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Navy Aquatic Hazardous Waste Sites:

The Problem and Possible Solutions

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Data on 367 hazardous waste disposal sites at 58 Navy and Marine Corps activities, located in the coastal zone, were reviewed to characterize the contaminants, disposal methods, and potentially impacted environments present at Navy aquatic hazardous waste sites. This report identifies Navy aquatic hazardous waste site problems, assesses technology requirements, and describes remedial pilot projects being initiated at impacted aquatic sites.

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SUMMARY

Data on 367 hazardous waste disposal sites at 58 Navy and Marine Corps activities, located in the coastal zone, were reviewed to characterize the contaminants, disposal methods, and potentially impacted environments present at Navy aquatic hazardous waste sites. This report identifies Navy aquatic hazardous waste site problems, assesses technology requirements, and describes remedial pilot projects being initiated at impacted aquatic sites.

The major waste types found were a combination of all hazardous wastes disposed at a single landfill site (27 percent), toxic organics (43 percent), petroleum hydrocarbons (26 percent), and heavy metals (20 percent). Releases into the environment were by spills or dumping on the ground (58 percent), landfill operations (25 percent), burial in lined pits (10 percent), leakage from storage tanks (4 percent), and direct discharge into waterbodies (3 percent). The most frequently threatened aquatic environments were bays (27 percent), rivers (27 percent), marshes (15 percent), and streams (14 percent).

While remedial action options at the waste sites are usually available, remedial action in the contaminated aquatic environment risks serious disruption to the community one is trying to protect. Competent risk analysis is required to determine the most effective remediation alternative. Remedial investigation pilot projects being initiated include verification and evaluation of hydrocarbon degradation (jet fuel) at NAS Patuxent River, MD; wildlife toxicity assessment demonstration project at NAS Whidbey Island, WA; and an environmental risk assessment pilot study at NCBC Davisville, RI.

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INTRODUCTION

Hazardous waste contamination of aquatic environments primarily occurs in coastal and estuarine areas where the Navy operates and deploys the majority of its assets. Figure 1 depicts the typical Naval installation. Immediately apparent is that the facility is surrounded by water. Therefore, the efficiency of the Navy's pollution abatement and cleanup programs will be reflected in the water and sediment quality of the adjacent water body.

The Navy and Marine Corps share many cleanup problems with the Army and Air Force. Soil and groundwater contamination from munitions disposal, spills of volatile organics, polychlorinated biphenyls (PCB), plating wastes, heavy metals, petroleum, oil, and lubricants (POL), as well as other wastes are common to the three services (U.S. Army Corps of Engineers, 1985; U.S. Air Force, 1985). What makes many of the Navy and Marine Corps waste cleanup problems unique is that contaminated sites may impact adjacent wetland areas. For example, when shore-based storage tanks leak, petroleum products seep into groundwater and the aquatic environment. Contaminants may leach from waterfront disposal sites, such as landfills and burn areas, into surrounding soil, groundwater, and aquatic environments. Chemical waste spills from plating shops or rework facilities, although initially occurring on land, are washed down storm sewers and drainage channels and, ultimately, end up in the aquatic environment.

The aquatic environment is the final sink for many contaminants, and the ultimate question of impact depends on the environment's ability to assimilate wastes. Aquatic contamination from waste disposal sites could have a direct effect on human health from the consumption of contaminated seafood, resulting in bans on commercial fishing, or the impoundment of tainted seafood. Recreational and swimming areas could also be closed because of unsafe levels of contamination. These actions could have a "ripple" effect on local economies dependent on commercial and sport fishing. Additional impacts could be incurred when sediment, contaminated from waste disposal sites, must be dredged. Contaminated sediment requires special removal and disposal methods and could prevent or delay and increase the cost of harbor maintenance. Conscientious management of waste sites impacting aquatic environments requires the ability to properly identify threatened habitats and select the necessary steps to mitigate impacts (Pavia, 1987).

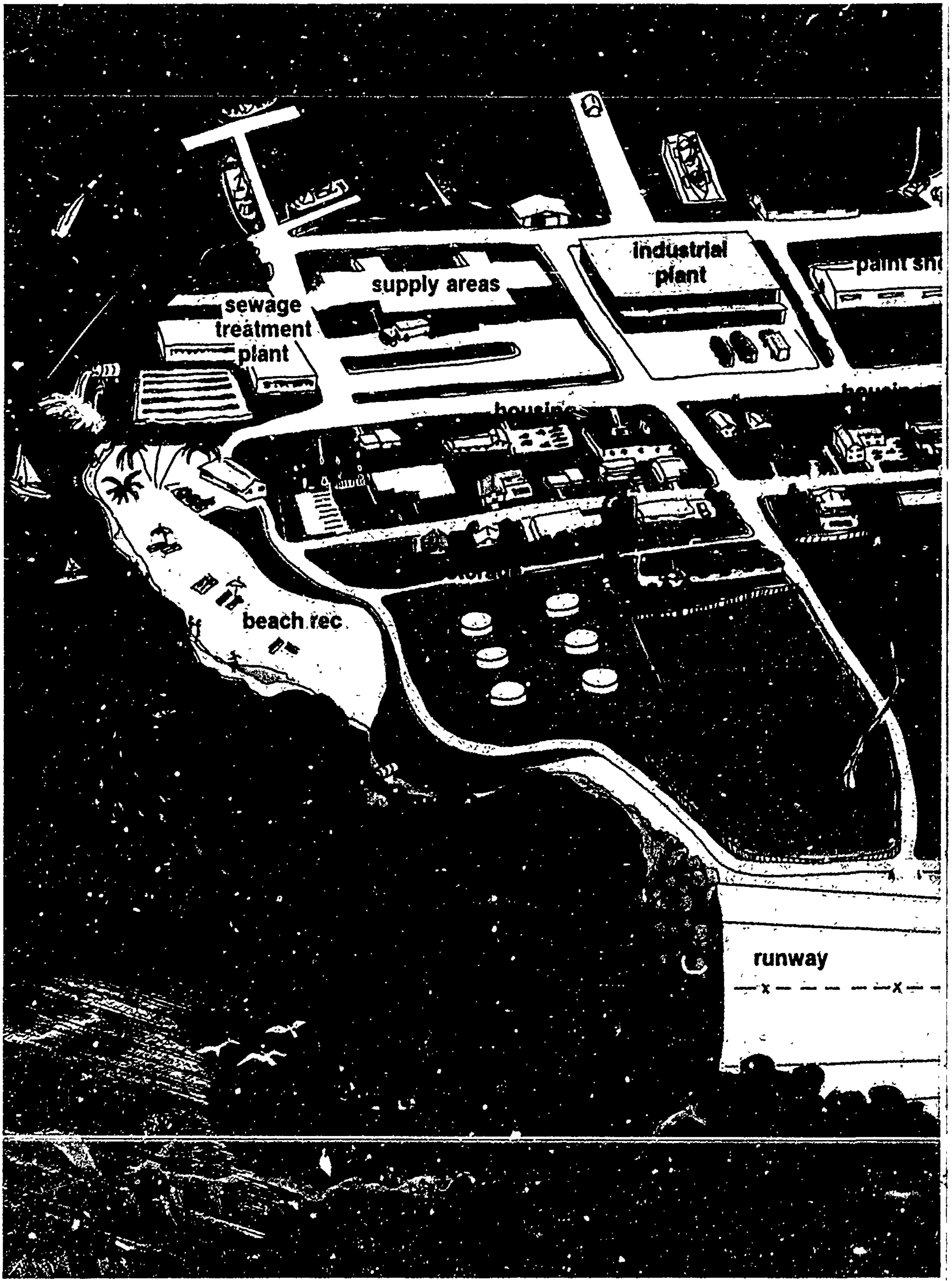

Figure 1. Typical naval installation.

PROBLEM DEFINITION

SITE CHARACTERISTICS

Potential aquatic site contamination problems were identified and evaluated by (1) reviewing Initial Assessment Studies (IAS) reports of Navy and Marine Corps Activities located in coastal and estuarine areas to determine types of contaminants present and types of environments being impacted and (2) visiting sites with identified aquatic site contamination to gain firsthand knowledge of the problems. Data on 367 hazardous waste sites at 58 Navy and Marine Corps activities were reviewed. Sites selected for this review were sites recommended for confirmation study and judged to have potential impact on aquatic environments. These sites represent more than half of the sites reviewed by the Initiation Decision Report (IDR) process (Olah, 1988).

Contaminants, disposal methods, and impacted environments at the sites reviewed were grouped into broad categories to facilitate overall summary and conform to contaminant-medium pairings used in the IDR process (Olah, 1988). These categories are described in table 1. While admittedly subjective, the broad categories were felt to share important characteristics. Those contaminants grouped into a given category tended to be coincident on site and require similar remedial treatment. Disposal methods within a category were felt to be similarly vulnerable to contaminant migration via surface runoff or ground water. Categories of aquatic environments were judged similar in their dilution rate, potential contaminant residence time, and subsequent impact on their biological communities. The IAS reports were also examined to determine mode of contaminant transport to further distinguish site characteristics. In nearly every case, both ground water and surface water transport contaminants into the surrounding environment and can be regarded as a universal site trait.

Figures 2, 3, and 4 summarize the number of sites characterized by particular contaminants, disposal method, and potentially impacted aquatic environment respectively. Combined wastes, a conglomeration of essentially all hazardous wastes disposed at a single site, accounted for 99 (27 percent) of the sites reviewed. Of the remaining 268 sites, 158 (43 percent) were contaminated with toxic organics, 94 (26 percent) were impacted with petroleum hydrocarbons, and 72 (20 percent) had evidence of heavy metal contamination. Note that more than one contaminant group was often present at the same site. Other wastes such as ordnance, radionuclides, and asbestos were present at only 11, 3, and 4 sites respectively (figure 2).

The primary method of combined waste disposal was by landfill (85 sites, 26 percent). Most wastes were released into the environment by "spills" or by dumping on the ground (185 sites, 56 percent). Burial in lined pits (36 sites, 11 percent), leaks from storage tanks (15 sites, 4 percent), and discharges directly into water bodies (10 sites, 3 percent) accounted for the remainder of the releases (figure 3).

The most frequently threatened environments were bays, rivers, marshes, and streams. Potential impacts to bays, mostly in the form of contaminated sediments and possible shellfish contamination, were identified at 100 (27 percent) of the sites. Impacts to riparian habitats were suggested at 99 (27 percent) of the sites reviewed. Sixty (16 percent) of the sites could directly affect surrounding marshlands and 48 sites (14 percent) threatened streams. Ponds and lagoons, beach and tidal areas, and open ocean areas were threatened at 30 (8 percent), 19 (5 percent), and 9 (3 percent) of the sites respectively (figure 4). Some sites could potentially impact more than one environment type, but only the most directly impacted water body was identified here.

Table 1. Contaminant types, disposal methods, impacted environments, and their elements.

Contaminant Type	Elements of Group
Combined wastes	All wastes including, organics, heavy metals, petroleum, oil, lubricants, solvents, paints, sludges, refuse, caustics, acids, etc.
Hydrocarbons	Petroleum-based fuels: diesel, JP-5, JP-4, AVGAS, bunker fuel, and gasoline; oils, sludges, and lubricants.
Toxic organics	All organic pollutants not associated with petroleum: solvents, paints, pesticides, and PCBs. Also includes otto fuel.
Heavy metals	Metals most often present were: Cr, Pb, Cd, Cu, Hg, Se, and Ar. Also included were cyanide, ash, coke, blasting grit, and plating wastes.
Ordnance	Includes explosive compounds: RDX, TNT, tetryl, DNT, DNB, picric acid, and nitrobenzene; bomb casings and other munitions.
Radioactive	Isotopes of radium.

Disposal Method	Elements of Group
Landfill	Includes well managed sanitary landfills as well as uncontrolled trash dumps.
Spill	Spills, surface disposal, unlined pits, storage leaks, and burn areas.
Lined pits	Pits lined with reinforced concrete or equivalent; deep disposal wells.
Leaking tanks	Aboveground tanks, underground tanks, and pipelines.
Water disposal	Ponds, lagoons, ditches, canals, marinas, and outfalls.

Impacted Environment	Elements of Group
Marshes	Marshes, mangrove swamps, swamps, and shallow estuaries.
Ponds	Ponds, lagoons, springs, sloughs, and canals.
Beaches	Rocky shores, sandy beaches, mudflats, and other intertidal areas.
Streams	Streams and creeks.
Bays	Bays, lakes, sounds, and other inland waters.
Rivers	Rivers, harbors, and deep estuaries.
Ocean	Open ocean or gulf.

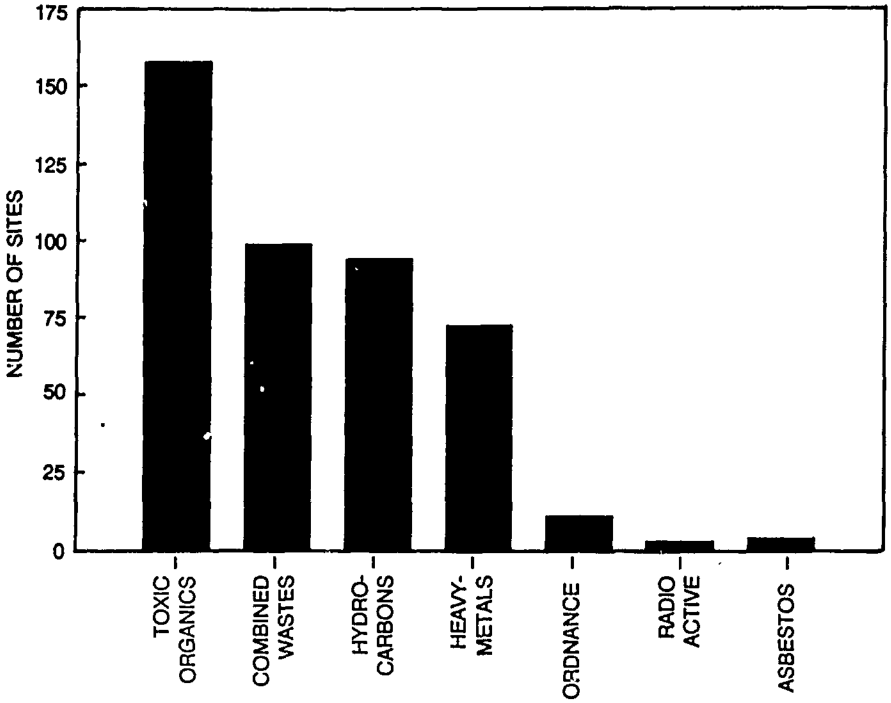

Figure 2. Contaminant groups disposed at Navy aquatic hazardous waste sites.

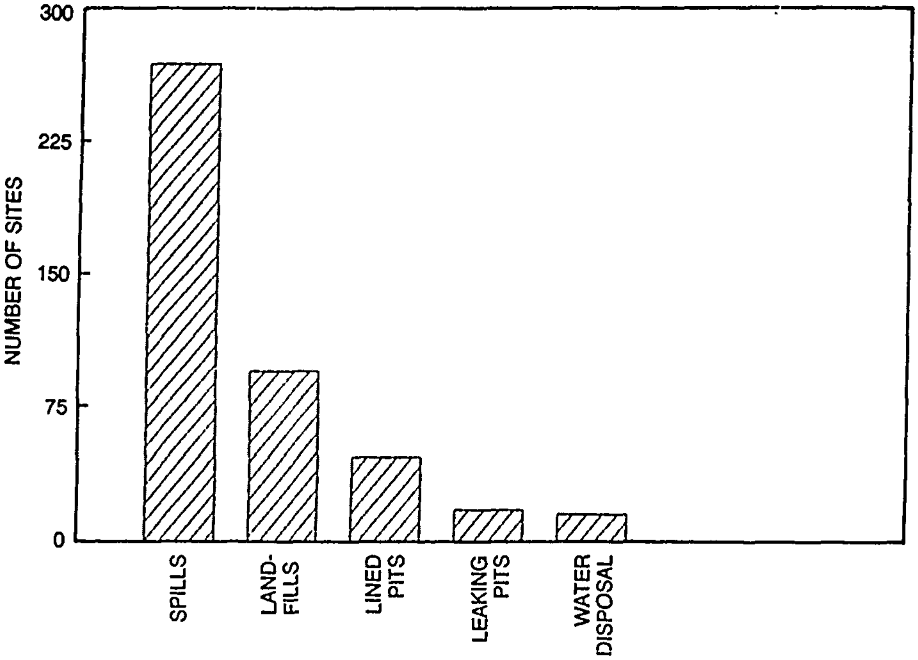

Figure 3. Disposal method used at Navy aquatic hazardous waste sites.

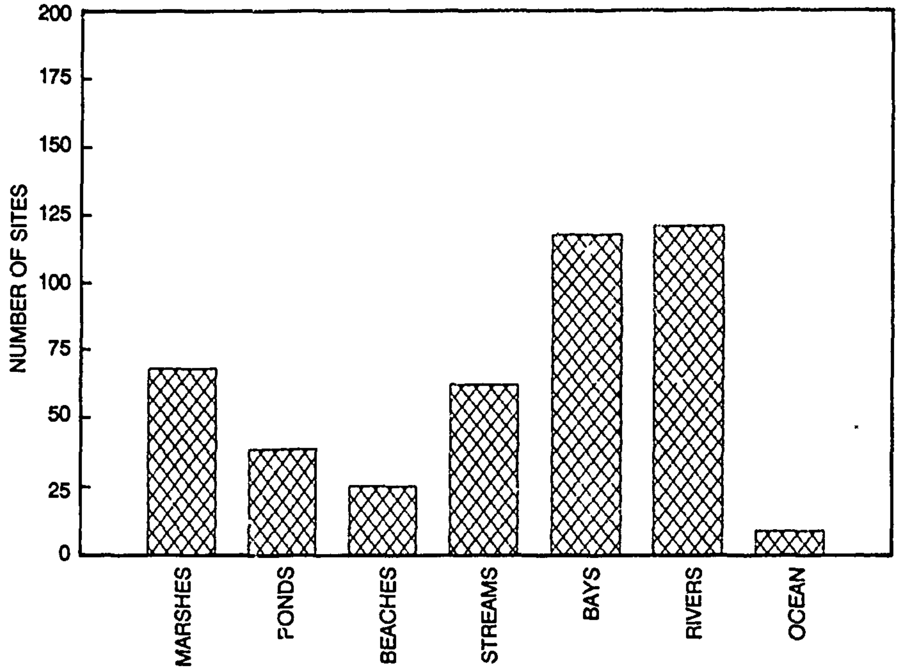

Figure 4. Potentially impacted aquatic environments at Navy aquatic hazardous waste sites.

To determine whether particular contaminants or disposal methods presented greater hazards to the environment and local human populations than indicated by their numerical occurrence alone, the numerical occurrences of contaminants, disposal methods, and impacted environments were multiplied by the Confirmation Study Ranking System (CSRS) scores reported in the IAS reports (NEESA, 1982). The CSRS weighting did not appreciably change the distributions shown in figures 2 to 4, other than increasing the relative importance of combined wastes disposed in landfills and decreasing the importance of hydrocarbons and toxic organics. This reflects, in part, the much larger volume of combined waste disposed in landfills compared to the hydrocarbons and toxic organics disposed of on the surface (usually through container leakage or spills).

Nearly all contaminants are found at landfills, while most hydrocarbons, toxic organics, and heavy metals are released through spills. Bays, rivers, marshes, and streams appear most impacted, primarily by combined wastes, toxic organics, hydrocarbons, and heavy metals. Comparable charts of occurrence weighted by CSRS scores did not appreciably affect the relative importance of contaminant groups on impacted aquatic environments.

IMPACTS TO MARINE RESOURCES

Results obtained from reviewing Navy and Marine Corps hazardous waste sites are comparable to the National Oceanic and Atmospheric Administration's findings during their review of 435 private sector hazardous waste sites located in coastal environments (Pavia, 1987; Pavia & Harris, 1985). Navy hazardous waste sites described are a representative subset of all Navy and Marine Corps sites; they are not distinguishable by their contaminants, method of disposal, or appropriate remedial technology. The problem is not so much the disposal site but rather the surrounding environment which is subjected to runoff and leachate from uncontrolled waste sites located in the coastal zone. While waste sites are relatively small, contained, and well defined, impacted environments are large and complex. Water dispersal and biological community interaction tend to spread or concentrate contaminants in complicated patterns. Both waste sites and impacted environments require action but prescribed treatment is different. In many cases, controlling the waste site or stopping the source of contamination may be sufficient to protect wetland areas. However, persistent wastes, such as heavy metals and PCBs, partition into the sediment and can result in long-term toxic effects to the ecosystem (Pavia, 1987).

Both waste sites and impacted environments must be characterized to determine what contaminants are present, at what concentrations they occur, and how they are distributed. Both must be monitored over time to judge the efficacy of remedial action at the source (waste site) and consequence to the sink (aquatic environment). For the case of the waste site, laboratory or in situ analysis of contaminants in water, soil, or biological, samples collected in confirmational studies may adequately map contaminant distribution. For the case of the aquatic environment, additional use of biological indicator species or species assemblages — a "miner's canary" — is needed to provide more realistic measure of biological toxicity of migrating contaminants, particularly if multiple contaminants act synergistically. While remedial action at the waste site is recommended and several options are usually available for particular contaminant-medium pairings, remedial action in the contaminated aquatic environment risks serious disruption to the community one is trying to protect. Rather, competent risk analysis of competing remedial techniques to determine potential impact is required.

One exception to this generalization is possible cleanup of aquatic sediments. Sediments are the ultimate sink for contaminants entering the aquatic environment. Contaminated sediments, whether resulting from Navy or non-Navy wastes, are dredged by the Navy. By law, the environmental impact of dredging must often be assessed and minimized. Academic and private research into terrestrial waste site remedial technologies is growing rapidly (Sayler, 1987; Symposium: Reducing Risks from Environmental Chemicals through Biotechnology, 1987). While terrestrial techniques might be extended to include contaminated aquatic sediments, relatively little research specifically addresses this area. Effective sediment remedial technologies are important to the Navy because their use would alleviate impact from nearby waste sites and facilitate necessary dredging. Stricter requirements will be enforced for dredging and disposal of contaminated sediments (Tilley, Jamison, & Phillips, 1987; Turner, 1987; Fredette, Morton, & Germano, 1987; Johns, Phillips, & Malek, 1987; State of Washington, 1987; & Evans, 1988).

GROUNDWATER CONTAMINATION IN THE COASTAL ZONE

Contamination from spills, discharges, leaking impoundments and landfills, or leaking underground tanks and pipes will enter the soil and local groundwater will migrate down-gradient. Those contaminants not tightly bound to the soil will ultimately discharge to adjacent aquatic environments if they are not intercepted or removed. Because groundwater contamination is a nearly universal problem at hazardous waste sites, this section will address considerations for assessing and remediating contaminated groundwater resources in the coastal environment.

Upon identifying the source of groundwater, contamination removal or isolation of the source should commence. The more difficult task of determining the impact of the contaminated groundwater and, if necessary, effecting its remediation still lies ahead.

Initially, it must be determined whether the level of contamination presents a significant threat or can be safely assimilated or degraded by the environment. Physical removal or in situ detoxification may work in some cases where contamination is localized, but often the plume of contamination is well dispersed and not easily available to removal technologies. Consequently, the discharge of contaminated groundwater to marshes, wetlands, bays, estuaries, and the ocean can occur and may impact water, sediment, and biota quality in these aquatic environments.

Groundwater flow near sea level can be influenced by many factors and may be quite variable over short periods of time. Tidal variability can cause tidal pumping of leachate which can accelerate rates of contaminant migration. The water table, in soils hydraulically connected to tidally influenced waters, is influenced sufficiently by the tides to increase mixing and physically disperse leachates. Seasonal rainfall, stream and river levels, and recharge rates can affect the concentration and velocity of contaminants both in the aquifer and after discharge to aquatic habitats. Flow direction may change seasonally due to precipitation, pumping of groundwater, or changes in irrigation patterns in the vicinity.

The consequences of contaminated groundwater entering the aquatic environment can range from negligible to severe. The magnitude depends upon the volume, concentration, and toxicity. The coastal environment often consists of very permeable soils and sediments, and hydraulic fill is usually quite permeable as well. Moderate to rapid dispersion of contaminants can occur. While troublesome, contaminated groundwater, if not used for potable or agricultural uses, is somewhat contained compared to the rapid dispersion of contaminants in most marine or estuarine settings. Tidal flushing, littoral transport, riverine flow, and wind-driven circulation mix can disperse contaminants at rates much greater than in groundwaters. It is, therefore, certainly more advantageous to remediate groundwater contamination before it enters the dynamic aquatic environment.

Contaminated groundwater may discharge to streams, rivers, or creeks and rapid downstream migration will result. Discharges may occur into marshlands, estuaries, bays, and other sensitive areas where tidal mixing, riverine flow, and wind-driven circulation can disperse the contaminants. Discharge to ocean waters can be rapidly dispersed by tide, wind, waves, and longshore and offshore currents. Effective methods of remediating contaminated water, sediment, and biota in aquatic environments are more difficult, time consuming, and expensive than remediation of the groundwater before it discharges to the aquatic environment.

AN OVERVIEW OF THE PROBLEMS AND POSSIBLE SOLUTIONS FROM A GEOLOGIC PERSPECTIVE

The purpose of this section is to identify and document common methods of obtaining information for investigations of potential hazardous waste sites with specific regard to the gathering of geologic information. Much of the potential and actual contamination at Navy sites impacts soils and groundwaters on and adjacent to Navy properties. In addition, methods of remediation of Navy sites will be addressed.

INFORMATION REQUIREMENTS

The minimum information requirements to begin to adequately characterize the distribution and fate of hazardous materials entering the environment include

1. Chemicals of concern and their degradation products
2. Characterization of the source of contamination

3. Contaminant distribution in

    a. surface water
    b. ground water
    c. soil and/or sediment
    d. air

4. Pathways of migration of chemicals of concern
5. Geologic and hydrologic regime influencing groundwater and its movement
6. Baseline/background concentrations of the chemicals of concern.

The following discussion will emphasize contamination of soils and groundwaters, but is generally applicable to contamination of other media as well.

The types of contaminants present may be determined in several ways. In some circumstances, especially where an individual spill, single disposal event, or a single leaking storage tank is involved, the contaminant is easily identified. Care must be taken, however, to look for the presence of naturally occurring degradation products of the parent compound or compounds. Soil gas surveys and simple in-field tests including pH, specific conductance, or dissolved oxygen concentration can identify contamination in the field in nearly realtime. In the case of mixed wastes, multiple leaking storage tanks, multi-use landfills, multiple spills, contamination from several sources, or identification of the chemicals of concern will often require that significant numbers of samples be analyzed in the laboratory.

A brief synopsis of generalized methods of identifying contamination in soil and water is presented below.

Soil contamination

Laboratory analysis

1. Atomic absorption spectroscopy
2. Gas chromatography
3. Gas chromatography/mass spectroscopy

Field analysis

1. Soil gas analysis to detect volatile vapors
2. Soil pH measurements

Groundwater contamination

Laboratory analysis

1. Atomic absorption spectroscopy
2. Gas chromatography
3. Gas chromatography/mass spectroscopy
4. Total organic carbon (TOC)
5. Total halogenated hydrocarbon (TOX)

Field analysis

1. pH
2. Specific conductance
3. Dissolved oxygen

Atomic absorption spectroscopy is capable of measuring most elements and is normally used to quantify metal concentrations. Gas chromatography is usually used to identify organic compounds and to quantify the amounts present. This method is usually not capable of absolutely unambiguous confirmation of a given compound. Gas chromatography/mass spectroscopy yields unambiguous results as to the exact compounds present in a sample. However, the method is extremely time and labor intensive and is best used as a confirmation of gas chromatography results if possible.

The determination of pH in the field is a measure of the acidity/alkalinity of the water or soil. Aberrant pH compared to background levels can indicate contamination. Specific conductivity is a measure of the capability of a water sample to conduct an electric current. This relates to the ionic strength of the water. Again, significant differences between background conductance and potentially contaminated area conductance can indicate contamination. Great care must be taken in establishing background concentrations at many contaminated Navy sites, as salt water intrusion from marine and estuarine waters occurs in many groundwaters underlying Navy sites and may be misidentified as nonnatural contamination. Depleted dissolved oxygen in groundwater may represent biological or chemical demand for oxygen.

Identification of the distribution of contaminants in soil and groundwater requires extensive and comprehensive placement of wells or boreholes in and adjacent to the area of contamination. The correct placement, drilling, and development of wells ultimately serves several purposes and is probably the single most critical parameter in identifying the subsurface geology, hydrology, and extent and distribution of contamination in the investigative process. In addition, correctly placed wells can be used to determine the effects of remedial measures used to decontaminate sites.

Any investigation of subsurface contamination requires a thorough and comprehensive understanding of the subsurface geology including the lithology of the formations, structure, and the potentiometric surface of the aquifer (or aquifers). The lithology and structure are determined from the geologist's log of cuttings or cores removed from the borehole during the drilling process. The lithology of the different units influences the capacity of the formations to allow or retard fluid flow and the capacity to store fluid. Knowledge of the structure allows for the intrepretation of which units have significant water-bearing capacity, which might retard flow, and if and how they are connected. When a series of holes have been logged and analyzed, the data are collated and a reasonable three-dimensional analysis of the subsurface structure can be obtained. In addition, the piezometric surface of the aquifer (or aquifers) must be determined. This surface is the uppermost elevation of the saturated zone, and the determination of this surface indicates the direction of groundwater flow. The precise measurement of the water level in each well is critical. As groundwater flow direction may change seasonally due to precipitation or evaporation, diurnally due to tidal influence, or periodically due to pumping of wells within the aquifer, both short- and long-term monitoring of the piezometric surface should be undertaken.

Other methods of determining subsurface structure have been reported in the literature. Acoustic survey methods, electrical resistivity differences at depth in a well, magnetometer surveys, and other nondirect methods of information gathering are currently in use. These methods do yield valuable information on subsurface structure but are not currently accepted as valid methods alone. However, their use in conjunction with accepted methodology can yield additional, valuable information. For instance, a resistivity log of a well hole can confirm changes in lithology with depth, leading to a greater degree of certainty in the interpretation of the well log.

Once the groundwater flow direction has been established, the appropriate placement of background wells can be performed. Correct placement of background wells is critical. They are to be placed upgradient of the site of contamination, sufficiently distant not to be influenced by the site, yet close enough to represent the same groundwater.

At an absolute minimum, a single background well must be established. This will only suffice in a homogenous aquifer. Under most conditions, two to three background wells should be developed and sampled to determine the level of variability in the groundwater. Additionally, the sampling should occur at several times during the year to account for seasonal differences. The use of multiple sample locations to determine background concentrations is also applicable to the collection of soil or sediment samples. Samples should be collected near enough to the site of contamination and in the same geologic unit and soil horizon to accurately characterize the sample, yet far enough from the site to be contaminant free. In addition, the use of multiple samples to determine the range of background variability should be routine.

Once the groundwater piezometric surface and, therefore, the direction of groundwater flow are determined, the accurate determination of hydraulic conductivities of the units present must be determined. Hydraulic conductivity is a function of the material fluid flowing through and the properties of the fluid itself. It has the dimensions of velocity (distance/time) and represents the average velocity of a fluid moving through the media. For example, sand or gravel will permit much greater fluid velocities than a clay or unfractured granite. The conductivity of a material can be measured in several ways. Undisturbed cores can be transferre to the laboratory and tested to determine the hydraulic conductivity. This method is discouraged as a sole measure as it only documents a small fraction of the material and may have been disturbed in transit. Field tests are recommended. Single hole tests can be conducted in a "slug" test. The standing water level in a well is determined. Then a known volume "slug" is placed in the well. The time it takes to restore the ambient water level is a function of the conductivity. This method, while better than laboratory tests, only measures the conductivity immediately adjacent to the well. The most accurate method is a multiple well test. A known volume is added to or removed from one well, and adjacent wells are monitored as to their response time and magnitude. This method is the best approximation of hydraulic conductivity in the field because it measures it directly and incorporates heterogeneities in the soil.

When the groundwater direction of flow is established, some of the initial wells may be suitable as either background wells or as monitoring wells if they have been situated correctly and constructed properly. Other wells may have to be drilled and developed to monitor downgradient plumes of contamination after some information has been obtained. However, additional wells may be required even if wells were correctly installed. The initial investigation may have determined that a leachate plume of contamination may have migrated further away from the site than previously anticipated. Therefore, additional wells downgradient may be required. Additionally, properly constructed wells made of polyvinyl chloride (PVC) plastic are sometimes not suitable to some types of organic solvent or petroleum hydrocarbon substances. Consequently, while the optimum situation of multiple use of wells for initial assessment, confirmation, and remedial investigation is desired, this may not always be an alternative. New wells may have to be installed due to information gathered during the investigative process, and some wells may have to be abandoned if not suitable for their intended purpose.

In summary, most of the information pertaining to subsurface geology and hydrology is obtained directly from samples recovered from wells and soil borings from in and in the vicinity of the contaminated sites. Information on the background levels of chemicals of concern is critical in determining if contamination has occurred. Most sites will require site-specific study of the groundwater flow patterns beneath them. However, in some cases, especially where regional flow patterns are well established and multiple sites are located in reasonable proximity to each other, a single series of background wells or borings may suffice to characterize the levels of background variability. Additionally, at these sites, individual monitoring wells or borings may be used to screen for contamination from multiple sources.

ISOLATING GROUNDWATER CONTAMINATION

In order to isolate or control a contaminated groundwater, the contaminated plume must be isolated from the regional groundwater. This may be accomplished by four separate methods. First, the plume can be physically isolated or contained. Second, the actual removal of the contaminated groundwater after the removal of the source has been accomplished. Third, manually lowering the water table underneath the source to eliminate leachate production. Fourth, the groundwater can be diverted upgradient from the source to isolate the source and prevent background quality water from contacting the source of contamination.

These methods can be accomplished by several means of currently available technology. Through the use of injection or withdrawal wells, water can be injected or withdrawn to alter groundwater flow patterns around a site or remove contaminated water for subsequent treatment. In addition, subsurface drains may be installed and actively pumped to remove contaminants. Also, low-permeability curtains or barriers may be installed in the ground to physically isolate the plume or source. Finally, technology involving in-situ treatment, either biologic or chemical, may be used to degrade toxic substances to nontoxic products in place or by being pumped to the surface, treated, and reinjected. The simultaneous uses of more than one technology are often effective and cost-effective measures.

The major criteria for determining the type or types of hydraulic manipulation are the effectiveness of each method in the specific conditions present at the site and the cost effectiveness if more than one method is deemed to be effective. Pumping and/or extraction wells normally are most effective in porous, homogenous media that possess high hydraulic conductivities. Subsurface drains and galleries are effective when contamination is near-surface and hydraulic conductivities are low or soils are heterogenous in hydraulic gradient magnitude. Subsurface drains, as they are gravity controlled, are usually more cost effective when long-term removal of groundwater is anticipated as they are less energy intensive than a series of wells. Subsurface vertical barrier walls or curtains are generally the least expensive method of isolating contaminated material. They are normally installed in poorly consolidated soils and are usually effective in preventing the spread of the contaminant. Their disadvantage is that in stand-alone conditions they do not remediate the site but merely insulate the groundwater from contact with it. In addition, some provision must be taken to reduce or eliminate infiltration of precipitation through the insulated area as downward percolation of water would create a leachate. In situ treatment of contaminated water will be discussed in a following section.

ISOLATING CONTAMINATED SOILS

The isolation of contaminated soils from groundwater or infiltration is often accomplished concurrently by the methods described above to remove or entrain contaminated groundwater. Groundwater manipulation and physical barriers normally serve both purposes. Physical removal of contaminated soils removes the potential for continued leachate formation, but does not address the contaminated groundwater. Other methods include the removal of contaminated soil for off-site disposal or the emplacement of a liner and subsequent replacement of the material. Additionally, chemical treatment to immobilize contaminants and electrothermal vitrification of soils in place to essentially encapsulate them are possibilities under some circumstances. A comprehensive review of methods of remedial action designed for hazardous waste sites can be found in EPA Document 625/6-85/006, *Handbook: Remedial Action at Waste Disposal Sites (Revised).*

IN SITU TREATMENT OF HAZARDOUS MATERIALS

In situ treatment consists of physical, biological, or chemical methods to degrade, immobilize, or remove hazardous wastes without significant excavation of the site. The applicability of a given site depends upon the site hydrogeology, the type and degradability of the waste, and in the case of biologic treatment, the suitability of the site to support microbial populations.

Biologic treatment may be aerobic (in the presence of oxygen), anaerobic (without oxygen), or by fermentation. Aerobic degrading bacteria are capable of degrading petroleum hydrocarbons, aromatics, phenols, biphenyls, organophosphates, polyaromatic hydrocarbons, and many herbicides and pesticides. Anaerobic bacteria are most suitable to the degradation of halogenated hydrocarbons, especially the alkyl halides. The microbes, either aerobic or anaerobic, use the carbon in the compounds as an energy source. They also require nutrients such as nitrogen and phosphorous, and oxygen in the case of aerobic organisms. These can be added to the soil and groundwater through wells or subsurface galleries. The same conduits for the introduction of nutrients and oxygen can also be used to add cultures of additional microorganisms to enhance the population occurring naturally. Normally, however, the native microbes are the ones best suited to metabolizing the compounds as they have adapted to the ambient conditions at the site.

Physical in situ treatment consists of ground-freezing, electrothermal heating, and vitrification. Ground-freezing is a special case of creating an impermeable barrier around a waste site. The soil adjacent to the wastes is frozen with refrigeration equipment, effectively making the ground impermeable. Vitrification uses electric current to heat the soil and contaminants to such a temperature as to make the soil an inert glass and to decompose or encapsule contaminants. Heating of a soil with steam can volatilize, degrade, or distill the contaminants in situ. Ground-freezing is not feasible as a long-term solution as energy costs become prohibitive. Heating and vitrification are viable alternatives to excavation under some circumstances.

In situ chemical detoxification can consist of any chemical reaction, precipitation, flocculation, or binding that immobilizes or degrades the compounds of concern in place. Addition of acids, bases, surfactants, chelators, precipitating agents, and oxidizers or reducers can be used to stabilize or flush out contami [illegible] method is usually best used with single contaminants or closely related contam [illegible] mical methods that effectively contain or inactivate one waste may mobilize ano [illegible] ste. In all cases where in situ treatment is considered, it is advisable to perform lab-sca [illegible] emonstrations of its feasibility and effectiveness. A very good review of the current remediation technologies can be found in NEESA Document 20.2-051, *Remedial Measures Technology Guide* (Blount et. al., 1986).

TECHNOLOGY ASSESSMENT

An assessment of the technology requirements needed to address aquatic hazardous waste contamination identified three major areas for research and development. These areas are developing technology for making better measurements at aquatic sites, technology for conducting toxicity assessments at aquatic sites, and technology for remediating aquatic site contamination. In order to meet this need, the Naval Ocean Systems Center (NOSC) has initiated research, development, and demonstration to fill in these technology gaps.

MEASUREMENT TECHNOLOGY

Organometal Analysis.

An analytical method for trace measurement of organotins in seawater has been optimized using hydride reduction. Volatile tin hydrides are concentrated in a liquid nitrogen cooled trap, volatilized in a hydrogen flame quartz burner, and detected by atomic absorption spectrophotometry. This method has been automated and is being modified for analysis of other organometals at hazardous waste sites. The objective of this project is to develop and operationally test an automated monitoring system for near-realtime analysis of organometals in aquatic environments.

Fiber-Optic Chemical Sensors.

Many Navy sites are contaminated with toxic organic compounds and or petroleum hydrocarbons. Of special concern are the polyaromatic or polynuclear hydrocarbons which are known carcinogens. Site investigations have documented the presence of these compounds in soils, groundwater, and sediments. Most present analytical methods are not suited for rapid in situ field analysis or detailed monitoring required for site investigation and clean up. The objective of this project is to develop portable fiber-optic based sensor system for realtime in situ field measurement of polyaromatic hydrocarbons in environmental samples for seawater, sediment, and groundwater.

Marine Environmental Survey Capability (MESC).

Conventional analytical techniques which involve sampling and subsequent laboratory analysis of discrete samples do not provide the temporal and spatial information required to make accurate assessments of dynamic near-shore environments. The objective of the MESC system is to develop a modular water-quality mapping system that can be used to survey chemical, biological, and hydrographic parameters in harbors, bays, and other near-shore environments. The MESC system is designed as a complete, stand-alone, modular system consisting of (1) a suite of towed and flowthrough water quality sensors, (2) an integrated navigational and positioning system, (3) an on-board data acquisition, processing, and display system, and (4) all required support equipment. The system can be deployed from a transportable survey craft or from any platform of opportunity to obtain realtime or near-realtime measurements of water quality.

Benthic Flux Measurements.

Studies conducted by the Army Corps of Engineers have shown that total sediment toxicant concentration is not always related to measured biological effects. A significant fraction of the toxic compounds may be absorbed on the particulate phase and not available biologically. For constituents that are significantly mobile, a greater risk may result from dredging the sediments than leaving the material in place. This project will provide a measurement system that can be used to quantify the actual in situ flux of toxicant from the sediment into the water column to facilitate cost-effective cleanup strategies. The device will consist of a dome and associated "landing gear" that can be lowered from a small craft and released. Samples will be collected within the dome at preprogrammed times, and the system will be retrieved using an acoustic release mechanism. The flux rate will then be calculated from analysis of the increase in toxicant over time.

Contaminant Dispersal and Prediction.

The remediation of hazardous sites impacting aquatic environments requires the potential long-term impact to be determined. Selection of the most cost-effective solution requires the capability to identify and predict the consequences of remediation before irreversible or costly environmental damage occurs. To do this, methods must be demonstrated which will analyze and predict contaminant dispersion from hazardous waste sites impacting aquatic systems. Modeling methods must be validated using time-varying hydrodynamic and contaminant data collected before they can be applied as a useful tool to improve monitoring designs and support remedial investigation/feasibility study (RI/FS) at sites impacting aquatic systems.

More than 40 hazardous wastes sites will require remediation of contaminated sediment. In cases where dredging is required to maintain navigable waterways or to remediate contaminated areas, the impact of material resuspension is unknown and difficult to estimate due to inadequate sampling techniques which cannot easily locate regions of dispersal. This project also will provide a realtime measurement system capable of tracking subsurface plumes of contaminated sediment. The approach is to determine the feasibility of using an Acoustic Doppler Current Profiler and high-precision positioning system deployed from a moving vessel to determine the dispersion characteristics of resuspended materials resulting from dredging contaminated sediment.The realtime projection will identify where and when to collect water-quality samples to quantify the dispersal of toxicants and estimate the potential effects on the marine environment.

TOXICITY ASSESSMENT TECHNOLOGY

Marine Bioindicator Systems.

The Department of Defense (DOD) (Navy) is required to clean up many hazardous waste sites located in the coastal zone. Chemical methods alone are inadequate to reliably determine the necessity or effectiveness of cleanup operations. The objective of this project is to develop methods and protocols for determining site specific toxicity using a suite of portable biological indicator systems. This system will be used in support of the RI/FS for NAS North Island, CA. Successful evaluation will result in methodology applicable to other aquatic hazardous waste sites. This project will combine in situ data collection and realtime chemical analysis capability with a portable marine bioindicator system for site-specific toxicity assessments. This capability will facilitate evaluating the effectiveness of cleanup operations at marine hazardous waste sites. The applicability of measuring in situ growth, bioaccumulation, biochemistry, and toxicity will be evaluated by comparing effects in a portable bioassay trailer, a portable microcosm, and with field bioindicators. The most effective bioindicator system will be identified and developed to evaluate cleanup effectiveness.

Portable Microcosms for Environmental Testing (POMFRET).

A major difficulty in compliance with cleanup requirements is the weakness of risk assessment techniques used to evaluate chronic environmental effects. The Navy has a requirement for the testing of possible environmental effects of Navy specific toxicants, dredge material, and hazardous wastes in the aquatic environment. The intent is to develop a capability to accomplish chronic and short-term community and population level tests for pollutant effects at specific harbor and shoreline locales of interest to the Navy. The key function of the POMFRET will be to provide a quick-response, mobile system capable of performing chronic and short-term biological tests for pollutant effects at specific near-shore locations. The system will allow cause and effect determinations of environmental impacts to be made, using environmentally realistic, yet controllable conditions. Such systems are now recognized by the Environmental Protection Agency (EPA) and other regulatory agencies as being a cost-effective means of obtaining realistic environmental assessment information.

Phytoplankton Bioluminescence Assay.

Many current bioassay techniques for assessing toxicity are time consuming, labor intensive, and expensive and use inappropriate species. An assay tool is needed that will address ecological impact at the sublethal level of exposure. The use of mortality as a common endpoint in presently used bioassays for decision making is inadequate for realistic risk assessments. A bioassay, currently being developed at NOSC, using dinoflagellate (algae) bioluminescence, chlorophyll fluorescence, and adenosine triphosphate levels will provide more sensitive sublethal indices of toxicity. The immediate advantages of using this technique are increased sensitivity of the assay compared to animal species, ease of use, less time required to run the assay, and lower cost in conducting the assay.

REMEDIATION TECHNOLOGY

Bioreactors.

The purpose of this project is two-fold: (1) develop small, laboratory scale bioreactors for rapid determination of optimal biodegradation conditions at specific sites and (2) develop a prototype bioreactor suitable for scale up to be used as a portable or mobile unit for hazardous waste detoxification onsite. Hazardous waste sites have specific factors affecting biological cleanup. This project will use bioreactors to evaluate factors specific to the site under investigation, including the nature of the waste material or mixture, type of soil or sediment, proximity to water, existing microbial population, pH, oxygen, and nutrients for optimal onsite remediation. Scaled up versions of successful laboratory bioreactors can be deployed to the specific site where they can be used to monitor the progress of ongoing cleanup. Bioreactor systems can also be engineered to provide closed systems for aboveground treatment of wastes using cultured or genetically altered organisms preventing their release into the environment.

Rapid Monitoring Of Remedial Detoxification.

Conventional analytical methods for the priority pollutants are expensive in time and money and are not adaptable for field use. Detection and identification of hazardous organic substances and monitoring cleanup measures can be expedited by using field-adaptable measurements to screen samples and reduce analytical costs. Structural characteristics of compounds can be used as the basis for identification and estimation of the substance by the presence or absence and intensity of distinctive ultraviolet or infrared absorption bands. Simple chemical measurements using portable, low-cost spectrophotometers can be used to screen samples and quantify the presence or absence of the compound(s) of interest, thus reducing the number of samples that must be sent to analytical laboratories for more detailed analysis. The validity of the methods will be verified using artificial mixtures, simulated contaminated samples, laboratory scale bioreactors, and field samples. The feasibility of this approach will be demonstrated by using a laboratory scale bioreactor system.

Complexation Capacity for Heavy Metals.

In natural waters there exists an important component which tends to mitigate toxicity called the complexation capacity. Complexation capacity is the tendency of ligands and other organic material (humus) to absorb or retain heavy metals and other toxins. Accurate measurements of the complexation capacity will provide more realistic measures of toxicity at disposal sites and provide useful information for the development of synthetic complexing agents for the cleanup of waste waters.

DEMONSTRATION PROJECTS

This section describes current demonstration projects being conducted at disposal sites to develop and apply methods for assessing and remediating hazardous waste sites located adjacent to aquatic environments. Demonstration projects were selected on the basis of three primary criteria: (1) that the demonstration would be politically acceptable to the activity and Naval Facilities Engineering Command, (2) the demonstration would be logistically doable on the basis of manpower, timing, and resources, and (3) the demonstration would be scientifically interesting and the results would be applicable to many other Navy and non-Navy hazardous waste sites. The current demonstrations and their start dates are verification of biodegradation of jet fuels at NAS Patuxent River, MD, July 1987; toxicology demonstration project at NAS Whidbey Island, WA, January 1989; and risk assessment pilot study at NCBC Davisville, RI, November 1988.

VERIFICATION OF BIODEGRADATION AT NAS PATUXENT RIVER

The scope of this project is to design and execute experiments to evaluate and verify in situ biodegradation of jet fuel spilled in a marsh area by (1) determining the rate of biological degradation of petroleum hydrocarbons before, during, and after remediation, and (2) identifying metabolites associated with biodegradation of petroleum hydrocarbons in soil, sediment, and water. The work is being conducted by Richard Lee, Skidaway Institute of Oceanography, University of Georgia, in coordination with the Naval Civil Engineering Laboratory.

The hydrocarbon degradation potential was determined for soil and water contaminated with spills and seepage of the jet fuels JP-4 and JP-5 near a fuel farm at NAS Patuxent River. About 4 acres were contaminated with petroleum products to a depth of about 7 meters. The deterioration of adjacent wetland habitat and the possible contamination of the Patuxent River, which enters the Chesapeake Bay, are areas of significant concern.

Hydrocarbon degradation rates were determined by adding radiolabeled hydrocarbons to soil or water samples and measuring rates of mineralization (production of $^{14}CO_2$). The radiolabeled hydrocarbons used were benzene, toluene, naphthalene, methylnaphthalenes, fluorene, hexadecane, and phenanthrene. The surface soils at the contaminated site were primarily sand, but a layer of peat was also present. The peat appeared to be saturated with oil. Hydrocarbon degradation rates were slower in peat relative to sand. The half-lives of naphthalene in oiled sand, oiled peat and "clean" reference soil were 1, 2, and 31 days respectively. Similar rates were found with the other jet fuel hydrocarbons. The slow degradation in the "clean" reference soil is presumably due to a low number of hydrocarbon degrading microbes, whereas in the oiled soils hydrocarbon degrading microbes may dominate the microflora. All of the hydrocarbons examined from the jet fuel, e.g., toluene, benzene, and naphthalene, were rapidly degraded in oiled soil. However, hydrocarbons not present in jet fuels, e.g., hexadecane and fluorene, were more slowly degraded in oiled soils than in "clean" reference soils. It appeared that the soil microbes in the oiled soil have adapted only to jet fuel hydrocarbons and cannot degrade other petroleum hydrocarbons, such as heavier weight polycyclic aromatic hydrocarbons and alkanes.

We are currently determining hydrocarbon degradation rates in streams and ponds into which oil is seeping from the contaminated soils.

TOXICOLOGY DEMONSTRATION PROJECT AT NAS WHIDBEY ISLAND, WA

Naval Air Station Whidbey Island has been nominated for addition to the National Priority List (NPL). A total of 28 disposal sites have been identified for remedial investigations at NAS Whidbey Island. Much of NAS Whidbey Island is forest, grassland, or marsh and provides habitat for numerous upland game birds, waterfowl, and other mammals and birds including the endangered peregrine falcon and threatened bald eagle. Beaches and bays around NAS Whidbey Island are popular fishing and shellfish gathering areas. Past disposal sites may potentially contaminate lowland areas, and the accumulation of persistent and biomagnifying pollutants in the food chain could affect higher order predators and man.

The purpose of this demonstration project is to conduct a toxicological evaluation to assess the impact of hazardous waste to wildlife, to evaluate risks associated with remediation of waste sites, and to demonstrate the use of an enhanced avian bioassay using starlings as bioindicators of toxicological impacts. A quadrat of nest boxes will be used to create an exposure gradient to quantify toxicological effects on survival, behavior, bioaccumulation, and reproductive success. Toxicants of concern will be identified by analysis of feeding behavior and bioaccumulation data.

The study is being conducted by The Institute of Wildlife and Environmental Toxicology (TIWET), at Clemson University, SC, and Huxley College of Environmental Studies at Western Washington University, WA. Under the direction of Ron Kendall, TIWET is conducting research to perform in situ toxicological evaluation of the impacts from hazardous waste sites on wildlife and the environment. The institute has extensive experience in the planning and execution of in situ tests on avian populations; the capability to perform field studies for collection of avian populations; including nest box deployment, rearing of juvenile starlings, nonlethal serum sampling of raptors, and nondisruptive assessments of great blue heron productivity and health; expertise in trapping and assaying rodents; and expertise for biochemical analysis of tissue samples for specific protein complexes as well as for toxic chemicals and their metabolites (Kendall, 1988; Robinson et al., 1988; Brewer et al., 1988).

Successful demonstration of the innovative approach of using starlings as bioindicators of toxicological impacts will provide an assessment tool that can be used at other Navy and non-Navy waste sites. The toxicological information will be used to determine the extent and potential impact (if any) of contamination to the environment for input to the RI/FS process. Follow-on studies to determine the effectiveness of remediation will be conducted if required.

RISK ASSESSMENT PILOT STUDY AT NCBC DAVISVILLE, RI

Allen Harbor at NCBC Davisville has been closed for shell fishing by the state's Department of Environmental Management due to suspected hazardous waste contamination from a landfill adjacent to the harbor. Analysis of sediment and bivalve tissues from Allen Harbor has shown increased levels of heavy metals and organics. The waste sites may be a source of leachate and low-level contamination to the harbor. Information is being obtained to assess the potential long-term impacts and identify risk management procedures. This project is developing and field-validating ecological risk assessment methods. Ecological risk assessment involves quantitative estimation of the likelihood of adverse ecological effects resulting from exposure to toxic substances from hazardous waste sites. Ecological effects will be determined using toxicological and biomarkers methodology. The completed risk assessment will support selection of remedial action or risk management of wastes. Monitoring will be conducted to measure the success of remediation technology.

A memorandum of agreement between the Naval Ocean Systems Center and the EPA-Environmental Research Laboratory (EPA-ERL), Narragansett, RI, was obtained to provide for cooperative research and development of risk assessment methodologies. The EPA-ERL is a center of excellence for marine coastal and estuarine water quality research and has the lead within the EPA to develop ecological risk assessment methodologies. The pilot study provides a site to use as a case study to develop methods for ecological risk by measuring and defining the extent of hazardous waste impact, assessing the toxicological and biological effect of the impact, and evaluating tools to detoxify and remediate. In addition the project will implement monitoring and assessment to support a Risk Management Plan for Allen Harbor.

The risk assessment pilot study at NCBC Davisville is being jointly funded by both the Navy and EPA. Also participating in the study are the Narragansett Bay Project, RI, the U.S. Food and Drug Administration Public Health Service Northeast Technical Services Unit, the University of Rhode Island, and TRC Inc. Overall planning and coordination for the project is being provided by the Naval Ocean Systems Center and Northern Division of Naval Facilities Engineering Command.

The anticipated products from this demonstration are (1) the risk assessment for Allen Harbor, selection of optimal cost-effective remediation, and verification of the effectiveness of cleanup, (2) the evaluation of innovative technology for conducting ecological risk assessments developed by conducting cooperative research and monitoring activities, and (3) guidance for ecological risk assessments at other Navy and non-Navy aquatic sites.

RECOMMENDATIONS

The technology development required to support the installation restoration program is shown in figure 5. Technology developed by the three areas of research will apply directly to the Remedial Investigational Feasibility Study (RI/FS) process (figure 5). Improved measurement technology will result in better site investigations and more realistic and achievable remedial options. Advances in remediation technology will assist in the development of feasibility studies and reduce the costs of cleanup. The development of toxicity/risk assessment technology is critical to the whole process. Toxicological information can be used to determine the severity of the problem, identify effective remedial options, and determine "How Clean is Clean?" Therefore, methods that allow the direct measurement of environmental health will be extremely useful for assuring the environmental safety of hazardous waste disposal sites and compliance with the law.

The following recommendations are pertinent Navy research and development interests.

1. Development of chemical sensors (Ostgaard, 1984; Hirschfeld, Deaton, Milanovich, & Klainer, 1983; and Lieberman, Inman, & Stromvall, 1987) and biochemical sensors (Jenkins & Sanders, 1986; Viarengo, 1985) to map and monitor contaminants in the water column and underlying sediment, preferably in realtime. Realtime display would allow directed sampling onsite, rather than force reliance on a priori sampling designs associated with subsequent laboratory analysis. Realtime analysis could focus on mapping "key" or representative contaminants as tracers to predict the distribution of other contaminants, which could be verified by standard laboratory analysis.

2. Identification of biological indicator species and assemblages to assess biological toxicity of multiple contaminants (Vernberg & Vernberg, 1974; Vernberg et al., 1977; Wise, 1985). These data are necessary inputs to risk models which aid in choosing preferred remedial measures. Navy personnel should become familiar with risk assessment methods and their role in remediation.

3. Development of remediation technologies designed for aquatic sediments. In situ techniques are preferred because they are suitable for environments where dredging may occur as well as those environments where dredging is not an issue. Monitoring and disposal of contaminated dredge spoils will require specialized methodology for assessment of impact as well as possible treatment options.

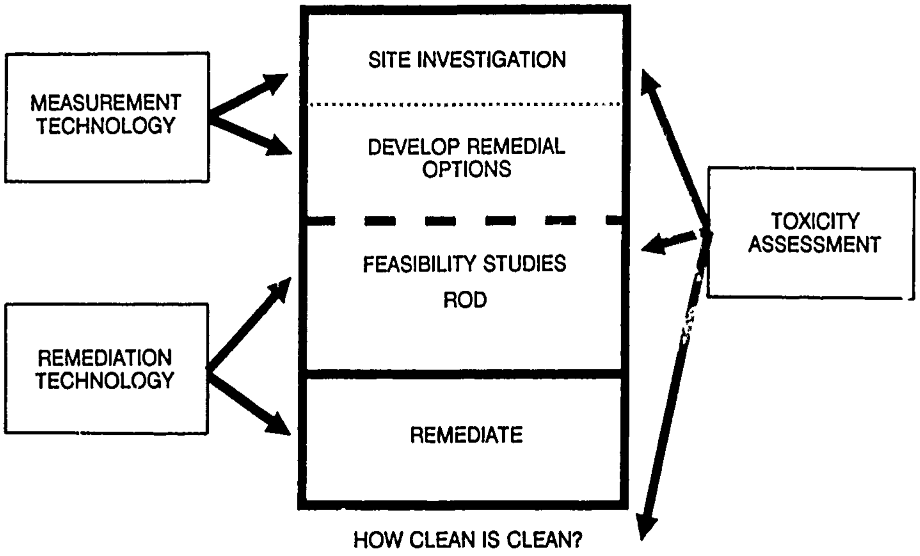

Figure 5. The RI/FS process includes the site investigation, development of remedial options, performance of feasibility studies, the signing of the record of decision, and remediation. Development of measurement, remediation, and toxicity assessment technology is needed to support the RI/FS process.

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APPENDIX A

SUMMARY OF HAZARDOUS MATERIALS AND POTENTIALLY IMPACTED AQUATIC RESOURCES AT NAVY INSTALLATIONS

IASs were used to compile numbers 001–104, and PAs were used to compile 105–189.

NEESA 13-002. *Naval Base Pearl Harbor, HI.* Contaminants including solvents, paints, PCB-containing oils, chlorinated organics, and other wastes are landfilled immediately adjacent to Pearl Harbor in the Pearl City Peninsula Landfill. Surface runoff and leachate from the landfill have strong potential to enter Pearl Harbor. The Red Hill Oily Waste Disposal Pit accepted waste diesel, JP-5, AVGAS, and Navy Special Oil at a site 300 feet from Halawa Stream, which enters Pearl Harbor. Migration to the stream could occur through groundwater or surface transport.

NEESA 13-007. *Naval Shipyard Charleston, SC.* Permeable soils and shallow groundwater discharging to the Cooper River would allow leachate from the landfill to enter the aquatic environment. This landfill contains multiple wastes including solvents, acids, oils, mercury, and PCBs. Three sites, the Oil Sludge Pits, POL Transfer Area, and Firefighting Training Pit, contain waste petroleum products that have potential to migrate through the groundwater. Two other sites, the Pesticide Mixing Area and the Caustic Pond, may also impact aquatic environments.

NEESA 13-008. *Naval Air Engineering Center Lakehurst, NJ.* Sixteen sites at this facility have the potential to impact the aquatic environments in the vicinity. Extremely permeable soils allow rapid migration of groundwaters to adjacent surface streams and swamplands. Sites can be divided into two general classifications, landfill-disposal sites and fuel farm underground storage of POLs and gas stations. The landfills and disposal sites contain oils, solvents, oily wastes, fuels, and other multiple wastes. Up to 6 inches of fuel have been documented as floating on top of the shallow groundwater. This fuel lens may enter the aquatic environment as free product as well as contaminate the water below it and enter in the dissolved phase.

NEESA 13-010. *Naval Shipyard, Norfolk, Portsmouth, VA.* This activity has four landfills which contain multiple wastes including oils and oily wastes. The sites are in the immediate vicinity of Paradise Creek and the Elizabeth River, two surface water bodies that empty into the Chesapeake Bay. The oils and other hazardous materials from these landfills may be carried by the shallow groundwater to the surface waters. The Acetylene Waste Lagoon, containing caustic materials, has the potential to leach into the groundwater and impact the surrounding surface waters. The other sites include two chemical disposal sites, an underground waste oil tank, and a hydraulic fill area, all of which may impact surface waters by groundwater leaching and transport.

NEESA 13-011. *Marine Corps Base Camp Le Jeune, NC.* Twenty-one of twenty-two sites recommended for confirmation studies had the potential to impact aquatic environments. Surface runoff and shallow groundwater discharges to the New River and its tributaries. Surface soils are relatively permeable and allow for moderate groundwater velocities. Potential and actual POL contamination is present at 10 of the 21 sites. These sites include underground fuel lines, underground leaking fuel tanks, past spills, oil and oily waste disposal pits, and the fire fighting training area. POL, pesticide, and mercury disposal occurred immediately adjacent to the New River.

NEESA 13-012. *Naval Shipyard Mare Island, Vallejo, CA.* Eight sites were identified as having potential to impact the water of Mare Island Strait. The landfill area is adjacent to the water body and only several feet above sea level. It contains waste oils, mercury, solvents, paints, PCBs, and other wastes. Wastes may enter the marine environment through tidal pumping of leachate and surface runoff. Sand blasting residue which includes tributyltin, copper, and other metals is located immediately adjacent to the shore. The Concord Annex waste area contains heavy metals, oils, nitrates, and other wastes and has significant potential to impact the nearby salt marsh, an environmentally sensitive area.

NEESA 13-013. *Naval Weapons Station Concord, CA.* This activity had 13 sites recommended for further study as having potential to impact the environment. These sites are listed below.

Site 1, Tidal Area Landfill; general disposal from 1944–1979.

Site 2, R Area Disposal Site; general ordnance scrap disposal.

Site 3, Kiln Site; soils contaminated with arsenic and lead.

Site 4, Allied Site A; soils contain copper, cadmium, zinc, arsenic, iron, and lead.

Site 5, Allied Site B; soils contain high levels of zinc, iron, and cadmium.

Site 6, Coke Pile Site; heavy metals and spent coke; low pH.

Site 9, Froil and Taylor Road Disposal Area; ordnance, scrap metal, and miscellaneous debris disposal.

Site 11, Wood Hogger Site; PCP-contaminated wood used as fill.

Site 13, Burning Area; munitions disposal for over 30 years.

Site 14, Kinne Boulevard Wells; fuel oils and other chemical contamination within wells.

Site 16, Black Pit at Redrock; solvent and paint disposal.

Site 25, K-2 Area; zinc and copper soil contamination.

Site 26, G-1 Area; lead and zinc soil contamination.

NWS Concord is located along San Francisco Bay. The landfill is adjacent to the bay and is subject to tidal influences and surface runoff. Many of the other sites are located within several hundred meters of the bay. Groundwater movement and surface runoff may also carry contaminants to the bay.

NEESA 13-014. *Naval Air Station Alameda, CA.* Seven sites have the potential to impact San Francisco Bay. The West Beach Landfill and the Disposal Area are adjacent to the bay, with wastes at or very near sea level. They contain multiple wastes including waste oil, solvents, acids, metals, pesticides, and low-level radiological wastes. Tidal influences may affect leachate migration from the site toward the bay. The Seaplane Lagoon received waste waters, runway runoff, oils and grease, and fuels which are known to have contaminated the sediments in the lagoon. Underground leaking fuel tanks on base near the lagoon may have contributed gasoline to the lagoon through groundwater and subsurface transport.

NEESA 13-015. *Naval Air Station Pensacola, FL.* The air station is surrounded by environmentally sensitive estuarine waters. Sherman Inlet is immediately adjacent to the base and coastal marshland has been used for shell fishing. The Sanitary Landfill contains paints, plating wastes, pesticides, and PCB-contaminated oils. Contamination could enter the aquatic environment by contaminated surface runoff as well as groundwater leachate transport. Multiple disposal sites received pesticides and mixed wastes and are also susceptible to subsurface migration of leachates in the porous soils. Leaks in the Fuel Farm Pipeline system have been documented, and fuel is known to be floating on the shallow groundwater as well as dissolved in the groundwater itself. Both the contaminated groundwater and the fuel floating on the groundwater discharge to the estuary.

NEESA 13-016. *Sewells Point Naval Complex, Norfolk, VA.* Six sites at this activity were determined to potentially affect the Elizabeth River area of Hampton Roads. Mason Creek and a complex drainage ditch network including underground culverts are located here. The ditch network and creek are tidally influenced and flow is toward the Elizabeth River and Willoughby Bay. Stormwater and other surface runoff enters the creek or ditches or is diverted to the underground culverts. The impacted sites include the following:

Slag pile: chromium, cadmium, and zinc residues

Drum storage: solvent and POL leakage into soils

Pesticide disposal: pesticides and pesticide rinsate solutions

Disposal area: cadmium dust and other wastes.

These contaminants have the potential to leach from the immediate soils to the groundwater and, consequently, enter the canals, creek, or Elizabeth River, all of which represent the upper surface of the surficial aquifer.

NEESA 13-019. *Naval Air Station Jacksonville, FL.* Eleven sites were identified as potentially impacting aquatic environments. Groundwater and surface waters discharge directly to the St. John's River. Four of the sites are hazardous material disposal sites. Materials disposed of at these sites include sewage, paint and paint wastes, waste oils, and metals including chromium. Five sites involve uncontained fuel disposal and fuel leaks and spills. Storm sewer discharge as well as groundwater discharge to the St. John's River may occur. One battery disposal area was identified. The combination of acid waste and metal contamination can cause increased mobility of the metals in the groundwater and transport to aquatic environments. The glass bead disposal area contains spent abrasives and metals from previous blasting activity.

NEESA 13-025. *Naval Submarine Base New London, CT.* Six sites during the IAS were identified as warranting further study, two of which may have significant impact on the aquatic environment. The Landfill Site contains oils, metals, waste chemicals, PCBs, and other wastes and is located within a marsh. The surface water discharge as well as groundwater leachate transport from the landfill directly enter the Thames River. Leakage of fuel storage tanks has caused a quantity of oil to be found floating on the groundwater under the base. Both this free product and the dissolved phase of oil in the groundwater discharge to the Thames River as well.

NEESA 13-027. *PWC Guam, QC.* Groundwater and surface water discharge to Apra Harbor and the Philippine Sea. Surface water discharges via ditches and storm drains as well as direct runoff. Disposal areas, abandoned drum sites, and waste oil tanks all contain potentially hazardous materials that might enter the marine environment.

NEESA 13-031. *Naval Air Station Brunswick, ME.* Seven sites may be impacting adjacent protected wetlands areas. Numerous brooks, the Brunswick River, and the wetlands areas as well as groundwater discharge to the above may cause insult to sensitive aquatic habitats. Two landfill sites contain waste oils, pesticides, and solvents which may have high mobility in groundwater. Three disposal sites contain waste solvents and paints. An acid pit and a caustic pit contain solvents and PCBs as well as acids and alkalis which can increase the mobility of the other hazardous materials.

NEESA 13-032. *Naval Ship Yard Portsmouth, NH.* One of four sites at this activity was recommended for a confirmation study during the IAS. This site is the Jamaica Island Landfill which contains metals, solvents, grit, paints and paint wastes, and asbestos. A clay liner surrounding the landfill is not an effective barrier to contamination. Tidal pumping causes leachate potentially to be drawn underneath the liner and directly into the Piscataqua River. A second site which may currently adversely affect the environment is the now inactive Industrial Waste Outfall. Increased levels of zinc, copper, and zinc have been identified in the sediments adjacent to the outfall effluent.

NEESA 13-036. *Marine Corps Air Station Kaneohe Bay, HI.* The H-3 Landfill is the one site identified as potentially impacting the marine environment. The landfill was originally a marshy and ponded area of the Nuupia Pond complex and was filled with multiple wastes including lead, mercury, paints, thinners, solvents, POLs, fuels, PCBs, and pentachlorophenol. These contaminants are in contact with the shallow groundwater which discharges to the adjacent Halekou Pond and Kaneohe Bay. In addition, surface runoff may carry contaminants to the ponds or Kaneohe Bay.

NEESA 13-040. *Naval Weapons Station Charleston, SC.* Four sites have the potential to impact the Cooper River and its tributaries. Two landfills on the base contain mixed oils and solvents, and the waste disposal site also contains oily wastes. The Pesticide Rinse Area contains arsenic impacted soils. Both groundwater and surface water discharge to the Cooper River and its tributaries.

NEESA 13-042. *Naval Air Station Patuxent River, MD.* This station contains 14 sites which may be adversely affecting aquatic environments. Several streams and ponds are located on base and these, along with storm water sewers and the surficial groundwater, discharge to the Patuxent River and Chesapeake Bay. Six landfill and disposal areas containing mixed wastes, POLs, solvents, and pesticides are located on base. Two sites are contaminated with spilled fuels and oils. Three sites involve solvent disposal, two sites contain metal disposal, and one site contains pesticide residue. Leachate from the landfills, solvent migration, and fuel and oil migration via groundwater transport are the most probable methods of these contaminants entering the Patuxent River.

NEESA 13-048. *Naval Air Station Barbers Point, HI.* Two of the three sites identified as warranting further investigation have the potential to impact the marine environment. The Coral Pit site contains waste oils, solvents, aircraft waste water, and other wastes. The bottom of this unlined pit is only 4 feet above sea level, and brackish groundwater is located immediately under the pit, indicating communication with the sea. The Sanitary Landfill contains multiple wastes including pesticides. Both sites occur on coral and limestone soils, which are extremely permeable and allow for rapid transport of fluids.

NEESA 13-049. *Naval Air Station Moffett Field, Sunnyvale, CA.* Six of the seven sites recommended for confirmation studies may impact the water quality of San Francisco Bay, which borders the air station. Both the shallow groundwater under the base and surface runoff to Marriage Road Ditch, Guadalupe Slough, and adjacent wetlands will ultimately reach San Francisco Bay. The six sites are summarized below.

Site 1. Runway Landfill: This site contains TCE, toluene, methylethyl ketone, paints, solvents, and waste oils and borders the wetlands area and the tidal Leslie Salt evaporator ponds.

Site 3. Marriage Road Ditch: The ditch was used to deposit waste oil, solvents, fuels, and paints that may enter the bay through the shallow groundwater.

Site 4. Former Industrial Wastewater Holding Ponds: Freon, MEK, fuel oil, TCE, and trichloroethane have entered Guadalupe Slough and the adjacent bay waters.

Site 5. Fuel Farm French Drains: Oil and fuel floating on the water table and in the dissolved phase in the groundwater have migrated away from the drain area down gradient toward the bay.

Site 7. Hangars 2 and 3: Unpaved areas were used for direct disposal of paints, oils, solvents, fuels, TCE, and other chlorinated solvents directly onto the soils. The surficial aquifer could easily carry these contaminants down gradient toward San Francisco Bay.

Site 9. Old Fuel Farm: AVGAS, MOGAS, and tetraethyl lead have entered the soils and groundwater and may reach the bay.

NEESA 13-051. *Naval Station Roosevelt Roads, Puerto Rico.* Thirteen of the sixteen sites recommended for confirmation may be impacting the marine environment. Surface and groundwater discharge to a system of on-base ditches, which intersect the bays and mangrove swamps adjacent to the base. These waters ultimately discharge to the Vieques Passage. Seven of the sites involve landfill or disposal sites containing oils or solvents. Four sites involve fuel or oil spills including the residual material from a tanker accident. One site involves pesticide residues. While there are four PCB contaminated sites, only one, where PCB contamination has entered the bay, is considered to be a threat to the marine environment.

NEESA 13-054. *Naval Underwater Warfare Engineering Station, Keyport, WA.* NUWES Keyport is located in the Puget Sound on a peninsula surrounded by Liberty Bay, Dogfish Bay, and a shallow lagoon. NUWES has been nominated for addition to the NPL due to past disposal practices. Disposal sites at NUWES Keyport include landfills and spill areas as well as direct discharge of pollutants into Liberty Bay and nearby marshes. Dogfish Bay supports commercial oyster fishing, and both Dogfish and Liberty bays are used for recreational fishing and shellfish gathering activities: Contaminants of concern at the NUWES Keyport landfill are paints, solvents, heavy metals, otto fuel, acids, caustics, pesticides, and treatment plant sludge. An estimated 30 tons of metals and cyanide wastes and 80,000 gallons of paint strippers and solvents containing chromium, cadmium, lead, nickel, zinc, MEK, trichloroethane, trichlorethlene, carbon tetrachloride, cyanide, and styrene were disposed into waters around NUWES Keyport. Otto fuel wastes from torpedo washing and servicing were also discharged into Liberty Bay.

The Indian Island Annex of NUWES Keyport occupies all of Indian Island and is located southeast of Port Townsend, WA, in the Puget Sound. Wastes disposed at the North End Landfill (Site 10) include paints, thinners, strippers, MEK, TCE, trichloroethanes, CCL_4, oil, lead, zinc, and polyurethane resins. Waters off the coast of Indian Island are used for recreational and commercial fishing. Potential migration of pollutants from the landfill could contaminate fish or shellfish. Bald eagles and peregrine falcons that feed and nest in marsh areas on Indian Island could be impacted by contaminant migration through the food chain.

Dabob Bay, located northwest of NUWES Keyport on Hood Canal, is used as a torpedo test range. From 1950 to the late 1960s about 5,000 gallons of otto fuel and 72,000 lb of lead counterweights were jettisoned from torpedoes during test range operations.

NEESA 13-055. *Naval Air Station Whidbey Island, WA.* NAS Whidbey Island has been nominated for addition to the National Priority List (NPL). A total of 28 disposal sites located at the Seaplane Base and Ault Field have been identified for remedial investigations at NAS Whidbey Island. Much of NAS Whidbey Island is forest, grassland, or marsh and provides habitat for numerous upland game birds, waterfowl, and other mammals and birds including the endangered peregrine falcon and threatened bald eagle. Beaches and bays around NAS Whidbey Island are popular fishing and shellfish gathering areas. Contaminants of concern include heavy metals and organic solvents disposed in landfills; PAHs, and waste oils burned during firefighting training; jet fuels an other POL spilled on the flight line and hangar areas; and pesticides. Past disposal sites may potentially contaminate lowland areas, and the accumulation of persistent and biomagnifying pollutants in the food chain could affect higher order predators and man.

NEESA 13-057. *Marine Corps Base Camp Pendleton, CA.* Camp Pendleton contains over 15 miles of ocean front in North San Diego County. Numerous streams and rivers cross the base and ultimately discharge to the Pacific Ocean. Five sites have been identified as potentially impacting groundwater and, consequently, discharging to streams and rivers. Site 8, the Las Pulgas Landfill, contains wastes including paints, PCP-treated wood, and asbestos and may discharge leachate into the Las Flores Creek Basin. Site 3, the Pest Control Wash Rack Area, contains soils that have been impacted with pesticides that may be transported by surface runoff or groundwater from the site. Site 4, the MCAS Drainage Ditch, received fuels and oils from air station activities which have entered the soils and may exist as free product, or in dissolved or adsorbed phases. Site 5, the Fire Fighter Drill Field, received flammable liquid wastes and low-level toxic foams. The unburned portions entered the soils and probably the groundwater at the site. The DPRO Scrap Yard (Site 8) received spills of PCB-contaminated oils, battery electrolite fluids, and hazardous waste drum storage activities. The shallow aquifer at this site may have carried away leachate from these activities.

NEESA 13-066. *Naval Amphibious Base Little Creek, VA.* Six sites may be impacting the aquatic environment adjacent to the base. Three landfill sites on base have received solvents, pesticides, metals, acids, and PCB-contaminated oils. The base plating shop disposed of metals and acids, while the base laundry waste storage facility has discharged trichloroethylene (TCE). A pentachlorophenol (PCP) wood treatment tank and rack allowed PCP to enter into the soils beneath it. The majority of the base is located within 2000 feet of a water body. These include Little Creek Harbor, Chesapeake Bay, and two small lakes adjacent to the base. Groundwater discharges to Little Creek Harbor, and surface drainage is to the harbor, bay or the lakes.

NEESA 13-067. *Naval Air Station Oceana, VA.* Five of the six sites recommended for confirmation studies may be impacting the aquatic environment. The air station is located adjacent to Lynnhaven and Linkhorn Bays, and Great Neck and London Bridge Creeks cross the base. West Woods Oil Disposal Pits received waste fuel, oil, and chlorinated and aromatic hydrocarbon solvents for over 10 years. Free product including JP-5, JP-3, and AVGAS are floating on the shallow water table and may be discharging to London Bridge Creek and from there, Lynnhaven Bay. The Line Shack Oil Disposal Areas received similar fuels and solvents from 1963 to 1981 and may be discharging them through the subsurface to West Neck Creek. The two base landfills operated during the 1950s contain solvents, pesticides, transformers, and mixed municipal wastes. Leachate from these landfills may be reaching Lynnhaven Bay and Linkhorn Bay. Fentress Landfill, located at the Auxiliary Landing Field, received multiple wastes including solvents and pesticides and may be producing leachate impacting the Pocaty River.

NEESA 13-068. *FCTC Atlantic, Dam Neck, VA.* This command is located on a barrier island. The sandy soils and other deposits are very permeable and possess very high hydraulic conductivities. Lake Tecumseh, Redwing Lake, and the Back Bay are all surface waters that might be impacted by contaminated groundwater in the surficial aquifer or by surface runoff. The Regulus Avenue Landfill (Site 1) contains pesticides, paints, solvents, waste oil, thinners, and other waste materials. The potential for leachate formation and migration is high at this site. The spill of PCBs in the former PCB Transformer Storage Area might have an impact on adjacent aquatic environments. Although PCBs sorb strongly to soils and are relatively immobile, transport of the soil by erosion or wind could carry the PCBs to the surface waters. The Public Works Disposal Area (Site 5) contains oils, 1,1,1 Trichloroethylene, paint thinner, and lead carbonate. Site 6, the former Pesticide Shop, discharged an estimated 20 gallons of DDT, Chlorodane, and other pesticides, and due to the high hydraulic conductivities of the soils and the toxicity of the compounds, this site may pose a threat even though the absolute amount of pesticide discharged was not large.

NEESA 13-070. *CBC Davisville, RI.* Two sites have been identified as probably impacting creeks, Allen Harbor, and the Narragansett Bay. Streams, shallow groundwater, storm drains, marshes, and creeks near the sites all discharge to Allen Harbor and the bay. Calf Pasture Point contains DANC, calcium hypochlorite, and chloride and may be impacting Allen Harbor. Allen Harbor Landfill received carbon tetrachloride, TCE, solvents, fuels, plating wastes, paints, PCBs, and other wastes. The water and sediment of Allen Harbor have been impacted and the harbor has been closed to shell fishing. Additional information on this site is contained elsewhere in this report, as this group is currently conducting a risk assessment/pilot study of the harbor.

NEESA 13-071. *Naval Air Station Key West, FL.* Six sites may be impacting aquatic environments. The station is situated on soils consisting of very permeable Miami Oolite and dredge spoils from the Seaplane Basin. Migration of contaminants may be occurring via groundwater transport through the porous soils and the underlying Key Largo Limestone, surface runoff, or tidal flushing and inundation to the adjacent surface waters. The six sites are described below.

Site 2, Transformer Oil Disposal Area: PCB containing dielectric fluids were broadcast for weed control.

Site 8, South Fleming Key Landfill: refuse, waste oil, paints, thinners, solvents, and other materials were mounded along the shoreline with direct pathways to the marine environment.

Site 4, Boca Chica Open Disposal Area: this site received refuse, oil, paints, and thinners, is adjacent to Geiger Creek, and is subject to tidal inundation.

Sites 3 and 5, Truman Annex and Boca Chica DDT Mixing Areas: these areas received spills and disposal of DDT and are subject to groundwater transport and tidal flushing.

Site 1, Truman Annex Refuse Disposal Area: paints, thinners, and solvents were disposed of at this site. The southern portion of the area borders the Atlantic, and the local groundwater is only 2 to 3 feet below the surface.

NEESA 13-064. *NCBC Gulfport, MS.* Five of the six sites at this activity are landfills in contact with the surficial aquifer. These landfills contain refuse, paint, oils, solvents, pesticides, and metals including cadmium, chromium, and lead. This aquifer is in a highly permeable formation and most transport is lateral, toward the Mississippi Sound, due to underlying clay deposits. The Fire Fighting Training Area received waste fuel, oil, solvents, and paint strippers which may be migrating through the groundwater or an adjacent ditch to the Mississippi Sound.

NEESA 13-079. *NCBC Port Hueneme, CA.* Contaminants from this activity may enter Port Hueneme Harbor and the Pacific Ocean through surface runoff, unlined drainage ditches, and canals emptying into the harbor and through the semiperched groundwater in the area which discharges to the canals, harbor, and beaches. Five sites may be impacting the marine environment. The Storage Yard Site contains fuel, oil, solvents, and PCBs. The earth moving area contains disposed waste oils, and the harbor and canals received waste oils, fuels, and pesticides. These fuels and oils are in the harbor and may be dissolved in and floating on the semiperched aquifer. The Hazardous Waste Magazine Site contains multiple wastes and the Proposed NCTC Building Site contains unknown waste or wastes discovered previous to construction.

NEESA 13-080. *Naval Air Station New Orleans, LA.* One site, the Fuel Tank Strippings Burn Pit, may be impacting the water quality of the Mississippi River. Unburned AVGAS and JP-4 may have entered the soils of the pit and be carried as dissolved phase in or free product on the groundwater to local drainage canals and ultimately the Mississippi River.

NEESA 13-084. *Naval Coastal Systems Center Panama City, FL.* Seven sites have the potential to contaminate aquatic systems. Surface water runoff and groundwater transport are toward several small creeks which discharge to St. Andrew Bay and the Gulf of Mexico as well as Alligator Bayou. Area soils are composed of fine sands and are moderately permeable. The seven sites are described below.

Site 6, Burn and Disposal Area: contains garbage, waste oil, solvents, and PCB-contaminated oil and is located adjacent to St. Andrew Bay with wastes washed directly into the bay.

Site 1, Original Disposal Area: acid, garbage, oil, solvents, and multiple chemicals were disposed of at this site and leachate entering the aquifer discharges to Alligator Bayou.

Site 2, Burn and Landfill Area: waste oil, lead paints, PCB oils, and solvents are entering Alligator Bayou via surface drainage and erosion.

Site 3, Old Fire Training Area: waste oil, paint, thinner, diesel fuel, gasoline, and JP-5 were disposed of here directly onto the soils. Some of the fluids entered the soils before burning could destroy them. The site is currently paved over so there is no possibility of surface runoff; however, groundwater transport of the substances may carry them to St. Andrew Bay, some 700 feet from the site.

Site 4, Underground Oil Contaminated Area: AVGAS and diesel have contaminated the soils at this site and are present as free product. This site is adjacent to Alligator Bayou and the soils are isolated from it by a subsurface bulkhead. Leaks in the structure may permit hydrocarbons to enter the bayou.

Site 5, Paint Equipment Cleaning Area: paint, thinners, acetone, and methylethyl ketone have entered the soil 800 feet from Alligator Bayou.

Site 8. Solvent Disposal (Bldg. 40): approximately 55 gallons of TCE was poured over a 20-square-foot area in 1973. The TCE plume may extend hundreds of feet.

NEESA 13-087. *Naval Station San Diego, CA.* Three sites may be impacting the water quality of San Diego Bay. The Mole Pier Disposal Area received oils and fuels that are presently in the soils. The Salvage Yard received mercury, POLs, and solvents and the former DPDO Storage Yard stored paints, lube oil, solvents, and PCB containing insulating oils. These wastes may enter San Diego Bay or Chollas and Patela Creeks before entering the bay through groundwater or surface runoff.

NEESA 13-088. *Naval Amphibious Base (NAB), Coronado, CA.* Two sites at this base and two additional sites at Outlying Field Imperial Beach have the potential to impact aquatic environments. NAB Coronado is built on hydraulic fill and surrounded by San Diego Bay on three sides. The potential for surface runoff and groundwater transport of contaminants to the bay is high. Waste oils, solvents, refuse, and unexploded ordnance were disposed of at the Old Refuse Disposal and Burn Area. Personnel have uncovered drums in the area and seeps of oil material have been observed rising to the surface in the area offshore of the fill. The Sandblast Grit Disposal Area contains the residues of antifouling and anticorrosive paints containing copper, arsenic, lead, and zinc. Airborne transport of these fine particles to the bay is an additional pathway for contamination to impact the marine environment. At OLF Imperial Beach, the Firefighting Area and the Fuel Farm Area both experienced uncontrolled discharge or leakage of fuels into the soils. Pathways of migration of the fuels include leaching of residual contaminants into the Tia Juana River as well as surface runoff of the contaminants to the river, Oneonta Slough, and the Pacific Ocean.

NEESA 13-089. *Naval Training Center San Diego, CA.* All surface runoff, storm drains, and probably groundwater discharge to the boat channel which enters San Diego Bay. A refuse disposal site contains oils, paints, solvents, and pesticides. Leachate from this site may be entering the boat basin channel, as groundwater under the base is shallow and tidally influenced. Four sites involve fuel or oil tanks that have leaked, including the center exchange gas station. The hydrocarbons may be floating on the groundwater as well as in the dissolved phase and entering the basin waters.

NEESA 13-090. *Naval Complex Point Loma, CA.* Seven sites may be impacting the water quality of San Diego Bay and the Pacific Ocean. Point Loma is bounded by San Diego Bay to the east and the Pacific to the south and west. Topographic relief is moderate to steep, and the soils are moderately erodable and highly permeable in one of the two formations outcropping in the area. Surface runoff and erosion have the potential to carry contaminants to the surrounding waters. Most groundwater on Point Loma is believed to move eastward, towards the bay, especially at the seven sites identified here. Three rubble or sludge disposal areas received sewage sludge containing potentially high concentrations of metals and chlorinated hydrocarbons. The Drum Disposal Area contains both full and empty cans and drums containing unknowns. Some containers are known to have leaked. Plating wastes were also improperly disposed of. At the fuel farm area, two sites received oil from tank bottoms: one, a pit for tank bottoms disposal, and two, a tank bottom spreading area.

NEESA 13-095. *Marine Corps Recruit Depot Parris Island, SC.* This activity is situated on a barrier island composed primarily of sand and silt. The shallow, surficial aquifer has very high hydraulic conductivities and is intercepted by marshes, creeks, and the Beaufort and Broad Rivers. Contamination may reach these waters through the aquifer or by surface erosion and runoff. Of the six sites identified as potentially impacting aquatic systems, three are landfill sites that have received multiple wastes and are located near inlets and tidal flats. Leachate migration velocities may be enhanced by tidal pumping in these tidally influenced areas. The Pesticide Rinsate Area received aldrin and other pesticides and is located 700 feet from a marsh. The Fire Training Pit received mixed oils and gas, which entered the soils and probably the aquifer, and is located 200 feet from a local creek. The Auto Shop Spill Site is located 900 feet from a stream and marsh area which may be impacted through contamination of the groundwater.

NEESA 13-103. *Naval Air Station Adak, AK.* Twenty of thirty-two sites were recommended for confirmation studies and two for remedial measures. Primary contaminant receptors are the aquatic biota in the numerous streams, lakes, lagoons, and bays. Contaminant migration may occur via surface runoff, shallow groundwater transport of leachate, and wind-driven dispersion of contaminated soils. Five sites are landfills which received wide ranges of wastes, and all may be leaching into the shallow aquifers. One site contains pesticide residues which may be impacting groundwater as well as being carried in surface runoff to the local surface waters. Four of the sites involve either oil spills or oil and fuel disposal pits. Low temperatures at the site, especially in winter, may retard the potential for natural biodegradation to occur at these sites. Seven sites have accepted drum disposal activities. While many of the drums were disposed of empty or did not contain hazardous materials, some drums are unlabeled and others were disposed of improperly. Consequently, the severity of the problem at these sites is difficult to quantify. Three sites, two involving PCB spills and one containing waste asbestos, may pose some threat to aquatic systems. Both materials are not highly mobile and, while hazardous, do not pose a large risk to the local aquatic environment.

NEESA 13-104. *Naval Station Mayport, FL.* Eight sites at this station may be impacting the St. John's River, Chicopit Bay, and the Atlantic Ocean. Surface runoff from the base enters Mayport Basin, the St. John's, and several creeks directly and through storm drains. The shallow aquifer discharges to the river, basin, and Atlantic, and the shallow soils have significant hydraulic conductivities. Five landfills, two fuel and oil spill sites, and the waste oil pit are located very near the St. John's River. These sites contain waste fuels, oils, metals, paints, solvents, acids, and pesticides. Moderate rainfall on the base and occasional deluge may cause periodic flushing of some contaminants to the aquatic system.

NEESA 13-116PA. *Naval Air Station (NAS) South Weymouth, MA.* Contaminants from five sites may migrate in ground or surface water to freshwater and saltwater wetlands in the towns surrounding the station.

Site 1, West Gate Landfill

Site 2, Rubble Disposal Area

Site 3, Small Landfill

Site 4, Former Fire Training Area

Site 5, Tile Leach Field

Contaminants which may have been disposed of at the sites include waste oils and fuels (Site 4, spilled on ground surface), waste battery acid (Site 5), and unknown liquid wastes from aircraft maintenance operations (Sites 1, 2, and 3 landfilled).

NEESA 13-129PA. *Naval Medical Command, National Capital Region, Bethesda, MD.* Contaminants from three sites may migrate in surface or groundwater to Stoney Creek, a tributary of the Potomac River.

Site 1, Laboratory Waste Disposal Area

Site 2, NMRI Xylene Disposal

Site 3, Asbestos Burial Area

Types of wastes are Site 1, xylene and alcohol, dumped on ground; Site 2, xylene, dumped on ground; Site 3, asbestos, landfilled.

NEESA 13-135PA. *Naval Hospital Portsmouth, Portsmouth, VA.* Contaminants from a shoreline fill area may leach into the Southern Branch of the Elizabeth River and, thence, to Chesapeake Bay. The site name is Site 1, Shoreline Fill Area. Demolition debris containing asbestos and incinerator ash possibly containing metals were disposed of at this site from pre-1942 to the 1960s.

NEESA 13-143PA. *Naval Air Station, Meridian, MS.* One site at NAS Meridian has a potential for impacting aquatic environments, Site 3, The Lake Martha Landfill and Metal Disposal Area. This site is actually split into two different areas and only the Lake Martha Landfill presents concerns for aquatic environments. The landfill occupies a natural drainage swale which empties into Lake Martha and, ultimately, Segars Creek. Automobile engines containing waste oils, paint cans, and solvent cans were reportedly disposed of at this site.

NEESA 13-144PA. *Naval Air Station, Glenview, IL.* One site at NAS Glenview has a potential for impacting aquatic environments, Site 3, Oil/Water Retention Basin. The basin is located in the flood plain of the West Fork North Branch of the Chicago River. The majority of surface drainage and infiltrated water on the air station enters the basin through either surface drainage pathways or a subsurface tile drain system which lies beneath most of the station. Water in the basin is separated from floating product and drained to the river and, ultimately, Lake Michigan. All spills of fuels or hazardous materials on the station which migrate in surface or groundwater eventually enter the basin. Contaminants which may be present in the basin include waste oils and leaded fuels, solvents, and paint wastes.

NEESA 13-148PA. *Naval Supply Center, Alameda Annex and Facility, Alameda, CA.* There are two sites at the annex, The Warehouse Area, and the Screening Lot and Scrapyard. Both sites have measured levels of heavy metals and organic compounds in soil and groundwater. Contaminants from either site could migrate in groundwater to Oakland Inner Harbor, about 1000 feet away, and thence to San Francisco Bay.

NEESA 13-149PA. *Naval Ocean Systems Center, Morris Dam Facility, Azusa, CA.* This facility has one site, known as the stained soil area near the Variable Angle Torpedo Launcher, which may pose a hazard to an aquatic environment. The site lies 150 feet up a steep hill above Morris Reservoir, a potable water supply owned by the Metropolitan Water District. Approximately 500 gallons of hydraulic fluids and grease have been spilled on the ground at the site. The local soils are readily erodible, and no attempt has been made to artificially stabilize or contain the stained soil.

NEESA 13-158PA. *Naval Supply Center, Oakland, CA.* Three potentially contaminated sites could impact San Francisco Bay. Site 1, Hazardous Waste Storage Yard, Lot 612, has cracks in the yard pavement. The soil beneath the cracks is gray and has an oily texture. Materials stored here include waste acids, paints, waste solvents, thinners, pesticides, and herbicides. Site 2, Stained Soil Areas Near Buildings 740, 740-C, and 741, has patches of soil which appear to contain oils, tar, and creosote. Site 3, Stained Soil Areas at Building 511E, has been used as a redrumming area for damaged containers of hazardous materials. The soil at the site has been stained by spilled liquids.

Each of these sites could impact surface water through migration of contaminants in surface drainage or groundwater to San Francisco Bay. Distances to the bay from the sites varies from several hundred yards to over one-half mile.

NEESA 13-159PA. *Point Molate Fuel Depot, Western Drive, Richmond, CA.* Two sites have been identified at Point Molate which may contribute contaminants to San Francisco Bay: Site 1, Waste Disposal Site Near Tank 20, and Site 2, Sandblast Grit Disposal Areas. Site 1 was used as a waste disposal site for over 20 years for mixed wastes which may have contained hazardous materials. Paint and oil cans and drums have been seen at the site. Site 2 consists of several sites spread around the Depot which have been used for disposal of sandblast grit. Both Sites 1 and 2 are subject to erosion and transport of soil and contaminants to the bay in surface runoff.

NEESA 13-187PA. *Naval Air Facility, Midway Island.* Three potentially contaminated sites have been identified on Midway which may release contaminants to the Pacific ocean in surface runoff or groundwater. Site 1, Bulky Waste Disposal Area, is located on fill placed over intertidal and subtidal area. Scrap metals and waste fuels used to burn trash have been disposed of at the site. Site 2, Runway Landfill, was used as a landfill for unidentified materials from the 1950s until recently. Fuels were used to burn wastes at the site to reduce volume prior to burial. Site 3, Asbestos Disposal Area, is estimated to have about 60 cubic yards of asbestos material from demolished buildings buried at the site. The water table on the island is expected to be very shallow, less than 10 feet in most places and less than that in areas near the shore. Consequently, buried contaminants could easily migrate to groundwater and then to the ocean.

NEESA 13-114PA. *Naval Underwater Systems Center, East Lyme, CT.* This facility is located on the shore of a freshwater pond that serves as the secondary water supply for the town of East Lyme. The pond is spring fed and has no natural surface inlets or outlets. The pond is also used for recreational fishing and swimming. Until 1987, tributyl tin oxide was used extensively to prevent fouling of equipment being tested in the pond. Site 1, Dodge Pond Sediments, has been recommended for sampling to determine if TBT has accumulated in the sediment.

NEESA 13-122PA. *Naval Underwater Systems Center, Fishers Island Annex, Fishers Island, NY.* The facility has one site, Site 1, Fishers Island Disposal Area, which has a potential for adversely impacting aquatic environments. The disposal area extends into wetlands on the shore of Block Island Sound. Scrap metals and empty 5-gallon and 55-gallon containers were noticed in the marsh during a recent PA site visit. The contents of the containers are unknown but it is likely that hazardous as well as domestic wastes were disposed of at the site. Mobile contaminants could impact the marsh or migrate to the sound in either surface or groundwater.

NEESA 13-105PA. *Naval Communication Station, Stockton, CA.* This facility is located on Rough and Ready Island in the San Joaquin River delta area. The island was originally a marshy grassland and swamp that was diked and drained to produce usable dry land. Portions of the island are below mean sea level and are kept dry by a system of drainage canals and a pumphouse which returns water to the river. Both surface runoff and groundwater on the island drain to the canals and are pumped over the levee. A variety of wastes and hazardous materials have been landfilled, dumped, burned, and/or spilled at 12 sites on the island. Any contaminants migrating from these sites in surface or groundwater will eventually find their way to the San Joaquin River. The sites and the types of wastes expected at each area as follows:

Site A, Floor Sump and Related Plumbing, B-816B. PCB, oils, solvents, toxic metals.

Site B, Waste Oil Tank South of B-816B. PCB, oils, solvents, toxic metals.

Site C, Railroad Car Service Pit, B-816B. PCB, oils, toxic metals, volatile organics.

Site D, Storm Drainage from B-816B and 916. PCB, oils, toxic metals, volatile organics.

Site E, Inactive Wastewater Treatment Plant. PCB, oils, toxic metals, volatile organics.

Site F, Inactive Wastewater Settling Ponds. PCB, oils, toxic metals, volatile organics.

Site G, Inactive Wastewater Treatment Plant Drainage. PCB, oils, toxic metals, volatile organics.

Site H, Inactive Pesticide Storage Building Near Treatment Plant. Pesticides, herbicides, toxic metals.

Site I, Storm Drainage Conveyances from B-816B and Storm Pump Station. PCB, oils, toxic metals, volatile organics.

Site J, Floor Sump at B-517. PCB, oils, toxic metals, volatile organics.

Former Landfill/Burn Area. PCB, TCE, DDT, paint residues with heavy metals.

Battery Acid Disposal Area. Lead sulfate, sulfuric acid.

APPENDIX B

OVERVIEW OF CONTAMINATION AT SELECTED U.S. NAVY INSTALLATIONS

This section provides an overview of 30 U.S. Navy and U. S. Marine Corps installations that were subject to Initial Assessment Studies. The list is not inclusive of all Initial Assessment Studies conducted but does represent a significant cross section of activities and types of potential contamination of concern. Categories of constituents of concern include disposal of ordnance, petrochemical, oil, and lubricants (POLs), pesticides/herbicides, solvents and paints, acids/alkalais, metals (including blasting grit wastes containing metals), asbestos, polychlorinated biphenyls (PCBs), and others which present a significant risk but do not fall into the above categories. These may include radiologic wastes, biologic or infectious wastes, and buried compressed gas cylinders of unknown content or pressure. Sites within this matrix which contain multiple hazardous wastes may be enumerated more than once if the quantities of suspected or actual hazardous materials present significant risks independently of each other. Table B-1 presents the summary. The data have been collected primarily from the Initial Assessment Studies conducted at each site. In several cases, updated information from Work Plans and the results from studies conducted to document sites identified in the Initial Assessment Studies have been included.

Review of table B-1 will yield total incidences of hazardous materials recommended for confirmation studies as shown in table B2.

Examination of table B-2 indicates that POLs and solvents or paints make up 49 percent of the hazardous materials responsible for contamination leading to Confirmation Studies. These chemicals have from low to high solubility in groundwaters and can be quite mobile in the subsurface. Most petroleum and petroleum products are present in three distinct phases in the subsurface. The contaminant can be found dissolved in the groundwater, adsorbed onto the soil, or as the free product, either floating on top of or sinking to the bottom of the aquifer when solubility of the constituent is exceeded. Remediation of these three-phase systems may consist of physical removal of free product by withdrawal via pumping and in situ treatment of the dissolved and adsorbed phases. This does not preclude other physical methods to contain the groundwater or adjust the groundwater flow patterns. Petroleum products, solvents, and pesticides and herbicides are three of the most readily biodegradable types of wastes present at Navy sites. Including these three classes of compounds, 56 percent of the incidences of suspected or real hazardous materials impacting either human health or the environment have the potential for bioremediation or other in situ mitigation or remediation. Pump and treat technology is also a potentially cost-effective and approved method to remediate some of these types of contamination. Ultimately, almost all sites will have to be dealt with individually.

Buried unexploded ordnance and occurrences of buried compressed gas cylinders that potentially contain toxic gases or were disposed of with unknown pressure are significant hazards. However, in almost all cases, excavation of these materials would be a tremendously greater risk than isolating the area from disturbance. If the sites are not scheduled for development and do not possess other hazards to human health or the environment, securing the area as out of bounds is a reasonable mitigation procedure. When this is not an alternative, such as when additional hazardous wastes are present, in situ methods of remediation may be an effective alternative to excavation and/or extensive drilling operations.

Table B-1. Categories of hazardous materials at selected U.S. Navy sites (continued).

Activity	Ord	POL	Pest/ Herb.	Solv/ Paint	Acid/ bases	Metals	ASB	PCB	Other
NS Mayport, FL		8	5	6	6	6	6	1	
NSB New London, CT		4				1		1	
NC Sewell's Pt., VA		3	3	1	1	2		1	
NB Little Creek, VA		1	3	5	4	4	1	3	
NAS New Orleans, LA		1				1			
NAS Miramar, CA		5	2	3	2	3	1	1	
NB Pearl Harbor, HI		2	1		1	1	1	1	
MCB Camp Pendleton, CA		4	1	4	2		1	1	
NC Point Loma, CA		4		1	1	2		1	1
NSY Philadelphia, PA		3				1		3	1
NAS Pensacola, FL		1				2		1	3
NYS Portsmouth, NH				1		1	1		1
NSY Norfolk, VA		1		3	2	3		5	

Abbreviations: Ord, Ordnance; POL, petrochemical, oil, and lubricant; Pest/Herb, pesticide and herbicide; Solv/Paint, solvents and paints; Asb, asbestos; PCB, polychlorinated biphenyls.

Table B-1. Categories of hazardous materials at selected U.S. Navy sites.

Activity	Ord	POL	Pest/ Herb.	Solv/ Paint	Acid/ bases	Metals	ASB	PCB	Other
NAS Barber's Pt. HI	1	1	1	1			1		2
NC Adak, AK	2	12	1					5	2
Hunter's Pt. Annex, CA		2		1	2	3	1	2	
NCBC Davisville, RI		2		1	1		1	2	1
NAS Whidby Island, WA		14	1	12				3	5
NAS Moffett Field, CA		3		7				3	2
NAS Alameda, CA		5	2	3	1	1	1	4	2
NWS Concord, CA	3			5	2	3	1		5
NAS Brunswick, ME		2	2	6	1		2	1	
NB Charleston, SC		3	1	1		2			
NCBC Gulfport, MS		6	1	6					
NAB Coronado, CA	1	3		2		1			
NAS Jacksonville, FL		6	1	4	1	4	1	1	1
MCAS Kaneohe, HI		1	1	1		1			
NCBC Lejeune, NC		13	5	5	3	4	1	3	
NAEC Lakehurst, NJ	6	12	1	6	2	4	1	1	1
NSY Mare Island CA		4		1		3	1	2	1

Table B-2. Number of incidences of each category of hazardous materials from table B-2.

Class	Number of Incidences	
POLs	126	(29%)
Solvents/paints	86	(20%)
Metals	53	(12%)
PCBs	41	(9%)
Herbicides/pesticides	32	(7%)
Acids/bases	32	(7%)
Others	32	(7%)
Asbestos	22	(5%)
Ordnance	13	(3%)

Contamination of soils with polychlorinated biphenyls (PCBs) normally fell within three types of input. The compounds could enter the soil by a localized spill of PCB-containing transformer oils, by unconfined disposal of PCB-contaminated material into a landfill or other disposal site, or by the spraying of PCB-contaminated oil over large areal extents for the purposes of dust control. Known sites of spills over small areas can normally be identified by discolored soil, as PCBs have a very strong affinity for soil and are not very mobile under most conditions. Removal of the soil in these cases may be the most efficient and cost-effective remedial action. Widespread contamination, either in surface soils or subsurface soils, is a much more difficult remedial decision and is not subject to generalization.

Acid and alkalai (base) contamination in groundwater can each individually be treated in situ with neutralization with the other. That is, an acid spill can be neutralized by the addition of base and vice versa. This is effective with single contaminant systems. It is not always feasible with multiple-contamination of a site. For example, if several metals are present in an acidic waste, the addition of base might mobilize one or more of the metals rather than produce an insoluble residue. Or the process might create a more toxic end product than the initial system. Metals contamination in soils and groundwaters are often the result of the unconfined disposal of plating wastes, spent batteries, and blasting grit. In the cases of plating wastes and battery disposal, acid or base contamination is also involved. Care must be taken to assess the total problem in these circumstances.

SUMMARY

To adequately assess contamination of soils and groundwater, the geology and hydrology of the site must be accurately determined. This is accomplished by thorough site investigation of the subsurface structure, lithology, hydraulic gradient, piezometric surface, soil geochemistry, and groundwater chemistry. Background and baseline measurements of soil and groundwater concentrations and variability must be determined initially. The primary method of determining subsurface parameters is through the drilling and development of wells and recovery of cores. Background wells and cores must be located upgradient from the source of contamination. At activities with multiple site contamination and a homogenous, well mixed aquifer, background wells and soil borings may be applicable to multiple sites.

With several phases of investigation as integral parts of the Navy's program, it is worthwhile to look ahead in the process as wells are initially bored and developed. With careful initial investigation prior to well emplacement and a knowledge of the suspected contaminants quantity and history, wells could be positioned and constructed with materials that would suffice to be acceptable in the remedial investigation phase even as the site investigation phase is beginning if significant contamination is anticipated. For example, rather than constructing a well with a PVC casing during the site investigation if hydrocarbon pollution is suspected, a metal-cased well could be installed. While the initial cost may be higher, a well of this construction could be used in remedial action to the site.

This report documented that over 50 percent of the sites identified in 30 Initial Assessment Studies were contaminated with POLs, pesticides and herbicides, or solvents. These contaminants are the most amenable to in situ bioremediation technologies. Native microorganisms often acclimate to site conditions and have been known to degrade significant amounts of these types of compounds with no artificial stimulation. Addition of nutrients, trace elements, and oxygen in the case of aerobic degradation has been documented to stimulate microbial populations to degrade these types of contaminants at even higher rates.

REFERENCES

Initial Assessment Studies (1983 to 1986) of the following U. S. Navy and U. S. Marine Corps Activities from the Naval Energy and Environmental Support Activities, Port Hueneme, California 93043:

NEESA 13-002 NB Pearl Harbor, HI
NEESA 13-007 NB Charleston, SC
NEESA 13-008 NAEC Lakehurst, NJ
NEESA 13-010 NSY Norfolk, VA
NEESA 13-011 MCBC Lejeune, NC
NEESA 13-012 NSY Mare Island, CA
NEESA 13-013 NWS Concord, CA
NEESA 13-014 NAS Alameda, CA
NEESA 13-015 NAS Pensacola, FL
NEESA 13-016 NC Sewell's Point, VA
NEESA 13-019 NAS Jacksonville, FL
NEESA 13-027 NSB New London, CT
NEESA 13-030 NSY Philadelphia, PA
NEESA 13-031 NAS Brunswick, ME
NEESA 13-032 NSY Portsmouth, NH
NEESA 13-036 MCAS Kaneohe, HI
NEESA 13-040 NWS Charleston, SC
NEESA 13-042 NAS Patuxent River, MD
NEESA 13-048 NAS Barber's Point, HI
NEESA 13-049 NAS Moffett Field, CA
NEESA 13-051 NS Roosevelt Roads, PR
NEESA 13-055 NAS Whidbey Island, WA
NEESA 13-057 MCB Camp Pendleton, CA
NEESA 13-058 NAS Miramar, CA
NEESA 13-059 Hunter's Point Annex, CA
NEESA 13-064 NCBC Gulfport, MS
NEESA 13-066 NAB Little Creek, VA
NEESA 13-067 NAS Oceana, VA
NEESA 13-068 FCTC Dam Neck, VA
NEESA 13-070 NCBC Davisville, RI
NEESA 13-071 NAS Key West, FL
NEESA 13-079 NCBC Port Hueneme, CA
NEESA 13-080 NAS New Orleans, LA
NEESA 13-084 NCSC Panama City, FL
NEESA 13-087 NS San Diego, CA
NEESA 13-088 NAB Coronado, CA
NEESA 13-089 NTC San Diego, CA
NEESA 13-090 NC Point Loma, CA
NEESA 13-095 MCRD Parris Island, SC
NEESA 13-103 NC Adak, AK
NEESA 13-104 NS Mayport, FL
NEESA 13-105PA NCS Stockton, CA
NEESA 13-114PA NUSC East Lyme, CT
NEESA 13-116PA NAS South Weymouth, MA
NEESA 13-122PA NUSC Fishers Island, NY

NEESA 13-129PA NMC Bethesda, MD
NEESA 13-135PA NH Portsmouth, VA
NEESA 13-143PA NAS Meridan, MS
NEESA 13-144PA NAS Glenview, IL
NEESA 13-148PA NSC Alameda, CA
NEESA 13-149PA NOSC Azusa, CA
NEESA 13-158PA NSC Oakland, CA
NEESA 13-159PA FD Richmond, CA
NEESA 13-187PA NAF Midway Island