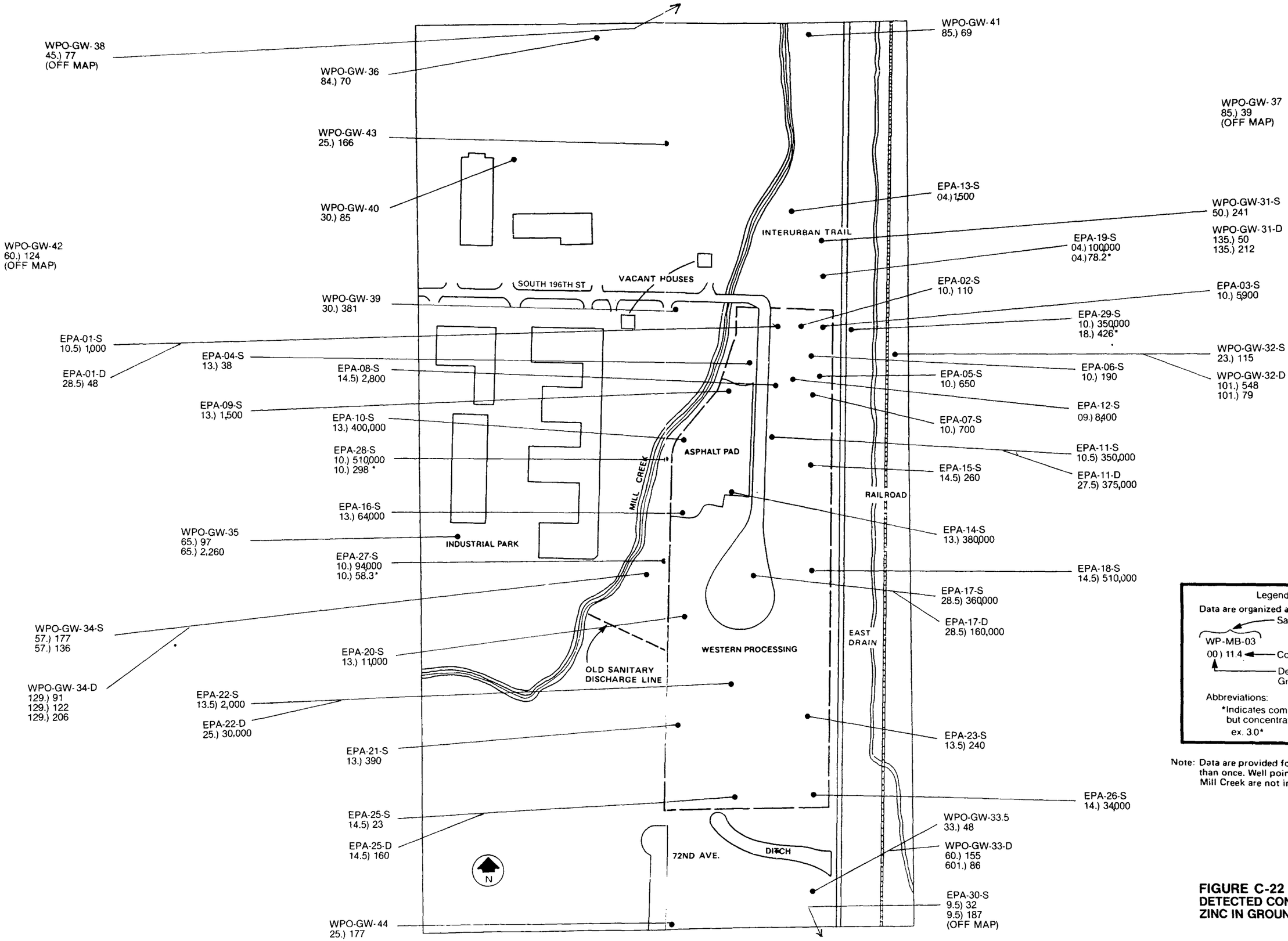
- WP-MB-03: Sample ID
- 00.): Depth Beneath Ground Surface
- 11.4: Concentration

Abbreviations:

*Indicates compound detected but concentration not quantified
ex. 30*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-21
DETECTED CONCENTRATIONS OF NICKEL IN GROUNDWATER (µg/L)



Legend.

Data are organized as shown below:

WP-MB-03
00) 11.4

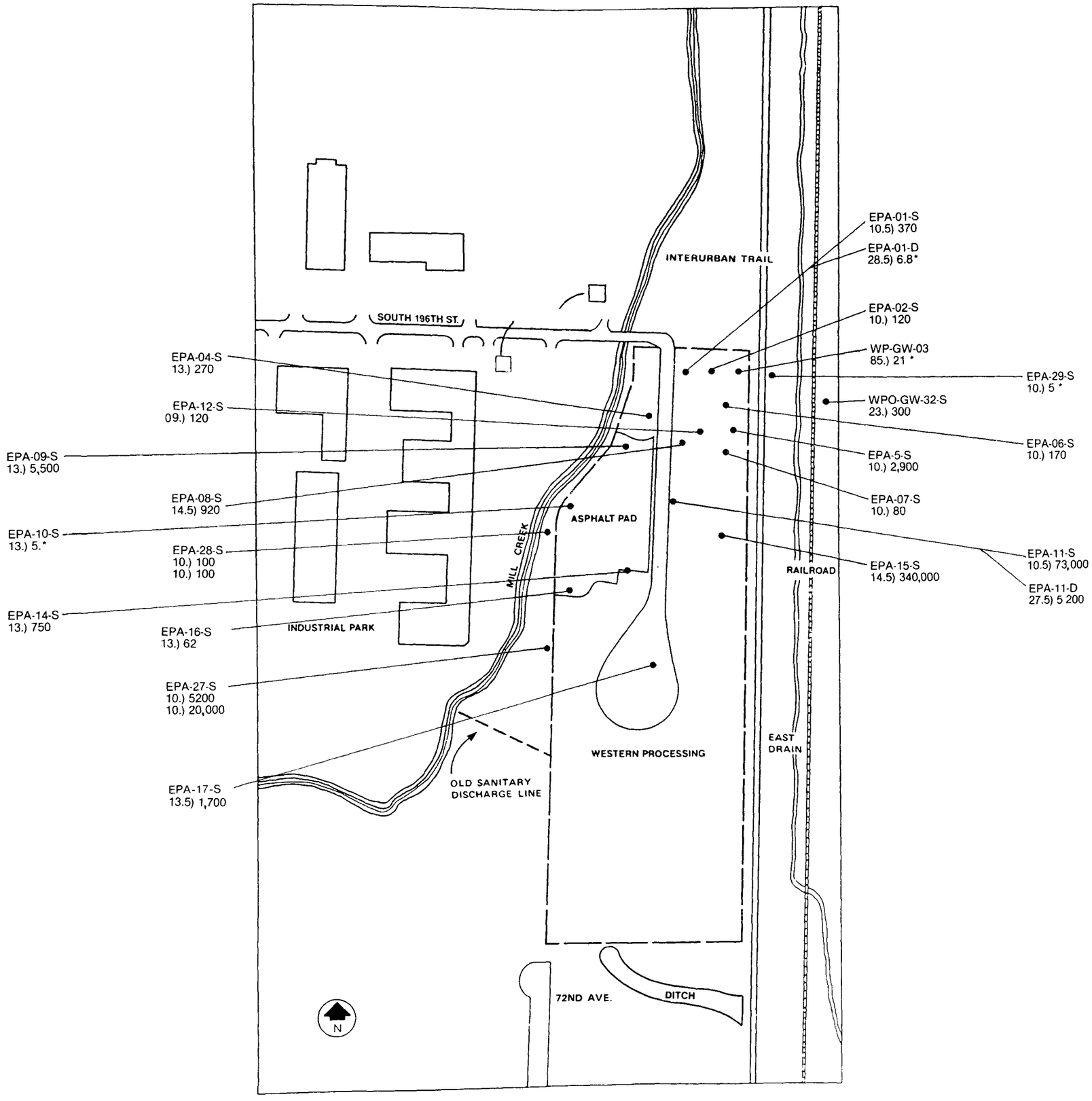
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations:

*Indicates compound detected but concentration not quantified
ex. 3.0*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-22
DETECTED CONCENTRATIONS OF ZINC IN GROUNDWATER (µg/L)

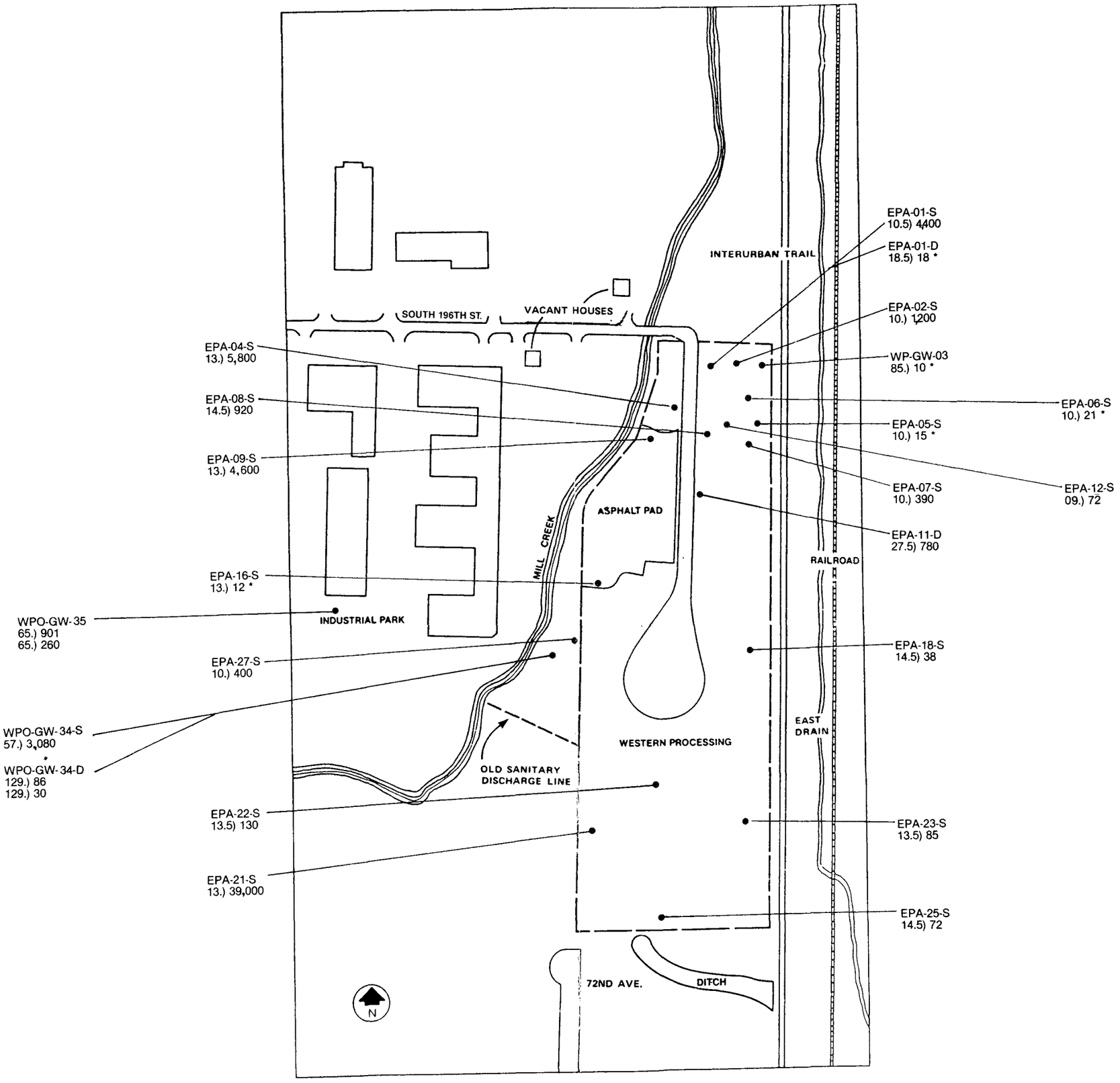


Legend.
Data are organized as shown below:
Sample ID
WP-MB-03
00) 11 4 ← Concentration
Depth Beneath Ground Surface

Abbreviations
*Indicates compound detected but concentration not quantified
ex 3.0*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-23
DETECTED CONCENTRATIONS OF 1, 1, 1, — TRICHLOROETHANE IN GROUNDWATER (µg/L)

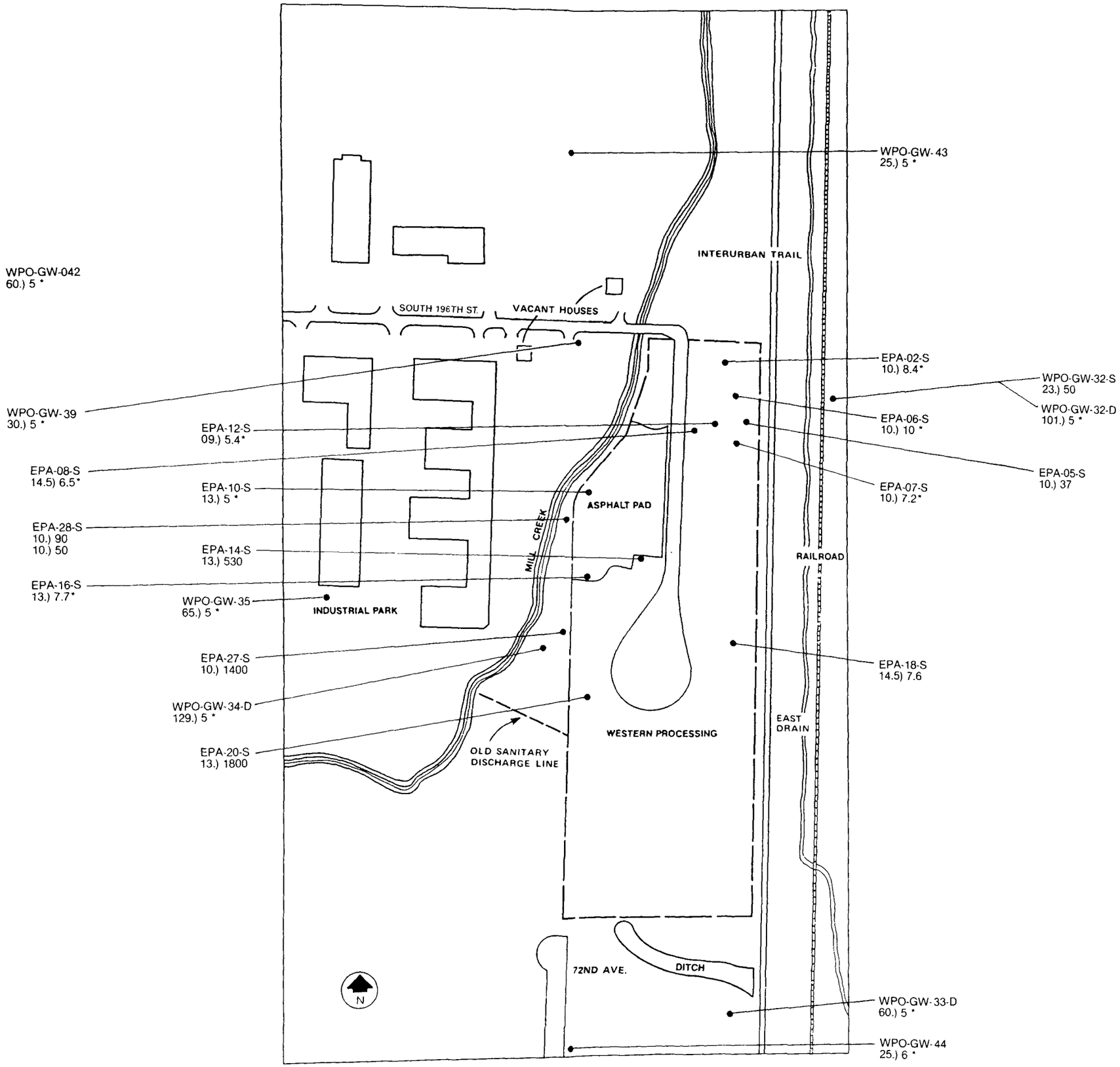


Legend:
Data are organized as shown below:
Sample ID
WP-MB-03
00.) 11.4 ← Concentration
Depth Beneath Ground Surface

Abbreviations:
*Indicates compound detected but concentration not quantified
ex. 3.0*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-24
DETECTED CONCENTRATIONS OF TRANS — 1, 2, DICHLOROETHENE IN GROUNDWATER (µg/L)



Legend:

Data are organized as shown below:

Sample ID

WP-MB-03

00.) 11.4 ← Concentration

Depth Beneath Ground Surface

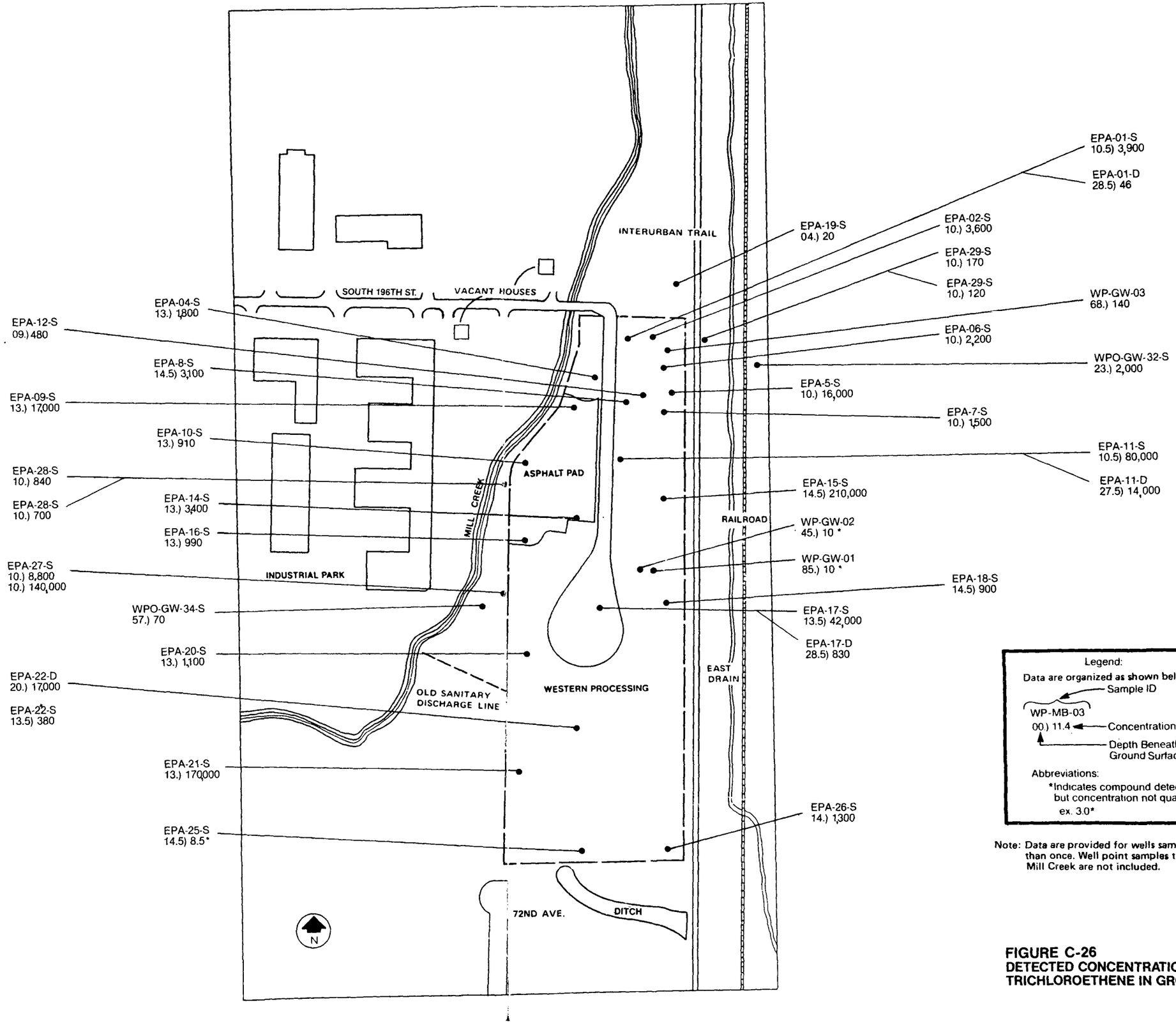
Abbreviations:

*Indicates compound detected but concentration not quantified

ex. 30*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-25
DETECTED CONCENTRATIONS OF TETRACHLOROETHENE IN GROUNDWATER (µg/L)



Legend:

Data are organized as shown below:

Sample ID

WP-MB-03

00.) 11.4 ← Concentration

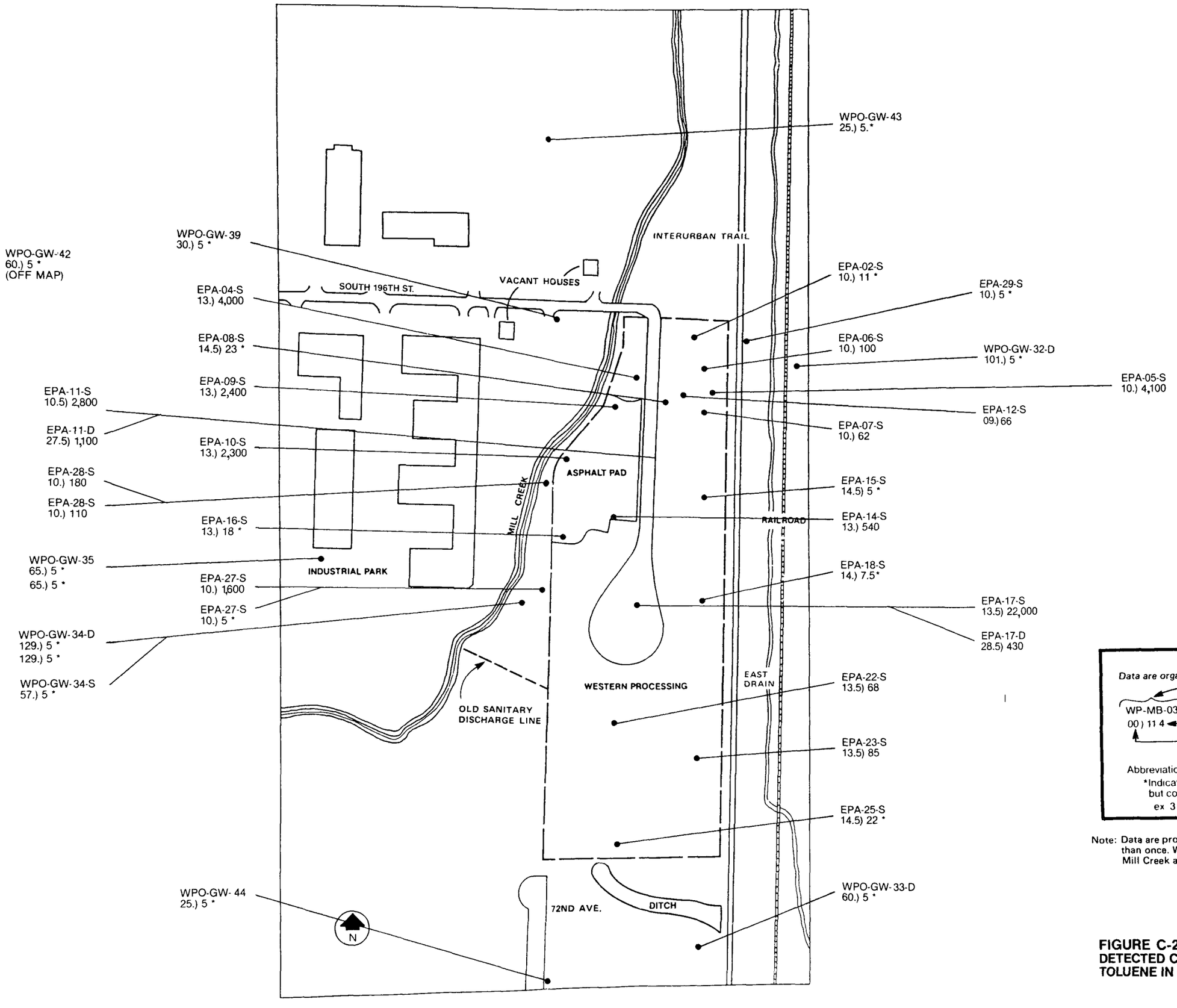
Depth Beneath Ground Surface

Abbreviations:

Indicates compound detected but concentration not quantified ex. 3.0

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-26
DETECTED CONCENTRATIONS OF TRICHLOROETHENE IN GROUNDWATER (µg/L)



Legend:

Data are organized as shown below:

WP-MB-03
00) 11 4

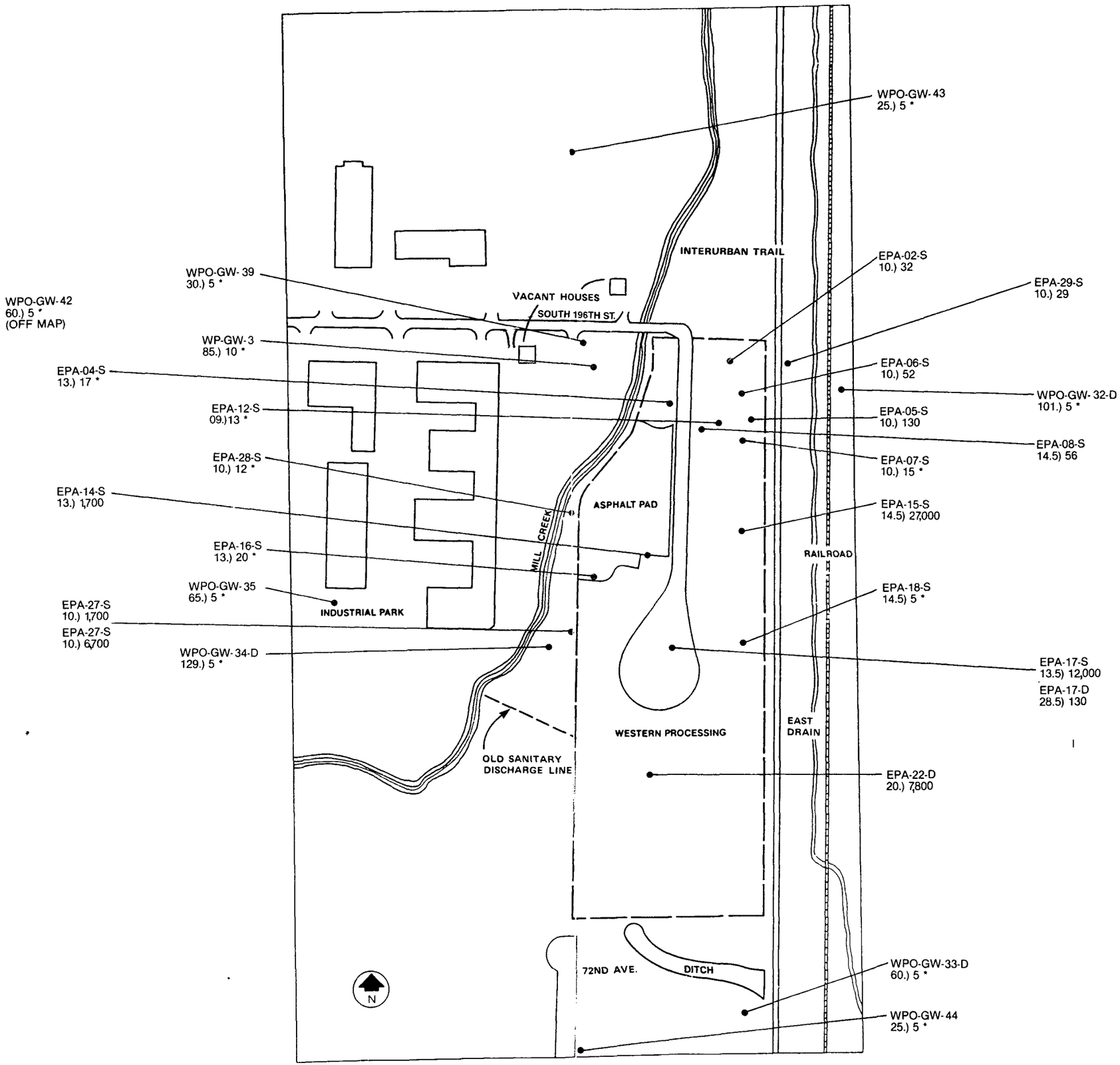
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations.

*Indicates compound detected but concentration not quantified
ex 30*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-27
DETECTED CONCENTRATIONS OF TOLUENE IN GROUNDWATER (µg/L)



Legend:

Data are organized as shown below:

WP-MB-03
00.) 11.4

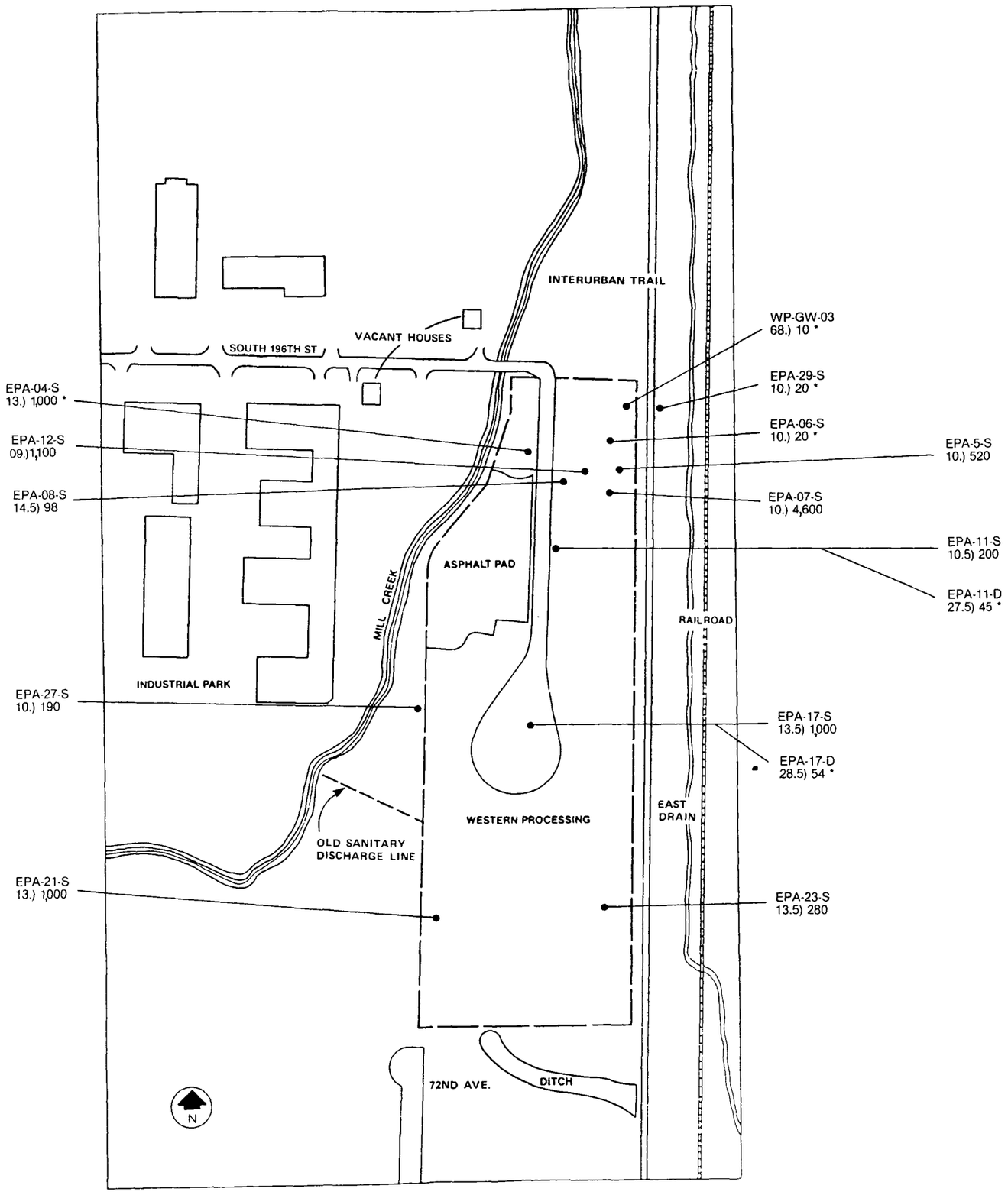
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations:

*Indicates compound detected but concentration not quantified
ex. 3.0*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-28
DETECTED CONCENTRATIONS OF CHLOROFORM IN GROUNDWATER (µg/L)



Legend:

Data are organized as shown below:

WP-MB-03
00.) 11.4

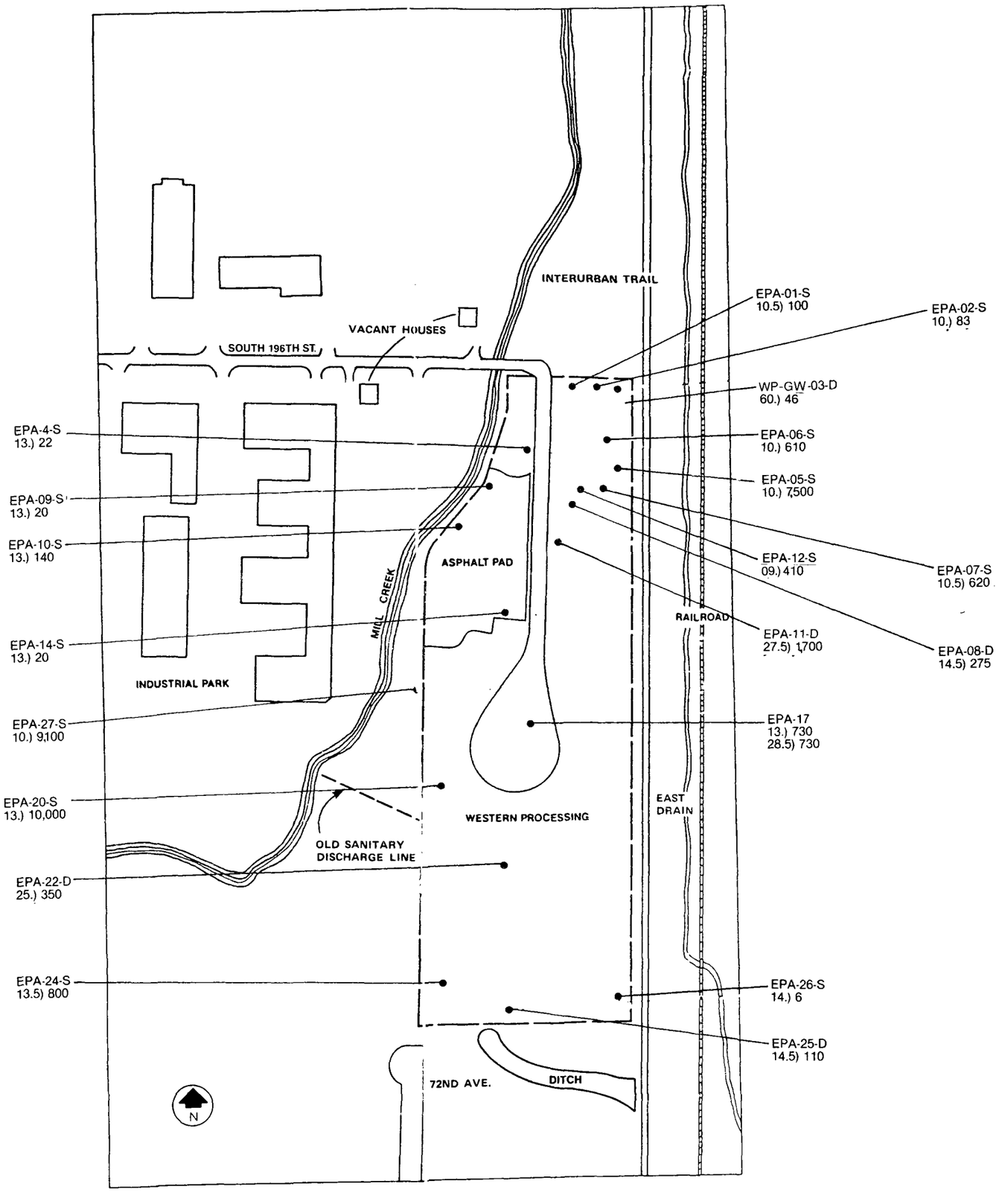
- Sample ID
- Concentration
- Depth Beneath Ground Surface

Abbreviations:

*Indicates compound detected but concentration not quantified
ex 30*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-29
DETECTED CONCENTRATIONS OF 2,4 — DIMETHYLPHENOL IN GROUNDWATER (µg/L)



Legend:
Data are organized as shown below:
Sample ID
WP-MB-03
00.) 11.4 ← Concentration
Depth Beneath Ground Surface

Abbreviations:
*Indicates compound detected but concentration not quantified
ex. 3.0*

Note: Data are provided for wells sampled more than once. Well point samples taken in Mill Creek are not included.

FIGURE C-30
DETECTED CONCENTRATIONS OF OXAZOLIDONE IN GROUNDWATER (µg/L) g/

Appendix D: Environmental Migration and Fate of Indicator Chemicals

Appendix D
ENVIRONMENTAL MIGRATION AND FATE OF INDICATOR CHEMICALS

This appendix contains migration and fate profiles that outline the general environmental behavior of the 17 indicator parameters discussed in Chapters 2 and 3. Given the nature of the contamination at Western Processing, their behavior in soils, groundwater, and aquatic systems is emphasized. The behavior of each chemical is discussed in terms of its mobility, or rate of movement relative to that of water, and its persistence, or the length of time the chemical may exist in the environment. Mobility is important because it determines the rate of chemical migration away from a site. Persistence is important because it determines if a chemical will remain in the environment long enough to reach a receptor.

Potential interactions between chemicals are given only minor consideration in constructing the migration and fate profiles. The effect of organic complexation and competing ions on metal mobility is discussed briefly. Other potential interactions (e.g., co-solvent effects and transformation byproduct formation) are not considered. The impact of these interactions on chemical mobility and persistence at Western Processing is uncertain. However, it should be recognized that important interactions may occur.

Table D-1 lists some of the key physical-chemical properties of each organic indicator chemical. The properties of oxazolidone are not included due to a lack of literature data. The properties of the metal indicators are not included because they are not as relevant in determining their environmental behavior. In addition, properties like solubility can vary significantly depending upon a number of factors, including pH, metal concentration, oxidation-reduction potential, soil type, and the presence of competing and complexing ions. With the exception of the data for PCB's, Callahan et al. (1979) were the source of the information in Table D-1. Mackay et al. (1983) were consulted to obtain the physical properties for PCB's. The properties in Table D-1 do not reflect any potential interactions between chemicals.

Tables D-2 and D-3 provide summaries of the environmental behavior of the indicator organic compounds and metals, respectively. Summaries are provided for three key sectors of the environment: subsurface soils and groundwater, surface soils, and aquatic systems. Potential transformation and transfer mechanisms are listed for each indicator chemical. Transformation mechanisms act to change the form of a chemical, while transfer mechanisms partition the chemical between media (e.g., volatilization is a water-air transfer; sorption

Table D-1
PHYSICAL-CHEMICAL PROPERTIES OF INDICATOR ORGANICS

	Molecular Weight	Boiling Point (°C)[a]	Vapor Pressure (torr)[b]	Solubility (mg/L)	Log Kow[c]
Volatile Organics					
1,1,1-trichloroethane	133.41	74.1	97.0[d]	480-4,400[d]	2.17
Trans-1,2-dichloroethene	96.94	47.5	200.0[e]	600[d]	1.48
Tetrachloroethene	165.83	121.0	14.0[d]	150-200	2.88
Trichloroethene	131.39	87.0	57.9[d]	1,100[f]	2.29
Toluene	92.13	110.6	28.7[d]	535[f]	2.69
Chloroform	119.38	61.7	150.5[d]	8,200[f]	1.97
Acid Compounds					
2,4-dimethylphenol	122.16	210.93	0.0621[d]	4,200[d]	2.50
Base/Neutral Compounds					
Benzo(a)anthracene	288.28	--	5×10^{-9}	0.014-0.009	5.61
Other Organics					
PCB[g]	189-499	558-729	1.7×10^{-2}-3×10^{-7}	7.2-2 x 10^{-4}	4.66-9.60

[a] Boiling point at 760 torr.

[b] torr = 1 mm of mercury (Hg).

[c] Kow octanol-water partition coefficient.

[d] Vapor pressure/solubility at 20°C.

[e] Vapor pressure at 14°C.

[f] Vapor pressure/solubility at 25°C.

[g] Ranges from Mackay et al. (1983).

is a water-soil transfer). The persistence of a chemical in a given sector of the environment is generally controlled by transformation mechanisms and volatilization. Chemical mobility in a given sector is mainly controlled by sorption. Both tables list if the mechanism has a significant (S), insignificant (I), or moderate (M) impact on behavior. In cases where the significance is uncertain or dependent on environmental conditions, the mechanism is denoted as possible (P).

Generic environmental behavior profiles are provided below for each indicator chemical. This appendix concludes with a brief discussion of how these chemicals are likely to behave at the Western Processing site.

Table D-2
SUMMARY OF ENVIRONMENTAL BEHAVIOR OF INDICATOR ORGANIC COMPOUNDS IN SUBSURFACE SOILS, GROUNDWATER, SURFACE SOILS AND AQUATIC SYSTEMS

	Subsurface Soils and Groundwater				Surface Soils					
	Transformation			Transfer	Transformation				Transfer	
Compound	Oxidation	Hydrolysis	Biodegradation	Sorption	Oxidation	Hydrolysis	Photolysis	Biodegradation	Volatilization	Sorption
1,1,1,Trichloroethane	I	6 mos.	P[a]	I	I	P	I	I	S	I
Trans-1,2-Dichloro-ethene	P[b]	I	P[a]	I	P	I	I	I	S	I
Tetrachloroethene	8.8 mos.	I	P[a]	I	P	I	I	I	S	I
Trichloroethene	10.7 mos.	I	P[a]	I	P	I	I	I	S	I
Toluene	I	I	P[b]	I	P	I	P	P[b]	S	I
Chloroform	I	1-3,500 yrs.	P[c]	I	I	P	I	P[a]	S	I
2,4-Dimethylphenol	I	I	P	M	P	I	P	P	I	M
Benzo(a)anthracene	I	I	P	S	P	I	P	P	I	S
Polychlorinated Biphenyls	I	I	Days-Mos.[b,e]	S	I	I	P[e]	Days-Mos.[e]	Mos.-Yrs.	S
Oxazolidone	-	-	P	-	-	-	-	P	-	-

[a] Under anaerobic conditions.
[b] Under aerobic conditions.
[c] Clear, well aerated systems.
[d] Waters high in iron and copper.
[e] Depends on degree of chlorination.

Notes: S = Significant
I = Insignificant
M = Moderate
P = Possible

Table D-2
(continued)

Compound	Aquatic Systems					
	Transformation				Transfer	
	Oxidation	Hydrolysis	Photolysis	Biodegradation	Volatilization	Sorption
1,1,1,Trichloroethane	I	6 mos.	I	P[a]	Min.-Hrs.	I
Trans-1,2-Dichloro-ethene	P	I	I	P[a]	Min.-Hrs.	I
Tetrachloroethene	8.8 mos.	I	I	P[a]	Min.-Hrs.	I
Trichloroethene	10.7 mos.	I	I	P[a]	Min.-Days	I
Toluene	P	I	P	P[b]	Hrs	I
Chloroform	I	1-3,500 yrs.	I	P	Min.-Hrs.	I
2,4-Dimethylphenol	P[d]	I	P[c]	P	I	M
Benzo(a)anthracene	38 hrs.	I	10-50 hrs	P	90 hrs.	S
Polychlorinated Biphenyls	I	I	P[e]	Days-Mos.[b,e]	Mos.-Yrs.	S
Oxazolidone	-	-	-	P	-	-

[a] Under anaerobic conditions.
[b] Under aerobic conditions.
[c] Clear, well aerated systems.
[d] Waters high in iron and copper.
[e] Depends on degree of chlorination.

Notes: S = Significant
I = Insignificant
M = Moderate
P = Possible

Table D-3
SUMMARY OF ENVIRONMENTAL BEHAVIOR OF INDICATOR METALS IN
SUBSURFACE SOILS, GROUNDWATER, SURFACE SOILS, AND AQUATIC SYSTEMS

	Subsurface Soils and Groundwater			Surface Soils				Aquatic Systems			
	Transformation		Transfer	Transformation		Transfer		Transformation		Transfer	
Compound	Oxidation-Reduction	Biotransformation	Sorption	Oxidation-Reduction	Biotransformation	Volatilization	Sorption	Oxidation-Reduction	Biotransformation	Volatilization	Sorption
Arsenic	S	P	S	S	P	P	S	S	P	P	S
Cadmium	I	I	S	I	I	I	S	I	I	I	S
Chromium	S	I	S	S	I	I	S	S	I	I	S
Copper	S	I	S	I	I	I	S	I	I	I	S
Nickel	I	I	S	I	I	I	S	I	I	I	S
Lead	I	P	S	I	P	P	S	I	P	P	S
Zinc	I	I	S	I	I	I	S	I	I	I	S

S = Significant
I = Insignificant
P = Possible

1,1,1-TRICHLOROETHANE

The behavior of 1,1,1-trichloroethane is largely controlled by its high vapor pressure. 1,1,1-trichloroethane will not persist in surface soils and aquatic systems because of its tendency to volatilize. Callahan et al. (1979) give an aquatic volatilization half-life on the order of several minutes to a few hours, depending upon the degree of agitation. Once in the atmosphere, 1,1,1-trichloroethane will tend to slowly degrade via photo-oxidation, with a reported half-life ranging from 1.1 to 8 years (Callahan et al., 1979).

Oxidation and hydrolysis of 1,1,1-trichloroethane in soils and aquatic systems proceed at rates that are slow relative to volatilization. The maximum reported half-life for hydrolysis is 6 months; the half-life for oxidation is unknown, but is reported to be very slow (Callahan et al., 1979). Thus, these fate mechanisms are insignificant in aquatic systems. Photodissociation in water or air is not expected to occur (Jaffe and Orchin, 1962).

Based on its octanol-water partition coefficient, sorption of 1,1,1-trichloroethane is expected to be limited. Dawson et al. (1980) state that sorption of 1,1,1-trichloroethane will be proportional to the organic content of soils and surface area of clays. Thus, its mobility in aquatic systems will be controlled mainly by the rate of water movement rather than sediment movement.

The persistence of 1,1,1-trichloroethane in subsurface soils and groundwater will be controlled by hydrolysis. Biodegradation has been found to occur, but usually under anaerobic conditions as a result of reductive dehalogenation (Bouwer and McCarty, 1983). Thus, biodegradation will not be important in aerated subsurface soils and groundwater. The rate of biodegradation is difficult to estimate on a site-specific basis.

The mobility of 1,1,-trichloroethane in subsurface soils and groundwater will be high because it has little tendency for sorption.

TRANS-1,2-DICHLOROETHENE

The behavior of trans-1,2-dichloroethene is largely controlled by its high vapor pressure. Trans-1,2-dichloroethene will not persist in surface soils and aquatic systems because of its tendency to volatilize. Reported volatilization half-lives in water are several minutes to a few hours, depending on the degree of agitation (Callahan et al., 1979). Once in the atmosphere, trans-1,2-dichloroethene is photo-oxidized by hydroxyl radicals, resulting in the formulation of formic acid, hydrochloric acid, carbon monoxide and formaldehyde.

The half-life for this photo-oxidation reaction is on the order of a day (Callahan et al., 1979).

Limited data are available on the transformation rates of trans-1,2-dichloroethene in aquatic systems. Callahan et al. (1979) use the behavior of two analogues to infer its behavior: tetrachloroethene and trichloroethene. Such an approach would suggest that trans-1,2-dichloroethene will oxidize, but at a very slow rate relative to volatilization. Callahan et al. (1979) cite oxidation half-lives of 10.7 months and 8.8 months for trichloroethene and tetrachloroethene, respectively. They also state that the oxidation of both analogues is accelerated in the presence of sunlight, and that the less-chlorinated trans-1,2-dichloroethene is likely to be even more susceptible than its analogues. The relative contribution of hydrolysis is unclear given the available data. One of the analogues, trichloroethene, was not hydrolyzed in water (EPA, 1975). Thus, hydrolysis is not a significant degradation mechanism. Photodecomposition is also likely to be insignificant given the behavior of the two analogues (Jensen and Rosenberg, 1975).

Sorption of trans-1,2-dichloroethene will be limited as reflected by its relatively low octanol-water partition coefficient. Thus, its mobility in aquatic systems will be controlled mainly by water (rather than sediment) movement.

The persistence of trans-1,2-dichloroethene in subsurface soils and groundwater will depend upon the degree of aeration. Under anaerobic conditions, trans-1,2-dichloroethene will be highly persistent, unless biodegradation occurs. Bouwer and McCarty (1983) have shown that chloroaliphatic compounds can be degraded under anaerobic conditions as a result of reductive dehalogenation. Rates of biodegradation are difficult to estimate on a site-specific basis. Under aerobic conditions, trans-1,2-dichloroethene may degrade as a result of oxidation.

The mobility of trans-1,2-dichloroethene in surface soils and groundwater will be high because of its limited tendency for sorption.

TETRACHLOROETHENE

The behavior of tetrachloroethene is largely controlled by its vapor pressure. Tetrachloroethene will not persist in surface soils and aquatic systems because of its tendency to volatilize. The volatilization half-life for tetrachloroethene in water is on the order of several minutes to a few hours, depending upon the degree of agitation (Callahan et al., 1979). In the atmosphere, tetrachloroethene has a half-life of about 10 days (Callahan et al., 1979). Its

degradation in air is a result of photo-oxidation forming trichloroacetylchloride and some phosgene.

While tetrachloroethene will degrade via photo-oxidation in surface soils and aquatic systems, the rate of degradation is slow relative to its rate of volatilization. Callahan et al. (1979) give a maximum oxidation half-life of 8.8 months. The relative contribution of hydrolysis is unclear given the available data. It is expected to be insignificant in surface soils and aquatic systems, as is photodecomposition.

Sorption of tetrachloroethene will be limited as evidenced by its octanol-water partition coefficient. Sorption will largely be controlled by the organic matter content of soils or sediments. Thus, its mobility in aquatic systems will be controlled by water (rather than sediment) movement.

The persistence of tetrachloroethene in subsurface soils and groundwater will be controlled by the degree of aeration. Under anaerobic conditions, tetrachloroethene will be highly persistent, unless biodegradation occurs. Biodegradation of tetrachloroethene is possible under anaerobic conditions as a result of reductive dehalogenation (Bouwer and McCarty, 1983). It has been demonstrated that tetrachloroethene degrades to form trichloroethene (Bouwer and McCarty, 1983). Rates of biodegradation are difficult to estimate on a site-specific basis. Under aerobic conditions, tetrachloroethene may degrade as a result of oxidation.

The mobility of tetrachloroethene in subsurface soils and groundwater will be high because of its limited tendency for sorption.

TRICHLOROETHENE

The behavior of trichloroethene is largely controlled by its vapor pressure. Trichloroethene will not persist in surface soils and aquatic systems because of its tendency to volatilize. Its reported volatilization half-life from water is on the order of several minutes to a few days, depending upon the degree of agitation (Callahan et al., 1979). Once in the atmosphere, trichloroethene rapidly degrades via a photo-oxidation reaction that produces dichloroacetyl-chloride and phosgene. Callahan et al. (1979) give a 4-day half-life for this reaction.

While trichloroethene will degrade via photo-oxidation in surface soils and aquatic systems, the rate of degradation is slow relative to volatilization. Callahan et al. (1979) give a maximum oxidation half-life of 10.7 months. The relative contribution of hydrolysis is unclear given the available data. It is expected to be insignificant in surface soils and aquatic systems, as is photodecomposition.

Sorption of trichloroethene will be limited due to its low octanol-water partition coefficient. Organic content will tend to control the extent of sorption. When the organic content is small compared to the clay content (less than 1 to 5), the inorganic fraction will control trichloroethene sorption (Richter, 1981). Its mobility in aquatic systems will be controlled by water (rather than sediment) movement.

The persistence of trichloroethene in subsurface soils and groundwater will be controlled by the degree of aeration. Biodegradation can occur under anaerobic conditions as a result of reductive dehalogenation (Bouwer and McCarty, 1983). Rates of biodegradation are difficult to estimate on a site-specific basis. Under aerobic conditions, trichloroethene may degrade as a result of oxidation.

The mobility of trichloroethene in subsurface soils and groundwater will be high because of its limited tendency for sorption.

TOLUENE

The behavior of toluene is controlled by its vapor pressure. Toluene will not persist in surface soils or aquatic systems because of its tendency to volatilize. Its estimated half-life in water is on the order of a few hours (Callahan et al., 1979). Photo-oxidation of toluene in the atmosphere is rapid, with a half-life of about 15 hours (Callahan et al., 1979); this value is inferred based on the relative reactivity of toluene and reported conversion rates for m-xylene and 1,3,5-trimethylbenzene. Benzaldehyde is the major photo-oxidation byproduct for toluene (Laity et al., 1973).

While oxidation and photodecomposition are possible in water, the rates of degradation are probably slow relative to volatilization (Callahan et al., 1979). No rate data are available for either process. Hydrolysis is not expected to occur, according to Callahan et al. (1979). Thus, the persistence of toluene in surface soils and aquatic systems is largely controlled by volatilization.

Sorption of toluene will tend to be limited given its low octanol-water partition coefficient. Its mobility in aquatic systems will be controlled by water (rather than sediment) movement.

Toluene persistence in subsurface soils and groundwater will be high due to the insignificance of hydrolysis as a degradation mechanism. In addition, oxidation appears to occur only in the presence of sunlight. Biodegradation is possible given appropriate acclimation of soil bacteria and aerobic conditions (Callahan et al., 1979; Dawson et al., 1980).

Rates of biodegradation are difficult to estimate on a site-specific basis.

The mobility of toluene in subsurface soils and groundwater will be high. Sorption is directly related to organic matter content (Callahan et al., 1979). Given its density (0.866 g/cm^3), toluene could float on water if present in the pure form (Dawson et al., 1980).

CHLOROFORM

The behavior of chloroform or trichloromethane will be controlled by its vapor pressure. Chloroform will not persist in surface soils or aquatic systems because of its tendency to volatilize. Callahan et al. (1979) give a volatilization half-life in water on the order of several minutes to a few hours depending upon the degree of agitation. In the atmosphere, chloroform degrades rapidly as a result of photo-oxidation by hydroxyl radical attack producing phosgene and chlorine oxide. Callahan et al. (1979) give a photo-oxidation half-life on the order of several months.

While hydrolysis of chloroform in water is possible, the rate of degradation is slow relative to volatilization. Callahan et al. (1979) present a minimum half-life of 15 months based on experimental work by Dilling et al. (1979). A maximum half-life of 3,500 years is also given based on an extrapolation made by Radding et al. (1977). Dawson et al. (1980) give a hydrolysis half-life of 18 months. Oxidation and photodecomposition are not significant, if they occur at all.

Sorption of chloroform will be limited given its octanol-water partition coefficient. The extent of sorption is controlled by the organic matter content and surface area of clays (Dawson et al., 1980). Chloroform mobility in aquatic systems will be controlled by water (rather than sediment) movement.

There is some uncertainty as to how persistent chloroform is in subsurface soils and groundwater. While hydrolysis can occur, it is difficult to estimate a rate of degradation. Given appropriate acclimation, biodegradation of chloroform is possible under anaerobic conditions (Bouwer and McCarty, 1983).

The mobility of chloroform in subsurface soils and groundwater will be high.

2,4-DIMETHYLPHENOL

A lack of literature data on 2,4-dimethylphenol makes it difficult to generate a definitive environmental behavior

profile. Callahan et al. (1979) developed an inferred profile based on the behavior of unsubstituted phenol and alkylbenzenes.

Their profile suggests that the persistence of 2,4-dimethylphenol in surface water will be controlled by photo-oxidation. Photodissociation of 2,4-dimethylphenol is most likely to occur in clear, well aerated aquatic systems. Waters high in iron and copper could also promote the oxidation of 2,4-dimethylphenol. No data were found on the rate of photo-oxidation. 2,4-Dimethylphenol will have little tendency to volatilize given its low vapor pressure and high solubility. 2,4-Dimethylphenol should be resistant to hydrolysis, and available information on the biodegradation of 2,4-dimethylphenol is conflicting (Callahan et al., 1979).

2,4-Dimethylphenol will have little affinity for sorption to clays, assuming it behaves like an unsubstituted phenol. It does, however, have an affinity for sediments high in organic matter. Thus, its mobility in aquatic systems will be affected by water movement and, possibly, sediment movement.

2,4-Dimethylphenol will tend to be highly persistent in subsurface soils and groundwater based solely on its limited potential for hydrolysis. Highly aerated conditions and the presence of iron and copper would be required for oxidation to occur. While Tabak et al. (1964) and others have shown that 2,4-dimethylphenol can biodegrade, statements as to its persistence on a site-specific basis are difficult to make.

2,4-Dimethylphenol will be moderately to highly mobile in subsurface soils and groundwater, depending upon the organic carbon content.

BENZO(A)ANTHRACENE

The mobility and persistence of benzo(a)anthracene are controlled by its affinity for sorption. Its high octanol/water partition coefficient indicates that benzo(a)anthracene will be strongly sorbed, especially to soils and sediments high in organic matter. As a result, the mobility of benzo(a)anthracene in aquatic systems is controlled by sediment movement. Under quiescent conditions, bed sediments can become aquatic sinks for benzo(a)anthracene. Sorption will also limit the mobility of benzo(a)anthracene in groundwater.

Sorption also affects the persistence of benzo(a)anthracene by limiting its susceptibility to degradation by photolysis and oxidation, and its susceptibility to volatilization. The dissolved fraction may undergo rapid transformation in aquatic systems. Callahan et al. (1979) report that the dissolved fraction can transform via: 1) photolysis with a half-life of 10 to 50 hours, and 2) oxidation with a

half-life of 38 hours. The volatilization half-life for benzo(a)anthracene is about 90 hours. Benzo(a)anthracene can also be biodegraded after long-term exposure of microbes.

The persistence of benzo(a)anthracene in groundwater will tend to be high because it is not amenable to hydrolysis. There is some potential for biodegradation. However, on a site-specific basis it is difficult to determine the significance of this mechanism.

POLYCHLORINATED BIPHENYLS

Polychlorinated biphenyls (PCB's) are a family of compounds whose environmental behavior can vary widely depending upon the degree of chlorination. In general, as the degree of chlorination increases so does the persistence and affinity for sorption; volatility and solubility decrease with degree of chlorination.

The mobility of PCB's is largely controlled by their high affinity for sorption and, to some extent, by their limited solubility in water. PCB sorption is a function of organic matter content and clay content, the former being the more important (Griffin and Chian, 1980). The mobility of PCB's in aquatic systems is controlled by sediment transport processes. Areas of high sediment deposition can become sinks of PCB and later sources as the PCB redissolves into the water column. PCB mobility in subsurface soils and groundwater is limited by sorption. However, under conditions where PCB is present in excess of its solubility, there is the potential for migration as a separate phase. Roberts et al. (1982) found that the migration of PCB as a separate phase in soil and groundwater explained why contamination at a spill site was more widespread than would be expected given its affinity for sorption.

Despite their relatively low vapor pressure and molecular weight, PCB volatilization from water and soil can occur. Adsorption dramatically reduces the rate of volatilization, however. Pal et al. (1980) has summarized volatilization half-lives for PCB's in water and soils. They range from tens to hundreds of days depending upon the type of PCB mixture and environmental conditions. Volatilization is an important mechanism because of the lack of other mechanisms that act to degrade PCB's.

The only important degradation process is biodegradation. However, it is only significant for the mono-, di-, and trichlorinated biphenyls. Biphenyls with five or more chlorines are essentially unaffected, while tetrachlorobiphenyls are moderately susceptible (Callahan et al., 1979). Leifer et al. (1983) state that there is no evidence for PCB biodegradation under anaerobic conditions, but that numerous aerobic

microorganisms are capable of degrading PCB's. Table D-4 gives estimates for biodegradation half-lives in different media.

Table D-4
HALF-LIVES OF PCB'S RESULTING FROM BIODEGRADATION
(Source: Leifer et al., 1984)

	Mono- & Dichloro	Trichloro	Tetrachloro	Pentachloro and Higher
Aerobic				
Surface Waters				
Fresh	2-4 days	5-40 days	1 wk-2+ mos.	>1 year
Oceanic	-------several months------		--------->1 year---------	
Activated Sludge	1-2 days	2-3 days	3-5 days	*
Soil	6-10 days	------12-30 days-----		>1 year
Anaerobic	---------- ∞ ----------			

*It is not clear how long the highly chlorinated PCB's would last under activated sludge treatment but there appears to be no significant biodegradation during typical residence times.

More highly chlorinated PCB's in solution have been observed to break down through photolysis. Sufficient data are not available to estimate photolysis half-lives for environmental conditions (Leifer et al., 1983). PCB's are resistant to both oxidation and hydrolysis (Callahan et al., (1979; Leifer et al., 1983).

OXAZOLIDONE

Few data are available for use in constructing an environmental fate profile for 3-(2-hydroxypropyl)-5-methyl-2-oxazolidionone (oxazolidone). Literature on the persistence of this compound do not exist. The compound may biodegrade in the soil environment. The rate at which this process would occur is unknown.

ARSENIC

In the natural environment, four oxidation states are possible for arsenic: -3, 0, +3, and +5. The +3 and +5 states are most commonly found in aqueous solutions, with the +5 state being the most stable and dominant. The -3 state is present in arsine (AsH_3) and is stable only under highly reduced conditions.

The environmental behavior of arsenic is largely determined by pH and the oxidation-reduction (i.e., redox) potential of the system. Rai et al. (1984) state that under oxidizing conditions, $H_2AsO_4^-$ and $HAsO_4^{2-}$ are the most common species, while H_3AsO_3, $HAsO_4^{2-}$ and $H_2AsO_4^-$ are most common under reduced conditions. Biologically mediated reactions and dissolved organic matter also have a significant impact on arsenic speciation.

Dissolved arsenic concentrations can be reduced by precipitation/dissolution reactions. These reactions have not been well characterized. Rai et al. (1984) state that $FeAsO_4$ is a possible solubility-controlling solid.

Dissolved arsenic concentrations can be further reduced by sorption reactions. Rai et al. (1984) note that the iron and aluminum hydrous oxide content of a soil or sediment will control the extent of sorption. Organic matter content and pH do not seem to have a significant impact. In general, arsenic is strongly adsorbed with the As(V) species showing a much greater affinity than As(III) species. Callahan et al. (1979) conclude that arsenic adsorption will be most significant in aerobic, acidic, fresh waters.

Arsenic mobility in aquatic systems will be controlled by sediment movement. In subsurface soils and groundwater, arsenic will be relatively immobile with the As(V) species being less mobile than the As(III) species.

In areas of high biological activity, arsenic can be mobilized through methylation reactions. Methylarsines can be produced by a number of yeasts, bacteria, and fungi (Callahan et al., 1979). These compounds can readily volatilize from water. Arsenic can also volatilize under highly reducing conditions as arsine (AsH_3). Arsine is rapidly oxidized, however, upon introduction to aerobic waters or the atmosphere (Callahan et al., 1979).

CADMIUM

In aqueous solutions, cadmium exists only in the +2 state. Dissolved cadmium can be in a free ionic form or an inorganic or organic complex. Generally, the most dominant species is Cd^{2+}. As conditions become more alkaline (i.e., pH >8-9), hydroxide and carbonate complexes become dominant. In organically polluted waters, cadmium can be readily complexed.

Most natural waters are undersaturated with respect to known solubility controlling phases for cadmium (Callahan et al., 1979). For alkaline soils, $CdCO_3$ and, in some cases, $Cd_3(PO_4)_2$ can be solubility-controlling solids (Rai et al., 1984).

Cadmium is adsorbed by soils and sediments containing aluminum, iron, and manganese oxides. In highly polluted aquatic systems, sorption onto organic materials can be significant (Callahan et al., 1979). Rai et al. (1979) note that competition with other cations (e.g., copper, lead, and zinc) and calcium and magnesium can reduce cadmium adsorption. They further note that there is a close relationship between cadmium adsorption and the cation exchange capacity of a soil. Cadmium adsorption shows a strong pH dependency with the extent of adsorption decreasing with pH.

Cadmium mobility in aquatic systems will be controlled by sediment movement. In subsurface soils and groundwater, cadmium will be relatively immobile.

Cadmium is not transformed or attenuated via biological activity. Thus, its persistence in soils, groundwater, and aquatic systems will be high.

CHROMIUM

In aqueous systems, chromium exists in two oxidation states: +3 and +6. Redox potential and pH both play an important role in determining their relative presence and mobility. Trivalent species can exist over a relatively wide range of redox and pH conditions; hexavalent species occur only under strongly oxidizing conditions.

Above a pH of 5, trivalent species rapidly precipitate as an oxide or hydroxide solid. Cr_2O_3 is probably the solubility-controlling solid under moderately oxidizing conditions, while $FeCr_2O_4$ may control under slightly reduced conditions (Rai et al., 1984).

Under oxidizing conditions hexavalent chromium exists as hydrochromate, chromate, and dichromate species. Their relative distribution varies with pH. In the pH range of natural waters, hydrochromate predominates, while chromate predominates in the alkaline range. Hexavalent chromium is a moderately strong oxidizing agent that can react with reducing materials to form trivalent chromium.

Both trivalent and hexavalent chromium are adsorbed onto inorganic solids, with trivalent chromium showing a stronger affinity than hexavalent chromium. Trivalent chromium may be strongly adsorbed by iron and manganese oxides (Rai et al., 1984). The affinity for trivalent chromium adsorption increases with pH. The presence of organic ligands can result in the formation of complexes that will limit adsorption. Hexavalent chromium is specifically adsorbed by iron oxides under acidic conditions; it is relatively mobile under neutral and basic conditions (Rai et al., 1984). Hexavalent

chromium adsorption may decrease in the presence of competing ions like SO_4^{2-}.

Chromium mobility in aquatic systems will be controlled by sediment movement. In subsurface soils and groundwater, chromium will be relatively immobile.

Biotransformation is not an important mechanism for chromium. Thus, its persistence in soil, groundwater, and aquatic systems will be high.

COPPER

Copper in aqueous solutions can exist in a +1 or +2 state. It has a pronounced tendency to form a number of inorganic and organic complexes. Under oxidizing conditions, Cu^{2+} or a Cu(II) complex with OH^-, CO_3^{2-} or SO_4^{2-} will dominate depending upon the pH and ligand concentrations; under reducing conditions, Cu^+ or a Cl^- complex will dominate.

Dissolved copper concentrations are typically controlled by the formation of $Cu(OH)_2$. In waters containing organic ligands, copper can form complexes that alter its solubility and precipitation behavior.

According to Rai et al. (1979), copper can adsorb to organic matter and iron and manganese oxides. Its affinity for adsorption is strongly dependent upon speciation since $CuOH^+$ is preferred over Cu^{2+}. Callahan et al. (1979) further note that in organically rich waters the ultimate dissolved copper concentration will be determined by competition between organic ligands and organic sorbants and clay particles. Thus, it is difficult to predict with certainty how copper will behave in polluted waters. In general, its mobility in aquatic systems will be controlled by sediment movement. In subsurface soils and groundwater, copper will be relatively immobile.

Biotransformation is not an important mechanism for copper. Thus, its persistence in soil, groundwater, and aquatic systems will be high.

NICKEL

Nickel exists in aqueous solutions in the +2 valence state. Under reduced conditions and in the presence of sulfide, nickel forms an insoluble complex. Under oxidizing conditions below a pH of 9, nickel will complex with hydroxide, carbonate, and sulfate ligands. Nickel will also readily complex with organic ligands. The resulting complexes are highly soluble.

Rai et al. (1984) found $NiFeO_2$ to be the most probable solubility-controlling solid under oxidizing conditions; NiS controls under reduced conditions.

Nickel can sorb on solids containing iron and manganese oxides and organic material. Callahan et al. (1979) note, however, that nickel is not extensively sorbed. Competition with Ca^{2+} and Mg^{2+} and inorganic and organic complexation can reduce nickel adsorption. Despite its relative mobility compared to other metals, nickel mobility in aquatic systems will be controlled by sediment transport. Nickel will be relatively immobile in subsurface soils and groundwater.

Biotransformation is not an important mechanism for nickel. Thus, nickel will be persistent in soil, groundwater, and aquatic systems.

LEAD

Lead is largely present in a +2 valence state in most aqueous solutions. The +4 state is stable only under highly oxidizing conditions that are not environmentally significant. Lead has a strong tendency to form hydroxide, carbonate, sulfide, and sulfate complexes. It also has a strong tendency to form organic complexes that can have a major effect on solubility controls and sorption.

Rai et al. (1984) state that lead-phosphates are probable solubility-controlling solids in noncalcareous soils, while $PbCO_3$ appears to control in calcareous and alkaline soils.

Lead is strongly adsorbed to solids containing iron and manganese oxides. According to Rai et al. (1984), it is also retained by ion exchange; competing ions have little effect on lead sorption at low concentrations. The affinity of lead for adsorption increases with the degree of organic complexation and with increasing pH. The mobility of lead in aquatic systems will be determined by sediment movement. Lead will be immobile in subsurface soils and groundwater.

Lead concentrations in surface soils and bed sediments can be reduced as a result of biologically mediated reactions. Lead methylation can produce a volatile compound (i.e., trimethyl lead) that either enters the atmosphere or is oxidized in the water column. Sufficient data are not available to determine under what exact conditions methylation will occur or at what rate.

ZINC

Zinc has an oxidation state of +2 in aqueous systems. Zinc can exist in its free ionic form or as an inorganic or organic complex. Under oxidizing conditions, hydroxide,

carbonate, and sulfate complexes can form. The dominance of a particular species will be determined by the pH and ligand concentrations.

Zinc precipitation is important under reduced conditions in the presence of sulfide. Zinc hydroxides and zinc carbonates are the most likely solubility-controlling solids under oxidizing conditions. However, relatively high zinc concentrations are required for them to form.

Zinc is primarily adsorbed onto solids containing iron, aluminum, and manganese oxides, clay minerals, and organic materials. Rai et al. (1984) note that while the effects of competing ions are not well understood, it is likely that cadmium and magnesium may reduce zinc adsorption through competition; certain anions may act to enhance zinc adsorption. The affinity for adsorption of zinc increases with pH. The mobility of zinc in aquatic systems will be controlled by sediment movement. Zinc will be relatively immobile in subsurface soils and groundwater.

Biotransformation is not an important mechanism for zinc. Thus, zinc will be persistent in soil, groundwater, and aquatic systems.

INDICATOR CHEMICAL BEHAVIOR

The site-specific behavior of the indicator chemicals can be discussed in terms of the profiles presented earlier and some basic site characteristics. It is convenient to group the indicator chemicals as follows given similarities in their behavior: volatile organics, 2,4-dimethylphenol, benzo(a)anthracene, PCB's, and metals.

The key site characteristics are the travel time of groundwater from the site to Mill Creek and the travel time of water in Mill Creek as it passes near the site. Using an average hydraulic conductivity of 2.5 feet per day, an effective porosity of 0.25, and an average horizontal gradient of 0.03, the approximate time for groundwater near the center of the site to travel to Mill Creek is 1.8 years. This is only an approximation; vertical gradients will lengthen the actual flow path and travel time for water originating at the center of the site. Groundwater near Mill Creek will have a shorter distance to travel, resulting in a shorter travel time. Chemicals with degradation half-lives in groundwater that are equal to or less than the 1.8-year travel time should experience some degradation prior to reaching Mill Creek.

Using an average flow rate of between 6 and 12 cfs for Mill Creek and an average cross-sectional area of 8 ft^2 yields a streamflow velocity of 0.75 to 1.5 ft/sec. Given that Mill Creek intersects the contaminated portion of the site for a distance of about 500 feet, the Mill Creek water travel time past the site is between 5 and 11 minutes. Again, chemicals with degradation or volatilization half-lives equal to or less than this travel time should dissipate somewhat prior to leaving the site.

As a group, the volatile organics will tend to migrate rapidly in groundwater towards Mill Creek. Along the way, 1,1,1-trichloroethane will likely experience some degradation given the magnitude of its hydrolysis rate relative to the travel time. Because the groundwater is relatively shallow, it is likely that aerobic conditions exist. If this is the case, trans-1,2-dichloroethene, tetrachloroethene, and trichloroethene may also experience some degradation prior to reaching Mill Creek. Neither toluene nor chloroform should experience significant degradation.

The volatile organics that reach Mill Creek should volatilize, although because the water travel time is short compared to the volatilization half-lives of these compounds, no detectable reductions in concentrations would be expected in the Western Processing reach. Volatile organics should not be found in high concentrations in Mill Creek sediments. The volatile organics should not persist in surface soils at the site.

2,4-Dimethylphenol in groundwater at Western Processing should experience little attenuation through either sorption or degradation. Its persistence in Mill Creek is difficult to estimate. Oxidation is possible given the copper levels in Mill Creek. Photolysis is likely to occur only to a limited extent given that Mill Creek is not a clear, well-aerated stream. 2,4-Dimethylphenol should be relatively persistent in onsite surface soils, assuming limited potential for biodegradation.

Migration of benzo(a)anthracene in groundwater at Western Processing is expected to be very slow with no significant degradation losses. Benzo(a)anthracene that reaches Mill Creek will be found primarily in the sediments. Under normal and low flow conditions, benzo(a)anthracene would tend to persist in Mill Creek, assuming limited potential for biodegradation. Under high flow conditions, sediment transport could be such that benzo(a)anthracene may migrate downstream. Benzo(a)anthracene persistence in surface soils will be higher, unless biodegrading organisms have been sufficiently acclimated.

PCB's will tend to persist in Mill Creek sediments, surface soils, subsurface soils, and groundwater at Western Processing. The latter two media are likely to exhibit very high persistence due to the lack of potential degradation through volatilization, photolysis, and biodegradation. Some degradation may be found in onsite surface soils, but it will be limited. Sediment transport under high flow conditions will determine the persistence of PCB's in Mill Creek.

As a group, the metals will tend to behave in a similar manner. All of the metals will be highly persistent in groundwater and will migrate very slowly towards Mill Creek. Sorption and, in some cases, precipitation reactions (e.g., arsenic, copper and lead) may act to dramatically reduce dissolved concentrations. Organics present in the groundwater may complex many of the metals and reduce their tendency to adsorb; competition between metals and other ions may have the same effect.

Metals that do reach Mill Creek will tend to concentrate in the sediments. Sorption reactions will be even stronger in Mill Creek due to an increase in pH and oxidation potential. Precipitation reactions could affect copper and zinc levels. The persistence of the metals in Mill Creek will be determined by high flow events that transport sediments away from the site.

With the exception of arsenic and lead, the metals will be highly persistent in onsite surface soils. Some potential exists for the biotransformation of arsenic and lead.

Appendix E: Estimating Lifetime Average Water and Soil Intake

Appendix E
ESTIMATING LIFETIME AVERAGE WATER AND SOIL INTAKE

The lifetime average soil ingestion rate (LASI) in g/kg body weight/day, and drinking water intake (LAWI) in L/kg/day were estimated as:

$$LASI = \frac{1}{M} \sum_{i=j}^{N} \frac{s_i}{b_i}$$

$$LAWI = \frac{1}{M} \sum_{i=j}^{N} \frac{w_i}{b_i}$$

where

s_i = soil ingestion rate in year i (g/day)
w_i = drinking water intake in year i (1/day)
b_i = body weight in year i (kg)
N = final year of exposure (assume 70 for residential scenario and 65 for industrial scenario)
M = years in a lifetime (assume 70)
j = starting year of exposure (assume 1 for lifetime scenario and 25 for industrial scenario)

LASI was estimated as 0.028 g/kg/day for the residential scenario and 0.00082 g/kg/day for the worker scenario. LAWI was estimated as 0.035 L/kg/day for the residential scenario and 0.016 kg/day for the worker scenario based on the data in Table E-1. A range of soil ingestion rates from 0.1 to 5 g/day for children 2 to 6 years in age (zero for other ages) has also been estimated (USEPA, November 1984) and was included in the endangerment assessment (Chapter 4). With an average body weight of 15 kg, this would lead to a lifetime soil ingestion rate ranging from 0.00048 to 0.024 g/kg/day.

Table E-1
ESTIMATED SOIL AND WATER INGESTION BY AGE

Age (years)	Body Weight (kg)	Ingested Soil[a] (g/day)	Ingested Drinking Water (L/day)
0-0.75	5	0	1
0.75-1.5	8	1	1
1.5-3.5	12	10	1
3.5-5	15	1	1
5-18	38	0.1	1.4
≥18	70	0.1	2

[a]Kimbrough, et al. (1983)

Appendix F: Methods, Assumptions, and Criteria for Contaminant Source Quantification, Groundwater Quality Analysis, Battelle Groundwater Flow/Transport Model

Appendix F
METHODS, ASSUMPTIONS, AND CRITERIA FOR
CONTAMINANT SOURCE QUANTIFICATION,
GROUNDWATER QUALITY ANALYSIS,
BATTELLE GROUNDWATER FLOW/TRANSPORT MODEL

CONTAMINANT SOURCE QUANTIFICATION

A contaminant distribution analysis of the Western Processing area was conducted to evaluate the effectiveness of various excavation alternatives and to generate site average contaminant levels for use in the groundwater quality analysis. The analysis estimates the mass and concentration distributions of 23 contaminants in soil and groundwater using data from the 3013, IRI, and RI reports (USEPA, May 1983; CH2M HILL, October 1983/April 1984 and December 1984).

The 23 contaminants include 14 of the 16 indicator parameters discussed in Chapter 3 (excluding oxazolidone and 2,4-dimethylphenol) and nine other selected contaminants that were detected 30 or more times in all of the soil samples. The 23 contaminants are:

Phenol	Pyrene
Methylene chloride	Fluoranthene
Trans 1,2-dichloroethene	Benzo(a)anthracene
Chloroform	Bis(2-ethylhexyl)phthalate
Trichloroethene	Nickel
1,1,1-Trichloroethane	Cadmium
Toluene	Zinc
Tetrachloroethene	Chromium
Ethylbenzene	Arsenic
Naphthalene	Copper
Phenanthrene	Lead
PCB	

The contaminants were selected because their total mass represents the vast majority of site contamination. They also were selected to represent the range of mobilities from each major priority pollutant class (volatiles, base/neutrals, acid extractables, and heavy metals). Oxazolidone was excluded because it is a tentatively identified compound and not a priority pollutant. Phenol was substituted for 2,4-dimethyphenol as being generally a more typical acid extractable compound.

METHODS AND ASSUMPTIONS

The analysis quantifies the distribution of contaminants in the upper 30 feet of soil and groundwater. This represents the major zone of contamination as identified in Chapter 3. The analysis was not used to quantify the full extent of

contamination because too few data exist at depth and on the contamination fringe. Contaminant data are associated with a depth below the land surface as it existed prior to surface cleanup. Topographic variations across the site therefore were not used in the analysis. The surface cleanup and grading conducted in the fall of 1984 greatly disturbed the existing surface. This analysis does not consider these changes because surface soil analyses are not available from the regraded site.

The analysis is based on the Thiessen polygon method. The concentrations measured at a particular point are assigned to polygons containing the sample location. The concentrations are assumed to be uniform within each polygon. The shape and size of individual polygons are determined by the distribution of sample locations. In general, closely spaced sample locations yield smaller polygons and more accurate results.

The existing database (discussed in Chapter 3) contains values from many different depths at the various sampling locations, thus potentially requiring a different set of polygons for each depth. To simplify the calculations, only three sets of polygons were constructed for the soil data:

1. Surface polygons for sample locations where analyses of samples collected from the surface were available (Figure F-1)

2. Intermediate polygons for sample locations where analyses of samples collected between one and 15 feet were available (Figure F-2)

3. Deep polygons for sample locations where analyses of samples collected between 15 and 30 feet were available (Figure F-3)

To further simplify calculation, the three polygon sets were combined into one "base" polygon set. Because most soil data were collected from one to 15 feet, the intermediate polygons were used as the base.

The concentrations assigned to the intermediate base polygons at the surface and deep layers were calculated as the area-weighted average of overlapping polygons from the surface and deep polygon sets. Because few data were collected below 15 feet, the concentrations in the 15- to 30-foot range were assigned to the average depth of 22.5 feet. If more than one value was available in the interval, the concentration at 22.5 feet was assigned the arithmetic average of the available values. The result of this process was a soil concentration versus depth profile for each base polygon

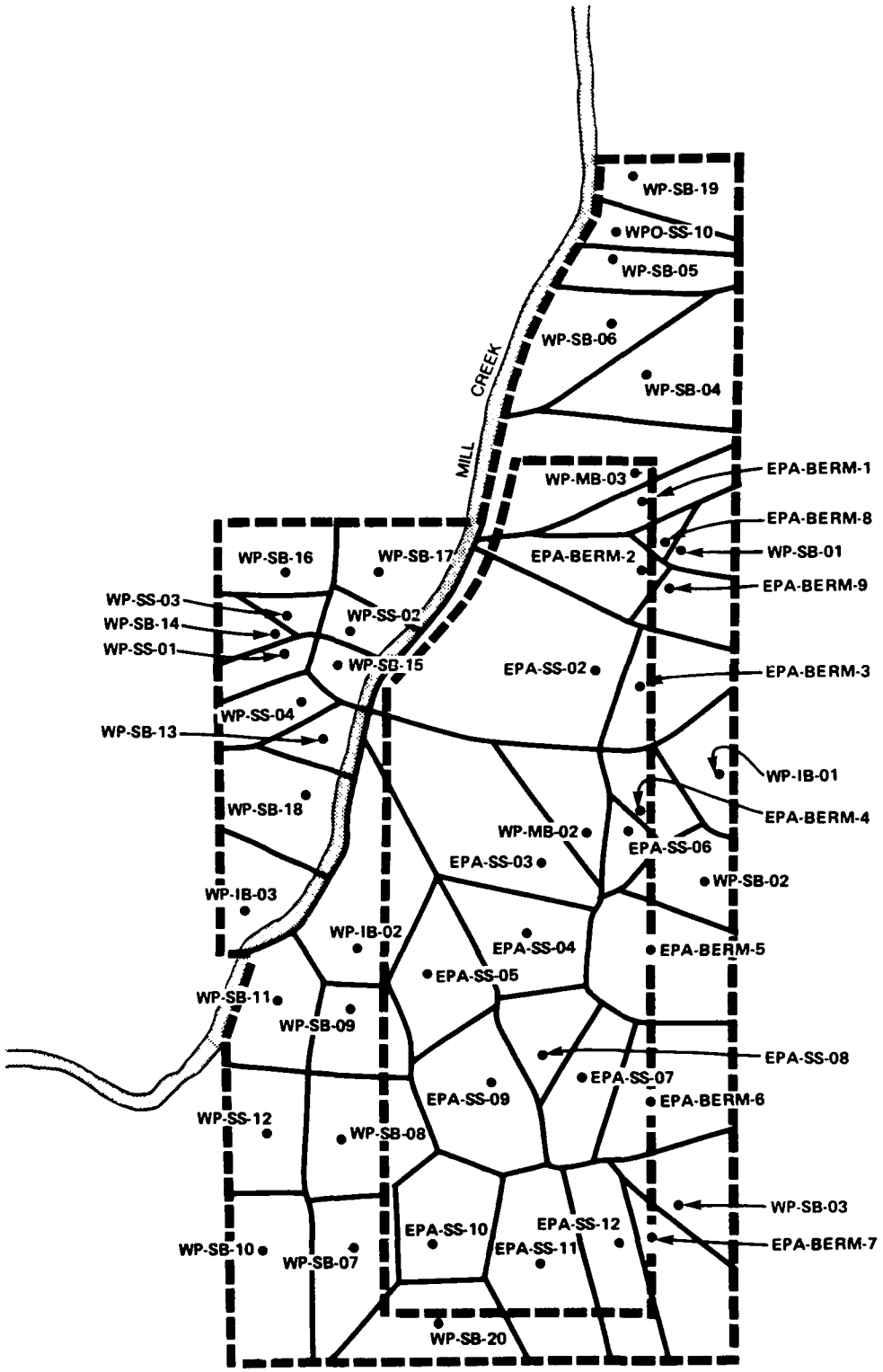


FIGURE F-1
SURFACE SOIL POLYGONS FOR CONTAMINANT DISTRIBUTION CALCULATIONS
WESTERN PROCESSING
Kent, Washington

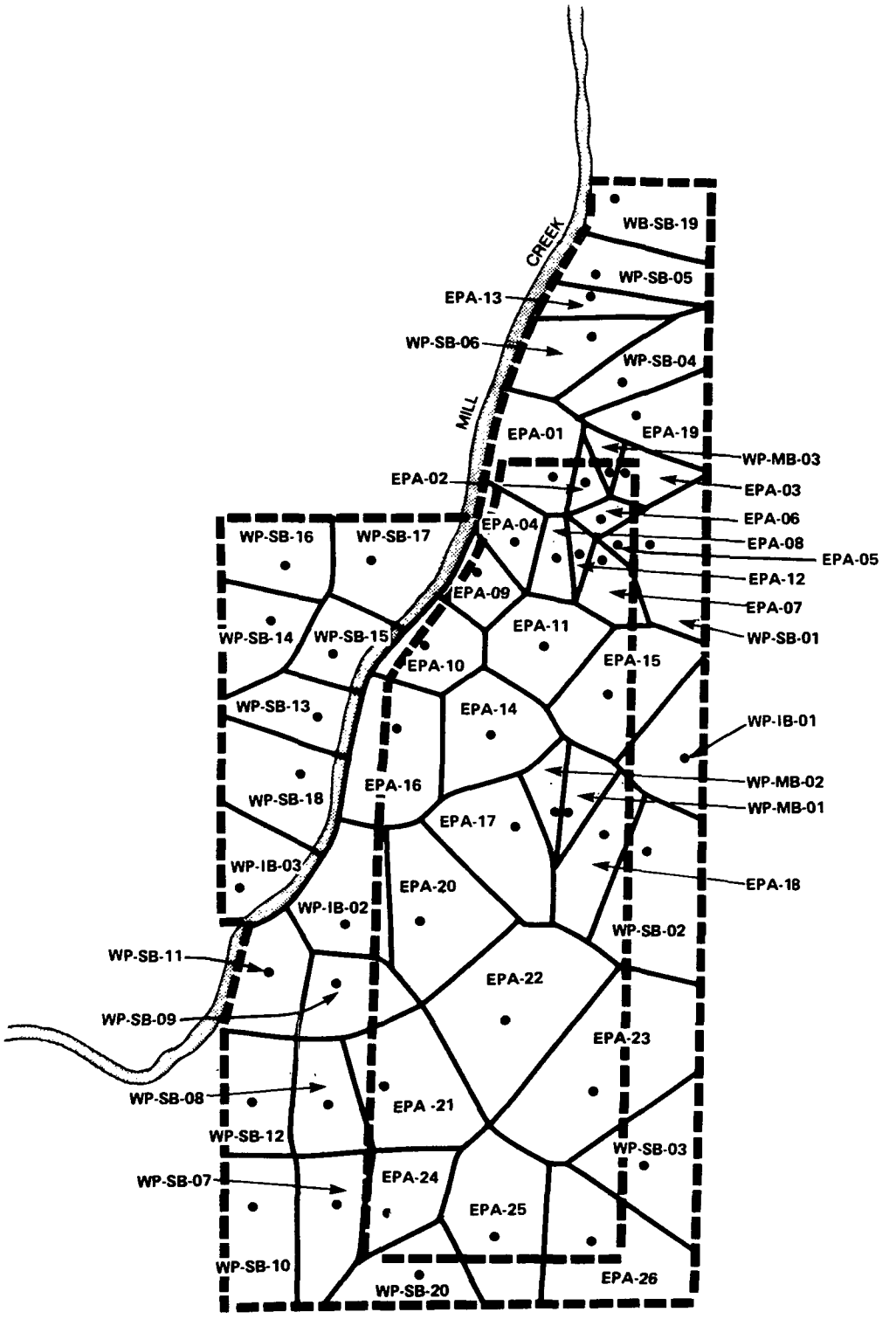


FIGURE F-2
INTERMEDIATE BASE POLYGONS FOR CONTAMINANT DISTRIBUTION CALCULATIONS
WESTERN PROCESSING
Kent, Washington

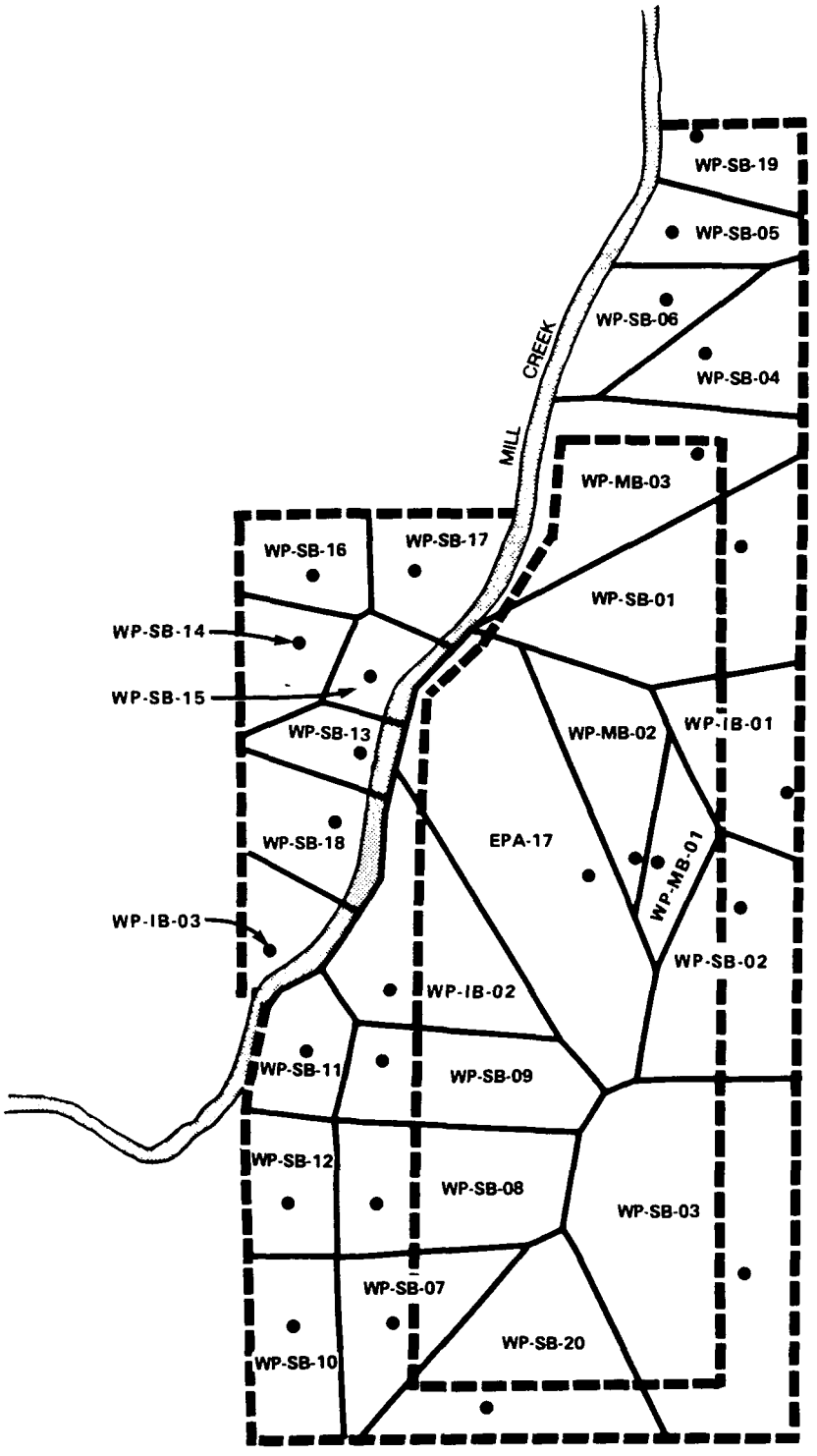


FIGURE F-3
DEEP SOIL POLYGONS FOR CONTAMINANT DISTRIBUTION CALCULATIONS
WESTERN PROCESSING
Kent, Washington

with a value assigned at zero and 22.5 feet, as described above, and the actual values for depths between one and 15 feet.

The next step in the analysis was to generate soil concentrations at standard depths of zero, 3, 6, 9, 12, and 15 feet. This was done by linear interpolation between values at the depths where data were actually available. An average concentration was then calculated for each 3-foot-thick polygon slice to 15 feet by averaging the concentration at the top and bottom of each slice. The average concentration within the 15- to 30-foot slice was assigned the value calculated for 22.5 feet. The result of this step was an estimated contaminant concentration for each soil block defined by the base set of polygons and standard depth intervals described above.

Two sets of polygons were constructed for groundwater: a shallow set using monitoring wells that were screened at depths less than 15 feet and a deep set between 15 and 30 feet (see Figures F-4 and F-5). The concentrations were translated to the base polygons by area weighting as described above. The result was a shallow and deep groundwater concentration assigned to each base polygon.

Groundwater concentrations were assumed to be uniform from the water table (at about 6 feet) to 15 feet and from 15 to 30 feet. They were assigned the values calculated in the previous step. This assumption was necessary because detailed (i.e., every few feet) groundwater quality versus depth data are not available.

The final step was to calculate the total mass and average concentration of each of the 23 contaminants in soil and groundwater by polygon and by depth. Partial excavation of a layer was approximated by using the ratio of removed thickness to total layer thickness. These final calculations were made assuming the following:

- Dry soil density = 1.44 g/cm^3
- Water density = 1.00 g/cm^3
- Total soil porosity = 0.30

RESULTS

The Western Processing area was divided into 10 areas for purposes of alternative evaluation (see Figure 1-4). The contaminant distribution analysis was conducted for Areas I and II, Area V, and Area IX (onsite plus the east drainage ditch, the area between the site and Mill Creek, and the triangular area north of the site). Contaminant masses in Area I/II are overestimated because area boundaries do not

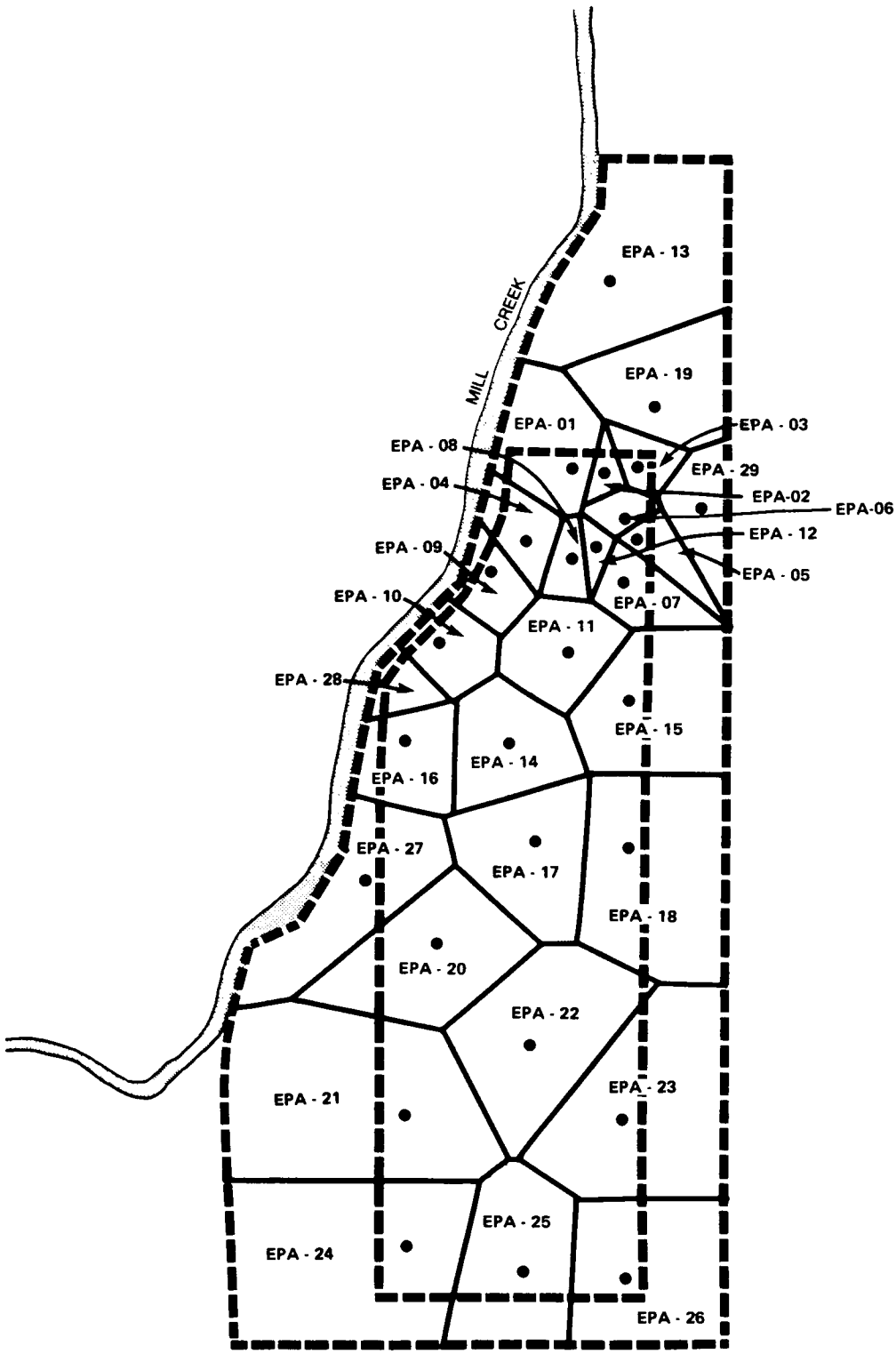


FIGURE F-4
SHALLOW GROUNDWATER POLYGONS FOR CONTAMINANT DISTRIBUTION CALCULATIONS
WESTERN PROCESSING
Kent, Washington

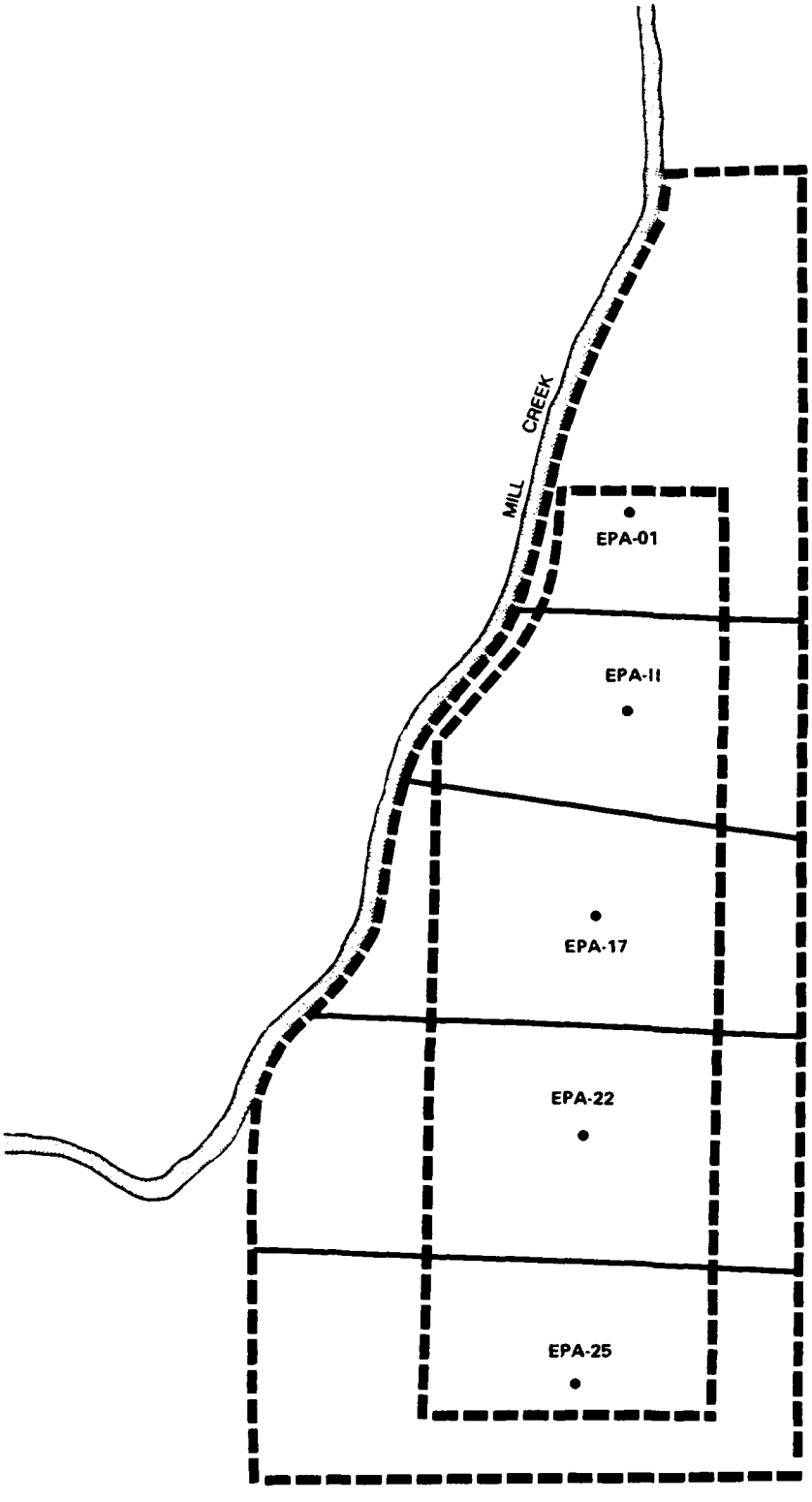


FIGURE F-5
DEEP GROUNDWATER POLYGONS FOR CONTAMINANT DISTRIBUTION CALCULATIONS
WESTERN PROCESSING
Kent, Washington

exactly coincide with polygon edges. The polygon area representing Area I/II is about 15.5 acres. The actual area is about 11.9. Concentrations are not affected because they are calculated using the larger contaminant masses divided by the larger soil volume times density.

The site average contaminant concentrations and total masses in Areas I/II, V and, IX are summarized in Tables F-1A and 1B. The two tables present a range of possible results based on the way non-detects were handled in the database. Table F-1A summarizes the results where the concentrations of the non-detects were set equal to the stated detection limit. These results represent the high end of possible contaminant levels. Table F-1B summarizes the results where the concentrations of the non-detects were set equal to zero. These results represent the low end of possible contaminant levels. The actual contaminant levels are most likely between these extremes.

Comparison of Tables F-1A and F-1B shows that the major difference in Area I/II occurs in the concentrations of the base/neutrals (naphthalene, phenanthrene, pyrene, fluoranthene, benzo(a)anthracene, and bis(2-ethylhexyl) phthalate). High detection limits were frequently associated with non-detects in the base/neutral data base (especially in groundwater). The groundwater average often was skewed one to three orders of magnitude higher than actual detected quantities when the non-detects were set equal to the detection limit. The lower concentration values are also supported on the basis of geochemical data that indicate the base/neutrals will be strongly adsorbed on soil. The actual groundwater concentrations would be significantly lower than those calculated with non-detects equal to detection limits if they were in equilibrium with the measured soil concentrations. All subsequent calculations used the lower values for the base/neutrals in groundwater and soils. The values presented in Table F-1A were used in subsequent calculations involving the other 17 contaminants in Area I/II because major changes did not occur. The use of these values also yielded slightly more conservative results.

Major differences occur in the concentrations of most organic contaminants in Areas V and IX. Like Area I/II, high detection limits were frequently associated with non-detects in the organics data base (especially in soils). The soil averages were often skewed one to three orders of magnitude higher than actual detected quantities when the non-detects were set equal to the detection limit. All subsequent calculations involving Areas V or IX soils used the lower organic concentration values shown in Table F-1B.

The use of site average groundwater concentrations should be done with caution. Because the shallow and deep polygons

Table F-1A
TOTAL MASSES AND SITE AVERAGE CONTAMINANT CONCENTRATIONS
(NONDETECTS = DETECTION LEVEL) WESTERN PROCESSING, KENT, WASHINGTON

Area	Contaminant	Total Mass in Soil 0-6 ft. (Kg)	Total Mass in Soil 6-15 ft. (Kg)	Total Mass in Soil 15-30 ft. (Kg)	Average Soil Concentration 6-15 ft. (µg/Kg)	Average Soil Concentration 15-30 ft. (µg/Kg)	Average Groundwater Concentration 6-15 ft. (µg/L)	Average Groundwater Concentration 15-30 ft. (µg/L)
I/II	Volatiles							
	Phenol	758	1,239	460	5,011	1,116	109,383	1,501
	Methylene chloride	364	358	62	1,447	149	56,886	48,974
	Trans 1,2-dichloroethene	67	69	2	215	5	20,312	158
	Chloroform	74	149	3	601	6	2,394	2,015
	Trichloroethene	2,292	5,221	19	21,112	46	29,521	7,245
	1,1,1-Trichloroethane	423	571	2	2,307	5	21,624	1,017
	Toluene	1,044	2,124	22	8,590	55	1,646	317
	Tetrachloroethene	205	289	2	1,168	4	125	5
	Ethylbenzene	129	251	3	1,017	7	19	5
	BN/AE							
	Naphthalene BN/AE	8,754	942	348	3,813	845	2,570	29
	Phenanthrene	22,887	1,126	374	4,555	907	2,570	20
	PCB	59	379	8	1,132	20	0.22	0.10
	Pyrene	17,496	821	348	3,319	845	2,758	20
	Fluoranthene	1,487	808	348	3,266	845	2,570	20
	Benzo(a)anthrancene	1,751	779	353	3,155	857	2,585	40
	Bis(2-ethylhexyl) phthalate	4,571	3,867	453	15,637	1,097	2,570	20
	Metals							
	Nickel	19,426	20,219	5,147	81,756	12,486	15,132	14,263
	Cadmium	4,739	7,782	610	31,466	1,480	2,392	964
	Zinc	777,160	463,049	93,713	1,872,331	227,355	126,448	117,687
	Chromium	76,329	164,687	16,681	665,907	40,469	5,253	316
	Arsenic	1,381	938	1,808	3,795	4,387	20	18
	Copper	51,046	84,428	10,678	341,383	25,905	1,357	785
	Lead	1,358,397	634,276	5,290	2,564,678	12,834	342	266

Table F-1A (cont.)

Area	Contaminant	Total Mass in Soil 0-6 ft. (Kg)	Total Mass in Soil 6-15 ft. (Kg)	Total Mass in Soil 15-30 ft. (Kg)	Average Soil Concentration 6-15 ft. (µg/Kg)	Average Soil Concentration 15-30 ft. (µg/Kg)	Average Groundwater Concentration 6-15 ft. (µg/L)	Average Groundwater Concentration 15-30 ft. (µg/L)
V	**Volatiles**							
	Phenol	758	1,239	124	2,140	1,229	746,973	57
	Methylene chloride	35	60	185	985	1,845	40,605	127
	Trans 1,2-dichloroethene	34	56	43	930	429	147,009	5
	Chloroform	34	56	43	930	426	1,217	3,789
	Trichloroethylene	34	58	44	953	431	89,536	8,312
	1,1,1-Trichloroethane	34	56	43	931	426	3,624	5
	Toluene	35	57	46	950	462	5	48
	Tetrachlorothylene	34	57	43	945	426	187	5
	Ethylbenzene	34	56	43	930	426	5	5
	BN/AE							
	Naphthalene	20	42	88	696	882	2,844	31
	Phenanthrene	19	42	88	693	882	2,844	20
	PCB	6	1	3	24	25	0.1	0.1
	Pyrene	19	42	88	693	882	2,844	20
	Fluoranthene	19	42	88	693	882	2,844	20
	Benzo(a)anthracene	20	42	88	695	882	2,858	40
	Bis(2-ethylhexyl) phthalate	19	40	92	667	920	2,844	20
	Metals							
	Nickel	654	654	951	10,840	9,456	1,341	478
	Cadmium	171	47	21	773	203	69	119
	Zinc	30,643	7,747	3,221	128,439	32,041	18,287	30,876
	Chromium	1,679	923	899	15,318	8,946	71	84
	Arsenic	306	324	818	5,382	8,135	13	21
	Copper	1,235	1,172	2,070	19,440	20,591	87	69
	Lead	7,057	796	239	13,200	2,376	33	25

Table F-1A (cont.)

Area	Contaminant	Total Mass in Soil 0-6 ft. (Kg)	Total Mass in Soil 6-15 ft. (Kg)	Total Mass in Soil 15-30 ft. (Kg)	Average Soil Concentration 6-15 ft. (µg/Kg)	Average Soil Concentration 15-30 ft. (µg/Kg)	Average Groundwater Concentration 6-15 ft. (µg/L)	Average Groundwater Concentration 15-30 ft. (µg/L)
IX	Volatiles							
	Phenol	31	42	78	1,038	1,157	20	20
	Methylene chloride	4	3	0.2	3	3	5	5
	Trans 1,2-dichloroethylene	0.1	0.1	0.2	3	3	123	18
	Chloroform	0.1	0.1	0.2	3	3	5	5
	Trichloroethylene	0.1	0.2	0.2	5	3	111	46
	1,1,1-Trichloroethane	0.1	0.1	0.2	3	3	15	7
	Toluene	0.1	0.1	1	5	20	5	5
	Tetrachlorothylene	0.1	0.1	0.2	3	3	5	5
	Ethylbenzene	0.1	0.1	0.2	3	3	5	5
	BN/AE							
	Naphthalene	18	26	46	625	676	20	20
	Phenanthrene	18	26	46	626	676	20	20
	PCB	38	1	4	35	70	0.1	0.1
	Pyrene	18	26	46	626	676	20	20
	Fluoranthene	18	26	46	626	676	20	20
	Benzo(a)anthracene	18	26	46	625	676	40	40
	Bis(2-ethylhexyl) phthalate	19	26	65	635	964	20	20
	Metals							
	Nickel	597	582	739	14,364	10,942	540	40
	Cadmium	135	82	28	2,018	412	95	1
	Zinc	15,478	14,221	4,319	350,817	63,915	36,101	48
	Chromium	9,470	3,767	817	92,928	12,092	13	10
	Arsenic	338	444	446	10,960	6,597	10	10
	Copper	2,337	1,758	1,637	43,359	21,373	52	50
	Lead	1,699	480	147	11,846	2,179	5	5

Table F-1B
TOTAL MASSES AND SITE AVERAGE CONTAMINANT CONCENTRATIONS
(NONDETECTS = 0) WESTERN PROCESSING, KENT, WASHINGTON

Area	Contaminant	Total Mass in Soil 0-6 ft. (Kg)	Total Mass in Soil 6-15 ft. (Kg)	Total Mass in Soil 15-30 ft. (Kg)	Average Soil Concentration 6-15 ft. (µg/Kg)	Average Soil Concentration 15-30 ft. (µg/Kg)	Average Groundwater Concentration 6-15 ft. (µg/L)	Average Groundwater Concentration 15-30 ft. (µg/L)
I/II	Volatiles							
	Phenol	293	724	190	2,929	460	108,583	1,490
	Methylene chloride	337	358	61	1,446	148	56,872	48,971
	Trans 1,2-dichloroethene	0.01	1	1	2	1	20,297	154
	Chloroform	28	99	1	403	2	2,378	2,012
	Trichloroethene	2,245	5,220	17	21,105	43	29,508	7,244
	1,1,1-Trichloroethane	376	883	1	2,275	1	21,609	1,014
	Toluene	1,016	2,122	22	8,582	52	1,633	314
	Tetrachloroethene	148	271	0.3	1,097	1	109	0
	Ethylbenzene	82	203	1	819	3	2	0
	BN/AE							
	Naphthalene	8,207	369	4	1,493	11	2	23
	Phenanthrene	22,391	549	0	2,221	0	0	0
	PCB	58	279	0	1,128	0	0	0
	Pyrene	17,003	83	0	334	0	0	0
	Fluoranthene	993	135	0	544	0	0	0
	Benzo(a)anthrancene	1,086	4	0	17	0	0.3	0
	Bis(2-ethylhexyl) phthalate	3,988	3,207	147	12,968	356	0	0
	Metals							
	Nickel	19,360	20,164	5,103	81,533	12,380	15,129	14,250
	Cadmium	4,738	7,778	605	31,451	1,468	2,391	964
	Zinc	777,160	494,287	93,713	1,872,331	227,355	126,447	117,687
	Chromium	76,329	164,679	16,681	665,879	40,469	5,249	313
	Arsenic	1,312	855	1,753	3,458	4,253	14	12
	Copper	51,022	84,395	10,678	341,250	25,905	1,333	757
	Lead	1,358,394	636,033	5,285	2,564,661	12,823	340	263

Table F-1B (cont.)

Area	Contaminant	Total Mass in Soil 0-6 ft. (Kg)	Total Mass in Soil 6-15 ft. (Kg)	Total Mass in Soil 15-30 ft. (Kg)	Average Soil Concentration 6-15 ft. (µg/Kg)	Average Soil Concentration 15-30 ft. (µg/Kg)	Average Groundwater Concentration 6-15 ft. (µg/L)	Average Groundwater Concentration 15-30 ft. (µg/L)
V	Volatiles							
	Phenol	29	75	0	1,240	0	745,954	39
	Methylene chloride	1	4	163	60	1,623	40,603	122
	Trans 1,2-dichloroethene	0	0.01	1	0.2	3	147,005	0
	Chloroform	0	0	0	0	0	1,213	3,787
	Trichloroethylene	0.1	1	1	23	6	89,535	8,310
	1,1,1-Trichloroethane	0	0	0	0	0	3,620	0
	Toluene	1	1	4	20	37	1	44
	Tetrachlorothylene	0.02	1	0.1	15	1	183	0
	Ethylbenzene	0	0	0	0	0	0	0
	BN/AE							
	Naphthalene	0	0	0	0	0	0	23
	Phenanthrene	0.1	0	0	0.06	0	0	0
	PCB	5	0	0	3	0	0	0
	Pyrene	0.1	0	0	0.06	0	0	0
	Fluoranthene	0.1	0	0	0.06	0	0	0
	Benzo(a)anthracene	0	0	0	0	0	0	0
	Bis(2-ethylhexyl) phthalate	0.01	0.04	0	1	0	0	0
	Metals							
	Nickel	654	654	951	10,840	9,456	1,327	461
	Cadmium	171	46	16	753	162	68	119
	Zinc	30,643	7,747	3,221	128,439	32,042	18,284	30,876
	Chromium	1,679	924	899	15,318	8,946	66	80
	Arsenic	306	324	813	5,381	8,807	5	15
	Copper	1,235	1,172	2,070	19,440	20,590	42	24
	Lead	7,057	796	233	13,199	2,324	29	21

Table F-1B (cont.)

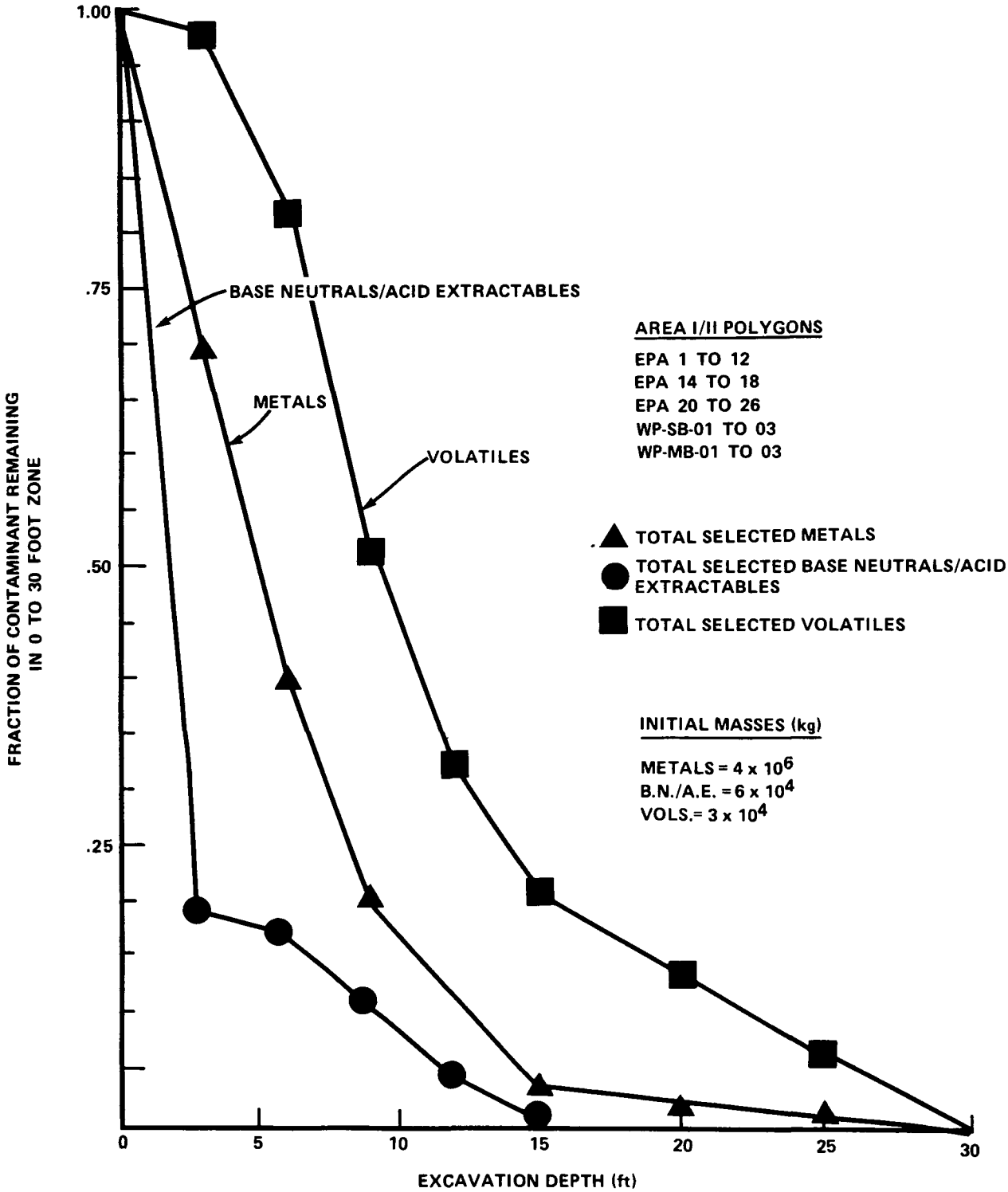
Area	Contaminant	Total Mass in Soil 0-6 ft. (Kg)	Total Mass in Soil 6-15 ft. (Kg)	Total Mass in Soil 15-30 ft. (Kg)	Average Soil Concentration 6-15 ft. (µg/Kg)	Average Soil Concentration 15-30 ft. (µg/Kg)	Average Groundwater Concentration 6-15 ft. (µg/L)	Average Groundwater Concentration 15-30 ft. (µg/L)
IX	**Volatiles**							
	Phenol	0	0	0	0	0	0	0
	Methylene chloride	4	3	4	67	68	20	5
	Trans 1,2-dichloroethylene	0	0	0	0	0	118	18
	Chloroform	0	0	0	0	0	0.3	0
	Trichloroethylene	0.01	0.1	0.01	2	0.1	106	46
	1,1,1-Trichloroethane	0	0	0	0	0	10	7
	Toluene	0.03	0.1	1	3	18	0.1	0
	Tetrachlorothylene	0	0	0	0	0	0	0
	Ethylbenzene	0.01	0.01	0	0.1	0	0	0
	BN/AE							
	Naphthalene	0.2	0	0	0	0	0	0
	Phenanthrene	0.02	0	0	0	0	0	0
	PCB	37	0	0	0	0	0	0
	Pyrene	0.2	0	0	0	0	0	0
	Fluoranthene	0.1	0	0	0	0	0	0
	Benzo(a)anthracene	0.3	0	0	0	0	0	0
	Bis(2-ethylhexyl) phthalate	1	1	443	10,719	6,557	0	0
	Metals							
	Nickel	594	547	728	13,509	10,770	540	0
	Cadmium	135	81	25	1,992	367	94	0
	Zinc	15,478	14,221					
	Chromium	9,470	3,767	817	92,928	12,092	7	0
	Arsenic	333	435	443	10,719	6,557	0	0
	Copper	2,320	1,738	1,429	42,872	21,161	3	0
	Lead	1,698	479	142	11,809	2,098	0	0

are generally much larger than the base polygons (caused by fewer groundwater data points) an extremely high contaminant concentration at one monitoring well can disproportionately affect a large area, particularly when the other wells have relatively low concentrations of the same compound. An example is trans 1,2-dichloroethene. Trans 1,2-dichloroethene was detected in 12 of 26 onsite wells. The site average is about 20,000 µg/L. Well 21 had a measured concentration of 390,000 µg/L. If this value is subtracted, the site average concentration is about 1,000 µg/L. Other contaminants that fall into this category are methylene chloride, and to a lesser degree, 1,1,1-trichloroethane, toluene, chloroform, and phenol.

The effectiveness of excavation in Areas I/II, V, and IX was evaluated. The total contaminant masses remaining (by contaminant class) versus excavation depth are summarized in Figures F-6, F-7, and F-8 and Table F-2A. The break in slope at 15 feet shown in the figures followed by a straight line decrease to 30 feet is caused by the use of the single concentration value at 22.5 feet to represent the 15- to 30-foot layer. The site average contaminant concentrations remaining versus excavation depth are summarized in Tables F-2B and F-2C. Table F-2B shows that a 15-foot excavation of Area I/II would remove the selected metals to background except for zinc, which would remain at about two times background. All metals are at background in Area V except zinc, which would require excavation to 3 feet to reach background levels. All metals are at background in Area IX except chromium and zinc, which would require excavation to 9 and 12 feet, respectively, to reach background levels.

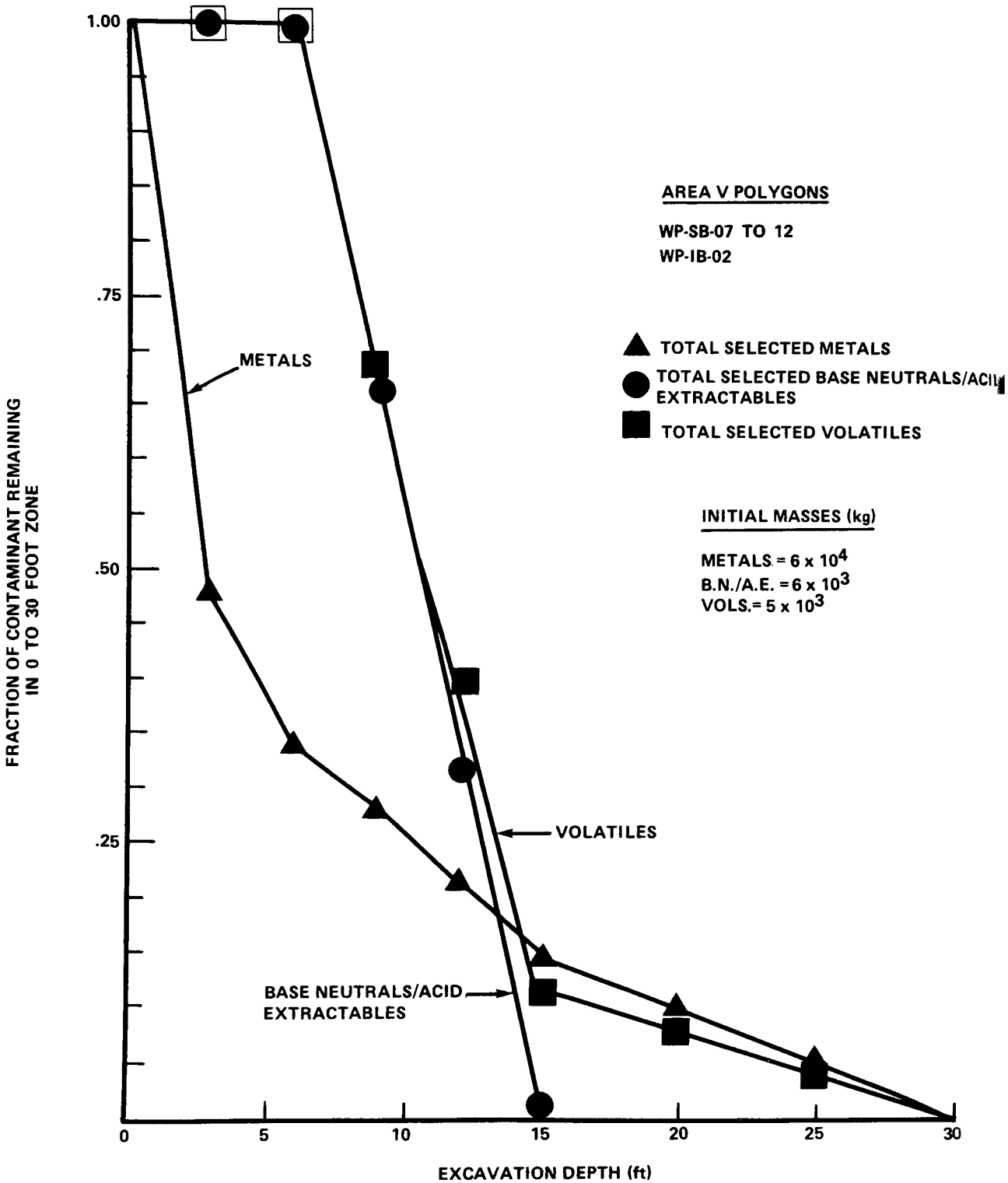
Table F-2A
EXCAVATION SUMMARY--FRACTION REMAINING
IN GROUNDWATER AND SOIL BY CONTAMINANT CLASS

Area	Excavation Depth (ft.)	Metals	Volatiles	BN/AE
I/II	0-6	.40	.82	.17
	0-15	.04	.20	.01
V	0-3	.48	1.0	1.0
	0-6	.32	1.0	1.0
	0-15	.13	.10	0
IX	0-3	.79	.86	.45
	0-6	.49	.76	.38
	0-15	.13	.44	.37



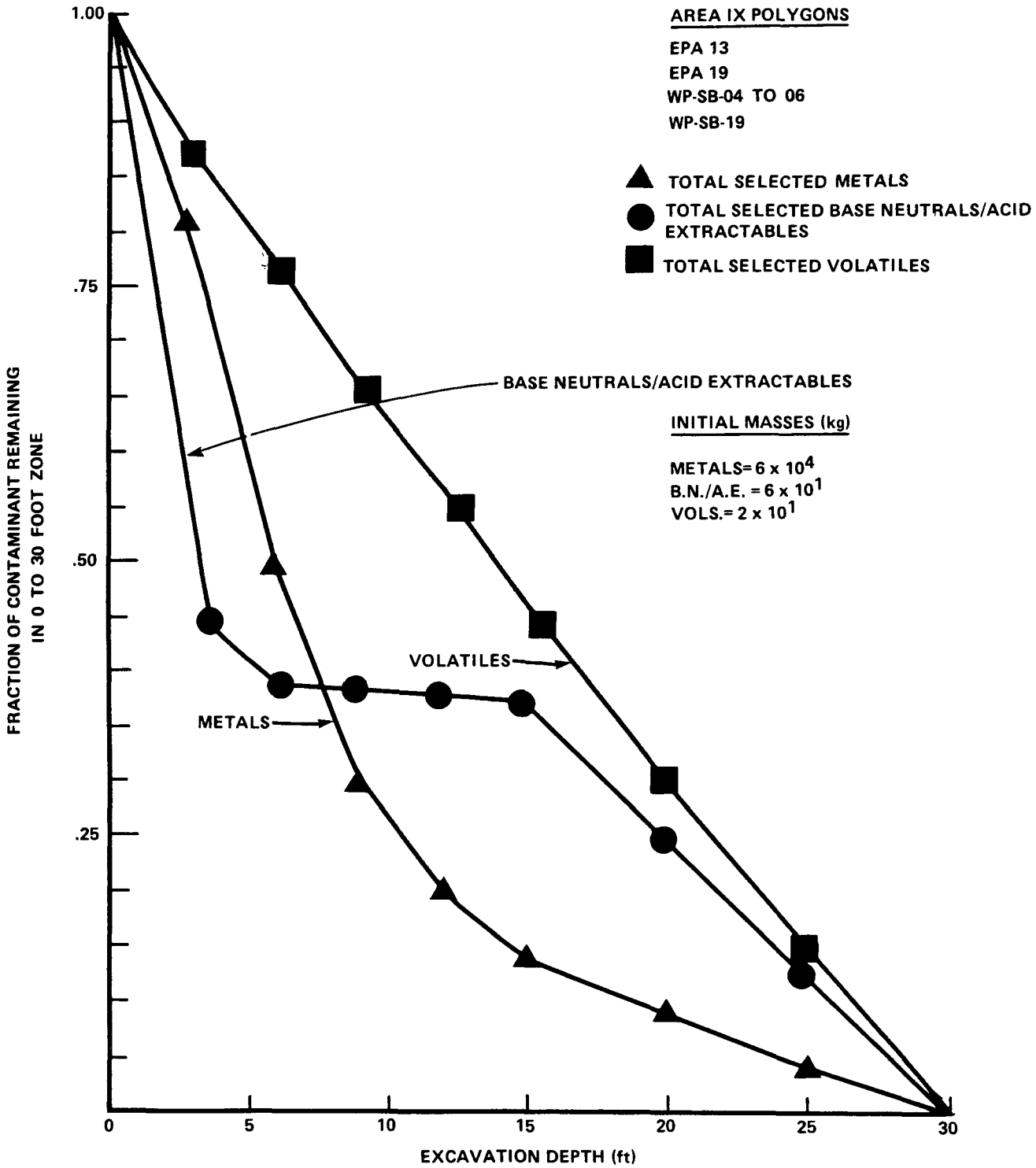
NOTE: SEE TEXT FOR LIST OF 23 SELECTED CONTAMINANTS

FIGURE F-6
EXCAVATION SUMMARY FOR AREA I/II
WESTERN PROCESSING, KENT, WASHINGTON



NOTE: SEE TEXT FOR LIST OF 23 SELECTED CONTAMINANTS

FIGURE F-7
EXCAVATION SUMMARY FOR AREA V
WESTERN PROCESSING, KENT, WASHINGTON



NOTE: SEE TEXT FOR LIST OF 23 SELECTED CONTAMINANTS

FIGURE F-8
EXCAVATION SUMMARY FOR AREA IX
WESTERN PROCESSING, KENT, WASHINGTON

Table F-2B
SOIL EXCAVATION SUMMARY--
SITE AVERAGE INORGANIC CONCENTRATIONS REMAINING

Area	Excavation Depth (feet)	Site Average Concentration Remaining in Soil From Excavation Depth to 30 Feet (µg/kg) Cd	Cr	Cu	Ni	Pb	Zn	As
I/II	0	15,900	313,000	177,000	54,300	2,420,000	1,620,000	5,000
	3	14,500	311,000	166,000	48,100	1,900,000	1,130,000	4,570
	6	12,700	275,000	144,000	38,400	968,000	844,000	4,160
	9	8,810	187,000	107,000	25,800	325,000	616,000	4,080
	12	4,240	102,000	64,000	18,200	105,000	392,000	4,180
	15	1,480	40,500	25,900	12,500	12,800	227,000	4,390
V	0	1,190	17,400	22,300	11,200	40,200	207,000	7,200
	3	580	13,100	20,700	10,400	13,400	94,500	7,050
	6	420	11,300	20,200	9,940	6,430	68,300	7,100
	9	330	10,400	20,000	9,600	6,200	63,300	7,300
	12	220	9,600	20,100	9,400	5,490	51,800	7,670
	15	200	8,950	20,600	9,460	2,380	32,000	8,130
IX	0	1,800	104,000	41,000	14,200	17,200	252,000	9,090
	3	1,500	84,400	36,800	13,000	11,700	230,000	8,760
	6	1,010	42,400	29,600	12,200	5,800	172,000	8,240
	9	640	17,700	24,500	11,600	2,580	120,000	7,640
	12	470	13,520	22,200	11,200	2,350	89,000	7,090
	15	410	12,100	21,400	10,900	2,180	63,900	6,600
Background Concentrations (µg/kg) From Table 3-5		2,900	40,000	73,000	43,000	76,000	109,000	12,000

Note: Underscored values are first concentrations below background.

Table F-2C
SOIL EXCAVATION SUMMARY--SITE AVERAGE ORGANIC CONCENTRATIONS REMAINING

Area	Excavation Depth (feet)	Site Average Concentration Remaining in Soil From Excavation Depth to 30 Feet (µg/kg)								
		Chloroform	Ethylbenzene	Methylene Chloride	Phenol	Tetrachloro-ethene	Toluene	Trans 1,2-dichloroethane	1,1,1-Trichloro-ethane	Trichloro-ethene
I/II	0	270	465	950	3,000	601	3,870	170	1,200	9,100
	15	6	7	150	1,100	4	55	5	5	46
V	0	0	0	830	520	5	26	2	0	11
	15	0	0	1,600	0	1	37	3	0	6
IX	0	0	0	82	0	0	10	0	0	0
	15	0	0	68	0	0	18	0	0	1

Area	Excavation Depth (feet)	Site Average Concentration Remaining in Soil (µg/kg)						
		Benzo(a) anthracene	Bis(2-ethyl-hexyl)phthalate	Fluoranthene	Naphthalene	PCB	Phenanthrene	Pyrene
I/II	0	1,300	8,900	1,400	10,400	400	27,800	20,700
	15	0	360	0	11	0	0	0
V	0	0	0	1	0	25	1	1
	15	0	0	0	0	0	0	0
IX	0	2	180	1	1	270	0	1
	15	0	340	0	0	0	0	0

Note: Nondetects = 0 except for Area I/II volatiles where nondetects = detection limit.

Table F-2C shows that with a 15-foot excavation of Area I/II, all selected organics would be reduced to nondetected or low levels except methylene chloride, phenol, and bis(2-ethylhexyl)phthalate. Methylene chloride in Area V and bis(2-ethylhexyl)phthalate in Area IX also would remain at levels above 100 µg/kg..

GROUNDWATER QUALITY ANALYSIS

A geochemical model of the Western Processing area was prepared to estimate contaminant concentration changes in surface water and groundwater associated with Alternatives 1, 2, 3, and 5. The results were used to support initial treatment process selection and conceptual design, to identify contaminants that could be significantly reduced during various lengths of pumping, and to qualitatively evaluate effectiveness of remedial actions on Mill Creek water quality.

Accurate prediction of groundwater contaminant concentrations versus time requires simulation of complex physical and geochemical processes. These processes include: contaminant partitioning between groundwater and the aquifer skeleton and other sorption sites such as particulate organic carbon and metal hydroxides; mixing processes such as dispersion and diffusion; recharge dilution; chemical reactions such as precipitation, hydrolysis, and chelation; cosolvent/common ion effects; and biological degradation.

The geochemical model presented here required numerous assumptions to make the problem tractable. Clearly most of the assumptions are violated to some degree in natural systems; however, many are offsetting. The usefulness of the model is its ability to estimate relative contaminant behavior.

The geochemical model was developed in two ways: (1) using a mass balance approach and (2) using an exponential decay approach. Both yield exactly the same results. The mass balance method is based on a series of recursive equations. Mass is "removed" from the system at the first timestep. The resulting mass then becomes the initial mass of the second timestep and is allowed to equilibrate with groundwater. The process is then repeated into the future. An exponential decay function of the form $C=Co\ \exp(-at)$ can be written to replace the recursive equations. The decay constant (a) for each chemical is calculated based on the retardation factor (velocity of water divided by the velocity of chemical).

ASSUMPTIONS

The mass balance method assumes that "equilibrated" groundwater containing contaminants is removed from the contaminated soil volume or cell as a slug (i.e., no dispersion,

diffusion, or recharge dilution). Groundwater free from contaminants then is moved into the cell to fill the pore space (one pore volume). Desorption equilibrium described by a linear isotherm with a constant distribution coefficient is assumed to occur between the aquifer skeleton and the groundwater. Equilibrium is assumed fast compared to groundwater flow and totally reversible. Cosolvent/ common ion effects and chemical and biochemical reactions are also assumed to be insignificant. The groundwater and aquifer skeleton equilibrium concentrations are determined using the linear isotherm and total mass of contaminant available in the cell (sum of contaminant adsorbed on the aquifer skeleton and dissolved in groundwater). The equilibrated groundwater containing contaminants then is removed from the cell as a slug and the process repeated. Each groundwater pore volume removes contaminants from the system, thus changing the estimated soil and groundwater concentrations with time in the cell.

The linear isotherm used here is:

$$Sc = Kd \times Wc$$

where

$$Sc = \frac{\text{mass of solute adsorbed or precipitated}}{\text{unit dry mass of soil}}$$

$$Wc = \frac{\text{mass of solute in solution}}{\text{unit volume of water}}$$

Kd = distribution coefficient

The distribution coefficients for organic compounds were estimated based on octanol/water partition coefficients, where available, or on solubility (Karickhoff et al., 1979). The distribution coefficients for the metals were approximated based on ratios of the average shallow soil to shallow groundwater concentrations determined from site-specific data. The relative metal mobilities (Ni>Cd>Zn>Cu>Pb), as represented by the distribution coefficients, agree with those reported in the literature (e.g., Abd-Elfattah and Wada, 1981; Huang et al., 1977; and Balistrieri and Murray, 1982).

Additional assumptions were as follows:

1) No slurry wall (Alternatives 2, 3, and 5)

2) Contaminated zone is 15 acres (11-acre site plus 4 adjacent acres) and 25 feet thick below the water table

3) Effective porosity = 0.25

4) Pumping is distributed uniformly throughout the contaminated area (Alternative 2 and less accurate but applicable to Alternative 3)

5) Total pumping rate = 100 gpm; effective pumping rate (i.e., removing water from or flushing only the contaminated zone) = 70 gpm (Alternatives 2, 3, and 5)

6) No significant changes in pore volume

7) Pore volume flushing time = 0.8 year (based on assumptions 1 through 6)

8) Site average contaminant distributions are appropriate.

9) Insignificant contaminant contribution from the unsaturated zone (i.e., contaminants in unsaturated zone have either been removed or capped) (Alternatives 2 and 3)

10) Soil density = 1.44 g/cm^3

11) Particulate organic carbon content of soil = 1 percent

Mass Balance Equations

The derivation of the recursive equations used in the mass balance approach was as follows:

Let

Total mass of contaminant = TMCONT
Mass of soil contaminant = MCSOIL
Mass of groundwater contaminant = MCGW
Density of soil = ρs
Density of water = ρw (assumed equal to one)
Volume of soil = Vs
Porosity of soil = ns

By definition:

$$TMCONT = MCSOIL + MCGW \quad (1)$$

and

$$Kd = \frac{MCSOIL}{\rho s \times Vs} \times \frac{\rho w \times ns \times Vs}{MCGW}$$

$$= \frac{MCSOIL}{MCGW} \times \frac{ns}{\rho s} \quad (2)$$

Rearranging Equation 2 yields:

$$MCSOIL = MCGW \times \frac{Kd \times \rho s}{ns} \quad (3)$$

or

$$MCGW = MCSOIL \times \frac{ns}{Kd \times \rho s} \quad (4)$$

Substituting Equation 3 into Equation 1 yields:

$$TMCONT = MCGW \times \frac{Kd \times \rho s}{ns} + MCGW$$

$$= MCGW \left(1 + \frac{Kd \times \rho s}{ns}\right) \quad (5)$$

Note: $1 + \frac{Kd \times \rho s}{ns}$ is by definition the Retardation Factor (R).

Then per pore volume time (n):

$$MCGW(n+1) = TMCONT(n)/R \quad (6)$$
$$MCSOIL(n+1) = TMCONT(n) - MCGW(n+1) \quad (7)$$
$$TMCONT(n+1) = MCSOIL(n+1) \quad (8)$$

Substituting Equation 4 into Equation 1 and proceeding as above yields from the soil viewpoint:

$$MCSOIL(n+1) = TMCONT(N) \times ((R-1)/R) \quad (9)$$
$$MCGW(n+1) = TMCONT(n) - MCSOIL(n+1) \quad (10)$$
$$TMCONT(n+1) = MCSOIL(n+1) \quad (11)$$

Exponential Decay Equation

The relative decrease in mass (or concentration) with time described by Equations 6 through 11 is constant, i.e., for each pore volume the same ratio of mass is removed from the system. With the constant ratio, the total mass removed per pore volume decreases over time. This constant reduction can be described by a first order exponential decay equation of the form

$$Mt = Mo \exp(-at) \quad (12)$$

where

Mt = Contaminant mass at time t
Mo = Initial contaminant mass
a = Decay constant (first order)
t = Time

(Note: Concentrations can be substituted for mass in Equation 12)

The decay constant can be calculated as:

$$a = \ln(Mo/Mp) \quad (13)$$

where,

Mo = Initial total mass of contaminant

Mp = Total mass of contaminant remaining after 1 pore volume

Using Equations 6, 7, and 8, Mo/Mp can be written as:

$$Mo/Mp = 1/(1-(1/R)) \quad (14)$$

or using Equations 9, 10, and 11

$$Mo/Mp = R/(R-1) \quad (15)$$

(Note: Equations 14 and 15 are equal)

Substituting Equation 15 into Equation 13 yields an expression for the decay constant in terms of the retardation factor:

$$a = \ln(R/(R-1)) \quad (16)$$

Equation 16 can be substituted into Equation 9 and corrected for fractional pore volume times to yield:

$$Mt = Mo \exp(-(\ln(R/(R-1)) \times \text{Time}/\text{Pore volume time}) \quad (17)$$

GROUNDWATER PUMPING RESULTS

Equation 17 was used to calculate the fraction remaining and concentrations versus time for the 23 contaminants discussed in the Contaminant Source Quantification section of this appendix. The results are presented in Tables F-3A, F-3B, and F-3C. The results must be interpreted remembering the assumptions and limitations of the analysis. They represent relative behavior and should not be relied upon alone for treatment process selection and conceptual design, or quantitative determinations of the effectiveness of groundwater pumping as a remedial action component.

Table F-3A shows that after five years of source pumping any contaminants with distribution coefficients less than about 1.3 would be reduced to 50 percent of initial concentrations. Typically these are the low molecular weight volatile organics (phenol through 1,1,1-trichloroethane on the list of 23 selected contaminants). Thirty years of pumping would reduce to 50 percent of initial concentrations those

Table F-3A

GROUNDWATER PUMPING SUMMARY--ESTIMATED CONTAMINANT FRACTION REMAINING IN SOILS AND GROUNDWATER VERSUS TIME

Compound/Element[a]	Kd[b]	Fraction Remaining After Time[c] (Years)					
		5	10	15	20	25	30
Phenol	0.03	$8x10^{-6}$	-	-	-	-	-
Methylene chloride	0.11	$3x10^{-3}$	$1x10^{-5}$	-	-	-	-
Trans 1,2-dichloroethene	0.19	0.02	$4x10^{-4}$	$7x10^{-6}$	$1x10^{-7}$	-	-
Chloroform	0.58	0.2	0.04	$8x10^{-3}$	$2x10^{-3}$	$3x10^{-4}$	$7x10^{-5}$
Trichloroethene	1.20	0.44	0.19	0.08	0.04	0.02	$7x10^{-3}$
1,1,1-Trichloroethane	1.30	0.47	0.22	0.10	0.05	0.02	0.01
Toluene	3.0	0.71	0.50	0.34	0.25	0.18	0.13
Tetrachloroethene	4.8	0.81	0.65	0.52	0.42	0.34	0.27
Ethylbenzene	9.1	0.89	0.79	0.71	0.63	0.56	0.50
Naphthalene	15	0.93	0.87	0.81	0.76	0.70	0.66
Phenanthrene	180	0.99	0.99	0.98	0.98	0.97	0.97
PCB	630	1	1	0.99	0.99	0.99	0.99
Pyrene	1,300	1	1	1	1	1	1
Fluoranthene	1,300	1	1	1	1	1	1
Benzo(a) anthracene	2,500	1	1	1	1	1	1
Bis(2-ethylhexyl) phthalate	3,300,000	1	1	1	1	1	1
Nickel	4	0.77	0.60	0.46	0.35	0.27	0.21
Cadmium	10	0.90	0.81	0.73	0.66	0.59	0.53
Zinc	15	0.93	0.87	0.81	0.76	0.70	0.66
Chromium	100	0.99	0.98	0.97	0.96	0.95	0.94
Arsenic	140	0.99	0.98	0.98	0.97	0.96	0.96
Copper	200	0.99	0.99	0.98	0.98	0.97	0.97
Lead	7,500	1	1	1	1	1	1

[a] Indicator contaminants (from Chapter 3) and other selected contaminants identified in more than 30 soil samples from the site and vicinity.

[b] Distribution coefficient.

[c] M/Mo or C/Co (mass or concentration basis).

Table F-3B
GROUNDWATER PUMPING SUMMARY--
PREDICTED GROUNDWATER CONCENTRATIONS
WITH CAPPING OR 6-FOOT EXCAVATION

BENZENE
Distribution Coefficient = .03
Initial Groundwater Concentration (ug/l) = 42000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.096773330	4064.
2.	.009365076	393.
3.	.000906290	38.
4.	.000087705	4.
5.	.000008487	0.
10.	.000000000	0.
15.	.000000000	0.
20.	.000000000	0.
25.	.000000000	0.
30.	.000000000	0.
60.	.000000000	0.
120.	.000000000	0.

TRICHLOROETHYLENE
Distribution Coefficient = 1.20
Initial Groundwater Concentration (ug/l) 16000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.848078200	13569.
2.	.719236600	11508.
3.	.609968900	9760.
4.	.517301300	8277.
5.	.438712000	7019.
10.	.192468200	3079.
15.	.084438090	1351.
20.	.037044000	593.
25.	.016251640	260.
30.	.007129791	114.
60.	.000050834	1.
120.	.000000003	0.

METHYLENE CHLORIDE
Distribution Coefficient = .11
Initial Groundwater Concentration (ug/l) 52000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.315048500	16383.
2.	.099255530	5161.
3.	.031270310	1626.
4.	.009851661	512.
5.	.003103750	161.
10.	.000009633	1.
15.	.000000030	0.
20.	.000000000	0.
25.	.000000000	0.
30.	.000000000	0.
60.	.000000000	0.
120.	.000000000	0.

1,1,1 TRICHLOROETHANE
Distribution Coefficient = 1.30
Initial Groundwater Concentration (ug/l) 8700.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.858243000	7467.
2.	.736581100	6408.
3.	.632165700	5500.
4.	.542551800	4720.
5.	.465641300	4051.
10.	.216821800	1886.
15.	.100961200	878.
20.	.047011700	409.
25.	.021890580	190.
30.	.010193160	89.
60.	.000103901	1.
120.	.000000011	0.

TRANS 1,2 DICHLOROETHYLENE
Distribution Coefficient = .19
Initial Groundwater Concentration (ug/l) = 7700.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.453147400	3489.
2.	.205342600	1581.
3.	.093050490	716.
4.	.042165590	325.
5.	.019107230	147.
10.	.000365086	3.
15.	.000006976	0.
20.	.000000133	0.
25.	.000000003	0.
30.	.000000000	0.
60.	.000000000	0.
120.	.000000000	0.

TOLUENE
Distribution Coefficient 3.00
Initial Groundwater Concentration (ug/l) 880.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.933693500	766.
2.	.871783500	715.
3.	.813978600	667.
4.	.760006400	623.
5.	.709613000	582.
10.	.503550600	413.
15.	.357326100	293.
20.	.253563300	208.
25.	.179931800	148.
30.	.127682000	105.
60.	.016302680	13.
120.	.000265778	0.

CHLOROFORM
Distribution Coefficient .58
Initial Groundwater Concentration (ug/l) = 2200.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.726637700	1599.
2.	.528002300	1160.
3.	.383666400	844.
4.	.278786500	613.
5.	.202576700	446.
10.	.041037330	90.
15.	.008313207	18.
20.	.001684063	4.
25.	.000341152	1.
30.	.000069109	0.
60.	.000000005	0.
120.	.000000000	0.

TETRACHLOROETHYLENE
Distribution Coefficient = 4.80
Initial Groundwater Concentration (ug/l) = 50.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.957595800	48.
2.	.916989700	46.
3.	.878105500	44.
4.	.840870100	42.
5.	.805213700	40.
10.	.648369100	32.
15.	.522075800	26.
20.	.420382600	21.
25.	.338497800	17.
30.	.272563100	14.
60.	.074290640	4.
120.	.005519099	0.

Table F-3B (Continued)

ETHYLBENZENE
Distribution Coefficient = 9.10
Initial Groundwater Concentration (ug/l) = 10.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.977216700	10.
2.	.954952400	10.
3.	.933195500	9.
4.	.911934200	9.
5.	.891157300	9.
10.	.794161300	8.
15.	.707722700	7.
20.	.630692200	6.
25.	.562046000	6.
30.	.500871400	5.
60.	.250872100	3.
120.	.062936830	1.

PYRENE
Distribution Coefficient = 1300.00
Initial Groundwater Concentration (ug/l) = 0.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999837200	0.
2.	.999674400	0.
3.	.999511700	0.
4.	.999348900	0.
5.	.999186300	0.
10.	.998373200	0.
15.	.997560800	0.
20.	.996749000	0.
25.	.995938000	0.
30.	.995127600	0.
60.	.990278800	0.
120.	.980652200	0.

NAPTHALENE
Distribution Coefficient = 15.00
Initial Groundwater Concentration (ug/l) = 15.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.986064400	15.
2.	.972323000	15.
3.	.958773100	14.
4.	.945412000	14.
5.	.932237100	14.
10.	.869066100	13.
15.	.810175700	12.
20.	.755275800	11.
25.	.704096100	11.
30.	.656384600	10.
60.	.430840700	6.
120.	.185623700	3.

FLUORANTHRENE
Distribution Coefficient = 1300.00
Initial Groundwater Concentration (ug/l) = 0.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999837200	0.
2.	.999674400	0.
3.	.999511700	0.
4.	.999348900	0.
5.	.999186300	0.
10.	.998373200	0.
15.	.997560800	0.
20.	.996749000	0.
25.	.995938000	0.
30.	.995127600	0.
60.	.990278800	0.
120.	.980652200	0.

PHENANTHRENE
Distribution Coefficient = 180.00
Initial Groundwater Concentration (ug/l) = 0.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.998825000	0.
2.	.997651400	0.
3.	.996479200	0.
4.	.995308300	0.
5.	.994138800	0.
10.	.988312100	0.
15.	.982519400	0.
20.	.976760700	0.
25.	.971035700	0.
30.	.965344400	0.
60.	.931889700	0.
120.	.868418500	0.

BENZO(A)ANTHRACENE
Distribution Coefficient = 2500.00
Initial Groundwater Concentration (ug/l) = 0.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999915200	0.
2.	.999830500	0.
3.	.999745800	0.
4.	.999661000	0.
5.	.999576300	0.
10.	.999152800	0.
15.	.998729500	0.
20.	.998306400	0.
25.	.997883400	0.
30.	.997460700	0.
60.	.994927800	0.
120.	.989881300	0.

PCB
Distribution Coefficient = 630.00
Initial Groundwater Concentration (ug/l) = 0.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999664000	0.
2.	.999328100	0.
3.	.998992300	0.
4.	.998656600	0.
5.	.998321100	0.
10.	.996645000	0.
15.	.994971700	0.
20.	.993301200	0.
25.	.991633500	0.
30.	.989968700	0.
60.	.980038000	0.
120.	.960474400	0.

BIS(2-ETHYLHEXYL)PTHALATE
Distribution Coefficient = 3300000.00
Initial Groundwater Concentration (ug/l) = 0

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	1.000000000	0.
2.	1.000000000	0.
3.	1.000000000	0.
4.	1.000000000	0.
5.	1.000000000	0.
10.	1.000000000	0.
15.	1.000000000	0.
20.	1.000000000	0.
25.	1.000000000	0.
30.	1.000000000	0.
60.	1.000000000	0.
120.	1.000000000	0.

Table F-3B (Continued)

NICKEL
Distribution Coefficient = 4.00
Initial Groundwater Concentration (ug/l) = 15000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.949535700	14243.
2.	.901561000	13523.
3.	.856037300	12841.
4.	.812812300	12192.
5.	.771763900	11577.
10.	.595628800	8934.
15.	.459688400	6895.
20.	.354773700	5322.
25.	.273803600	4107.
30.	.211313400	3170.
60.	.044653350	670.
120.	.001993922	30.

ARSENIC
Distribution Coefficient 140.00
Initial Groundwater Concentration (ug/l) =

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.996489700	19.
2.	.996981700	19.
3.	.995476000	19.
4.	.993972500	19.
5.	.992471400	19.
10.	.984999400	19.
15.	.977583800	19.
20.	.970223900	18.
25.	.962919400	18.
30.	.955669900	18.
60.	.913305100	17.
120.	.834126200	16.

CADMIUM
Distribution Coefficient 10.00
Initial Groundwater Concentration (ug/l) 1500.

YEARS	FRACTION REMAINING C/Co	Gw CONC (ug/l)
1.	.979288300	1469.
2.	.958888100	1438.
3.	.938970300	1408.
4.	.919466300	1379.
5.	.900367400	1351.
10.	.810661800	1216.
15.	.729893300	1095.
20.	.657172100	986.
25.	.591696400	888.
30.	.532744200	799.
60.	.283816300	426.
120.	.080551720	121.

COPPER
Distribution Coefficient 200.00
Initial Groundwater Concentration (ug/l)

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.998942400	999.
2.	.997885900	998.
3.	.996830500	997.
4.	.995776200	996.
5.	.994723100	995.
10.	.989474000	989.
15.	.984252600	984.
20.	.979058800	979.
25.	.973892400	974.
30.	.968753300	969.
60.	.938482900	938.
120.	.880750200	881.

ZINC
Distribution Coefficient = 15.00
Initial Groundwater Concentration (ug/l) 121000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.986064400	119314.
2.	.972323000	117651.
3.	.958773100	116013.
4.	.945413000	114395.
5.	.932237.00	112801.
10.	.869066100	105157.
15.	.810175700	98031.
20.	.755275800	91388.
25.	.704096100	85196.
30.	.656384600	79423.
60.	.430840700	52132.
120.	.185623700	22460.

LEAD
Distribution Coefficient 7500.00
Initial Groundwater Concentration (ug/l)

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999971800	290.
2.	.999943600	290.
3.	.999915400	290.
4.	.999887200	290.
5.	.999859000	290.
10.	.999718000	290.
15.	.999577000	290.
20.	.999436100	290.
25.	.999295200	290.
30.	.999154300	290.
60.	.998309300	290.
120.	.996621400	289.

CHROMIUM
Distribution Coefficient = 100.00
Initial Groundwater Concentration (ug/l) 2200.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.997886800	2195.
2.	.995778100	2191.
3.	.993673800	2186.
4.	.991573900	2181.
5.	.989478500	2177.
10.	.979067800	2154.
15.	.968766600	2131.
20.	.958573800	2109.
25.	.948488200	2087.
30.	.938508700	2065.
60.	.880798600	1938.
120.	.775806200	1707.

Table F-3C
GROUNDWATER PUMPING SUMMARY--
PREDICTED GROUNDWATER CONCENTRATIONS
WITH 15-FOOT EXCAVATION

PHENOL
Distribution Coefficient = .03
Initial Groundwater Concentration (ug/l) = 1500.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.036818690	55.
2.	.001355616	2.
3.	.000049912	0.
4.	.000001838	0.
5.	.000000068	0.
10.	.000000000	0.
15.	.000000000	0.
20.	.000000000	0.
25.	.000000000	0.
30.	.000000000	0.
60.	.000000000	0.
120.	.000000000	0.

TRICHLOROETHYLENE
Distribution Coefficient = 1.20
Initial Groundwater Concentration (ug/l) = 7200.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.791178700	5704.
2.	.627547100	4518.
3.	.497129500	3579.
4.	.393815300	2835.
5.	.311978100	2246.
10.	.097326610	701.
15.	.030363190	219.
20.	.009472469	68.
25.	.002955147	21.
30.	.000921923	7.
60.	.000000850	0.
120.	.000000000	0.

VINYL CHLORIDE
Distribution Coefficient = .11
Initial Groundwater Concentration (ug/l) = 49000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.195348230	9572.
2.	.038160910	1870.
3.	.007454665	365.
4.	.001456255	71.
5.	.000284477	14.
10.	.000000081	0.
15.	.000000023	0.
20.	.000000000	0.
25.	.000000000	0.
30.	.000000000	0.
60.	.000000000	0.
120.	.000000000	0.

1,1,1 TRICHLOROETHANE
Distribution Coefficient = 1.30
Initial Groundwater Concentration (ug/l) = 1000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.805635700	806.
2.	.649048900	649.
3.	.522836900	523.
4.	.421264400	421.
5.	.339385600	339.
10.	.115182600	115.
15.	.039091330	39.
20.	.013267030	13.
25.	.004502640	5.
30.	.001528132	2.
60.	.000002335	0.
120.	.000000000	0.

TRANS 1,2 DICHLOROETHYLENE
Distribution Coefficient = .15
Initial Groundwater Concentration (ug/l) = 160.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.355553220	56.
2.	.108656600	17.
3.	.033232250	5.
4.	.011375630	2.
5.	.003715089	1.
10.	.000013808	0.
15.	.000000051	0.
20.	.000000000	0.
25.	.000000000	0.
30.	.000000000	0.
60.	.000000000	0.
120.	.000000000	0.

TOLUENE
Distribution Coefficient = 3.00
Initial Groundwater Concentration (ug/l) = 320.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.907559400	290.
2.	.823664100	264.
3.	.747524100	239.
4.	.678422600	217.
5.	.615708800	197.
10.	.379057300	121.
15.	.233413500	75.
20.	.143714800	46.
25.	.088486430	28.
30.	.054481870	17.
60.	.002968874	1.
120.	.000008811	0.

CHLOROFORM
Distribution Coefficient = .58
Initial Groundwater Concentration (ug/l) = 2000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.636836200	1273.
2.	.405382000	811.
3.	.258105200	516.
4.	.164334600	329.
5.	.104631200	209.
10.	.010947680	22.
15.	.001145469	2.
20.	.000119852	0.
25.	.000012540	0.
30.	.000001312	0.
60.	.000000000	0.
120.	.000000000	0.

TETRACHLOROETHYLENE
Distribution Coefficient = 4.80
Initial Groundwater Concentration (ug/l) = 5.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.940579700	5.
2.	.884830000	4.
3.	.832121400	4.
4.	.782678500	4.
5.	.736169600	4.
10.	.541945600	3.
15.	.398983900	2.
20.	.293705100	1.
25.	.216816700	1.
30.	.159172200	1.
60.	.025335780	0.
120.	.000641902	0.

Table F-3C (Continued)

ETHYLBENZENE
Distribution Coefficient = 9.10
Initial Groundwater Concentration (ug/l) = 5.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.967941600	5.
2.	.936911000	5.
3.	.906875100	5.
4.	.877803200	4.
5.	.849661300	4.
10.	.721924300	4.
15.	.613391200	3.
20.	.521174700	3.
25.	.442822000	2.
30.	.376246700	2.
60.	.141563100	1.
120.	.020040100	0.

PYRENE
Distribution Coefficient = 1300.00
Initial Groundwater Concentration (ug/l) =

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999769900	0.
2.	.999539700	0.
3.	.999309700	0.
4.	.999079700	0.
5.	.998849700	0.
10.	.997700800	0.
15.	.996553200	0.
20.	.995406900	0.
25.	.994262000	0.
30.	.993118300	0.
60.	.986284000	0.
120.	.972756100	0.

NAPTHALENE
Distribution Coefficient = 15.00
Initial Groundwater Concentration (ug/l) = 23.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.980254500	23.
2.	.961055800	22.
3.	.942214900	22.
4.	.923705000	21.
5.	.905558800	21.
10.	.820036600	19.
15.	.742591300	17.
20.	.672460100	15.
25.	.608952100	14.
30.	.551441800	13.
60.	.304088100	7.
120.	.092469600	2.

FLUORANTHRENE
Distribution Coefficient = 1300.00
Initial Groundwater Concentration (ug/l) =

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999769900	0.
2.	.999539700	0.
3.	.999309700	0.
4.	.999079700	0.
5.	.998849700	0.
10.	.997700800	0.
15.	.996553200	0.
20.	.995406900	0.
25.	.994262000	0.
30.	.993118300	0.
60.	.986284000	0.
120.	.972756100	0.

PHENANTHRENE
Distribution Coefficient = 180.00
Initial Groundwater Concentration (ug/l) = 0.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.996333300	0.
2.	.996681200	0.
3.	.995033900	0.
4.	.993373400	0.
5.	.991723600	0.
10.	.983515700	0.
15.	.975375700	0.
20.	.967303100	0.
25.	.959297400	0.
30.	.951357800	0.
60.	.905081700	0.
120.	.819.72900	0.

BENZO(A)ANTHRACENE
Distribution Coefficient = 2500.00
Initial Groundwater Concentration (ug/l)

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999080200	0.
2.	.998760400	0.
3.	.998440600	0.
4.	.998120800	0.
5.	.997801100	0.
10.	.996802500	0.
15.	.995804300	0.
20.	.994806500	0.
25.	.993808900	0.
30.	.992811800	0.
60.	.988836500	0.
120.	.985724300	0.

PCB
Distribution Coefficient = 630.00
Initial Groundwater Concentration (ug/l) = 0.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999525000	0.
2.	.999050200	0.
3.	.998575600	0.
4.	.998101300	0.
5.	.997627300	0.
10.	.995260000	0.
15.	.992896400	0.
20.	.990542500	0.
25.	.988198100	0.
30.	.985847300	0.
60.	.971894900	0.
120.	.944579600	0.

BIS(2-ETHYLHEXYL)PTHALATE
Distribution Coefficient = 3300000.00
Initial Groundwater Concentration (ug/l)

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	1.000000000	0.
2.	1.000000000	0.
3.	1.000000000	0.
4.	1.000000000	0.
5.	1.000000000	0.
10.	1.000000000	0.
15.	1.000000000	0.
20.	1.000000000	0.
25.	1.000000000	0.
30.	1.000000000	0.
60.	1.000000000	0.
120.	1.000000000	0.

Table F-3C (Continued)

NICKEL
Distribution Coefficient = 4.00
Initial Groundwater Concentration (ug/l) 14000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.929364800	13011.
2.	.863718900	12092.
3.	.802709900	11238.
4.	.746010400	10444.
5.	.693315800	9706.
10.	.480686800	6730.
15.	.333267700	4666.
20.	.231059600	3235.
25.	.160197400	2243.
30.	.111067400	1555.
60.	.012335960	173.
120.	.000152176	2.

ARSENIC
Distribution Coefficient = 140.00
Initial Groundwater Concentration (ug/l) 18.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.997865400	18.
2.	.995735500	18.
3.	.993610000	18.
4.	.991489100	18.
5.	.989372700	18.
10.	.978858300	18.
15.	.968455700	17.
20.	.958163600	17.
25.	.947980900	17.
30.	.937906400	17.
60.	.879668400	16.
120.	.773816500	14.

CADMIUM
Distribution Coefficient 10.00
Initial Groundwater Concentration (ug/l) 960.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.971759900	932.
2.	.942374600	905.
3.	.914815500	878.
4.	.888070000	853.
5.	.862102700	828.
10.	.743221000	713.
15.	.640732900	615.
20.	.552377500	530.
25.	.476206200	457.
30.	.410538600	394.
60.	.168542000	162.
120.	.028406400	27.

COPPER
Distribution Coefficient 200.00
Initial Groundwater Concentration (ug/l) 790.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.998505100	789.
2.	.997012400	788.
3.	.995521900	786.
4.	.994033700	785.
5.	.992547700	784.
10.	.985150900	778.
15.	.977809300	772.
20.	.970522300	767.
25.	.963289700	761.
30.	.956111000	755.
60.	.914148200	722.
120.	.835666800	660.

ZINC
Distribution Coefficient 15.00
Initial Groundwater Concentration (ug/l) 118000.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.980354900	115682.
2.	.961095800	113409.
3.	.942214900	111181.
4.	.923705000	108997.
5.	.905558800	106856.
10.	.820036600	96764.
15.	.742591300	87626.
20.	.672460100	79350.
25.	.608352100	71856.
30.	.551441800	65070.
60.	.304088100	35882.
120.	.092469600	10911.

LEAD
Distribution Coefficient = 7500.00
Initial Groundwater Concentration (ug/l) = 270.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.999960100	270.
2.	.999920200	270.
3.	.999880400	270.
4.	.999840500	270.
5.	.999800700	270.
10.	.999601400	270.
15.	.999402100	270.
20.	.999202800	270.
25.	.999003600	270.
30.	.998804500	270.
60.	.997610500	269.
120.	.995226700	269.

CHROMIUM
Distribution Coefficient 100.00
Initial Groundwater Concentration (ug/l) = 320.

YEARS	FRACTION REMAINING C/Co	GW CONC (ug/l)
1.	.997013700	319.
2.	.994036300	318.
3.	.991067800	317.
4.	.988108100	316.
5.	.985157300	315.
10.	.970534900	311.
15.	.956129600	306.
20.	.941938000	301.
25.	.927957100	297.
30.	.914183700	293.
60.	.835731900	267.
120.	.698447800	224.

contaminants with distribution coefficients less than about 10. Typically these are the higher molecular weight volatile organics and the most mobile heavy metals (toluene through ethylbenzene, and nickel and cadmium on the selected contaminant list).

Tables F-3B and F-3C present the estimated groundwater concentrations versus time for the capping or 6-foot excavation and 15-foot excavation alternatives. The results indicate that groundwater pumped from the source area would have contaminant levels requiring treatment (before discharge) even after 30 years of pumping. The higher weight volatiles, base/neutrals, and acid extractables would require treatment for the capping or 6-foot excavation alternative. Lower levels of heavy metals would result from the 15-foot excavation alternative, but also would require treatment before discharge. The capping and 6-foot excavation alternatives yield the same results because it was assumed the soil zone above the water table would not contribute contaminants due to the cap or soil removal.

These results show that groundwater pumping is not an effective source reduction remedial action except for the most mobile volatile organics. Excavation is probably the best source reduction action for relatively immobile contaminants.

MILL CREEK RESULTS

The impacts of Alternatives 1, 2, 3, and 5 on Mill Creek water quality were qualitatively analyzed using the results of the geochemical model. The analysis assumed that groundwater contaminant mass loading to the creek is directly proportional to total contaminant mass in soil and groundwater (source strength). This was based on the earlier assumption of linear contaminant desorption isotherms. It also was assumed that natural groundwater flow to the creek is about 70 to 100 gpm.

Table F-4 shows the number of times the source strength would have to be reduced to meet modified ambient water quality criteria for metals in Mill Creek. The table was prepared by dividing the estimated monthly concentrations in Mill Creek (Table 3-65) by the modified 24-hour and maximum concentration criteria in Table F-5. Table F-5 is based on the criteria presented in Table 3-47 assuming a hardness of 100 mg/L as $CaCO_3$. Because the water quality of Mill Creek is primarily controlled by groundwater, especially in summer, average background groundwater concentrations were substituted if they were higher than the Table 3-47 values. The average concentrations, based on a log-normal distribution, were calculated using the lowest reported values for wells 30S, 31D, 32D, 33S, 33D, 36, 37, 38, 40, 41, 42, 43, and 44.

Table F-4
RATIO OF ESTIMATED MILL CREEK AVERAGE CONTAMINANT CONCENTRATIONS TO MODIFIED AMBIENT WATER QUALITY CRITERIA

Month	Zn	Cr+3	Cr+6	Cu	Ni	Pb	Cd
Jan	1.9[a]	0.11	0.37	0.029	0.13	0.052	0.54
	0.44[b]	0.0010	0.23	0.029	0.0065	0.007	0.50
Feb	2.0	0.12	0.41	0.032	0.14	0.057	0.61
	0.47	0.0011	0.25	0.032	0.0070	0.0076	0.56
Mar	2.4	0.15	0.50	0.039	0.17	0.070	0.75
	0.56	0.0014	0.31	0.039	0.0087	0.0093	0.70
Apr	3.4	0.20	0.67	0.052	0.22	0.10	1.0
	0.78	0.0019	0.41	0.052	0.011	0.013	0.93
May	4.9	0.30	1.0	0.079	0.33	0.14	1.5
	1.1	0.0028	0.62	0.079	0.017	0.019	1.4
Jun	6.4	0.39	1.3	0.10	0.43	0.18	1.9
	1.5	0.0036	0.81	0.10	0.022	0.024	1.8
Jul	9.6	0.57	1.9	0.15	0.65	0.28	2.9
	2.2	0.0053	1.2	0.15	0.034	0.037	2.6
Aug	12	0.73	2.5	0.20	0.83	0.36	3.6
	2.8	0.0068	1.5	0.20	0.043	0.048	3.3
Sep	12	0.70	2.4	0.19	0.80	0.35	3.6
	2.8	0.0066	1.5	0.19	0.042	0.047	3.3
Oct	10	0.59	2.0	0.16	0.68	0.29	3.0
	2.3	0.0055	1.2	0.16	0.035	0.039	2.8
Nov	4.2	0.25	0.85	0.065	0.28	0.12	1.3
	0.97	0.0023	0.52	0.065	0.015	0.016	1.2
Dec	2.2	0.14	0.46	0.035	0.15	0.061	0.64
	0.50	0.0013	0.29	0.035	0.008	0.0081	0.60

[a] 24-hour criteria ratio.

[b] Maximum criteria ratio.

Note: See Table F-5 for modified criteria and Table 3-65 for estimated Mill Creek concentrations.

Chromium +3 and +6 were set equal to the reported total chromium because separate values were not reported. The ratios in Table F-4 indicate that chromium +3, copper, nickel, and lead are below the modified concentration criteria; therefore, they were not considered further.

Table F-5
MODIFIED AMBIENT WATER QUALITY CRITERIA FOR METALS IN MILL CREEK

Metal	Groundwater Background (µg/L)	Criteria 24-hour (µg/L)	Criteria Maximum (µg/L)
Zinc	74	74*	321
Lead	23	23*	172
Nickel	<40	96	1,844
Copper	75	75*	75*
Chromium[a]	13	44 (13*)	4,692 (21)
Cadmium	2.8	2.8*	3.02

[a]Chromium +6 criteria in parentheses.
*Denotes values modified from Table 3-47.

Table F-6 shows the estimated times to meet modified ambient water quality criteria in Mill Creek for the no action Alternative (Example Alternative 1). It shows that zinc, cadmium, and chromium +6 would remain above the criteria within the range of 60 to over 120 years.

Table F-7 shows the estimated pumping times to meet the modified criteria in Mill Creek after pumping stops for Alternatives 2 and 3. Capping or 6-foot excavation accounts for a 58, 30, and 36 percent reduction in zinc, chromium +6, and cadmium, respectively. The table shows that these metals would remain above the criteria during summer within the range of 30 to 120 years.

The effects of a 15-foot source removal in Area I/II (Alternative 5) also was evaluated. The results show that excavation is sufficient by itself to reduce zinc, cadmium and chromium +6 contamination to the levels required to meet modified creek water quality criteria. Zinc, chromium, and cadmium would be reduced about 93, 94, and 95 percent, respectively. Some residual contamination would remain in the unexcavated

Table F-6
ESTIMATED TIME TO MEET MODIFIED 24-HOUR AND MAXIMUM AMBIENT WATER QUALITY CRITERIA IN MILL CREEK (NO ACTION ALTERNATIVE)

Month	Time (years) Zn	Cd	Cr+6
January	30-60[a]	-	-
	-[b]	-	-
February	30-60	-	-
	-	-	-
March	60-120	-	-
	-	-	-
April	60-120	-	-
	-	-	-
May	60-120	15-20	1
	5-10	10-15	-
June	>120	30-60	>120
	25-30	30-60	-
July	>120	30-60	>120
	30-60	30-60	60-120
August	>120	60-120	>120
	60-120	30-60	>120
September	>120	30-60	>120
	60-120	30-60	>120
October	>120	30-60	>120
	30-60	30-60	60-120
November	60-120	5-10	-
	-	4-5	-
December	30-60	-	-
	-	-	-

[a] Based on 24-hour criteria.

[b] Based on maximum criteria.

Note: "-" denotes modified criteria would be met without remedial action.

Table F-7
ESTIMATED PUMPING TIME TO MEET MODIFIED 24-HOUR AND MAXIMUM AMBIENT WATER QUALITY CRITERIA IN MILL CREEK AFTER PUMPING STOPS (ALTERNATIVES 2 AND 3)

Month	Time (years) Zn	Cr+6	Cd
January	-[a]	-	-
	-[b]	-	-
February	-	-	-
	-	-	-
March	1	-	-
	-	-	-
April	25-30	-	-
	-	-	-
May	30-60	-	-
	-	-	-
June	60-120	-	5-10
	-	-	5-10
July	60-120	60-120	25-30
	-	-	25
August	120	>120	30-60
	10-15	20-25	30-60
September	60-120	>120	30-60
	10-15	20-25	30-60
October	60-120	60-120	30-60
	-	-	25-30
November	30-60	-	-
	-	-	-
December	-	-	-
	-	-	-

[a] Based on 24-hour criteria.

[b] Based on maximum criteria.

Notes: "-" denotes modified criteria would be met without pumping.
Mill Creek water quality should meet criteria during pumping.

portions of Areas V and IX. This would be partially mitigated by dewatering pumping and treatment during the approximate 4-year excavation process.

The predicted groundwater concentrations in Tables F-3B and F-3C should not be compared with the Mill Creek impact assessment results shown in Tables F-6 and F-7. The predicted groundwater concentrations are representative of the site average source, whereas the Mill Creek impacts are representative of conditions at the source edge. The Mill Creek results also reflect an integration of all the physical and geochemical processes that affect water quality changes.

GROUNDWATER QUALITY STANDARDS AND CRITERIA

Because the shallow aquifer may possibly be used as a future potable water source, groundwater quality in Area I/II was compared to the drinking water standards, criteria, and cancer risk levels discussed in Chapters 2 and 4. The contaminants considered all have published standards, criteria, or cancer risk levels. They include 17 of the 23 indicator contaminants discussed earlier in this appendix plus 12 additional contaminants. The known or suspected carcinogens are listed in Table F-8 and noncarcinogens in Table F-9.

The standards, criteria, and cancer potencies include the federal drinking water standards, acceptable daily intakes (ADI's), excess lifetime cancer risks, drinking water quality criteria for human health, and suggested no adverse response levels (SNARL's). The federal and state drinking water standards are legally enforceable requirements and apply to municipal and community drinking water systems. Standards have been set for several priority pollutant metals and a single indicator organic compound (chloroform). The ADI's, water quality criteria, and SNARL's are advisory, but address more of the organic priority pollutants found at Western Processing.

The ADI's assume ingestion of 2 L/day, and the excess lifetime cancer risks were calculated using the worker scenario discussed in Chapter 4. The mean observed onsite groundwater concentrations are those used in Chapter 4. These concentrations differ slightly from those presented earlier in this appendix. However, the differences do not significantly affect the results of this analysis.

The percent reduction needed to achieve a particular standard, criterion, or cancer risk level was first calculated. The reductions were then compared to Table F-3A values to estimate the years of pumping at 100 gpm needed to achieve the target levels. The percent reductions and estimated number of years are presented in Tables F-8 and F-9.

Table F-8
REDUCTION IN GROUNDWATER CONCENTRATIONS REQUIRED TO ACHIEVE SPECIFIED STANDARDS OR CRITERIA FOR KNOWN OR SUSPECTED CARCINOGENS
(Example Alternatives 2 and 3)

Chemical	Mean Observed Onsite Concentration (mg/L)(d)	Excess Lifetime Cancer Risk(1 x 10-5)(e)			Excess Lifetime Cancer Risk(1 x 10-6)(e)		
		Current Level	% Reduction to Achieve Target	Pumping Time(yr)(f,g)	Current Level	% Reduction to Achieve Target	Pumping Time(yr)(f,g)
Benzene (a)	0.043	2.4E-05	50.89	(5	2.4E-05	95.89	(5
Chloroform (b)	2	1.6E-03	99.37	(20	1.6E-03	99.94	(20
1,2-Dichloroethane	0.38	2.3E-04	95.56	(5	2.3E-04	99.56	(5
Methylene chloride (c)	34	2.3E-04	95.71	(5	2.3E-04	99.57	(5
Tetrachloroethene (c)	0.047	1.8E-05	44.13	(15	1.8E-05	94.41	(15
1,1,2-Trichloroethane (c)	0.0083	5.2E-06	0.00	—	5.2E-06	80.67	—
Trichloroethene (c)	18	3.7E-03	99.73	(40	3.7E-03	99.97	(40
Vinyl chloride (a)	0.023	4.4E-06	0.00	—	4.4E-06	77.16	—
Arsenic	0.017	2.8E-03	99.64	Never	2.8E-03	99.96	Never
Total		8.6E-03	99.99		8.6E-03	99.88	

Chemical	Mean Observed Onsite Concentration (mg/L)(d)	Drinking Water Standard			Suggested No Adverse Response Level(SNARL)					
		Standard (mg/L)	% Reduction to Achieve Std.	Pumping Time(yr)	10-day (mg/L)	%-Reduction t Achieve Crit.	Pumping Time(yr)	Longer-term (mg/L)	%-Reduction t Achieve Crit.	Pumping Time(yr)
Benzene (a)	0.043				0.23	0.00	—	0.07	0.00	—
Chloroform (b)	2	0.1	95.24	(15	0.02	99.05	(15			
1,2-Dichloroethane	0.38									
Methylene chloride (c)	34									
Tetrachloroethene (c)	0.047				0.18	0.00	—	0.02	57.45	(20
1,1,2-Trichloroethane (c)	0.0083									
Trichloroethene (c)	18				0.2	98.89	(30	0.08	99.56	(40
Vinyl chloride (a)	0.023									
Arsenic	0.017	0.05	0.00	—						

(a) Cancer potency estimated from the ambient water quality criteria document.
(b) Drinking water standard is for sum of concentrations of chloroform, bromodichloromethane, dibromochloromethane and bromoform.
(c) IARC believes that there is inadequate evidence to classify as a human carcinogen.
(d) Nondetects are set equal to the detection limit.
(e) Lifetime water ingestion rate: 0.016 liters per kilogram body weight per day
Annual exposure fraction: 0.68
(f) Pumping time notes: (= less than;) = greater than;)) = very much greater than
When a pumping time exceeds 30 years but is less than some number, the pumping time is between 30 years and the time shown.
(g) Pumping times assume that a cap is in place and/or all materials in the unsaturated zone have been removed. Times are based on Table F-3A & F-3B.

Table F-9
REDUCTIONS IN GROUNDWATER CONCENTRATIONS REQUIRED TO ACHIEVE SPECIFIED STANDARDS OR CRITERIA FOR NONCARCINOGENS
(Example Alternatives 2 and 3)[e]

Chemical	Mean Observed Onsite Concentration (mg/L)(d)	Acceptable Daily Intake(a)			Drinking Water Standard			Water Quality Criteria for Human Health(Drinking Water Only)			Suggested No Adverse Response Level(SNARL)					
		Value (mg/day)	% Reduction to Achieve ADI (a)	Pumping Time(yr)	Standard (mg/L)	% Reduction to Achieve Std.	Pumping Time(yr)	Criteria (mg/L)	% Reduction to Achieve Crit.	Pumping Time(yr)	10-day (mg/L)	%-Reduction to Achieve Crit.	Pumping Time(yr)	Longer-term (mg/L)	%-Reduction to Achieve Crit.	Pumping Time(yr)
1,1-Dichloroethane	0.62															
Trans-1,2-dichloroeth	14										0.27	0.00	(10			
2,4-Dimethylphenol(b)	0.93							0.4	0.00	(10						
Ethylbenzene	0.0086	1.6	0.00	—				1.4	0.00	—						
Phenol	75	7	95.33	(5				3.5	0.00	(5						
Bis(2-ethylhexyl)phth	0.85	42	0.00	—				21	0.00	--						
Toluene	0.57	30	0.00	—				15	0.00	—	2.2	0.00	—	0.34	0.00	(10
1,1,1-Trichloroethane	7.6	38	0.00	—				19	0.00	—				1	0.00	(15
Boron	5.9		NA													
Cadmium (c)	1.1	0.17	92.27	)120	0.01	99.09	))120	0.0154	0.00	)120						
Chromium (assumed VI)	1.5	0.175	94.17	Never	0.05	96.67	Never	0.05	0.00	Never						
(assumed III	1.5	125	0.00	—				170	0.00	--						
Cobalt	0.42		NA													
Copper (b)	0.74		NA					1	0.00	—						
Cyanide	0.19	7.6	0.00	—				0.2	0.00	—						
Iron	85		NA													
Lead	0.21	0.1	76.19	Never	0.05	76.19	Never	0.05	0.00	Never						
Manganese	89		NA													
Mercury	0.0077	0.02	0.00	—	0.002	0.00	—	0.01	0.00	—						
Nickel(g)	11	1.5	93.18	(120(f)				0.0154	0.00	)120						
Zinc (b),(h)	93							5	0.00	))120						

(a) Assumed ingestion of 2 L/day.
(b) Water quality criteria based on organoleptic considerations.
(c) ADI is not strictly an ADI but represents an oral threshold effect level for smokers.
(d) Assumes nondetects are set equal to the detection limit.
(e) The pumping times shown assume a cap is in place and/or all materials in the unsaturated zone are removed. Times are based on Table F-3A & F-3B.
(f) Pumping time notes: (= less than;) = greater than;)) = much greater than. When a pumping time exceeds 30 years but is shown as less than some number, the pumping time is between 30 years and the time shown.
(g) The nickel detection limit in background samples was too high to compare actual nickel background concentrations to criteria. If background is is approximately 40 ug/L, then pumping time is (120 years.
(h) The background concentration of zinc is above the water quality criteria for drinking water(0.074(bgnd) vs. 0.053(crit.) both mg/L). Pumping time to achieve background is still)120 years. See also note (b).

Four of the contaminants in Tables F-8 and F-9 that currently exceed criteria are not listed in Table F-3A. To evaluate these contaminants, their distribution coefficients were obtained as described earlier in this appendix. The pumping time for each contaminant was then interpolated from Table F-3A. These contaminants and their distribution coefficients are:

Benzene	0.89
1,2-Dichloroethane	0.19
1,1,2-Trichloroethane	0.91
Vinyl chloride	0.025

A remedial action similar to Example Alternative 2 or 3 would reduce the concentrations of organic contaminants in the groundwater in Area I/II to drinking water standards in less than 15 years, and to the SNARL for longer term use in approximately 40 years. Forty years of pumping would also reduce the lifetime excess cancer risk for organics to 1×10^{-5} for the worker scenario.

Example Alternative 2 or 3 would not be effective in achieving drinking water standards for some metals. The lead and chromium (if hexavalent) concentrations in Area I/II groundwater would for all practical purposes never be reduced to drinking water standards, and cadmium would require more than 120 years of pumping. Zinc and nickel water quality criteria are below background groundwater concentrations; therefore, backgrounds were used as the appropriate target levels. Approximately 120 years of pumping would reduce zinc and nickel concentrations to background.

A slightly different approach was taken to estimate the effect of the 15-foot excavation and temporary dewatering of the construction area included in Example Alternative 5. For the contaminants with federal drinking water standards or SNARL's, the percent reduction achieved by excavation was calculated by dividing the contaminant mass removed from the saturated zone by the total contaminant mass in the saturated zone using data in Table F-1B. The groundwater concentrations were assumed to be directly proportional to source strength (contaminant mass in soil) as in the Mill Creek discussion. The percentage reduction achieved by excavation was then compared to the percentage reduction required to meet the target levels in Table F-9.

The excavation component of Example Alternative 5 would reduce the concentrations of lead, chloroform, tetrachloroethene, toluene, and 1,1,1-trichloroethane in Area I/II to below the federal drinking water standards or SNARL's. Excavation and groundwater extraction would reduce trichloroethene and trans 1,2-dichloroethene concentrations to below the SNARL's. Cadmium and chromium (if hexavalent)

may not be reduced sufficiently by Example Alternative 5 to achieve federal drinking water standards.

BATTELLE GROUNDWATER FLOW/TRANSPORT MODEL

The groundwater flow and contaminant transport system was modeled by Battelle (Bond et al., September 1984). This report is currently being extensively revised with a completion date estimated to be early 1985. The purpose of the modeling was to evaluate the overall effectiveness of each example remedial action in reducing contaminant concentrations in Mill Creek. To date, only trichloroethene (TCE) reductions have been simulated. The following brief discussion is based on preliminary results obtained from Battelle prior to issuance of their final report. The mechanics of model development and discussion of assumptions and limitations will be in the final Battelle report.

FLOW MODELING

The model area is 2,800 feet wide and 4,000 feet long. The Western Processing site lies just south of the model region's center. The model approximates site conditions to a depth of 100 feet below the water table. Simplifying assumptions were necessary because of hydrogeologic complexity. The initial, boundary, and calibration data, however, were all consistent with the results of the field investigations.

Subsurface conditions were represented as a two-layer system. The upper layer, extending to 40 feet beneath the water table, was classified as clay, silt, and sand. Beneath this layer were more permeable sands extending to 100 feet below the water table.

Horizontal and vertical hydraulic conductivities used in the model are listed below. Vertical hydraulic conductivities were assumed to range from one-tenth to one-twentieth of horizontal hydraulic conductivities as typically reported in the literature. The use of one-twentieth the horizontal hydraulic conductivity for the vertical component of the shallow unit is supported by the complex stratification that restricts vertical flow. The hydraulic conductivities used in the model are:

Layer	Depth Below Groundwater (feet)	K-Horizontal (ft/day)	K-Vertical (ft/day)
Sand, silt, and clay	0-40	2.5	0.13
Sand	40-100	25	2.5

Mill Creek and the east drain were simulated using a stream boundary option that considers the stream surface elevation, stream width, bed thickness, and bed permeability. Preliminary model results indicate a flow increase for Mill Creek in the model area of 0.3 cfs, which is close to the 0.5 cfs measured in the field by USEPA in May 1982.

SOLUTE TRANSPORT MODELING

Trichloroethene (TCE) was chosen for transport modeling because it was widespread at high concentrations and because the geochemistry of TCE is better understood than many of the other site contaminants. The initial TCE distribution and total mass are consistent with the results of the contaminant source quantification analysis discussed earlier in this appendix.

Model results indicate that under existing conditions Mill Creek is the primary receptor of TCE leaving Western Processing. The east drain receives the remainder. The calculated mass flux of TCE to the creek is about 0.7 pound per day based on current assumptions of parameters that affect migration rates.

The percent reduction during the 1988 to 1993 timestep relative to the no action alternative during the 1983 to 1988 timestep for Example Alternatives 1, 2, 4, and modified 5 (i.e., no-action; cap with pump and treat; PRP; and 6-foot source removal with pump and treat) is presented below.

RELATIVE EFFECTIVENESS

Alternative	Percent Reduction
1 (no action)	25
2 (cap, pump and treat)	96
4 (PRP)	70
5 (excavate, pump and treat)	95

It must be noted that TCE is currently below applicable ambient water quality criteria in Mill Creek. Moreover, because different contaminants will migrate at different rates (different R values), the relative TCE reductions may not be applicable to the other contaminants.

Appendix G: Methods, Assumptions, and Criteria for Groundwater Treatment Process Selection/ Design

Appendix G
METHODS, ASSUMPTIONS, AND CRITERIA FOR GROUNDWATER TREATMENT PROCESS SELECTION/DESIGN

This section is divided into three subsections. The first subsection discusses technical considerations that impact the scope and cost of the groundwater treatment system. The second subsection discusses individual treatment technologies and their advantages and disadvantages for treating Western Processing groundwater. The third subsection illustrates an example groundwater treatment system that was used to develop order-of-magnitude costs for Alternatives 2, 3, and 5 in Chapter 6.

TECHNICAL CONSIDERATIONS

The process requirements, equipment sizing, and capital and operating cost of a groundwater treatment system depend primarily on the following four factors:

1. Groundwater flow rate to the treatment system
2. Groundwater quality
3. Treatment objectives
4. Duration of treatment

Each factor is discussed in the sections below.

FLOW RATE

The flow rate to the groundwater treatment system is controlled by hydrogeologic factors and/or by hydraulic limitations imposed by various discharge receptors.

Based on available hydrogeologic information, the groundwater collection system can be pumped continuously at a maximum rate of 0.5 gpm per well point. Therefore, for Alternatives 2 and 5, the maximum flow rate is about 170 gpm (340 well points). For Alternative 3 the maximum is 85 gpm (170 well points). Groundwater can be extracted at a slower rate by turning off portions of the well field.

There are several possible receptors for treated groundwater, including the municipal sewer system, Mill Creek, the Green River, and the groundwater aquifer below the site.

The Municipality of Metropolitan Seattle (Metro), which has primary authority over the municipal sewage collection and treatment system in the Seattle area, has indicated that for hydraulic reasons discharge from Western Processing to the municipal sewer system may be restricted to 140,000 gallons per day (approximately 100 gpm). It is possible that additional hydraulic capacity could be gained by increasing sewer

diameters or modifying pump stations, but this possibility was not considered in this feasibility study. Also, further investigation may reveal that additional hydraulic capacity is available without modifications to the sewer system.

According to the Washington State Department of Ecology (WDOE), any point source discharge from Western Processing to either Mill Creek or the Green River must be restricted to no more that 15 percent of the stream discharge rate. In Mill Creek, measured flows during summer have been as low as 2 cfs, meaning that during this time only 194,000 gallons per day, or 135 gpm, could be discharged. High flows could be accepted during most of the year. The Green River could accept the maximum flow of 170 gpm from the treatment system at all times.

With a properly designed groundwater recharge system there should be no flow restrictions if treated groundwater were to be returned to the aquifer.

GROUNDWATER QUALITY

Available data show that existing groundwater quality is highly variable throughout the site, especially with depth. Also because of physical and geochemical factors groundwater quality will be variable over time. For this reason, the required treatment level will vary as a function of time.

Representative "worst case" initial groundwater quality for the treatment system was estimated using site averages for each constituent developed from the contaminant source quantification analysis discussed above. Table G-1a shows average organic and inorganic contaminant concentrations for Areas I and II with a 0- to 6-foot excavation depth. Table G-1b shows average concentrations for Areas I and II with a 15-foot excavation depth. The values represent a typical composition that might be achieved during the early stages of pumping.

No data are available for several parameters that could significantly affect the groundwater treatment system. For example, no groundwater samples were analyzed for 5-day biological oxygen demand (BOD5), chemical oxygen demand (COD), or total organic carbon (TOC). Without these parameters, it is impossible to accurately predict chemical oxidant dosage or to determine whether biological treatment is a viable option. Additional analyses also are necessary to determine the concentrations of major cations and anions present in the groundwater. Without these data, any estimates of precipitation chemical requirements, sludge generation rates, and equipment sizing can only be tentative.

Table G-1a
GROUNDWATER CONTAMINANT CONCENTRATIONS, AREA I/II
WESTERN PROCESSING, KENT, WASHINGTON
(WITH A 0- TO 6-FOOT EXCAVATION)

	Site Average (in µg/L)
Volatiles	
Methylene chloride	52,000
Trichloroethene	16,000
Trans 1,2-dichloroethene	7,700
1,1,1,-Trichloroethane	8,700
Chloroform	2,200
Toluene	820
Tetrachloroethene	50
Ethylbenzene	10
Nonvolatiles	
Phenol	42,000
Bis(2-ethylhexyl)phthalate	0
Naphthalene	15
Metals	
Zn	121,000
Ni	15,000
Cr	2,200
Cd	1,500
Cu	1,000
Pb	290
As	19

Table G-1b
GROUNDWATER CONTAMINANT CONCENTRATIONS, AREA I/II
(WITH A 15-FOOT EXCAVATION)

	Site Average (in µg/L)
Volatiles	
Methylene chloride	49,000
Trichloroethene	7,200
Trans 1,2-dichloroethene	160
1,1,1,-Trichloroethane	1,000
Chloroform	2,000
Toluene	320
Tetrachloroethene	5
Ethylbenzene	5
Nonvolatiles	
Phenol	1,500
Bis(2-ethylhexyl)phthalate	0
Naphthalene	23
Metals	
Zn	118,000
Ni	14,000
Cr	320
Cd	960
Cu	790
Pb	270
As	18

There is a high probability of reactions taking place that could affect the removal efficiency, chemical dose requirement, and overall viability of various treatment processes due to the presence of numerous tentatively identified and unidentified compounds in the groundwater. The only way to determine the treatability of the groundwater is through bench-, pilot-, and/or full-scale testing of various treatment processes. At an absolute minimum, bench- or pilot-testing will take 3 to 4 months to complete. Without bench- and/or pilot-testing, the effectiveness of most treatment processes, particularly chemical and biological oxidation, activated carbon adsorption, and heavy metals precipitation, cannot be assessed until the full-scale system is operational.

TREATMENT OBJECTIVES

The objectives of groundwater treatment can be based on technical requirements (e.g., activated carbon treatment), percent removal requirements (e.g., 99 percent removal of all priority pollutants), or effluent concentration limitations (e.g., Metro pretreatment requirements).

The effluent concentration limitations are different for each potential discharge point. For discharge to the Metro sanitary sewer system, preliminary effluent limitations are shown in Table G-2. The effluent limitations were taken from the current Metro discharge permit allowing discharge of treated storm runoff from Western Processing to Metro. Metro engineers have indicated that the effluent limitations would probably remain the same for treated groundwater, but they could not guarantee this until the actual permit application is processed. The current permit expires in August 1985, and it is possible that different limits might be imposed.

The Washington State Department of Ecology (WDOE) regulates discharge of liquid wastewater into Mill Creek or the Green River. The WDOE bases its NPDES discharge requirements on USEPA ambient water quality criteria for the protection of aquatic life or human health. These criteria are shown in Table G-3. The maximum allowable concentration cannot be exceeded in the effluent. In addition, 24-hour criteria (Column 3 of Table G-3) cannot be exceeded at the edge of the mixing zone. The mixing zone itself cannot be more than 15 percent of the stream width. This limitation could severely restrict the degree of initial mixing obtainable in Mill Creek.

The effluent requirements necessary for discharge to a groundwater recharge/recirculating system would likely be the same as the ambient water quality criteria used for Mill Creek or the Green River.

Table G-2
PRELIMINARY LIMITATIONS FOR DISCHARGE TO
METRO SANITARY SEWER SYSTEM

Compounds	Daily Maximum Concentration
Total oils and greases	100 mg/L
pH range	5.5-12.5
Cyanide (total)	2.0 mg/L
Total toxic organics (TTO)	2.13 mg/L
Arsenic (As)	1.0 mg/L
Cadmium (Cd)	1.2 mg/L
Chromium (Cr)	6.0 mg/L
Copper (Cu)	3.0 mg/L
Lead (Pb)	3.0 mg/L
Mercury (Hg)	0.1 mg/L
Nickel (Ni)	6.0 mg/L
Zinc (Zn)	5.0 mg/L

Table G-3
CURRENT AMBIENT WATER QUALITY CRITERIA
FOR NPDES DISCHARGE[a]

Compound	Maximum Allowable Concentration in Effluent (µg/L)	Maximum Average Concentration at Edge of Mixing Zone (µg/L)
Cd	3.02	0.0025
Cr	21	0.29
Cu	22.2	5.6
Pb	172	3.8
Ni	1,844	96
Zn	321	47
Chloroform	28,900	1,240
1,1,1-Trichloroethane	18,400	--
Trans-1,2-dichloroethene	11,600	--
Tetrachloroethene	5,280	840
Trichloroethene	45,000	--
Toluene	17,500	--
2,4-Dimethylphenol	2,120	--

[a]Assumes hardness to be 100 mg/L as CaCO3.

Using the maximum allowable concentrations (that are likely to be less severe for Mill Creek than the 24-hour average concentrations), the degree of additional treatment required to remove various heavy metals can be calculated. Table G-4 shows the additional removal efficiency required for various heavy metals. (Specific criteria are not available to compare organics.) The table shows that an extremely high-efficiency heavy metals removal system will be required for discharge to Mill Creek. This system is likely to include expensive treatment processes, such as multiple ion exchange units. It is likely that the amortized capital and operating cost of additional treatment to allow discharge to Mill Creek, the Green River, or to groundwater will exceed the user fee for discharging to the Metro system, which is estimated to be approximately $150,000 per year. For this reason, discharge to Metro has been used to illustrate the treatment level that might be required. The only drawback of discharging to Metro will be the 100-gpm hydraulic restriction currently imposed on wastewater flow. However, it is likely that this restriction would not interfere with implementation of remedial actions. Additional capacity might be also obtainable by increasing the capacity of the sewage collection system, or by additional treatment and use of another discharge point in excess of 100 gpm.

Table G-4
DEGREE OF INITIAL TREATMENT REQUIRED
FOR DISCHARGE INTO MILL CREEK VERSUS METRO

Compound	Minimum Percent Increase in Removal Efficiency Required For Discharge to Mill Creek
Cd	99.7
Cr	99.7
Cu	99.3
Pb	94.3
Ni	69.3
Zn	93.6

PUMPING DURATION

USEPA has indicated that one goal for remedial actions is that pumping and groundwater treatment continue until groundwater concentrations are lowered to meet ambient water quality criteria. Tables G-5a and G-5b show the expected Area I/II average groundwater concentrations at the end of 30 years at 100 gpm for 0- to 6-foot and 15-foot excavations, respectively. These estimates were on the geochemical model presented earlier in this appendix. The analysis predicts that most volatile organics will be reduced to levels in the

Table G-5a
PREDICTED AREA I/II GROUNDWATER CONCENTRATIONS
AFTER 30 YEARS OF PUMPING AT 100 GPM
(WITH 0- TO 6-FOOT EXCAVATION)

	Expected Average Concentration (µg/L)	
Volatiles	Initial	After 30 Years
Methylene chloride	52,000	0
Trichloroethene	16,000	110
Trans-1,2-dichloroethene	7,700	0
1,1,1-Trichloroethane	8,700	90
Chloroform	2,200	0
Toluene	820	100
Tetrachloroethene	50	14
Nonvolatiles		
Phenol	42,000	0
Bis(2-ethylhexyl)phthalate	0	0
Heavy Metals		
Cd	1,500	800
Cr	2,200	2,070
Cu	1,000	970
Ni	15,000	3,170
Pb	290	290
Zn	121,000	79,400

Table G-5b
PREDICTED AREA I/II GROUNDWATER CONCENTRATIONS
AFTER 30 YEARS OF PUMPING
(WITH 15-FOOT EXCAVATION)

	Expected Average Concentration (µg/L)	
Volatiles	Initial	After 30 Years
Methylene chloride	49,000	<0.1
Trichloroethene	7,200	51
Trans-1,2-dichloroethene	160	<0.1
1,1,1-trichloroethane	1,000	10
Chloroform	2,000	<0.1
Toluene	320	41
Tetrachloroethene	5	1
Nonvolatiles		
Phenol	1,500	<0.1
Bis(2-ethylhexyl)phthalate	0	0
Heavy Metals		
As	18	17
Cd	960	511
Cr	320	300
Cu	790	765
Ni	14,000	2,958
Pb	270	270
Zn	118,000	77,453

low mg/L range or lower. Phenols are predicted to be at nondetectable levels. However, phthalates (and nonvolatile chlorinated organics, which are not shown) will most likely still be present at detectable levels in the groundwater. Heavy metals will also be present in the groundwater, at levels above ambient water quality criteria.

For ambient water quality criteria to be met, pumping and groundwater treatment will probably be needed for more than 30 years. However, because the effect beyond 30 years on the present worth economic analysis is minimal, only a 30-year planning horizon was used in this feasibility study.

AVAILABLE GROUNDWATER TREATMENT TECHNOLOGIES

As described in Chapter 5, there is a wide range of groundwater treatment technologies that can be employed to reduce contaminant concentrations to acceptable levels for discharge to Metro, surface water, or groundwater.

This section briefly describes the primary treatment alternatives that were evaluated. The treatment alternatives are divided into those primarily intended for metals removal and those for organics.

HEAVY METALS REMOVAL

The basic removal processes for metals are precipitation and concentration. The following treatment processes were evaluated for applicability to Western Processing.

- Alkaline precipitation
- Sulfide precipitation (Sulfex Process)
- Ion exchange
- Reverse osmosis

Alkaline Precipitation

Most metal hydroxides are insoluble at elevated pH levels. Lime, sodium hydroxide, and magnesium hydroxide are alkaline agents used to raise pH to precipitate metals. In this process, the alkaline agent is added to water to achieve pH levels from 8 to 11 to precipitate metal hydroxides. Lime is the most commonly used alkaline agent in metals precipitation because of low cost, relative ease of handling, and good dewatering characteristics of the sludge. Concentration reduction of metals actually attainable is a function of lime dosage, operating pH, the presence of complexing agents such as ammonia and organics, and the means employed to remove the insolubles from the water. Lime precipitation is effective for removing trivalent chromium, but ineffective for removing hexavalent chromium. If there are significant amounts of hexavalent chromium present, it will have to be reduced chemically or electrochemically prior to alkaline precipitation for this treatment process to be effective.

Advantages and disadvantages of lime precipitation can be summarized as follows:

Advantages	Disadvantages
o Proven technology	o Must be followed by filtration to achieve low concentrations
o Low capital cost	
o Moderate operating cost	o Dewatering and disposal of potentially hazardous sludge required
o Continuous method	
o Moderate sludge volumes	o On wastes above approximately 1,500 mg/L sulfate, calcium sulfate may precipitate and cause severe scaling problems and/or add significantly to the volume of sludge requiring disposal

Sulfide Precipitation

Almost all metal sulfides are less soluble than metal hydroxides. The use of sulfide ion as a precipitant for removal of heavy metals can, therefore, accomplish more complete removal than the use of hydroxide for precipitation.

The Sulfex Process, developed by Permutit, uses iron sulfide to provide sulfide ion. Sufficient iron sulfide is added so that all of the heavy metals present can be converted to sulfide. By maintaining pH in the 8 to 9 range, excess iron in the system will precipitate as iron hydroxide. For an acidic waste, an alkali source is needed for maintaining favorable pH conditions. The Sulfex Process is generally less cost-effective than lime precipitation when total influent metal concentrations exceed 50 mg/L. The difficulties encountered in removing hexavalent chromium by alkaline precipitation also apply to sulfide precipitation.

Advantages and disadvantages of sulfide precipitation are summarized as follows:

Advantages	Disadvantages
o Most metal sulfides are more insoluble than hydroxides, yielding better theoretical removals	o Must be followed by filtration to achieve low concentrations
	o Chrome removals are no greater than with lime
	o Potential exists for hydrogen sulfide evolution

Ion Exchange

The use of ion exchange resins to remove undesired constituents from waste streams is well established. Specific resins for heavy metals removal have been developed by Rohm & Haas, Dow, and Nalco, among others. In this process, most of the metals are adsorbed on cationic resins, with the notable exception of hexavalent chromium which is adsorbed onto anion resin.

Performance of ion exchange systems is usually dependent on pH, temperature, and ion concentrations. Pretreatment or preconditioning of waste streams is often required to assure satisfactory operation, especially when organics are present. Significant quantities of spent regenerant requiring disposal are produced during the regeneration of resins.

Advantages and disadvantages of ion exchange are summarized as follows:

Advantages	Disadvantages
o High effluent quality theoretically possible	o High capital cost
	o Requires pretreatment
	o Produces a concentrated solution that requires disposal
	o For wastes containing many metals, in-bed precipitates during loading or regeneration can occur

Reverse Osmosis

Heavy metals can also be removed using reverse osmosis. This process applies an external pressure to a solution in contact with a semipermeable membrane to force water through the membrane while dissolved solids and metals remain in the waste brine reject solution. The reverse osmosis membranes must be protected from fouling by prefiltration. Advantages and disadvantages of reverse osmosis treatment are summarized as follows:

Advantages	Disadvantages
o High effluent quality	o High capital and operating costs o Requires pretreatment o Produces a brine reject flow that must be treated, equal to 10 to 25 percent of raw water flow o High fouling potential for mixed wastes

ORGANICS REMOVAL

Table G-6 contains a summary of the process technologies evaluated for organics removal and identifies advantages and disadvantages of each. Primary technologies considered are described further in the following text.

Stripping

Volatile organic compounds can be removed from aqueous streams by air or steam stripping. Steam stripping is technically applicable but inappropriate for the Western Processing site due to high energy costs. Air stripping usually is the least expensive and most reliable method for removing volatile organic compounds (VOC) from contaminated water and has been used at a number of sites to clean up drinking water contaminated with these compounds. It is not effective for removing extractable organic compounds.

Air stripping takes place in a tower in which water cascades down through packing material while air is forced up through the packing. The large interfacial area created promotes vapor-liquid equilibrium conditions that allow the volatiles to escape into the flowing air stream. Generally the concentration of contaminants in the discharge air is below emission standards, and it has usually been considered environmentally acceptable to discharge this air directly to the atmosphere. When emission control is required, the volatile organics can be adsorbed in a vapor phase carbon system on the vent. Such a requirement would significantly add to the capital and operating costs.

Oxidation

Theoretically, all organic pollutants can be oxidized to carbon dioxide. The methods normally used for oxidation are chemical or biological.

Chemical oxidation of organics in water involves chemical reactions between the organic molecules and an oxidizing chemical. The reaction may oxidize the original organic molecule to a harmless compound, or may generate different compounds, possibly even more toxic than the original material. Oxidation products depend on the original molecule, the type of oxidant used, and reaction conditions. Commonly used chemical oxidants are ozone, hydrogen peroxide, chlorine, and chlorine dioxide.

Ozone (O_3) is the triatomic form of oxygen (O_2). On a thermodynamic scale, ozone has approximately 1.5 times the oxidizing potential of chlorine. Oxidation of organics in water by ozone is normally carried out in contact tanks, in which ozone is bubbled through a diffuser system. Multistage contacting systems are usually required to properly utilize the ozone. Recent developments in ozone-generating equipment have reduced operating costs of ozonation to near that of other chemical oxidants, but capital costs associated with an ozonation system are high. Ozone must be generated at the point of use.

Hydrogen peroxide (H_2O_2) is a strong oxidant frequently used in the chemical industry for waste treatment. Hydrogen peroxide is a relatively mild oxidant compared to ozone or chlorine. The effectiveness of hydrogen peroxide on organics other than phenol is not well reported. Hydrogen peroxide and ozone have each been shown to be ineffective in oxidizing some organics. While those oxidants have high oxidation potentials, in some cases they do not possess the activation energy required for reaction.

Chlorine (Cl_2) is perhaps the most commonly used oxidizing agent for wastewater treatment in the United States. The technology of chlorine shipment, handling, measurement, and application is well established and relatively reliable. The use of chlorine to oxidize chlorinated hydrocarbon compounds is ineffective on some of the chemical bonds, and where effective, may generate additional chlorinated compounds. These oxidation end-products may also require removal because of their known or suspected toxicity.

Chlorine dioxide (ClO_2) has been used experimentally to oxidize phenolic compounds and other hydrocarbons in water. Chlorine dioxide is an unstable gas which, like ozone, must be generated onsite. Several chlorinated reaction products have been identified from the oxidation reaction of hydrocarbons with chlorine dioxide. Little is known about

Table G-6

COMPARISON OF ORGANICS REMOVAL TECHNOLOGIES

TREATMENT PROCESS	COMPLEXITY OF OPERATION	PROBABILITY OF ACHIEVING DESIRED REMOVAL	RELATIVE CAPITAL COST	RELATIVE O&M COST	POTENTIAL OPERATING PROBLEMS	TYPES & POTENTIAL VOLUMES OF RESIDUES GENERATED	COMMENTS
PHYSICAL/CHEMICAL SEPARATION							
• ALKALINE PRECIPITATION	LOW	LOW	LOW	LOW	——	PRECIPITATION SLUDGE REQUIRING DISPOSAL	THE HEAVY METAL REMOVAL PROCESSES WILL INCIDENTALLY REMOVE SOME ORGANICS
• AIR STRIPPING	LOW	LOW	MODERATE	LOW	RELEASE OF VAPOR BEARING OFF GASES	POTENTIAL AIR CONTAMINATION	ONLY REMOVES VOLATILES
• SOLVENT EXTRACTION	HIGH	LOW	HIGH	HIGH	SOLVENT SEPARATION AND HANDLING	CONTAMINATED SOLVENT REQUIRING TREATMENT OR DISPOSAL	——
ADSORPTION							
• GRANULAR ACTIVATED CARBON	MODERATE	HIGH	MODERATE	MODERATE	SELECTIVE COMPOUND BREAKTHROUGH	SPENT CARBON REQUIRING DISPOSAL OR REGENERATION (OFFSITE)	MANY INSTALLATIONS
• POWDERED ACTIVATED CARBON (INDEPENDENT PROCESS OR AS ADJUNCT TO HEAVY METALS REMOVAL OR BIOLOGICAL TREATMENT)	LOW	MODERATE	MODERATE	MODERATE	SELECTIVE COMPOUND BREAKTHROUGH	SPENT CARBON REQUIRING DISPOSAL	REQUIRES SPECIAL EQUIPMENT
CHEMICAL OXIDATION							
• OZONE	HIGH	LOW	HIGH	HIGH	POTENTIAL GENERATION OF TOXIC REACTION PRODUCTS	NONE	——
• HYDROGEN PEROXIDE	LOW	LOW	LOW	HIGH	POTENTIAL GENERATION OF TOXIC REACTION PRODUCTS	NONE	——
• CHLORINE	MODERATE	LOW	MODERATE	MODERATE	POTENTIAL GENERATION OF TOXIC REACTION PRODUCTS	NONE	——
• CHLORINE DIOXIDE	HIGH	LOW	HIGH	MODERATE	POTENTIAL GENERATION OF TOXIC REACTION PRODUCTS	NONE	——
• OZONE WITH UV	HIGH	HIGH	HIGH	HIGH	POTENTIAL GENERATION OF TOXIC REACTION PRODUCTS	NONE	UV REPORTEDLY REDUCES REACTION TIME
• HYDROGEN PEROXIDE WITH UV	HIGH	HIGH	HIGH	HIGH	POTENTIAL GENERATION OF TOXIC REACTION PRODUCTS	NONE	UV REPORTEDLY REDUCES REACTION TIME
MEMBRANE SEPARATION							
• REVERSE OSMOSIS	HIGH	MODERATE	HIGH	HIGH	MEMBRANE FOULING	MODERATE TO HIGH VOLUME REJECT STREAM REQUIRING SEPARATE TREATMENT	PRETREATMENT REQUIRED TO MINIMIZE MEMBRANE FOULING
• ULTRAFILTRATION	LOW	MODERATE	MODERATE	MODERATE	MEMBRANE FOULING	SMALL VOLUME REJECT STREAM REQUIRING SEPARATE TREATMENT	——
• ELECTRODIALYSIS	HIGH	MODERATE	HIGH	HIGH	MEMBRANE FOULING	SMALL VOLUME REJECT STREAM REQUIRING SEPARATE TREATMENT	PRETREATMENT REQUIRED TO MINIMIZE MEMBRANE FOULING
BIOLOGICAL TREATMENT							
• ACTIVATED SLUDGE AND SIMILAR BIOLOGICAL PROCESSES	MODERATE	MODERATE	MODERATE	MODERATE	ORGANICS MAY INHIBIT OR KILL ORGANISMS	WASTE BIOLOGICAL SLUDGE	CHANCES OF SUCCESSFUL PERFORMANCE IMPROVED WITH POWDERED ACTIVATED CARBON ADDITION (PACT)

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oxidation of volatile chlorinated hydrocarbons with chlorine dioxide, but it is likely that problems similar to those for chlorine will also occur with chlorine dioxide.

Ozone has been used in combination with ultraviolet (UV) radiation for oxidation of organics in water. The UV radiation enhances the formation of chemical species that have a higher oxidation potential than ozone alone. This technology may be superior to ozone in oxidation performance while retaining the advantage over chlorine in that no chlorinated reaction products are formed.

Oxidation of organics in wastewater by hydrogen peroxide (H_2O_2) and UV radiation has also been reported. A proprietary process by Enercol, Inc., utilizes cavitational shock, an organic catalyst, and UV radiation to form hydroxyl radicals ($OH^{\bullet}$) from hydrogen peroxide. The hydroxyl radicals are a very powerful oxidizing species that react with organic molecules, especially by reaction with single hydrogens on the carbon chain or ring. Like ozone, hydrogen peroxide with UV radiation may have the potential to be an effective oxidizing system without the problem of chlorinated reaction products. Pilot testing would be required to determine its actual effectiveness.

Other oxidants include permanganate, chromate, bromine, and persulfuric acid. None of these chemicals were considered suitable for further investigation.

Biological oxidation is well-proven and relatively inexpensive but may be difficult to operate in this application because of potentially inhibitory and toxic effects of certain organic compounds and heavy metals, and because of waste variability. A heavy metals pretreatment step, as previously described in this section, is a likely requirement for successful biological treatment of Western Processing water. It is possible that inhibitory organic removal by activated carbon or other processes may also be required.

Aerobic, anaerobic, or a combination of both types of systems are theoretically possible for organics removal. Anaerobic systems are reportedly highly sensitive to feed variability and inhibitory compounds and should not be considered further. Standard aerobic oxidation, in its many variations as described in sanitary engineering textbooks, is the preferred approach.

One aerobic system, the PACT system, has technical merit for this particularly difficult application. This process, originally developed by DuPont and currently marketed by Zimpro, uses powdered activated carbon as an additive to the activated sludge process. In theory, the activated carbon provides sites for biological growth and acts to adsorb the

more refractory contaminants so that the biological organisms can more easily oxidize them. The carbon is also believed to protect the organisms from high loadings of highly concentrated toxic contaminants.

As with the chemical oxidation processes, biological oxidation would have to be pilot tested to verify its applicability and effectiveness for treating Western Processing wastewater.

Adsorption

A common method of removing organics from water is adsorption on activated carbon. This method has been used at hazardous waste sites to clean up contaminated water. Generally, activated carbon is most effective for organic contaminants having high molecular weight and low water solubility, polarity and degree of ionization. Heavy metals can also be removed by activated carbon, but at significantly lower removal rates than are achievable with organics.

In water contaminated with a number of organics such as at Western Processing, the effectiveness of carbon is less predictable because of preferential or competitive adsorption behavior. Initially, high removals of most organics may be achieved through a fresh bed of carbon. As the carbon becomes loaded with organics, contaminants with low adsorption rates may begin to break through the carbon bed and appear in the effluent. Because individual compound breakthrough is governed by intrinsic chemical properties rather than by desired order, it is commonly necessary to adsorb most of the stream organics to obtain acceptable performance on the target compounds. This leads to somewhat unpredictable, but generally high, carbon dosages.

The two common commercial forms of activated carbon are granular activated carbon (GAC) and powdered activated carbon (PAC). If GAC were used for this application, it would be used in fixed or pulsed beds typical of those found in an advanced wastewater treatment plant. Spent GAC may be regenerated for reuse or disposed directly. Regeneration facilities can be onsite, or offsite through a contractor. For this application, offsite regeneration would probably be the preferred approach because direct disposal or onsite regeneration are likely to be very expensive.

PAC can be used directly in its own process or as an adjunct to another process. There are no theoretical limitations to including PAC into the heavy metals removal processes previously described as a second additive for organics removal. However, there is limited experience with this practice. PAC could be added to its own flocculation and clarification system to achieve organics removal. PAC can also be added

to an activated sludge system as discussed above. PAC can be regenerated or disposed of in a suitable landfill.

Solvent Extraction

Solvent extraction involves intimately contacting a liquid stream with one or more solvents. The solvents preferentially extract one or more components of the liquid stream. The liquid stream and solvent are generally immiscible or only slightly miscible. The solvents are recovered through distillation or other techniques. Usually, residual solvent is stripped from the raffinate stream (treated leachate in this case). Different solvents will selectively extract different organics. There also are solvents that will extract certain metals. To find a solvent or solvents to preferentially extract the compounds desired from a complex leachate wastewater is almost impossible. For this reason and because of high cost, this process will not be considered further.

Membrane Separation

Separation of constituents from solutions can be achieved through the use of polymeric membranes as in reverse osmosis, electrodialysis, and ultrafiltration. Semipermeable membranes allow the transport or separation of different molecules depending on the material and pore sizes of the membrane. The driving force through the membrane is pressure, concentration, or voltage. The diffusion rate of molecules is proportional to concentration. A relatively concentrated waste stream is generated that contains most of the separated organics.

All membrane processes are somewhat imperfect with respect to organic separation, so the "dilute" stream will still contain organics. Previous experience with membrane systems indicates that severe organic fouling is likely unless sophisticated pretreatment steps are used and precise operating conditions are maintained. Considering the complex character of Western Processing water, these processes would not be applicable.

EXAMPLE TREATMENT SYSTEM

As previously discussed, there is insufficient information at this time to size a treatment system with any degree of certainty that the system will meet the required removal efficiencies. To illustrate the cost of an example treatment system and level of treatment that might be required, the following major assumptions were made:

1. Groundwater flow rate to the system will be 100 gpm, 24 hours a day, 365 days a year.

2. The treated groundwater will be discharged to Metro.

3. There are no complexing agents in the wastewater that would reduce the efficiency of heavy metals precipitation.

4. Hydrogen peroxide dose is assumed to be two times the stoichiometric dose required to oxidize phenol to carbon dioxide and water. (NOTE: This could be low by several orders of magnitude if high levels of TIC's appear in the groundwater.)

5. Lime dose is assumed to be two times the stoichiometric dose required to precipitate the known heavy metals in the groundwater.

6. Sludge quantities are assumed to be two times the stoichiometric reactions with known heavy metals.

7. Activated carbon dose is assumed to be 10 pounds of carbon per 1,000 gallons of water.

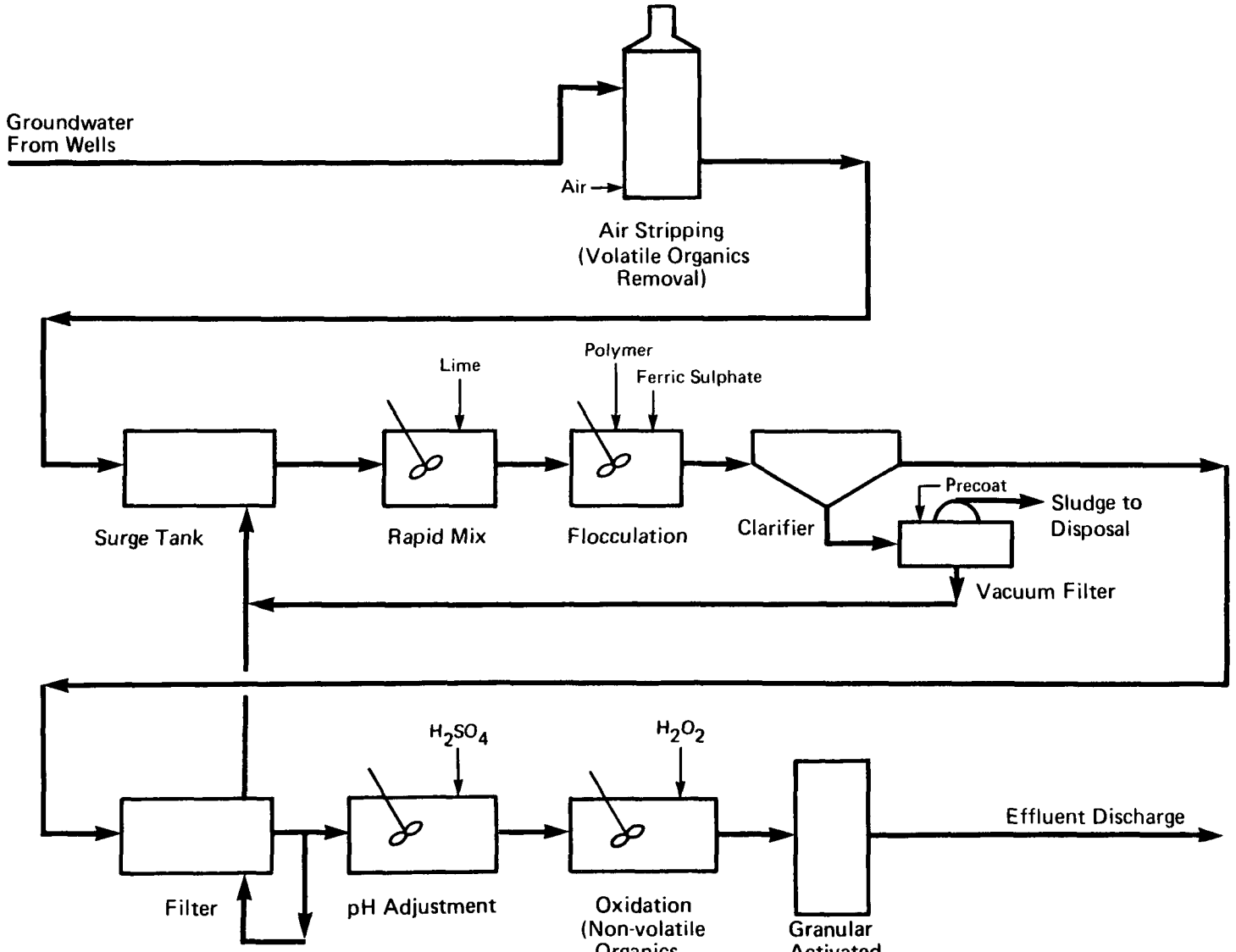
8. The predicted site average groundwater quality presented in Table G-4 is an accurate assessment of the variability of groundwater composition with time.

Bench- or pilot-scale testing is essential to confirming these assumptions.

Using these assumptions, an example conceptual groundwater treatment system was developed. The treatment units were selected and sized using the onsite average groundwater contaminant concentrations shown in Tables F-2 and F-3 (Appendix F) and the effluent limitations for discharge to the Metro sanitary sewer system shown in Table G-2. There are likely to be other process configurations that could achieve similar effluent quality and that could even be more cost effective than this example.

A process schematic for the example treatment configuration is illustrated in Figure G-1. The groundwater will be treated for organics and heavy metals removal using a combination of four unit processes:

- Air stripping for volatile organics removal
- Lime precipitation for heavy metals removal, followed by clarification and filtration
- Chemical oxidation of organics using hydrogen peroxide
- Granular activated carbon adsorption for additional organics removal



Notes:

1. Process configuration shown is based on present knowledge of groundwater composition. Pilot tests will be required to verify process selection. It is possible that additional (or fewer) processes will be required.
2. Sequence of processes is subject to variation based on outcome of pilot tests.

FIGURE G-1
GROUNDWATER TREATMENT
PROCESS FLOW CHART

ORGANICS REMOVAL

Removal of organics is required to comply with the total toxic organics pretreatment criterion. This criterion results from USEPA's categorical determination of industries' ability to meet such a specification. The complexity and strength of Western Processing organics may render compliance with this limitation difficult even with the best of demonstrated treatment processes. Treatability test work is necessary to determine whether this pretreatment criterion is technically feasible.

Applicability of the total toxic organics criterion to Western Processing groundwater may need to be evaluated further. USEPA regulations specify that the intended manner for industry compliance with this criterion is through best management practices rather than end-of-pipe treatment technology. However, best management practices for total toxic organics are not applicable because the extracted groundwater to be treated contains contaminants that have been transported from generators' facilities, deposited at the site, and released to the environment.

Air stripping has been selected for the removal of volatile organic contaminants. It is a reliable method for removing volatile organics from contaminated water and has been used at a number of hazardous waste sites to clean up contaminated groundwater. The air-stripping tower was sized for a volatile organics removal efficiency of approximately 99.5 percent. It has been assumed that the resulting vapor emissions would be very dilute and will meet air quality standards on both a concentration and a mass basis. No gas-phase scrubbing equipment was included in this design because other stripping towers have been installed in the local area without gas treatment. However, this assumption needs to be confirmed with the local regulatory agencies.

Chemical oxidation with hydrogen peroxide is used to oxidize nonvolatile organics such as phenol. Chemical oxidation has the advantages of low capital cost and easy operation and can be adjusted to handle fluctuating organic loadings. In fact, it is possible that hydrogen peroxide chemical oxidation may be discontinued after several years due to lowered organic concentrations (especially phenol) in the groundwater. However, hydrogen peroxide will not selectively oxidize toxic organics. Reactions with other organic compounds may also consume peroxide, increasing dosage requirements.

Granular activated carbon adsorption is included in the treatment process as a polishing step to remove residual organic contaminants still remaining after air stripping and chemical oxidation. Adsorption of organics on activated carbon has been used extensively in similar applications and

the technology is well established. It may be possible that adequate total toxic organics removal can be achieved by activated carbon absorption without being preceded by chemical oxidation using hydrogen peroxide. However, optimization cannot be made until testing is conducted on actual groundwater samples.

INORGANICS REMOVAL

The average cyanide concentration is less than the Metro effluent limitation of 2 mg/L and therefore separate cyanide removal processes have not been included in the treatment configuration. There are apparently no boron effluent standards for discharge to Metro and therefore specific boron removal processes have not been included. If the groundwater boron concentration is subsequently found to be unacceptable, an additional boron removal process such as selective ion exchange would be required.

Heavy metals will be removed using a lime precipitation, clarification, and filtration process. Most metal hydroxides are insoluble at elevated pH levels and in this process, lime is added to raise the pH level to between 9 and 11 to precipitate metal hydroxides. The metals hydroxides are settled in a gravity clarifier and removed as sludge. A vacuum filter has been provided to dewater lime sludge, which can be trucked to landfill disposal. Heavy metals removal by lime precipitation is a proven method with low capital and moderate operating costs. In addition, the process can be operated on a continuous basis. Effluent from the lime precipitation is filtered prior to further treatment. pH adjustment may be required prior to hydrogen peroxide addition and/or activated carbon treatment, but would not normally be required to meet Metro's effluent pH range of 5.5 to 12.5.

SIZING ESTIMATE

Table G-7 shows preliminary equipment sizes for the 100-gpm example groundwater treatment system. This information was used to develop capital and operating costs presented in Chapter 6 under the specific alternatives that employ groundwater treatment at a 100-gpm flow rate (Alternatives 2 and 5). For the 85-gpm system used in Alternative 3, the estimated capital costs would be approximately 90 percent of those used for a 100-gpm system.

Table G-7
EXAMPLE SIZING ESTIMATE
100 GPM EXAMPLE GROUNDWATER
TREATMENT SYSTEM

Equipment	Quantity	Units	Example Dimensions[a]	Example Sizing Criteria[a]
Air Stripping				
Pumps	2	Each		1.5 hp, 100 gpm @50'TDH
Fans	2	Each		5 hp, 2,700 cfm @8"
Towers	1	Each	8'D x 26'H	16' packing depth
Precipitation				
Rapid Mix	2	Each	4'D x 4'6"H	3 min. detention
Flocculation	2	Each	7.5'D x 8'H	20 min. detention
Clarifier	2	Each	20'D x 10'H	460 gpd/sq ft
Filtration				
Filters	2	Each	6' x 8'	2 gpm/sq ft
Surge Tank	1	Each	14'D x 14'H	2 hrs, 30 min detention
Backwash Pump	2	Each		750 gpm @60'TDH, 20 hp
Polisher Feed Pump	2	Each		100 gpm @40'TDH, 2 hp
pH Adjustment				
Mix Tank	1	Each	8'D x 10'H	30 min. detention
Equalization Tank	1	Each	14'D x 14'H	150 min. detention
Sludge Dewatering Filter	1	Each		1,950 lb/hr (wet sludge 1.5%) vacuum filter
Lime Storage Bin	1	Each	10'D x 16'H	900 lb/day, 27 t storage
Ferric Sulfate Handling	1	Each		25 lb/day, Drums
Sulfuric Acid Handling	1	Each		negligible amount
Polymer Storage	1	Each		5 lb/day
Sludge Storage	4	Each	7.5'D x 8'H	1,350 lb/day dry 6 t storage
Control Building	6,000	sq ft		60' x 100'
Peroxide Contact Tank	1	Each	7.5'D x 8'H	20 min detention
Hydrogen Peroxide Feed System	1	Each	10.5'D x 12'H Storage Tank	1,517 lb/day 1 week storage when down 1 truck
Activated Carbon Bed	2	Each	7.5' x 12'	Contact time 15 min. Loading: 2.3 gpm/sq ft Bed depth: 5 ft

[a]Used for example sizing purposes only. This information should not be used for process design.
D = diameter.
H = height.