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RCRA CORRECTIVE ACTION
PORTSMOUTH NAVAL SHIPYARD
KITTERY, MAINE
CORRECTIVE MEASURE OVERVIEW

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PORTSMOUTH NAVAL SHIPYARD

CORRECTIVE MEASURES OVERVIEW

1.0 INTRODUCTION

Discovery of hazardous wastes buried during past disposal operations has created a significant concern over recent years. New legislation introduced to regulate the waste disposal process (RCRA, SARA) and to develop remediation strategies (HSWA, CERCLA) has provided the basis for dealing with and preventing future problems. The increased concern for future liabilities (landfill failures) and public opposition to disposal facilities in their backyard (NiMBY) has created the current waste management hierarchy of source reduction, recycle, reuse and treatment/disposal.

As this approach will decrease the potential of the future liability issue, focused attention on technically sound, cost effective and implementable treatment technologies is needed. The clean-up standards attainable are derived from the treatment technologies' effectiveness. The need for these levels will be based on the human and aquatic health risk assessment of the contaminants observed.

This demand for technology is particularly relevant in the inactive hazardous waste site remediation program - both Federal and State Superfund - where development and demonstration of alternative/innovative technologies is a top priority. It is also an important aspect to the RCRA corrective action program under which the Portsmouth Naval Shipyard (PNS) is governed.

Much of what is utilized today in site remediation is based upon technologies that have been developed and used to treat industrial waste water flows. A reasonable understanding of and experience with these technologies, especially in the application of groundwater pump and treat remediation is required to properly assess each technology.

In applying these technologies for contaminated soil, we are confronted with a more complex set of conditions: mixed waste (organic/inorganic; solid/liquid; sludge/soil); tougher clean-up standards (often based upon risk assessments); critical cost considerations; site applicability, and acceptability.

A number of innovative treatment technologies involving thermal destruction, chemical, physical, biological treatment for site remediation are under evaluation by the regulatory agencies, industries and academia.

Technologies being considered can be placed within three (3) categories:

(a) Destruction (thermal and biological) - results in transforming the waste into a non-hazardous material, substantially reducing the volume of the hazardous waste and resulting in some residual management requirements.

(b) Separation/concentration (physical/chemical) - results in the separation of the hazardous constituent from the affected media, which allows concentration of the separated constituent for recycle, reuse and more effective final treatment and disposal.

(c) Encapsulation/containment (solidification, stabilization, conventional containment) - basically contains, binds, or dewaters the contaminated media to reduce mobility and potential for exposure.

These technologies must be evaluated as to whether they are:

(1) Emerging - technologies in early state of development i.e. laboratory or pilot scale. These technologies must progress from the laboratory into a field demonstration.

(2) Demonstratable - technologies that have been sufficiently well developed at full scale with some test data (possibly incomplete) for performance and cost available. These types of technologies are generally accepted by the regulatory agencies.

(3) Demonstrated technologies that are considered "fully proven," have been applied at full scale and are considered commercially available. The definition "fully proven" must to be defined.

Knowledge and experience in the application of these technologies has been summarized in Table I. This treatment technology overview matrix presents the technology category, a brief description, applicable contaminants treated, benefits, constraints, and relative cost for each major technology. It should be recognized that cost, a function of a variety of site-specific factors such as contaminants of concern, media affected, extent of contamination, etc., is presented as a relative cost to provide some degree of generic comparison among the technologies.

Identify and Screen Remediation Technologies:

Once the objectives of remediation have been determined, remediation technologies will be identified. The chemical and physical characterization of the PNS is considered in the identification of the remediation technologies. A number of technologies are currently available which can be used to address issues at the PNS. The purpose of this task is to identify, describe and determine which technologies can be used to satisfy, in whole or in combination, the remediation objectives for the site. The remediation technologies that cannot be implemented at the site due to technical constraints or which are not appropriate due to site conditions will be eliminated from further consideration.

Remediation technologies are identified through a review of USEPA guidelines, relevant literature, and through experience in developing remediation action plans for similar sites. Technologies are identified to address both source control of the on-site materials and control of the off-site migration, if any, of the substances identified during prior investigations (e.g. RFI). Innovative alternative technologies and resource recovery technologies are given particular consideration.

TABLE 1
Treatment Technologies Matrix

Technology	Description	Applicable Contaminants	Benefit	Constraints	Relative Cost
Physical/Chemical (1) Contaminant extraction	Physical Transfer process	Organics and certain Inorganics.	Offers treatment for inorganics that can reduce/concentrate contaminant	In-situ flushing requires well-defined groundwater flow pattern.	Medium
	Mobilization of contaminants using washing fluid - surfactant, acid and bases, water.		Demonstrated removal efficiencies range from 70-99% depending on contaminant	May need physical barrier (In-Situ)	
	In-situ - flushing		May produce usable clean soil	Soil characteristics critical	
	Ex-situ - washing		Potential recycle of wash fluid	Technology still being proven	
			Equipment available	Water treatment needed	
				Residual disposal needed	
(2) Stripping - vapor extraction, thermal desorption (hot air, steam)	Physical transfer process	Volatile and semi-volatile organics	Well proven for highly volatile organics in vadose zone	Soil type critical	Low-High
	Contaminants are driven off through the application of induced air flow, (heat and/or mechanical) to volatilize contaminants into a gas stream.	Certain volatile metals	Inexpensive	Treatment needed for extracted contaminant	
			Minimal site disruption	May need cap to reduce air releases	
		Usually applied to vadose zone	Demonstrated removal efficiencies range from 65-99% depending on contaminant	Estimating clean-up time	
			Ease of installation		
			Flexible operation		

TABLE 1 (CONTINUED)

Treatment Technologies Matrix

Technology	Description	Applicable Contaminants	Benefit	Constraints	Relative Cost
Bioremediation	Bioremediation is a destruction process that uses bacteria, fungi and yeasts to degrade organic contaminants Can be accomplished by aerobic and anaerobic processes	Organics	Demonstrated for certain organics i.e., petroleum, contaminants, benzene, phenol Can degrade a wide range of organic compounds Simple application	Environmental factors critical Ability to deliver oxygen and nutrients Metabolic byproducts Added substances may may react with the soil components Time frame	Low
Immobilization Stabilization/ solidification	Waste is mixed with binding agent to immobilize contaminants Reduces mobility without causing significant contaminant destruction or removal	Primarily inorganic Some organics	Reduces pollutant mobility Improves handling and physical characteristics Basic process is familiar i.e., mixing, curing and deposition	Incompatible waste reduce effectiveness Organics can be secondary environmental problem Longevity still at issue Results in volume increase (20-80%)	Medium
Vitrification-In-situ	Exposure of waste to temperature that melt the waste to point of fusion. Process includes chemical incorporation and physical encapsulation Heat generally applied by electric current	Inorganics, possible for organics	Results in continuous monolith. Long term durability No pretreatment required	Not applicable for large volumes Results in volume reduction (20-40%) Off gas treatment is needed for organic vapors Site conditions crticial i.e., soil type, groundwater, moisture content May have overmelt	Medium-High
Thermal					
Incineration	Controlled high temperature combustion to destroy or detoxify hazardous waste Complete combustion converts contaminants to carbon dioxide and water	Organic	Proven technology for wide range of waste i.e., greater 99.99% removal Complete destruction Human health risk seems minimal	Difficult to handle inorganics/salt and heavy metals Needs air pollution control for off gas treatment	High

TABLE 1 (CONTINUED)

Treatment Technologies Matrix

Technology	Description	Applicable Contaminants	Benefit	Constraints	Relative Cost
Thermal (Continued)					
Incineration	Consists of feed, primary chamber, secondary chamber air emissions control and residual management			Type of waste can cause handling problems Needs residual management Public Perception	
Pyrolysis	Converts contaminants to carbon dioxide and water in an oxygen - starved system at temperatures that pyrolyze the contaminants	Organic	Reduces concerns for volatilization Air pollution control needs minimized	High fuel requirements Greater uncertainty for incomplete construction	High

Past experience suggests that treatability studies should be conducted early in the remedial planning process. Remedial decisions should not be made without the benefit of treatability and/or pilot studies. These studies assist to protect the ultimate financial commitment, support the regulatory process, and can help to successfully interact with the public. These studies are generally low in cost and provide data that ensure that:

- technology performance expectations can be met on the specific waste matrix,
- design and operating parameters for upscale are made available,
- cost is better estimated, and
- uncertainty is reduced especially in regard to conformance with clean-up standards.

Two key aspects regarding site remediation and innovative technology evaluation are process integration and recognition of risks. These are explained as follows:

Process Integration:

The waste matrix is a complex waste which is menu heterogeneous in nature. It can contain large particles, debris, etc.. Therefore, materials handling and process integration are needed. Process integration will technically address the clean-up objectives and facilitate the most effective use of technologies (for example, vacuum extraction might be implemented in conjunction with stabilization for a mixed organic/inorganic waste matrix).

Recognition of Risk:

Using alternative/innovative technologies will, in many instances, require some risk evaluation. Treatability studies will of course, reduce the risk. However, site-specific conditions can impede ultimate remediation, i.e.,full scale application over a period of time will consistently meet remediation objectives, reduce the potential for failure, and identify inherent problems found on the site. This technical/legal issue should be collectively considered by the regulators and the regulated. The public must also be part of this process.

The remediation alternatives evaluated and eventually employed at PNS will be implemented to attain the clean-up objectives. These alternatives, which may be integrated together at any particular Solid Waste Management Unit (SWMU), may also be employed at another SWMU on-site with the same characteristics. Likewise, a remediation scenario implemented may have already been proven at a similar site. The ultimate remediation alternative will be used to minimize the impact of the site on human health. This goal is attained after the appropriate information has been gathered and evaluated; the substances of concern present are identified and quantified; and the extent of contamination and exposure pathways determined.

2.0 Remedial Action Technologies

The following sections provide a brief description of the potential remediation technologies considered for the SWMUs at PNS.

2.1 In-Situ Soil Vapor Extraction

Soil vapor extraction entails the induction of an advective air phase through contaminated vadose zone soils. In the unsaturated zone, the optimal air flow field can be established with combinations of withdrawal and injection (if required) wells and/or trenches. The advective air flow induces intraphase transfer of the contaminants from the immiscible and water phases into the air phase. Air laden with contaminant vapors moves along induced flow paths toward the withdrawing system where it is analyzed, treated, and/or released to the atmosphere. The success of the method depends on the rate of contaminant transfer from the immiscible and water phases into the air phase, and in particular, the ability to establish an air flow field that intersects the distributed contaminants.

The movement of volatile organic compounds (VOCs) in the vadose zone is a function of several physical/chemical processes occurring on a micro-scale, including: the partial pressures of the particular VOCs, partitioning and solubility coefficients of the VOCs in the upper portion of groundwater, depth of the contaminant source, and the diffusivity of the VOCs in the vadose zone.

As the VOCs are transferred to the surface, typically, on-site treatment is required to meet federal, state and local air emission requirements. The choice of this treatment system depends on several of the above conditions as well as the VOC concentration levels, allowable emission concentrations, seasonal variations, flow rates, and site construction limitations.

2.1 In-Situ Stabilization

Stabilization, like solidification, refers to treatment processes that are designed to accomplish one or more of the following: (1) improve the handling and physical characteristics of the wastes (reduced free liquids); (2) decrease surface area of waste exposed through which contaminant mobilization occurs; and (3) limit solubility of the waste constituents (pH adjustment to "tie up" contaminants).

The major benefit of stabilization is that the solubility or mobility of the contaminants is limited or reduced. The physical characteristics of the wastes are sometimes improved and/or changed. Materials (e.g., lime dust) are added to the soils to ensure the hazardous constituents are maintained in their least mobile or toxic form. The basic principle of operation for stabilization is that leachable metals in a waste are immobilized following the addition of other chemicals. The formation of either a lattice structure or chemical bonds bind the heavy metals present to the solid matrix and limit the amount of metals that can be leached when exposed to a mild acidic solution (pH 4-6). The two common materials used include cement and lime/pozzolan. The addition of silicates is also employed to control curing rates, reduce permeability and enhance the solid material properties.

The cement based process includes the mixing of the anhydrous cement with the soil and through the addition of water, hydration occurs causing the cement to set. During this setting stage, a colloidal gel of indefinite structure is formed. Constituents present on the waste/cement/water slurry (hydroxide and carbonates of metals) are incorporated into the interstices of thin, density packed silicate fibrils. The metals tend to stay in the form of insoluble hydroxides and carbonate salts due to the high pH of the cement.

Pozzolan containing non-crystalline silica such as fly ash or cement kiln dust becomes like cement upon the addition of lime. The metals in the soils are converted to insoluble silicates or hydroxides and bound in the mix similar to the cement process.

Some factors affect the performance and effectiveness of these stabilization processes: (1) concentration of fine particles; (2) concentration of oil and grease; (3) concentration of sulfate and chloride compounds; and (4) concentration of organic compounds.

Fine silt (material passing a 200 mesh sieve) weaken the binding between the metals and the cement/pozzolan binder by coating the metals. The chemical bond formation is inhibited resulting in a decrease in the mass resistant to leaching. The presence of oil and/or grease can also coat the metals resulting in the weakening of the chemical bonds. Presence of organic compounds, sulfates and chloride compounds also interfere with the stabilization reactions by affecting the duration of curing of the material and weakening the bond strength.

The implementation of a stabilization process is affected by the amount and type of stabilizing agent and additives, the degree of mixing required, the residence time and the stabilization temperature/humidity. These parameters are critical to the effectiveness of the stabilization process employed.

Inappropriate weight ratios of additives and stabilization agents to the soils combined with incorrect water quantity may result in an ineffective bonding of the hazardous constituents.

Mixing is required to verify a homogeneous distribution of the hazardous constituents, the stabilizing agents and any additives employed. Undermixing will result in a non-homogeneous mixture and waste particles are neither chemically bonded to the agent nor physically located within the lattice structure formed during hydration. Overmixing may inhibit lattice formation and ion adsorption.

Duration of curing or the residence time is critical to the formation of stable chemical bonds. Sufficient time (typically 7-28 days) is necessary to effectively stabilize the wastes in the soil. Temperature and humidity are important factors in the determination of the curing time required.

2.3 Encapsulation

Encapsulation processes are utilized to contain solid wastes that may leach hazardous constituents. These processes can be used to treat individual waste particulates or masses of waste. Previous testing has shown encapsulation to be an effective method of treatment for a variety of hazardous waste containing heavy metals.

The encapsulation process involves placing a previously dewatered (or non-liquid containing) waste in a coating or jacket of inert material (such as organic polymers). The operation of the process requires that the waste be mixed or covered with a hardening resin which is placed in a mold. The resin cures, resulting in a solid block with reduced leachability potential.

An advantage of encapsulation over stabilization is that there is a minimal volume increase for the resin coating relative to the original waste volume. A major drawback to the encapsulation process is the uncertain effectiveness of the resin utilized to contain the waste over a long period of exposure to harsh conditions. Loose materials are typically agglomerated by a polybutadiene binder and finally encapsulated by a high density polyethylene.

The key issue to be considered in the evaluation of encapsulation includes the compatibility of the waste and surrounding soils with the encapsulant. Other characteristics typically determined include the waste viscosity and water content. These two (2) issues are not of concern regarding the mercury burial vaults.

The design of an encapsulation process used at the mercury burial cell (SWMU N° 9) must take into account the size of the cell and the encapsulant features. The encapsulant must be compatible with the surrounding soils and groundwater if encountered. The cell would have to be lifted, placed in a mold and held in place while the encapsulant cures.

2.4 Subsurface Barriers

Subsurface barriers refer to a variety of methods where by a low permeability material, in the form of cut-off walls or diversions, is installed below ground to contain, collect or redirect groundwater flow in the area where contamination may exist. The most commonly used subsurface barriers are slurry walls, usually comprised of a soil-bentonite slurry. Concrete slurry walls, grouted barriers and sheet piling cut-off walls are also utilized to a much lesser degree. Grouting is often required to create horizontal barriers along the surface of an aquaclude or aquatard.

Slurry walls are constructed in a vertical trench that is excavated under a slurry comprised of bentonite and water. The slurry acts as a drilling fluid to prevent the trench from collapsing and it also forms a filter cake on the trench wall thus reducing high fluid losses. A soil-bentonite (SB) or concrete-bentonite (CB) mixture is used to form the slurry wall. In some instances, pre-cast or cast in place concrete panels are employed to form the barriers. The soil bentonite slurry walls are usually the lowest cost to install, has the widest range of compatibilities and lowest permeabilities. On the negative side, these walls have the least strength, require a large work area, and are applicable to sites that are generally flat.

Upgradient placement of a slurry wall refers to a barrier installed at the boundary of the waste contamination on the side from which groundwater is entering the site. Downgradient placement is used as a blocking wall to capture the mobile contaminants prior to leaving the site.

Major concerns in the application of soil bentonite walls is the compatibility of the slurry wall with the contaminant(s) located at the site. Additionally, content of the backfill is critical as these slurry walls are not able to withstand strong acids, bases, some organic materials and strong saline solutions. The long term performance data on the ability of slurry walls to withstand permeation and contact with certain contaminants are not available.

A number of chemical compounds can have a significant detrimental effect on soil bentonite walls. Table 2-1 identifies the effect of some chemicals on the slurry wall permeability. Permeabilities have been shown to increase (orders of magnitude) for slurry walls that have come in contact with some organic fluids.

TABLE 2-1
SOIL BENTONITE PERMEABILITY INCREASES DUE TO LEACHING WITH VARIOUS POLLUTANTS

Pollutant	Backfill*
Ca^{++} or Mg^{++} @ 1,000 ppm	N
Ca^{++} or Mg^{++} @ 10,000 ppm	M
NH_4NO_3 @ 10,000 ppm	M
Acid (pH > 1)	N
Strong acid (pH < 1)	M/H*
Base (pH < 11)	N/M
Strong base (pH > 11)	M/H*
HCl (1%)	N
H_2SO_4 (1%)	N
HCl (5%)	M/H*
NaOH (1%)	M
CaOH (1%)	M
NaOH (5%)	M/H*
Benzene	N
Phenol solution	N
Sea water	N/M
Brine (SG=1.2)	M
Acid mine drainage ($FeSO_4$, pH ~ 3)	N
Lignin (in Ca^{++} solution)	N
Organic residues from pesticide manufacture	N
Alcohol	M/H

N - No significant effect; permeability increase by about a factor of 2 or less at steady state.
M - Moderate effect; permeability increase by factor of 2 to 5 at steady state.
H - Permeability increase by factor of 5 to 10.
* - Significant dissolution likely.
+ - Silty or clayey sand, 30 to 40% fines.

Slurry walls are not typically the only action taken in the remediation of a site. Surface barriers, and/or extraction wells or drains will be required to address the contaminated waters contained.

The installation of a slurry wall using the slurry trench method is illustrated in Figure 2-1. The slurry preparation process is shown on Figure 2-2. The slurry is introduced just after the trenches are opened and before the water table is encountered. The slurry acts as a hydraulic shoring to prevent trench collapse and contributes to a lower permeability of the completed wall. The backfill is lowered into the excavated trench or packed into the trench in a layered fashion. The trench continues and backfill placement is carefully watched to verify proper installation. The trench excavation material will require special handling based on the analytical results of a composite sample collected. If the soils fail the TCLP test for heavy metal concentrations, trench spoils will be sent to a secure hazardous waste landfill for disposal.

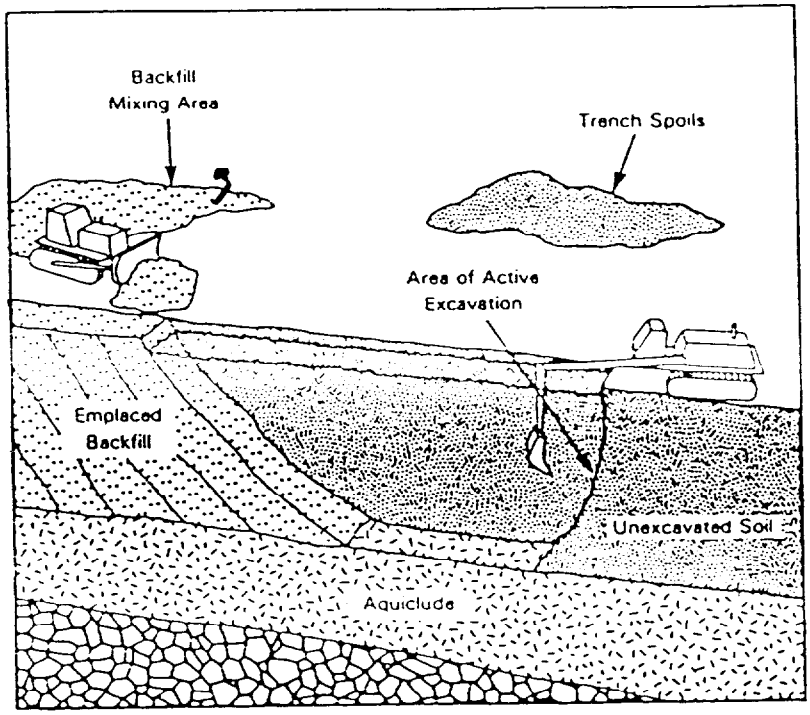
A cement-bentonite (CB) slurry wall uses the same principle as the soil-bentonite (SB) slurry wall, however, the soil backfilling procedure is not necessary. The slurry of a CB mixture is commonly used as the backfill, thus eliminating the need for a large area to be mixed as with the soil bentonite method.

The cement-bentonite wall has a permeability of about $1x10^{-6}$ cm/sec (versus $1x10^{-8}$ cm/sec for soil-bentonite) and is more susceptible to chemical attack by sulfates and other highly ionic substances. The cost of the CB wall is typically higher than the SB wall due to the cost of Portland Cement.

Grouting is a process whereby a fluid is injected into a rock or soil formation and allowed to set in place in order to reduce water flow. The costs associated with grouted barriers are much more expensive than SB or CB barriers and usually have higher permeability rates. Cement grouts have been used for water cut-off operations and are best suited for open soils (high void ratio). Additives, such as clay, bentonite and alkali silicates

FIGURE 2-1

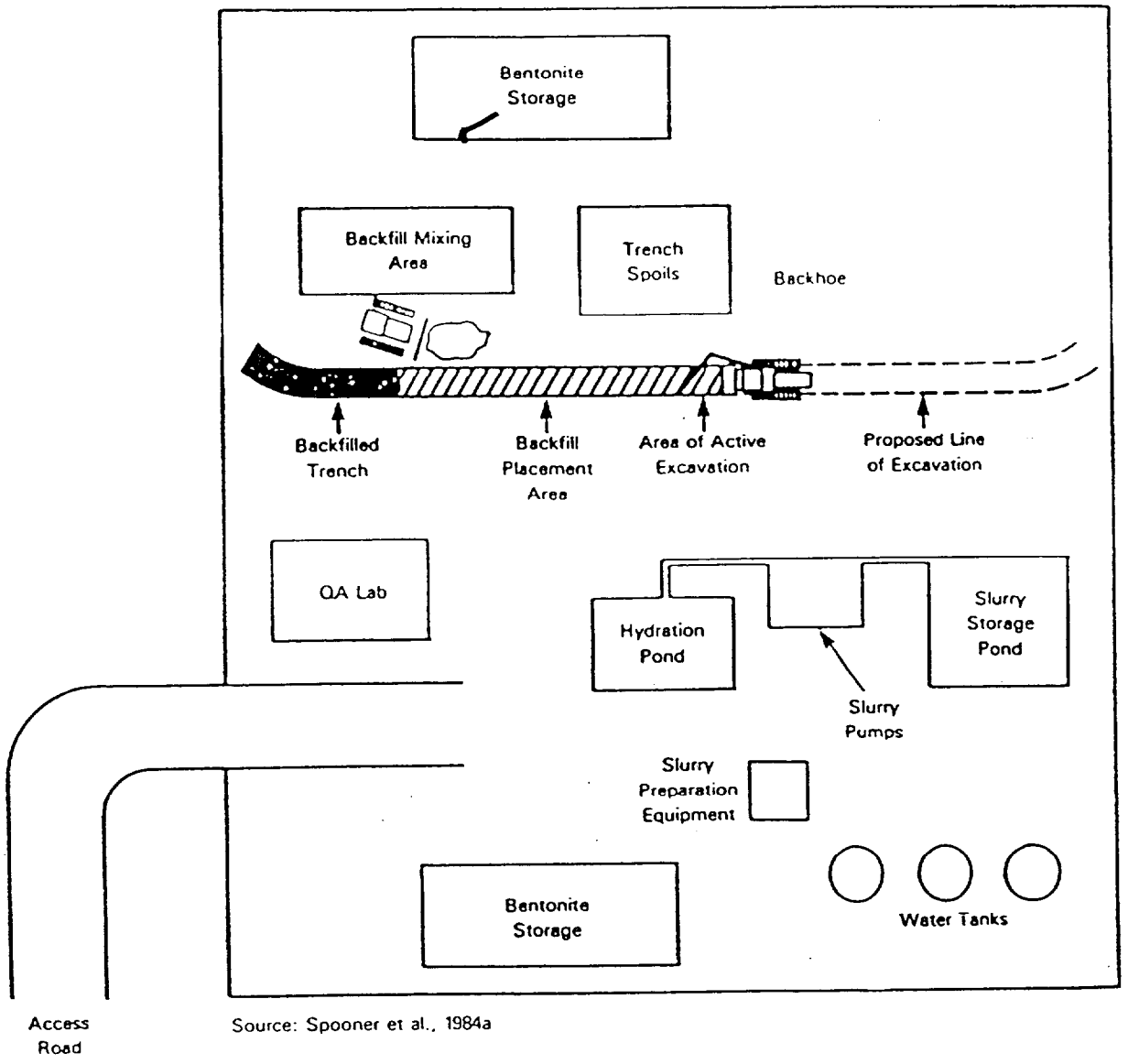
CROSS-SECTION OF SLURRY TRENCH, SHOWING EXCAVATION AND BACKFILLING OPERATIONS



Source: Spooner et al., 1984a

FIGURE 2-2

TYPICAL SLURRY WALL CONSTRUCTION SITE



Source: Spooner et al., 1984a

are used to enhance the grout characteristics. Cement grouts are better suited for high permeability formations, whereas the silicate grouts are best suited for formations with permeabilities less than $1x10^{-2}$ cm/sec. Organic polymers (acrylamide, phenolic, urethane, epoxy, etc.) can also be utilized which consists of organic monomers that polymerize and crosslink to form an insoluble gel. The cost for implementing a grouting system is considerably higher than slurry walls and has not been well documented for use at a hazardous waste site.

Sheet piling can also be used as a groundwater barrier much like slurry walls. The largest draw-back of this method is the problem encountered where the formation contains many rocks and boulders. Damage to or deflection of the piles will likely render the driven wall ineffective as a groundwater barrier. Due to the soil conditions, the performance of a sheet piling wall can be severely reduced. Aggressive soils (low pH) can reduce the duration to less than ten years.

2.5 Surface Water Controls

Surface water controls include a wide range of containment, diversions and collection methods which are designed to minimize off-site transport of contaminants that have been in contact with surface waters.

Surface water control technologies are designed to perform one or all of the following functions:

- Prevention of run-on
- Interception of run-off
- Control of erosion
- Collection and transfer of waters
- Prevention of infiltration
- Storage and discharge of water
- Protection from flooding

A summary of surface water controls is tabulated in Table 2-2. The most effective strategy for managing surface waters and off-site discharge of contaminants may include a combination of several of these water control technologies.

TABLE 2-2
SUMMARY OF SURFACE WATER CONTROLS

Technology	Primary Function					
	Prevent of Intercept Run-on/Run-off	Prevent or Minimize Infiltration	Reduce Erosion	Collect and Transfer Water	Protection from Flooding	Discharge Water
Capping		X				
Lagoon Covers		X				
Grading	X		X			
Revegetation	X	X	X			
Dikes and Berms	X		X		X	
Channels and Waterways			X	X		
Terraces and Benches	X		X			
Chutes and Downpipes			X	X		
Seepage Basins and Ditches						X
Sedimentation Basins and Ponds	X					X
Levees and Floodwalls	X				X	

The following provides a brief discussion of the surface water control technologies considered for the PNS solid waste management units.

2.6 Capping

Capping is a process used to cover buried waste materials to prevent their contact with the land surface and groundwater. The design of modern caps usually conform to the performance standards in 40 CFR 264.310, which addresses RCRA landfill closure requirements. These standards include minimum liquid migration through the wastes, low cover maintenance requirements, efficient site drainage, high resistance to damage by settling or subsidence, and a permeability lower than or equal to the underlying liner system or natural soils. These performance standards may not always be appropriate, particularly in instances where the cap is intended to be temporary, where there is very low precipitation, or when the capped waste is not leached by infiltrating rainwater.

There are a variety of cap designs and capping materials available. Most cap designs are multi-layered to conform to the above-mentioned design standards. The selection of capping materials and a cap design is influenced by specific factors such as local availability and costs of cover materials, desired functions of cover materials, the nature of the wastes being covered, local climate and hydrogeology, and projected future use of the site in question.

Capping is necessary whenever contaminated materials are to be buried or left in place at a site. In general, capping is performed when extensive subsurface contamination at a site precludes excavation and removal of wastes because of potential hazards and/or unrealistic costs.

Capping is often performed together with the groundwater extraction or containment technologies to prevent, or significantly reduce further plume development; thus reducing the time needed to complete groundwater clean-up operations. In addition, groundwater monitoring wells are often used in conjunction with caps to detect any unexpected migration

of the capped wastes. A gas collection system should always be incorporated into a cap when wastes may generate gases. Surface water control technologies such as ditches, dikes and berms are often associated with capping because these structures are often designed to accept rainwater drainage from the cap. Two other surface water control technologies, grading and revegetation, are incorporated into multi-layered caps.

The main disadvantages of capping are the need for long-term maintenance and uncertain design life. Any cap will need to be periodically inspected for settlement, ponding of liquids, erosion, and naturally occurring invasion by deep-rooted vegetation. In addition, the groundwater monitoring wells, often associated with caps, need to be periodically sampled and maintained. However, these long-term maintenance requirements usually are considerably more economical than excavation and removal of the wastes.

Another disadvantage to capping is the high cost of appropriate soil and drainage materials in certain areas of the country. However, these high costs would seldom result in selection of the excavation and removal alternative on the basis of economics. The most probable reason for not selecting the capping alternative at a site with extensive subsurface contamination would be an unacceptable risk to a source of drinking water (groundwater).

The primary purpose of a cap is to minimize contact between infiltrating rainwater and the emplaced wastes. There are two basic designs: multilayered and single-layered. Of these, the multi-layered caps are the most common and are required by the RCRA land disposal regulations of 40 CFR, Subparts K through N and are preferred, if not required, by State agencies for industrial and municipal landfills. It should be noted that a gas collection system should always be included in the design of a cover when there is any indication that the underlying wastes may generate gas.

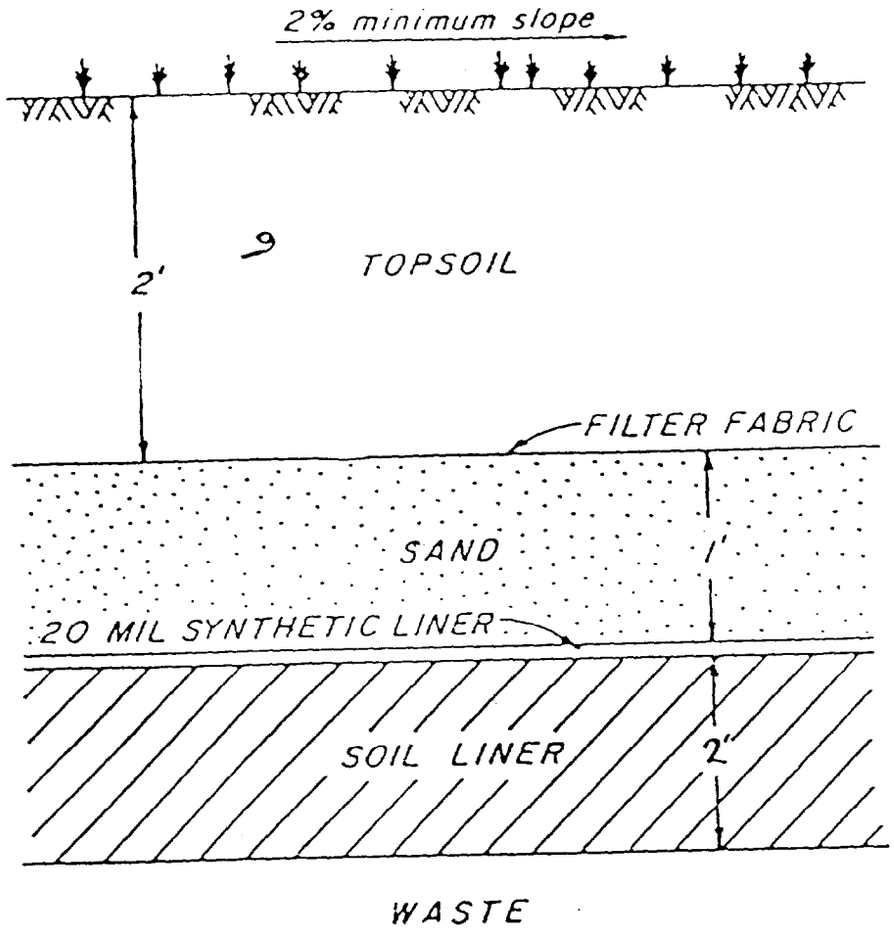
The design of multi-layered caps generally conforms to EPA's guidance under RCRA which recommends a three-layered system consisting of an upper vegetative layer, underlain by a drainage layer over a low permeability layer (USEPA, 1982). Figure 2-3 provides an example of a multi-layered cap. The vegetative layer is served by the topsoil layer; the drainage layer is composed of sand; and the low permeability layer is formed by the combined synthetic and soil liner system. The cap functions by diverting infiltrating liquids from the vegetative layer through the drainage layer and away from the underlying waste materials.

The low permeability layer of the multi-layered cap can be composed of natural soils, admixed soils, a synthetic liner, or any combination of these materials. However, a synthetic liner overlying at least two (2) feet of low permeability natural soil or soil admixture is recommended because the synthetic liner allows virtually no liquid penetration for a design minimum of 20 years, while the soil layer provides assurance of continued protection even if the synthetic liner fails.

Standard design practices specify permeabilities of less than or equal to 10^{-7} cm/sec for the soil liner (Cope et al., 1984). This specification would require a natural soil in the CL/CH range of the Unified Soil Classification System (USCS) (not less than 50 percent by weight passing a No. 200 sieve); however, blending of different on-site soil types can broaden the grain size distribution of a soil and can minimize its infiltration capacity. Well-graded soils are less permeable than those with a small range of grain sizes, and mixing of local coarse and fine-grained soils is a cost-effective method of creating stronger and less porous cover soil (Lutton, Regan, and Jones, 1979).

FIGURE 2-3

MULTIMEDIA CAP



When sufficient fine grained soils are not available to achieve the desired permeability, clay material can be brought in. Bentonite, a natural clay with high swelling properties, is often transported to a site and mixed with on-site soil and water to produce the low permeability layer of the cap. Blending can often be accomplished in place using a blade or harrow to turn and mix the soil to suitable depths (Lutton, Regan, and Jones, 1979).

Chemical stabilizers and cements can be added to relatively small amounts of on-site soils to create stronger and less permeable surface sealants. Portland cement or bitumen (emulsified asphalt or tar) is suitable for mixing with sandy soils to stabilize and waterproof them. Site-specific mixing, spreading, and compacting procedures are required. For a soil-cement, approximately eight (8) percent (by weight) dry cement is blended into the soil with a rotary hoe or tiller as water is added. Intermittent sprinkling over several days may be required before compaction and solidification are achieved (Lutton, Regan, and Jones, 1979).

Soils may also be treated with lime, fly ash, bottom ash, and furnace slag, however, these materials should be tested for hazardous metals and organics prior to use. These materials contribute pozzolanic (cementing) properties to the resulting mixture, optimize the grain size distribution, and reduce the shrink/swell behavior. Lime applied as 2 to 8 percent (by weight calcium oxide or hydroxide) is suitable for cementing clayey soils. Sands and gravels are more suitable for combined lime-fly ash treatment than are finer-grained soils (Lutton, Regan, and Jones, 1979). Rotary tiller mixing followed by water addition and compaction is the general application sequence for these mixtures. If a synthetic liner is present, liner life may be prolonged by adding lime to the supporting soil (Fields and

Lindsay, 1979). Other soil additives include chemical dispersants and swell reducers. Soluble salts such as sodium chloride, tetrasodium pyrophosphate, and sodium polyphosphate are added primarily to fine-grained soils with clay minerals to deflocculate the soils, increase their density, reduce permeability, and facilitate compaction. Additives are more effective with montmorillonite clay than with kaolinite or illite.

Flexible synthetic membranes are made of polyvinyl chloride (PVC), chlorinated polyethylene (CPE), ethylene propylene rubber, butyl rubber, Hypalon(R) and neoprene (synthetic rubbers), and elasticized polyolefin. Synthetic liners are generally more expensive and require labor-intensive sealing materials that necessitate the use of special field installation methods. Thin sheets are available in sections of variable width. During installation, the sheets are overlaid and spliced in the field according to the manufacturer's specifications, using special adhesives and sealants to ensure liner integrity. The chemical resistance of a cap synthetic liner is not usually critical. However, the potential for organic and/or corrosive vapors should be carefully evaluated before dismissing the resistance factor. The thickness and flexibility of a cap synthetic liner are crucial and should be carefully researched during the material selection process. Cope et al. (1984) and Matrecon, Inc. (1983) describe several important considerations for selecting synthetic liners. The slope of the low permeability layer should be between 3 and 5 percent to prevent erosion (if the upper synthetic layer fails) and pooling of rainwater. The underlying base of this layer should consist of fine to medium grade fill which will support the weight of the entire cap and not abrade the liner. If a clay or similarly fine grained soil liner is to be used, the underlying base must be sufficiently fine to preclude piping of the liner. Piping occurs when sections of an overlying fine-grained soil layer erode and fall into an underlying coarser grained soil layer (Matrecon, Inc., 1983). Piping may be prevented by placement of a suitably fine-meshed filter fabric between the two layers.

Capping is a reliable technology for sealing off contamination from the aboveground environment and significantly reducing underground migration of wastes. Caps can be constructed over virtually any site, and can be completed relatively quickly if the ground is not frozen or saturated. Most of the soil materials for capping are readily available in most areas of the country, and the synthetic materials are widely manufactured and distributed. The equipment used for implementing this technology is standard road construction equipment, however, some specialized testing equipment must be supplied by the liner installer or a soil testing company.

2.7 Grading

Grading is the general term for techniques used to reshape the surface of covered landfills in order to manage surface water infiltration and run-off while controlling erosion. The spreading and compaction steps used in grading are techniques practiced routinely at sanitary landfills. The equipment and methods used in grading are essentially the same for all landfill surfaces, but applications of grading technology will vary from site to site. Grading is often performed in conjunction with surface sealing practices and revegetation as part of an integrated landfill closure plan.

Erosion control may be considered a complicating variable in the design and performance of a grading scheme. The design of graded slopes at waste disposal sites should balance infiltration and run-off control against possible decreases in slope stability and increases in erosion. The design of specific slope configurations, the choice of cover soil type, the degree of compaction, and the types of grading equipment used will all depend upon local topography, climate, future land use of the site, and drainage methods.

Improperly graded slopes may deform or fail, opening cracks, exposing wastes, and allowing lateral seepage of leachate. Soils used to cover graded slopes should be selected on the basis of shear strength and erodibility (Lutton, Regan, and Jones, 1979). Soils high in silt and fine sand and low in clay and organic matter are generally most erodible (USEPA, 1976). Also, the longer and steeper the slope is, and the sparser the vegetation cover, the more susceptible it is to erosive forces.

Surface grading of covered disposal sites, when properly designed and constructed to suit individual sites, can be an economical method of preventing infiltration, diverting run-off, and minimizing erosion. A properly sealed and graded surface will aid in the reduction of subsurface leachate formation by minimizing infiltration and promoting erosion-free drainage of surface run-off. Grading can also be used to prepare a cover soil capable of supporting beneficial plant species.

2.8 Drainage and Flood Controls

Several technologies are available to control surface water run-off which minimize contact with the ground surface area containing hazardous constituents during remediation and reduce the potential of infiltration where the constituents reside below the ground surface. These methods are generally short term remediation techniques employed during remediation, but can be utilized during post remediation site maintenance in preventing erosion damage. The following describes potential technologies for the SWMU's at PNS.

2.8.1 Dikes and Berms

Dikes and berms are well-compacted earthen ridges or ledges constructed immediately upslope from or along the perimeter of disturbed areas (e.g., SWMUs). These structures are generally designed to provide short-term protection of critical areas by

intercepting storm run-off and diverting the flow to natural or manmade drainage ways, to stabilized outlets, or to sediment traps. The two terms, dikes and berms, are generally used interchangeably; however, the term dike is used exclusively when referring to flood containment levees.

Dikes and berms may be used to prevent excessive erosion of newly constructed slopes until more permanent drainage structures are installed or until the slope is stabilized with vegetation (USEPA, 1976). They are widely used to provide temporary isolation of wastes until they can be removed or effectively contained. They have particularly widespread use during excavation and removal operations where it is necessary to isolate drums or contaminated soils which have been temporarily staged on-site. The dikes not only prevent runoff, but can also prevent mixing of incompatible wastes. These temporary structures are designed to handle relatively small amounts of run-off; they are not recommended for drainage areas larger than five (5) acres (Virginia SWCC, 1980). Diversion of storm run-off will decrease the amount of water available to infiltrate the soil cover, thereby reducing the amount of leachate production.

- Intercepter dikes which are built with zero (0) percent grade and are designed only to reduce slope length.
- Diversion dikes which are built with a grade sufficient to drain and are designed to intercept and divert surface flow as well as to reduce slope length.

Dikes and berms ideally are constructed of erosion-resistant, low permeability, clayey soils. Compacted sands and gravel, however, may be suitable for interceptor dikes and berms. The general design life of these structures is on the order of one year maximum; seeding and mulching or chemical stabilization of dikes and berms may extend their life expectancy. Stone stabilization with gravel or stone rip-rap immediately upslope of diversion dikes will also extend performance life.

2.8.2 Chutes and Downpipes

These structures are used to carry concentrated flows of surface run-off from an elevated level to a lower level in a manner that is controlled away from the SWMU and constructed from materials that eliminates erosion. They generally direct waters collected from stormwater run-off to stabilized outlets. They are effective in preventing erosion on long steep slopes and usually used to channel uncontaminated run-off to stabilized waterways (i.e. Piscataqua River) for off-site transport.

Chutes are open channels that are lined with either cement, grouted riprap, bituminous concrete or similar erosion resistant material.

Downpipes are structures constructed of rigid piping (corrugated aluminum) or flexible tubing. A prefabricated entrance and exit structure is usually installed to remove the water collected. These systems are usually utilized for drainage of areas less than five acres in size.

The construction of these systems are typically inexpensive and quick to fabricate. They are usually designed to withstand severe storms which threaten to erode the slopes of a disposal area or redirect the storm water from the disposal area or SWMU.

Periodic inspections and maintenance of the chutes or downpipes is required to ensure proper performance. The inspections would occur both during and after heavy rainfalls to verify the operation of the structures and check the integrity of the structure.

2.8.3 Floodwalls and Levees

Levees and floodwalls serve as flood protection structures for areas subject to tidal flow. Levees are typically constructed of earthen materials, while floodwalls are of concrete. A levee is typically used at locations where periodic flooding may occur. A floodwall is designed to withstand the hydrostatic pressure exerted by the adjacent water at

the maximum height. Since floodwalls are subject to hydrostatic pressure on only one side of the wall, an adequate foundation is required. Interior drainage systems may be required to handle any seepage and leachate buildup.

A levee is less suited for the PNS facility SWMU's due to the presence of subsurface contaminants. The earthern levee is more susceptible to seepage and potential migration of contaminants from the site. A sheet pile cut off to an impervious stratum and upgradient filter drain/collection sump would be required. A floodwall must extend to the impervious stratum or be used in conjunction with a sheet pile set up. This method is very similar to the barrier wall system discussed previously.

The surface water diversion and containment systems previously described are well established methods. Many of the methods are ineffective as long term remedial measures. Frequent inspection and maintenance of the system may be required. Failure of floodwalls can be costly.

Proper design, often involving an integrated system of several measures, is critical to the effectiveness and reliability of the diversion and collection technologies. Proper construction practices are also very important in implementing effective controls. Improperly installed systems can worsen the conditions at a SWMU.

2.9 Groundwater Controls

Groundwater contamination control involves the objectives; (1) containment of contaminants; (2) removal of the contaminants contained; (3) diversion of upgradient groundwater from entering the contaminated area and; (4) prevention or removal of leachate. Several remediation technologies, some utilized in conjunction, others are available to complete the above objectives. The technologies utilized are (1) in-situ biological/chemical treatment of contaminants; (2) subsurface interception of groundwater; (3) low permeability barriers to control groundwater movement; and (4) groundwater pumping to collect contaminated groundwater.

2.9.1 Subsurface Drains

Subsurface drains provide a continuous zone of collection of contaminated groundwaters through a series of buried pipelines. The pipelines lead to a collection sump where the groundwater is extracted by a pump and transferred in an aboveground treatment system designed to remove the contaminants.

The components of a subsurface drainage system are:

- drainage pipe for conveying the contaminated groundwater to a storage tank or collection sump
- filter for removal of fine particles that may clog the system
- site restoration to minimize ponding/infiltration
- surface water controls
- collection sumps or wet wells
- storage tanks.

Subsurface drains act like a continuous line of extraction wells used to lower the groundwater table and remove the contaminants present in the subsurface. They are best applied to shallow subsurface contamination in low or variable hydraulic conductivity soils. Where groundwater removal is projected for several years, subsurface drains are preferred over extraction wells because of the reduced operation and maintenance costs.

At any SWMU, the use of subsurface drains is used to intercept the contaminated groundwater downgradient of the SWMU. Often a subsurface barrier is used to separate the SWMU from external inflow due to groundwater depression near the collection sump during groundwater extraction. The extraction of the contaminated waters collected by the drains just upgradient of a barrier wall will minimize contact of the groundwater with the barrier.

The major factor in determining the applicability of subsurface drains is depth to groundwater and change in elevation of the groundwater to be removed. Additional factors to be considered include viscous or reactive chemicals and biological growth that clog the

drain and the presence of iron, manganese or calcium carbonate. Pipe drain collection systems are typically employed and the pipe must be compatible with the constituents encountered. Gravel drains are seldom employed due to excessive movement and clogging of the gravel by fine grained sands and silts.

The major elements of a subsurface drainage system design are:

- pumping station capacities
- properties of filter materials
- piping hydraulics
- location of pipeline(s).

Contaminated groundwater is collected by gravity from drainage pipes in an underground sump. A pumping system, usually automatic, is used to remove the contaminated wastewaters for aboveground treatment. Issues such as groundwater flow potential, storage capacity required, treatment system flow rate, collection sump size and pump specifications are determined to remediate the site.

Filters and envelopes are used to prevent soil particles from entering the drain and improve water flow with reduced flow velocity to the drains. Filter fabrics, made of geotextiles (polypropylene, polyethylene, polyester) are chosen based on soil characteristics and hazardous constituent characteristics. The envelope material must have a hydraulic conductivity greater than that of the surrounding soils, determined in conjunction with the filter utilized.

Pipe diameters and the "as-installed" slope are the parameters evaluated during design of the pipelines. Collected waters must be conveyed to the collection sump without a build up of pressure. Commonly used drainage pipes include perforated and flexible PVC, steel, aluminum and vitrified clay. Pipeline diameters are determined by the discharge, hydraulic gradient and roughness coefficient.

Interception drains are installed perpendicular to groundwater flow. Relief drains are installed parallel to groundwater flow or around the perimeter of the SWMU. Installation of the pipeline drains is based on hydraulic conductivity data, plume boundary limits, and geologic cross-sections that were obtained during the remedial investigation. The drains are typically installed on top of a layer of low hydraulic conductivity. If soil layers or pockets with high hydraulic conductivity underlie the drain, leachate with soluble contaminants may flow beneath the drain. Underflow can be minimized by placing an impermeable liner material at the base of the trench before laying a 1-3 foot thick gravel bedding. Where pockets of highly permeable soils are found (landfill and demolition debris), a manhole can be constructed with a small lift station to pump the liquids to a gravity drain system or storage tank. Another option most commonly used includes the installation of a downgradient barrier wall to a low permeability layer. The placement of the drainage pipelines is based on a good estimate of the upgradient and down gradient influence of the drain. Depth of the drain is based on the groundwater table fluctuation, the contaminant solubility/specific gravity and stratum particle grain size. Drain spacing may be determined by the boundaries of the SWMU if excavation within the SWMU is unsafe.

2.9.2 Groundwater Pumping

The remediation technology of groundwater pumping utilizes groundwater extraction to remove or manipulate the movement of contaminants. Different types of wells (well points, deep wells, ejection wells) are used to provide the point of groundwater removal. The actual well utilized depends on the depth to groundwater and the hydraulic conductivity of the aquifer. In most instances, more than one extraction well will be required for site remediation. Well systems have proven to be very effective in containing, removing, diverting or preventing the development of plumes.

Well pumping is very effective where the aquifer has a high hydraulic conductivity, however, a line of extraction wells may be required to stop the advance of the contaminants. Extraction wells are frequently used in conjunction with a slurry wall which reduces the quantity to be pumped for treatment especially when the contaminants are miscible in water.

A combination of extraction/injection wells is used for sites where the hydraulic gradient is relatively flat and hydraulic conductivities are moderate. The injection well is used to direct contaminants (including immiscible) toward the extraction well. Maintenance and operational problems are often encountered with the injection well. Several well points can be connected to a common header for shallow high yield aquifers (<20'). Deep wells and ejection wells are better suited for extraction of groundwater at depths greater than 20'. Table 2-3 provides the general criteria used for well selection.

Well system design for a particular site depends on the aquifer type encountered, aquifer depth and soil conditions. In an unconfined aquifer as encountered at PNS, there is no upper confining layer. The water table at PNS changes radically with the surrounding surface water levels, and water table alterations.

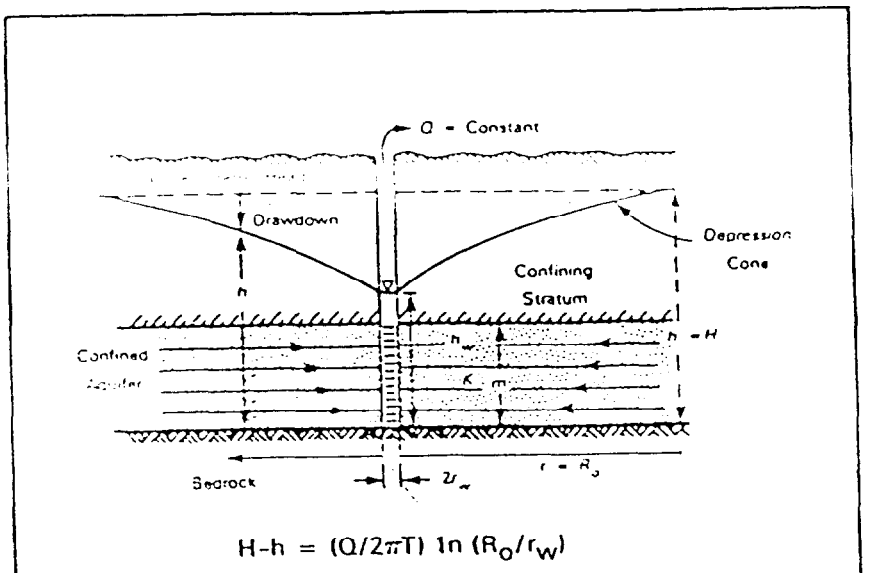
Alteration of the water level around a well being used for extraction is illustrated on Figure 2-4. Drawdown, or the change in water table height as a result of pumping is greater at and near the well, and small at greater distances from the pumping well. The radius or distance away from the well that is affected by groundwater pumping increases with higher hydraulic conductivities. The size of the cone of depression is dependent on the pumping rate, period of pumping, hydraulic barriers, aquifer characteristics and recharge. The transmissivity (how much water can be removed by pumping) is determined during a pump test. This information is used to determine pumping rates, number of wells and assist in determining the expected duration of groundwater extraction for site remediation.

TABLE 2-3
CRITERIA FOR WELL SELECTION

Parameters	Well Points	Suction Wells	Ejector Wells	Deep Wells
Hydrology				
• Low hydraulic conductivities (e.g., silty or clayey sands)	Good	Poor	Good	Fair to Poor
• High hydraulic conductivities (e.g., clean sands and gravel)	Good	Good	Poor	Good
• Heterogeneous materials (e.g., stratified soils)	Good	Poor	Good	Fair to Poor
• Proximate recharge	Good	Poor	Good to Fair	Poor
• Remote recharge	Good	Good	Good	Good
Depth of Well	Shallow <20ft	Shallow <20ft	Depth >20ft	Deep >20ft
Normal Spacing	5 - 10 ft	20 - 40 ft	10 - 20 ft	>50ft
Normal Range of Capacity (per unit)	0.1 - 25 gpm	50 - 400 gpm	0.1 - 40 gpm	25 - 3000 gpm
Efficiency	Good	Good	Poor	Fair

FIGURE 2-4

CONFINED AQUIFER FLOW



$$H-h = (Q/2\pi T)\ \ln (R_0/r_W)$$

Source: Davis and DeWiest, 1966

Well system design includes the number and spacing of wells, well construction, pumping rates and discharge handling. Key issues considered during design include; equilibrium vs. non-equilibrium pumping, radius of influence, well spacing, pumping rates of each well, and the integration of the system with the other remediation technologies utilized. The components of each well must be determined (casing, well screen, gravel pack material, and pump type). The well installation methods are shown in Table 2-4.

Due to site conditions at the PNS SWMUs, air rotary drilling would be the best well installation technique. This method uses compressed air for drill cutting removal. As the drill bit is advanced, the high pressure air pushes the cuttings out the top of the borehole.

Well completion, gravel packing and well development are the key issues considered during well installation. Proper well development will provide increased well yields, reduced particulate fines and decreased corrosion and encrustation.

Groundwater pumping systems are the most flexible of the groundwater control technologies. They are used to contain, remove or divert the contaminants at a site under a wide range of hydrogeologic circumstances. When integrated with a cap and barrier wall, the groundwater pumping system can be used to remediate a site very efficiently.

2.10 IN-SITU Treatment

In-situ or in-place treatment, utilizes chemical or biological agents or physical alteration of the soils to remove or immobilize the contaminant present. The three major processes (chemical, biological, and physical) are determined suitable for remediation based on site-specific data. Biodegradation is the process of stimulating microflora to decompose the contaminants (organics only). Chemical treatment involves the introduction of chemicals to degrade, immobilize or flush the contaminants (organic and inorganic). Physical methods, such as heating or freezing is sometimes used. In-situ treatment may be the most cost effective method when included in a combination of several other techniques (i.e. in-situ coupled with capping and aboveground treatment).

TABLE 2-4
METHODS OF WELL INSTALLATION

Method		Applications			Casing/Screen Treatment	Comments
Basic	Variations	Geological Material	Max. Well Diameter	Max. Well Depth		
Hand	Augers	Soft, without excess sand and water, no boulders	6	20	Driven after opened	
	Driving Points	Soft soil free of boulders	3	30	Driven as hole proceeds	Wider and deeper holes can be machine driven
Boring	Rotary Auger Bucket	Soft soils without excess boulders	48	90	Driven after hole opened	Typically limited to 24-in diameter wells or less
	Spiral Auger	Soft soils without excess sand and water, no boulders	6	90	Driven after hole opened	Cannot be used below water table, must be used in combination with other techniques
Jetting	Self jetting	Soft soils free of boulders	8	50	Drives as hole opened	Jetted wells require less development
	Wellpoint/Riser Unit	Soft soils free of boulders	8	50	Driven as hole opened	Method uses large quantities of water
	Separate Temporary Jetting Pipe	Soft soils free of boulders	8	100	Placed after hole opened	
	Separate Permanent Jetting Pipe	Soft soils free of boulders	8	100	Driven as hole opened	

TABLE 2-4 (CONTINUED)
METHODS OF WELL INSTALLATION

Method		Applications			Casing/Screen Treatment	Comments
Basic	Variations	Geological Material	Max. Well Diameter	Max. Well Depth		
Jetting (cont.)	Rotary Hole-puncher	Soft soil, sandstone, schist	24	200	Driven as hole opened	
Rotary Drilling	Conventional Hydraulic	Any type	--	--	Placed after hole opened	Typically used for deep wells, quickest drilling method
	Reverse Hydraulic	Any type, boulders may be a problem	60	--	Placed after hole opened	Requires large quantities of water
	Air Rotary	Any type	12	--	Placed after hole opened	Very fast method
	Air Rotary with Pneumatic	Any type	8	--	Placed after hole opened	
Cable Tool	Conventional	Any type	--	--	Driven during or after hole opened log well	Typically used for deep wells, provide ability to closely monitor and
	California Stove Pipe	Any type	--	--	Pushed with jacks as hole opened	Quicker and less expensive than conventional cable tool

2.10.1 Bioremediation

Bioremediation involves altering the existing conditions to enhance a microbial activity that breaks down and detoxifies the contaminants present. The three microbial activities are aerobic respiration, anaerobic respiration and fermentation.

Aerobic bacterial activity involves microorganisms that rely on the presence of oxygen to decompose the organic matter present. Indigenous naturally occurring bacteria is commonly utilized given proper quantities of oxygen and nutrients. Specific microorganisms may be genetically manipulated and introduced where appropriate.

Anaerobic bacteria that function only in the absence of oxygen, are most successful in the breakdown process of halogenated organics (e.g. PCE-TCE-TCA-DCA).

The applicability of biodegradation as an in-situ remediation technique is governed by the site on which it is to be utilized and the waste contaminants present. The factors considered are:

- organic contaminant biodegradability
- site conditions and hydrogeology
- environmental conditions of the surrounding area.

Generally, petroleum products, aromatics and most pesticides/herbicides are best treated by aerobic bacteria. Anaerobic bacteria are amenable to halogenated alphaltic hydrocarbon (saturated and unsaturated) degradation. Methane gas may be used as a primary food source for aerobic bacteria for these compounds. In either case, the availability and solubility of the contaminants present dictate the biodegradability.

Site conditions play a major role in affecting the degree of microbial activity. Specific factors that directly influence the degradation rate include:

- levels of organics and inorganics
- oxygen level
- redox potential of contaminants
- % moisture
- conductivity
- temperature
- toxin presence (cyanides, heavy metals)
- predators
- contaminant classification and concentration

Bacteria requires nutrients such as nitrogen and phosphates as well as carbon and an energy source to survive. Extremely high or low temperatures can destroy the bacteria present, while cooler temperatures decrease the biodegradation rate. Toxin presence can also destroy the bacteria. Cyanide and certain heavy metals are often the cause for reduced biological activity. The contaminant itself can act as a toxin if present in very high concentrations. A free product removal system may be needed prior to biodegradation for these sites. The hydraulic conductivity of the soil is also critical in the evaluation of bioremediation. A short residence time is required so that the additives (nutrients, oxygen) are properly utilized in the degradation of the contaminants.

The introduction of the nutrients and support materials is the key to the biological treatment design. The method of injection, soil characteristics, contaminants present and their concentration will determine the quantity and rate of injection necessary to promote microbial growth.

Air or pure oxygen is often injected through aeration well diffusers into the saturated zone. Pure oxygen will provide sufficient oxygen to degrade up to 30 mg/l of organic material. Hydrogen peroxide can also be used to provide dissolved oxygen, and is introduced with the nutrient solution rather than through air injection aeration wells. Ozone can also be utilized but at much lower dosage rates due to the potential for microbial activity interference.

Nutrients are added to supply the microbes with a sufficient source of food. Nitrogen and phosphate are typically needed in the largest quantity with potassium, magnesium, calcium, sulfur, sodium, manganese and iron at trace quantities. Some of these materials are naturally present and do not require addition.

A properly designed injection and recovery system is required to provide hydrologic control of and adequate control time for the treatment agents. To complete the remediation process, spent treatment solutions are extracted downgradient of the contaminated area and used to carry the nutrients that are injected upgradient of the contaminated area.

Anaerobic bioremediation has been used at sites contaminated with PCE and its' daughter products TCE, TCA, DCE and DCA. The reduction process, dehydro-halogenation, yields a less toxic compound as it progresses.

Anaerobic respiration using nitrate or sulfate and the fermentation/methanagenic process together describes the anaerobic metabolism mechanism. The compounds that are degradable by this process are limited and maintaining anaerobic conditions is often difficult. Maintenance of the bacterial population at the desired level, especially for

selectively created organisms that are sensitive to environment conditions may require reinoculation of the subsurface continuously. Injection wells and aeration wells are susceptible to blowout (free movement of the material to the surface around the well) and biomass clogging.

Bioremediation may be more effective than the pump and treat method where the contaminants have a higher affinity to adsorb to the soils. Pumping systems can develop mechanical/electrical failures more often but usually at a lower repair cost and less down time. Exposure to the contaminants is minimal using bioremediation methods and proper choice/usage of nutrients will not create a significant environmental threat. The time required to remediate a site using bioremediation is dependant on the contaminants present, the degradation rates, soil permeability, temperature, and the amount of oxygen and nutrients present. Duration required for remediation will exceed excavation and removal, and dependent on the site, may be longer than conventional pump and treat technologies.

2.10.2 Chemical Treatment

Chemical treatment including precipitation, chelation and polymerization is used to immobilize organic and inorganic contaminants. Mobilization of the contaminants as achieved through soil flushing procedures which utilize surfactants, acids, bases and water. Additional detoxification may be required using oxidation reduction neutralization and hydrolysis. Table 2-5 is a summary of in-situ chemical treatment methods employed at waste sites. Table 2-6 is a listing of specific characteristics identified critical to evaluating in-situ treatment technologies.

TABLE 2-5
SUMMARY OF IN-SITU CHEMICAL TREATMENT METHODS FOR ORGANICS

Method	Amenable to Treatment	Treatment Reagents	Process
Soil Flushing			° Contaminated soils are flooded with water or a water chemical mixture and the elutriated solution is collected.
- Water flushing	Hydrophilic compounds (high solubility, low K_{ow})	Water	
- Water with surfactants	Hydrophobic compounds (low solubility, high K_{ow})	Aqueous solutions of surfactant	° Contaminants are mobilized into solution by reason of solubility, formation of emulsion or reaction.
Oxidation	Benzene and substituted benzenes Phenols Halogenated phenols Nitro aromatics PAHs Heterocyclic nitrogen and oxygen compounds Aldehydes and ketones Sulfides, disulfides	Ozone, hypochlorite, or hydrogen peroxide	° Oxidation state of compounds is increased by loss of electrons. ° Contaminants are detoxified, mobility is increased or compounds are made more amenable to biological degradation.

(Continued)

TABLE 2-5 (CONTINUED)
SUMMARY OF IN-SITU CHEMICAL TREATMENT METHODS FOR ORGANICS

Method	Amenable to Treatment	Treatment Reagents	Process
Hydrolysis (base-catalyzed)	Esters Amides Carbamates Organophosphorus compounds Certain pesticides (i.e., parathion, malathion, 2-4D Esters, DDT)	Water with lime or NaoH	° Attack of nucleophile (e.g., water or hydroxyl ion) on an electrophile (e.g., carbon on phosphorus) resulting in bond cleavage and displacement of the leaving group.
Polymerization	Aliphatic, aromatic and oxygenated monomers - vinyl chloride - isoprene - acrylonitrile	Catalyst activation	° Conversion of a compound to a larger chemical multiple of itself. ° Reduces mobility of compound in soil.

TABLE 2-5 (CONTINUED)
SUMMARY OF IN-SITU TREATMENT METHODS FOR INORGANICS

Method	Inorganics Amenable to Treatment	Treatment Reagents	Process
Precipitation		Sodium or calcium sulfide	Formation of insoluble metal precipitate thereby reducing the mobility of the metal.
- sulfide	Heavy metals		
- carbonate/hydroxide	Heavy metals	Lime, calcium carbonate	
- phosphate	Heavy metals	Superphosphate fertilizer	
Soil Flushing			
- acids/bases	Heavy metals	Dilute solutions of acids or bases	Involves solubilizing the metals followed by extraction of the metal ions
- chelates	Heavy metals	Chelating agents such as citric acid or EDTA	Formation of stable metal chelates; depending on chelating agent, metal chelate is either strongly sorbed to soil or is highly mobile and can be flushed using water or dilute acid solutions.
Oxidation	Trivalent arsenic	Potassium permanganate	Oxidizes trivalent arsenic to pentavalent arsenic, and results in precipitation of arsenic-iron-manganese compounds.
Reduction	Hexavalent chromium Hexavalent selenium	Ferrous sulfate Ferrous sulfate	Reduces Cr (VI) to Cr (III) Reduces Se (VI) to Se (IV)

TABLE 2-6
SITE AND SOIL CHARACTERISTICS IDENTIFIED AS IMPORTANT IN IN-SITU TREATMENT

Characteristics

Site location/topography

Slope of site-degree and aspect

Soil, type and extent

Soil profile properties
- depth
- boundary characteristics
- texture*
- amount and type of coarse fragments
- structure*
- color
- degree of mottling
- presence of carbonates
- bulk density*
- cation exchange capacity*
- clay content
- type of clay
- pH*
- Eh*
- surface area*
- organic matter content*
- nutrient status*
- microbial activity*

Hydraulic properties and conditions
- depth to impermeable layer or bedrock
- depth to groundwater*, including seasonal variations
- infiltration rates*
- permeability* (under saturated and a range of unsaturated conditions)
- water holding capacity*
- soil water characteristic curve
- field capacity/permanent wilting point
- flooding frequency
- run-off potential*
- aeration status*

Climatological factors
- temperature*
- wind velocity and direction

* factors possibly controlled to enhance treatment processes
USEPA 625/6-85-006

The use of chemical treatment technologies requires the delivery and extraction of fluids to the subsurface. Minimum permeabilities will be required to assure appropriate injection and extraction rates. Subsurface containment may also be required to collect contaminants and reduce chemical migration and reduce uncontaminated groundwater flow into the area. Proper selection of chemicals employed is critical for the desired remediation. A specific chemical may immobilize one contaminant while it makes another contaminant more toxic or mobile. A complete evaluation is required to minimize the risk of incompatible or undesired reactions.

The following provides a brief description of the potential technologies considered.

Soil flushing--extraction of contaminants from the soils using solutions containing water, acids/basis and/or complexing/chelating agents. The agents may be anionic, cationic, non-ionic and amphoteric.

Immobilization--rendering the contaminants insoluble to minimize leaching of the contaminants from the soil. Specific methods include precipitation, chelation and polymerization. Polymerization involves injection of a catalyst which transforms the fluids into a gel-like non-mobile mass.

Detoxification--destroy, degrade or reduce toxicity of the contaminants. Processes include neutralization, hydrolysis, oxidation/reduction enzymatic degradation and permeable treatment beds. Permeable treatment beds are excavated trenches placed down gradient of the contaminated area. The bed is filled with a specific material (activated carbon, glauconitic green sands, limestone) through which contaminated groundwater flows and the contaminants are adsorbed, neutralized or detoxified.

The chemical treatment methods considered must be bench and pilot tested prior to implementation. These in-situ methods may be more cost effective than conventional pump and treat methods or excavation and off-site disposal. Cost estimates could be better determined after bench tests simulating site conditions are completed.

2.10.3 Physical Treatment

In-situ heating, vitrification and ground freezing are potential treatment technologies that are currently in the development stages.

Heating methods used to destroy or remove only organic contaminants include steam injection and radio frequency application. The radio frequency process utilizes a grid of horizontal conductors placed on the ground above the contaminated area. After excitation using an RF generator, the decontamination (removal) of organics is achieved at temperatures greater than 300°C and takes several days up to two weeks. A gas recovery system is needed to collect the vapors that discharge from the ground surface.

Ground freezing is used to contain the contaminants in an area by freezing the soils surrounding the location and creating a practically impermeable barrier.

In-situ vitrification utilizes the formation of a glassy or non-crystalline material. An electrical current is passed through a mass of material. The soil is converted into a durable glass and the contaminants are pyrolyzed or crystallized. Any gasses released are collected and treated. The process does not work well at increasing depths due to the reduced vapor release limited by the overburden soils.

2.11 Waste Treatment Methods

There are several waste treatment methods utilized to detoxify, reduce or destroy industrial waste containing hazardous constituents. The wastes may be in the form or aqueous/liquid, gaseous and or solid. The major categories of these treatment methods are:

- solid waste separation/dewatering
- solidification/stabilization
- gas collection and treatment
- incineration/thermal treatment
- aqueous/liquid treatment

Aqueous treatment required as a result of groundwater extraction or surface water treatment depends on the processes utilized at a particular site. The volume of waste and the contaminants present will be dependent on the site conditions. Sources of aqueous wastes may include the following:

- sludge dewatering operations (dredging or clarifiers)
- decontamination wash waters
- contaminated run-off
- leachate from subsurface drains or groundwater extraction systems
- wastewater treatment process waters

The above treatment process to be employed will be dependent on the contaminants present and the volume of waste to be treated. Unit treatment processes are frequently used in combination to achieve the desired contaminant removal and include:

- activated carbon
- activated sludge
- air stripping
- chemical reduction/oxidation
- filtration
- ion exchange
- precipitation/sedimentation/separation
- reverse osmosis
- neutralization

These unit processes may be employed on-site using mobile or permanent facilities. Alternatively, contaminated water may be discharged to a POTW after pretreatment or shipped off-site to a permitted facility. Several factors have to be evaluated in determining the appropriate method including permitting, POTW acceptance and proximity of off-site treatment facilities.

Activated carbon treatment involves the passage of the wastewaters through a bed(s) of carbon which selectively adsorbs many organic and some inorganic molecules. The carbon will require regeneration or replacement as the carbon surfaces are saturated with the contaminants.

Activated sludge is utilized by most POTWs to biodegrade the contaminants in the wastewater stream. Aeration is utilized to facilitate aerobic decomposition by microorganisms. The liquid fraction is separated from solids and treated. The resultant sludge is generally dewatered.

Air stripping is the process of passing the contaminated wastewater through a column of counterflow air to extract the contaminants from the wastewater. This process is best suited for particular organics with minimal, if any, effect on inorganics. The discharge of the air through the top of the tower is collected and treated through chemical adsorption.

Reduction/oxidation is a chemical change where an element either gains or loses an electron that results in a differently charged element or the formation of a different compound. Reduction occurs concurrently with oxidation. The resulting compounds may or may not be less toxic than the original compounds and must be fully evaluated.

Filtration is utilized to separate settleable solids (sludge) from the liquid phase. The method increases the percent of solids in the sludge through removal of the liquid fraction. There are several types of filters available to perform the separation process including plate and frame, belt press, rotary vacuum and diaphragm. Liquids that pass through the filter (filtrate) are either discharged (if within the desired treatment limits) or redirected to additional processes prior to discharge. The filtered sludge is then stabilized, solidified encapsulated or disposed (incinerated, landfilled).

Ion exchange is a process where the contaminants (ions) are removed from the aqueous phase by exchange with a relatively harmless ion. Synthetic organic materials containing the functional exchange ions are structurally stable, exhibit a high exchange capacity and are chosen based on selectivity towards the contaminants to be removed. Anionic resins (positively charged) and sorptive resins for organic removal are also available. The contaminants typically removed include all metallic elements, inorganic anions (halides, sulfate); organic acids (carboxylics, sulfonics) and some organic amines.

Precipitation/sedimentation is the process whereby settleable solids are allowed to settle to the bottom of a vessel. If colloidal particles are present, the addition of alum or polymers causes a floc to form which increases the mass of particles, thereby, increasing the settling velocity of the contaminants and decreasing the detention time. The resulting settled material is then either thickened or dewatered using filtration or other separation methods (centrifuge).

Reverse osmosis is the application of sufficient pressure to a concentrated solution containing the contaminants which overcomes the osmotic pressure and forces the water through a membrane. The normal osmotic principle is for the movement of water through a separating membrane from a low concentration solution to a high concentration solution. Reverse osmosis produces the opposite effect, resulting in the concentration of the contaminant on one side of the membrane and the passage of the cleaned wastewater for discharge from the other. Reverse osmosis is an effective technology for removal of dissolved solids both organic and inorganic. The major factor in determining the acceptability of reverse osmosis is the compatibility of the membranes with the contaminants present and selection of the appropriate pore size for the membrane relative to the contaminant to be separated.

Neutralization involves the addition of chemicals to render the wastewater less hazardous. This technology is commonly utilized in the regulation of the percent hydronium ion concentration indicated by pH measurement. The pH of neutral water is approximately 7. A solution with a pH less than 7 is acidic and greater than 7 caustic. Extremely high pH (>12.5) is neutralized with acid and an extremely low pH (<2) is neutralized with a caustic to attain a less corrosive solution. The reaction of an acid and a caustic results in a solution of water and salts. (i.e. $HCI + NaOH \text{-----}> NaCl + H_2O$). The salts generated must be evaluated for toxicity with a potential for requirements for further treatment.

3.0 SWMU Corrective Measures Screening

The corrective measure to be selected to remediate each SWMU will be dependent on the contaminants present, the concentration of the contaminants and site characteristics specific to each SWMU. The processes previously discussed can be implemented solo as the only treatment process used to achieve the desired cleanup level for the contaminants of concern or as a component of an intequated system of processes . The presence of a contaminant does not automatically warrant the implementation of a corrective measure. A corrective measure need will be based on contaminant mobility, migration pathway and exposure potential. A risk assessment is routinely performed to determine the impact of a contaminant on human health and the environment. The result establishes a clean-up standard necessary to minimize environmental impact (i.e. $< 1x10^{-6}$ cancer risk).

There are five SWMUs under evaluation at the PNS. These are the DRMO, the Fuel Oil Pipeline, the Mercury Burial Sites, the Underground Storage Tanks, and the Jamaica Island Landfill (JILF). Three areas of concern; the Child Development Center (CDC), Quarters S&N and the fresh water ponds, may require interim and/or final corrective measures. The offshore sediment, due to the dynamic conditions of the bay/river, is not addressed for corrective measures at this time. Most sediment collected and analyzed will have moved from the sampling location by the time a corrective measure has been evaluated.

McLaren/Hart has conducted four separate phases of investigation at the SWMUs and area of concern at the PNS. The work conducted in Phase I-IV was summarized in the following documents:

> RCRA Facility Investigation Field Work, Phase I, Portsmouth Naval Shipyard, Kittery Maine, May 31, 1990.
>
> RCRA Corrective Action, Portsmouth Naval Shipyard, Kittery, Maine, Phase II Field Work Report and Appendices I & II, April 26, 1991.

RCRA Corrective Action, Portsmouth Naval Shipyard, Kittery, Maine, Phase III Field Work Report and Appendices I & II, June 5, 1991.

RCRA Corrective Action, Portsmouth Naval Shipyard, Kittery, Maine, Phase IV Field Work Report and Appendices I & II, December 17, 1991.

The following text describes the findings of the site investigations and addresses each SWMU or area of concern separately.

3.1 DRMO

The DRMO was investigated during Phase I, II, III and IV field activities. Surface soil samples were collected and analyzed for metals, TPH and PCBs. Samples were also collected and analyzed from deeper soil borings (0-16'). The range of values observed were as follows:

Analyte	Shallow Highest Value (ppm)	Deep Samples Highest Value (ppm)
Antimony	60.9	6510
Arsenic	83.8	17.4
Beryllium	2.1	2.4
Cadmium	8.1	10.3
Chromium	95.3	134
Copper	5740	1460
Lead	12100	130000
Mercury	0.75	20
Nickel	4970	957
Selenium	1.1	ND
Silver	8.1	7.8
Thallium	Unusable Result	0.0014
Zinc	1230	2960
TPH	810	7500
PCB	0.790	69.8

Concentrations of metals, especially lead, were elevated in both the shallow and the deep soil samples. The concentrations of TPH and PCB observed suggest that petroleum products are present in the subsurface soils.

The DRMO facility, approximately three (3) acres in size is used for the segregation and storage of scrap metals for recycling and recovery. The DRMO is located at the base of the hill south of the Quarters S&N and north of the Piscataqua River. Materials are stored on either blacktop, concrete, or bare earth. While there are no run-off control structures on-site to prevent washing of stored scrap materials during precipitation events, there is a stormwater collection system which drains the area. Additionally, there are two (2) wooden structures utilized for special material storage that provides protection from precipitation for a limited quantity of materials (i.e. electronic gauges, instruments, etc.).

A sample collected from the sediment of a stormwater catch basin located within the DRMO during Phase IV had very high concentrations of copper (13,200 ppm), lead (13,200 ppm), nickel (1,340 ppm), and zinc (1,140 ppm). The effluent of this stormwater collection system leads directly to the river located approximately 50 feet to the south of the DRMO. Additionally, several metals were present at levels exceeding the EPA National Primary Drinking Water Regulations limits in water samples collected from the groundwater monitoring wells installed around the DRMO perimeter. Exceeded limits included those for arsenic, barium, cadmium, chromium, and lead.

3.1.1 Corrective Measures

McLaren/Hart previously recommended the implementation of interim corrective measures;

- Staking of hay bales along the river and performance of weekly inspections
- Surface water run-on/run-off measures
- Control of catch basin discharges

The potential long-term remediation technologies suited for the DRMO are:

- Surface water control
- Capping
- Soil removal
- Cut-off wall
- Groundwater pump and treat
- Bioremediation

The remediation of the DRMO will most likely utilize a combination of the technologies identified. Bioremediation could be used to reduce the PCBs and TPH concentration. Some emerging bioremedial technologies might also be effective in removing metals from the soil matrix if complemented by the installation of barriers to control migration of solubilized product. Otherwise, soil removal and treatment may be required to reduce the gross metal concentration in the surface soils. An impermeable cap would have to be installed to eliminate surface water migration and mobility of the metals. If the material storage procedure cannot be modified (under roof operation), surface water controls (chutes, dikes) could assist in reducing precipitation contact with stored materials. Since the groundwater was found to contain particulate metal concentrations exceeding groundwater standards, a groundwater pumping system may be necessary to extract the contaminants followed by a specific treatment technology (chemical/physical precipitation). A cut-off wall may be utilized to reduce the washing of the subsurface soils from tidal elevation changes. This could be used in conjunction with a groundwater pump and treatment system or an in-situ soil stabilization/fixation process. This process may include cement or slurry injection into the subsurface to fill the voids, reduce groundwater flow and immobilize the contaminants present. The catch basins and stormwater collection system should be cleaned and the discharge piping redirected to the on-site treatment plant. Otherwise the stormwater collection system should be modified to include a filter prior to discharge.

3.2 Fuel Oil Pipeline (SWMU #27)

A fuel oil pipeline, reportedly containing #6 fuel oil, had sustained a failure resulting in a release of product. The pipeline is located to the east of Berth N° 6 on approximately 2.5 acres between the Piscataqua River and Buildings 288, 293, 246, 180 and 164, and is of steel construction. The pipeline was used to covey fuel from the barges to on-site storage tanks.

Three (3) phases of investigation were completed during Phases II, III and IV.

During Phase II, three (3) test pits were excavated and the soils were analyzed for TPH. The concentrations observed ranged from 200--4,600ppm. Ten (10) soil borings were installed during Phase III field work. The borings were completed until refusal, around six (6) feet (assumed to be large boulders). The soil borings were sampled and analyzed for TPH and polynuclear aromatic hydrocarbons (PAH). The TPH concentrations observed ranged from 140 to 2,000ppm. Only one location had an appreciable concentration of PAH (10 ppm). The chromatograph of the oil observed matched that of a weathered diesel fuel (borings 5 and 6) rather than the #6 fuel oil. An additional six (6) borings were completed as monitoring wells during Phase IV activities. The groundwater collected from the wells was analyzed for TCL organics and TAL inorganics. Monitoring wells 1, 2, and 4 had qualitative concentrations of organics. None of the wells showed measurable quantities of semi-volatile organics, pesticides or PCBs. The salinity of the groundwater, when sampled, ranged between 18 and 22°/∞ (parts per thousand). Development water analyzed had salinity readings between 17 and 25°/∞. The tidal elevation changes approximately 10 feet between low and high tide.

3.2.1 Corrective Measures

The remediation technologies considered for SWMU #27 include:

- Bioremediation
- Excavation and removal
- Containment
- Groundwater pumping with product recovery

Bioremediation appears to be the best suited technology for application at this SWMU. The tidal change will provide a continual resupply of some of the oxygen needed for aerobic bacterial growth. Nutrients such as nitrogen and phosphorous could be added to assist in specific biological growth to eliminate petroleum products encountered in the

alternating vadose/saturated zone. Concentration reduction estimates are 6-8 months for 5,000 to 1,000 ppm and approximately two (2) years for 5,000 to 100 ppm. To verify that bioremediation is an appropriate remediation alternative, a sample of the contaminated soil should be evaluated for biological activity.

A second option, excavation and disposal off-site, may provide a more rapid remediation, but the presence of the existing utility lines will make this technology extremely difficult and costly at best. Existing pipelines and utilities (natural gas, electrical) will require that considerable care be taken in the excavation process to minimize the safety hazards encountered, and the potential periods of loss of utility.

Containment, using slurry walls and/or sheet piling, will also be very costly and impractical to implement. Although control of the tidal effects will be easier, a groundwater depression system will have to be operated in which the water would be continuously treated prior to discharge. This system could be utilized in conjunction with bioremediation in the event that the altering saturated/unsaturated conditions that currently exist adversely effected the functioning of the bacteria.

Finally, a system of groundwater depression with free product recovery might assist in removal of large quantities of oil. Only well MW-6 (south end of Berth 6) had a considerable amount of free product.

The actual location of the source is not currently established. McLaren/Hart feels a pipeline testing program should be completed to pinpoint probable areas of concern. By closing off some sections of the pipeline and testing those sections, the potential areas requiring recovery or removal could be identified. Likewise, this will assist in reducing the duration required for bioremediation provided that future discharges were eliminated or minimized. Since the material appears to be a light non-aqueous phase liquid (LNAPL),

floating product may be found at the top of the water. The change in water elevation allows the oils to come in contact with and possibly be adsorbed by the soils. The area excavated in May 1990 by the Navy is one location where a large quantity of free product may currently exists. N° 6 fuel oil is not as mobile as N° 2 fuel oil at moderate temperatures (40-60°F) and will remain in one area of the release.

3.3 Mercury Burial Site (SWMU #9)

Several concrete cells with mercury containing wastes were reportedly placed in two separate locations at the JILF. The wastes possibly include liquid mercury, solids contaminated with mercury (soils, clothing) and other articles (glass, steel, wood). The concrete cells were poured as one unit after the waste was placed in wooden forms. A concrete base was prepared and allowed to cure prior to cell construction.

McLaren/Hart completed field investigations at the Mercury Burial Sites during Phases I-IV. Soil samples and water samples analyzed during Phase I did not indicate any significant leakage of mercury. Additional wells were installed during the third phase of field work at the JILF and Mercury Burial Sites. The analytical data did not indicate there was a release of mercury at either Burial Site. Elevated levels of some metals (excluding mercury) was noted in the groundwater during phases II through IV of field work. Low levels of pesticides and PCBs were noted during Phase III. The mercury burial cells at Mercury Burial Site I were excavated and reviewed for integrity. Each unit was noted to be in reasonably good condition. Cells were not found at Mercury Burial Site II. On-site PNS personnel indicated the cells may be located under the blacktop parking lot east of the bowling alley.

Additional research and interviews are required for Mercury Burial Site II. Cognizant personnel must be contacted to better pinpoint the approximate location of the cells. Further excavation to locate the cells at Site II under the blacktop parking lot north of the Phase IV excavation area could start after this information was evaluated. A contingency plan for encountering asbestos should be developed prior to any further excavations.

3.3.1 Corrective Measures

- Encapsulation
- Removal and off-site disposal
- Groundwater pump and treat

The mercury burial cells may be encapsulated in an additional concrete slurry, bentonite slurry, or resin. An elevated pH is desirable to "tie up" the heavy metals present in a hydroxide form. The encapsulation process could be complemented with a cap over the area. Surface water controls should be implemented to reduce precipitation migration through the cell area.

As a second option, removal and off-site disposal, may be the best suited technology. Even though there is no known current problem associated with the burial sites, removal of the cells would eliminate the future liability. The cells may have to be broken up on-site prior to transport, although, transport to a secure landfill (i.e. Chemical Waste Management, Model City, New York) as a whole unit is preferred. This requires that an exemption from D.O.T. be secured and that the action be approved by the disposal facility. Complete information regarding the cell contents is required prior to acceptance by and shipment to the disposal facility. Previous reports that liquid mercury was encased in the cells could be confirmed by weighing an entire cell and comparing that value to the calculated weight of the cell (i.e., 5' x 6' x 8' x 150 pounds per ft^3). Metallic mercury weighs approximately 850 lbs/ft^3 providing a significant difference in potential weight. Land ban restrictions mandate that the off-site disposal option be completed by May 8, 1992.

The groundwater, as observed in the monitoring wells around the Mercury Burial Sites, may be improved (if required) through a groundwater extraction and treatment system. The treatment systems best suited for metals removal would include precipitation/sedimentation and/or filtration.

3.4 Underground Storage Tanks (SWMUs 10, 11, 12, 13, 16, 21, 23)

There were several underground storage tanks (UST) utilized for the storage of liquid wastes generated at the PNS. The following table outlines each tank designated as a SWMU that was evaluated during field investigations:

SWMU N°	Name	Content Description	Tank Description
10	Battery acid tank	Spent battery acid	Tank pulled
11	Waste oil tank N° 6 & 7	Use lubricating oil and degreasers	7,500 gal. each capacity; steel construction; inspected 11/86; pulled 6/89
12	Boiler blowdown tank N° 25	Heated water	3,800 gal. capacity; 1974 to present
13	Rinse water tank N° 27	Unspecified rinse water	695 gal. capacity; steel construction; 1974 to 11/91
16	Rinse water tank N° 34	Unspecified rinse water	750 gal. capacity; steel construction; 1978 to 11/91
21	Acid/alkaline drain tank	Spent cleaning solutions	695 gal. capacity; pulled 11/91
23	Chemical cleaning facility tank	Spent cleaning solutions	2,270 gal. capacity; 1978 to 11/91

Four USTs were removed from the ground by PNS during November 1991 (SWMUs 13, 16, 21, 23). Oversight of tank excavation and removal was followed by soil sampling and analyses to determine the extent of spills, if any, at each tank location. Four composite samples were collected from each excavation (two along bottom of excavation, and two from the side walls). There was no visual contamination or odor noted at SWMUs 13, 16 or 23.

Two large holes were noted on each end of the acid/alkaline drain tank (SWMU 21). Visual evidence of soil contamination was noted at this location. All samples were collected, labelled and marked prior to shipment to CEIMIC under proper chain-of-custody procedures. The analytical work has not been completed as of this date for the samples collected during this phase of field work. The SWMU 21 may require additional corrective measures after the analytical data has been reviewed and the extent of contamination has been defined.

If the analytical results indicate that significant contamination exists at any of these locations the following remediation technologies would be considered:

- Off-site soil disposal,
- In-situ soil stabilization (inorganics),
- Biodegradation (organics), and
- Groundwater pump and treat (organics/inorganics).

Specific unit processes (i.e. limestone beds, air stripping, chemical precipitation) will be determined based on the analytical results.

The SWMU 11 (waste oil tanks 6 and 7) was decommissioned in June 1989 with the removal of tanks from the ground. Soil contamination was observed prior to backfilling the excavation. Soil borings were completed in the area surrounding the tank during the Phase IV field investigations. Samples were collected and found to contain heavy metals, semi-volatile organics, TPH and volatiles (freon).

The remediation technologies suited for this SWMU include:

- Contaminated soil removal and off-site disposal,
- Bioremediation, and
- Groundwater pump and treatment.

SWMU 10 (spent battery acid tank) was removed from the ground. Soil borings were completed and samples collected to determine the concentration of potential contaminants. There were no TCL Volatiles or TCL pesticides/PCBs detected above published guidance values. There were detectable concentrations of semi-volatiles in the soil samples with none above the Proposed Federal Action Levels. Several metals (arsenic, beryllium, cadmium, copper, lead, mercury and zinc) were present at or above New Jersey ECRA guidance values with only beryllium above the Proposed Federal Action Levels.

Potential treatment technologies to be employed at this SWMU include:

- Groundwater pump and treatment,
- In-situ stabilization, and
- Off-site soil disposal.

The specific treatment requirements will be based on contaminant migration potential, the human health and ecological risk assessments and the established media protection standards.

3.5 JILF (SWMU #8)

The JILF and surrounding areas have been investigated during the former phases of investigation. A summary of the findings is as follows:

- Low to moderate soil contamination was observed across the landfill.
- Groundwater has suspended metal contamination and very little dissolved metals.
- Petroleum products were present in soils near SWMU #11 and monitoring wells JW-16, JW-16B and JW-13B.
- Low concentrations of chlorinated hydrocarbons were detected in bedrock well JW-13B.
- Groundwater was generally "clean".

Based on the current data, significant contamination does not currently exist at the JILF, however, the groundwater monitoring well data indicates the groundwater quality may have been affected, possibly by past operations at the JILF. However, the concentrations observed do not appear to be immediately dangerous to life and health. The need for a corrective measure at the JILF will be determined based on an ecological and human health risk assessment. Potential corrective measures to be employed (if necessary) include:

- RCRA cap
- In-situ stabilization
- Groundwater pump and treatment
- Surface water controls
- Cut off wall
- Bioremediation
- Excavation and off-site disposal

An individual treatment technology could be employed at each individual contaminated location identified or in combination with others. Due to the tidal effect on the eastern and northern perimeters of the JILF, a cut off wall may be required in conjunction with in-situ stabilization, groundwater treatment, or a RCRA cap.

3.6 Child Development Center/Quarters S&N

Surface soil samples were collected from the area surrounding the Child Development Center/Quarters S&N during the Phase III and IV sampling events.

Two of sixteen surface soil samples collected in Phase IV exhibited total volatiles in excess of 1 ppm. The source of this contaminant is uncertain. Two samples also exceeded the ECRA guidance value for total base neutral extractables (10 ppm). Pesticide levels observed in two samples exceeded the proposed Federal Action Level. Elevated metal concentrations were observed in five of the sixteen surface soils collected.

The exceedances observed were generally isolated and not consistently observed in all samples collected. The source of the contamination observed is not known but may be attributed to previous controlled pesticide spraying conducted by the PNS personnel.

The need for remediation of this area will be based on a human health risk assessment based on the current and proposed future use of the area. Potential technologies considered for this area may include:

- Off-site contaminated soil disposal,
- Capping and/or RCRA cover, and
- In-situ stabilization (by landfarming).

The implementation of any corrective measure at this location will be based on a human health risk assessment of the contaminants observed and their concentration, the exposure potential and potential migration pathways. Future additional controls of pesticide application may be warranted if the current levels pose a significant threat.

3.7 Fresh Water Ponds

The fresh water ponds located on either side of Meade Avenue were sampled during Phase IV. The sampling focused on the sediment present within each pond. The sediment collected was principally described as a dense blue-grey clay in the sampling interval (approximately 0-9").

The analysis of sediment samples is summarized as follows:

- No volatile compounds were present above published guidance values. Acetone was detected in most samples.
- No semi-volatile organic compounds were present above published guidance values.
- No pesticides or PCBs were detected in any sample.

- Cyanide was not detected in any sample.
- Detectable metal concentrations were found in all samples. Beryllium was present in all samples above guidance values. Cadmium and copper were present above guidance values in two separate samples.

Metals were the only contaminants present in the sediment above guidance values which might require implementation of a corrective measure. The actual need for remediation will be based on an ecological and human health risk assessment based upon the contaminant and the concentration.

Surface water and surface sediment sampling was conducted during Phase III. The surface water samples had no detectable concentrations of contaminants (volatiles, semi-volatiles, pesticides/PCBs, herbicides, inorganics) exceeding published guidance values. Three surface sediment samples exceeded ECRA guidance value of 1 ppm total volatiles with acetone present above its respective guidance value. Semi-volatile organics were present in all eight surface sediment samples and exceeded the ECRA guidance value of 10 ppm in six of the samples. No PCBs were detected but low levels of pesticides were detected in every sediment sample. There were no detectable herbicide, cyanide or sulfide concentrations. Detectable metal concentrations above ECRA guidance values but below proposed Federal Action Levels, were found in all samples. This phase of investigation indicated the contaminants are residing in the sediment but are not dissolved in appreciable quantities in the surface water.

Potential corrective measure for the fresh water ponds (if necessary) would include sediment dredging, sludge dewatering/stabilization and off-site disposal.

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