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December 8, 1998

To: Consumers of API's Publication 4663, *Remediation of Salt-Affected Soils at Oil and Gas Production Facilities*

From: The American Petroleum Institute: Health and Environmental Sciences Department

Enclosed is a single, double-sided, replacement sheet for pages H-3 and H-4 of Appendix H of the *Remediation of Salt-Affected Soils at Oil and Gas Production Facilities* publication. Note the following changes in bold type to page H-3 only:

Final volume needed = [(spill volume)(spill soil EC - target soil EC)]/(target EC - receiver EC)

Using previous example (assumes receiver EC = 0 mmhos/cm):

Final soil volume needed = [(300 cu ft)(24 - 4)/(4 - 0) = ~~4,800~~ 1,500 cu ft

Then, (~~4,800~~ 1,500 cu ft) = ~~4,800~~ 1,500 sq ft @ 1 ft thickness

Since incorporated thickness is 0.5 ft, then ~~3,600~~ 3,000 sq ft total area is required

Then, [(300 cu ft)/(~~3,600~~ 3,000 sq ft)][12 in/ft] = **+ 1.2 inch thick salt-affected soil spread over ~~3,600~~ 3,000 sq ft**

Please remove the old sheet and insert the corrected version.

Therefore, 300 cu ft salt-affected soil spread to 1 inch thickness over 3,600 sq ft and incorporated to a final depth of 6 inches will decrease EC from 24 to 4 mmhos/cm.

However, if the receiver soil also contains a measurable salt concentration, a more refined calculation may be required. The following data are required: target salt concentration (salt criteria to be met), salt level of the salt-affected soil, salt level of the receiver soil, and volume of spill-affected soil. The calculation provides the final soil volume required, which is then converted into final land area required based on 3 inches of available depth. The calculation is performed as follows:

$$\text{Final volume needed} = [(\text{spill volume})(\text{spill soil EC} - \text{target soil EC})]/(\text{target EC} - \text{receiver EC})$$

Using previous example (assumes receiver EC = 0 mmhos/cm):

$$\text{Final soil volume needed} = [(300 \text{ cu ft})(24 - 4)/(4 - 0)] = 1,500 \text{ cu ft}$$

Then, (1,500 cu ft) = 1,500 sq ft @ 1 ft thickness

Since incorporated thickness is 0.5 ft, then 3,000 sq ft total area is required

Then, $[(300 \text{ cu ft})/(3,000 \text{ sq ft})][12 \text{ in/ft}] = 1.2 \text{ inch}$ thick salt-affected soil spread over 3,000 sq ft

Example 2: Spill soil volume = 300 cu ft; spill soil EC = 24 mmhos/cm; receiver EC = 1.5 mmhos/cm; target EC = 4 mmhos/cm

$$\text{Final soil volume needed} = [(300 \text{ cu ft})(24 - 0)/(4 - 1.5)] = 2,400 \text{ cu ft}$$

Then, (2,400 cu ft) = 2,400 sq ft @ 1 ft thickness

Since incorporated thickness is 0.5 ft, then 4,800 sq ft total area required.

Then, $[(300 \text{ cu ft})/(4,800 \text{ sq ft})][12 \text{ in/ft}] = 0.75 \text{ inches}$ (or 3/4 inch) thick salt-affected soil spread over 4,800 sq ft and incorporated to a final 6 inch thickness will decrease EC from 24 to 4 mmhos/cm

Similar calculations can be made for exchangeable sodium percentage (ESP), total petroleum hydrocarbons (TPH), and other constituents with linear concentration expressions. Because its concentration is expressed in logarithmic form, pH cannot be calculated by this method.

The land area required and thickness of spreading should be adjusted to allow for sampling and analytical variability. An expansion of the final land area required and a corresponding reduction of spreading thickness of about 1.3 times should provide for this variability.

Because of the potential for salt concentrations to increase at the soil surface during evaporative periods, a top dressing of gypsum may help minimize soil dispersion.

BURIAL PROCEDURES

Shallow burial (<4 ft) is undesirable because the salt will typically remain in the root zone and may cause significant vegetative stress for many years.

The process of deep burial involves cutting a slot the width of a bulldozer blade of sufficient depth to allow 5 ft of freeboard when the salt-affected soil is placed in the excavation. The soil removed from the slot is then used to cover the slot and replace the salt-affected soil.

The 5-ft depth is normally sufficient to prevent capillary action from bringing the salt back to the surface. If desired, a capillary barrier of clay or plastic can also be used if the slot is kept narrow. (The slot may have to be wider than a bulldozer blade for safety. The salt-affected soil should be placed only in the center of the excavation when backfilling.)

Groundwater is the critical issue in deep burial. Deep burial is most appropriate in arid areas with deep soils and groundwater. If groundwater is >100 ft and a plastic or clay cap is used, the potential risk of groundwater contamination is minimal.

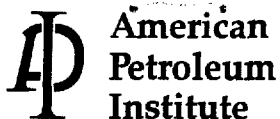
The cost of deep burial techniques (if there is sufficient soil) is on the order of \$2,000 for a modest-sized spill site. If the soil is shallow with underlying bedrock, the cost of deep burial can be ten times as great.

DISPOSAL WELL INJECTION

If produced water spillage is in a shallow depression with relatively loose soil, slurry and injection may be appropriate. In slurry/injection, freshwater is added to the spill site and mixed with the salt-affected soil. The slurry is then removed by vacuum truck and taken to a commercial disposal well permitted for oil and gas waste. This procedure is limited to very small spills where the slurry can be thin enough not to cause injection problems.

IN SITU AND EX SITU SOIL WASHING

Soil washing is a very fast but often costly operation which combines high mechanical energy agitation with application of chemical amendments in order to remove salts, including sodium, from the salt-affected soil. The soil is often, but not always, removed from its original location. Soil washing is typically performed by soil washing contractors who have appropriate equipment and are aware of the soil chemistry involved. Generally, the soil is kept in a chemically flocculated slurry during the entire process. Depending on soil texture, salinity, sodicity, and pH levels, salts are leached with increasingly less saline water to a certain salinity level before chemical amendments are added to begin to displace sodium. When the soil is at an acceptable salinity and sodicity level, it can be returned to its original location or taken to another site. Although this process is rapid and has the potential to be very thorough, it tends to be expensive.



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10/15/98

To: Purchasers of Publication 4663, Remediation of Salt-Affected Soils at Oil and Gas Production Facilities

From: Health and Environmental Sciences Department

Attached are errata pages B-34 and H-3 – H-4 for API Publication 4663, *Remediation of Salt-Affected Soils at Oil and Gas Production Facilities*. Page B-34, Worksheet 5 – Post-Remediation Monitoring and Project Termination, was excluded from your publication in error. Insert this page at the end of Appendix B (as the final page). A correction was made to page H-3 of Appendix H, which is backed to page H-4. Both pages should be replaced.

Thank you.

A handwritten signature in black ink, appearing to be 'PM' with a horizontal line through the 'P'.

WORKSHEET 5 - POST-REMEDATION MONITORING AND PROJECT TERMINATION

Site Name: _____ Spill ID No.: _____

Date Initially Reported: _____ Date Remediation Completed: _____

Date Termination Anticipated (2 yr from date remed. complete): _____

Category of Remediation Used: _____

Criteria for Soil Monitoring and Completion of Remediation (list below):

Report to	Date		Criteria	Result		Acceptable (Y/N)
	Due	Sent		Spill Site	Background	

Comparative Plant Yield Documentation:

Report to	Date		Plant Type	Plant				Acceptable (Y/N)
	Due	Sent		Height		Biomass		
				Site	Bkgd.	Site	Bkgd.	

Photographs of Site and Background:

Year	Winter Date Taken	Spring Date Taken	Fall Date Taken
0-1			
1-2			

Project Termination:

Interest Group	Declared to	Declared Date
Regulatory		
Legal		
Corporate		

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REMEDIATION OF SALT-AFFECTED SOILS AT OIL AND GAS PRODUCTION FACILITIES

Health and Environmental Sciences Department
Publication Number 4663
October 1997



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Remediation of Salt-Affected Soils at Oil and Gas Production Facilities

Health and Environmental Sciences Department

API PUBLICATION NUMBER 4663

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EXECUTIVE SUMMARY

Water separated from oil and gas during production contains dissolved solids, including salts. If improperly handled, produced water with sufficient salt concentrations can damage plants and soils.

This manual is designed to assist the oil and gas environmental professional and field personnel in (1) assessing sites with salt-affected soils, (2) evaluating remedial alternatives, and (3) conducting remedial activities, if necessary.

Remediation of salt-affected sites can be performed for a number of reasons. Landowner claims; lease agreements; federal, state, and local regulations; reduction in long-term liabilities; company policies; and protection of useable land and water resources may be the driving forces behind the need to assess and restore a site affected by a saltwater release. These driving forces are considered along with site-specific geologic and engineering factors when developing a remediation goal. Often, the remediation goal is a self-sustaining vegetative cover consistent with the land use which avoids groundwater contamination and offsite migration of produced water salts.

The natural capability of land for various uses, its soil, climate, and water, are environmental factors that influence the success of a salt-related remediation project. A review of soil science fundamentals that are relevant to the fate and transport of salt during a remediation effort is provided in this manual.

Total salt and total sodium concentration in a saltwater release can cause the soil to become saline and sodic, respectively. The total salt concentration is of greatest concern to plants; the proportional sodium content is of greatest consequence to soil. Analyses to classify soil salinity (electrical conductivity) and sodicity (exchangeable sodium percentage and sodium adsorption ratio) are discussed.

Excessive soil salinity can inhibit plant growth by restricting plant uptake of water. Excessive sodium can cause soil dispersion, a condition that inhibits water infiltration and drainage, and causes reduced soil aggregation. Dispersed soils may become susceptible to future erosion.

ES-1

Care must be taken when addressing salinity and sodicity. For example, freshwater applied to salt-affected soil without prior application of chemical amendment can cause soil clays to disaggregate which can lead to dispersed conditions. Disaggregation occurs when salinity is decreased by leaching while sodium is the dominant cation over calcium and magnesium.

Site assessment may be the most critical activity in addressing salt-affected soils. The assessment process includes gathering and organizing data about the site conditions and developing realistic remediation goals. Efficient assessments are geared toward gathering only the information needed to select a remedial option. This manual provides forms for organizing assessment information and conducting sample collection and analysis.

Remediation options for salt-affected soils are divided into three primary groupings: natural remediation, *in situ* chemical amendment remediation, and mechanical remediation. Natural remediation is the process of allowing an affected area to recover with little human assistance. *In situ* chemical amendment remediation involves adding chemical amendments (including water) to the soil to displace sodium and leach salts permanently to a location below the root zone but above groundwater. Mechanical remediation entails removing the soil from the site and disposing of it in a proper manner offsite or mechanical manipulation of the soil onsite in a way that meets the site remediation goals. Mechanical remediation may be selected when neither natural remediation nor chemical remediation are technically viable or cost effective. A decision tree and worksheets are provided to aid in the selection of a remedial option(s). Technical approaches for applying each group of remedial options are discussed.

A number of appendices provide supplementary information on various aspects of salt-affected soil remediation including: techniques for addressing drainage problems, revegetation materials (including halophytic vegetation), types of chemical amendments and amendment application procedures, and procedures for mechanical remediation technologies. The appendices also contain tools to develop customized field manuals for remediation of small areas of salt-impacted soils.

Section 1

INTRODUCTION AND OVERVIEW

The E&P industry uses great care during the handling and disposal of saltwater to avoid possible damage to the environment, including surface land, surface waters, and groundwater. However, unintentional releases of saltwater do occur. This manual is designed to assist oil and gas exploration and production (**E&P**¹) environmental professionals and field personnel in remediating salt-affected **soils** resulting from saltwater spills. Information is provided for assessment, data interpretation, decision making, and remediation of **surface soils** exposed to saltwater. This includes saltwater containing low levels of petroleum hydrocarbons.

BACKGROUND

Most oil and gas E&P operations produce formation water simultaneously with oil or gas. Salt concentrations of this “**produced water**” vary from water with low salt concentrations, to **brackish water** [i.e., **total dissolved solids (TDS)** less than 4,000 parts per million (**ppm**)], to **brines** with salt concentrations greater than 100,000 ppm.

Spills of produced water with high concentrations of total salts (**salinity**) and sodium (sodicity) can have a detrimental effect on terrestrial and **freshwater** environments. Excessive salts can create adverse chemical and physical conditions in soils and damage or kill vegetation.

Spills of Produced Water onto Surface Soils

Oil and gas production sites vary in size from less than 0.25 acre at a single well pad, to a few acres at a tank battery, to many acres at a gas plant. Large volumes of produced water (up to thousands of barrels per day) are routinely handled in many of the production operations located on these sites.

The current practice for disposal of most inland produced waters is by injection into enhanced oil recovery or produced water disposal wells (Class II injection wells). Some inland facilities may use evaporation pits to dispose of produced water.

Surface spills of produced water do occur as a result of equipment failure, pipeline corrosion, weather, or human error. Such mishaps can occur at production sites, along produced water injection pipelines, or at other field locations.

¹ Terms in **bold type** appear in the glossary (Appendix D).

Produced Water Pits

There are several types of pits traditionally associated with oil and gas production. Following are three types of salt-related pits:

- Production pits
- Reserve pits
- Produced water storage (emergency) pits

Historically, production pits were used for saltwater storage, oil and water separation, and solids settling (Moseley, 1983). In arid regions, production pits were also constructed to dispose of produced water through evaporation (API, 1997). Today, evaporation pits are used in a few western states at sites with relatively low-salinity produced water where the potential for affecting underground drinking water sources is also low.

Reserve pits are used for solids separation during drilling and workover operations and for holding waste drilling muds and cuttings. Even when a freshwater mud is used, pit contents can become a source of accumulated salts where saltwater-bearing formations are drilled. As a result of evaporation during drilling and pit dewatering, salt concentrations in reserve pits can be high.

Produced water storage, or emergency pits are constructed to contain produced waters temporarily in the event of equipment malfunction, such as a failure of the injection system or a disposal well. These emergency pits generally serve many wells, a lease, or a field. They usually are in sporadic use during the lifetime of an oil or gas field. Most states require the emergency pit to be emptied after use, but salts can accumulate over time in soil at the bottom and sides of unlined pits.

This manual does not specifically address the remediation of salt-affected pit sites. However, many of the techniques described in this manual can be adapted to various aspects of pit remediation. Spills from overflow, for example, can be remediated using this manual. If the pit is to be closed, and material in the pit must normally be mechanically remediated (e.g., mixing with clean soil or soil removal) it may be possible to handle the closed pit **subsoils** in the same manner as a spill site.

PURPOSE OF MANUAL

The overall purpose of this manual is to assist oil and gas environmental professionals and field personnel in: (1) assessing sites with salt-affected soils, (2) evaluating remedial alternatives, and

(3) conducting remediation activities (if necessary). Included with this manual are tools to create a field manual (Appendix A) organized to provide field personnel with a simplified template for remediating relatively uncomplicated spill sites. The full manual provides more detailed guidance and reference materials.

Scope

This manual focuses on remediation of typical spill sites on common soils and landscapes. The information and concepts provided are applicable to the remediation of some pit sites and some large spill areas. However, the scope of this manual does not address remediation of severe or chronic spill areas, pits deeper than 6 ft or containing non-soil constituents, or groundwater or surface water.

Low concentrations of petroleum hydrocarbons also may be present in produced waters. Remediation of more than very low levels of hydrocarbons (<2%) in soils is beyond the scope of this manual. If high concentrations of hydrocarbons are present (>2%), the user should consult references specific to hydrocarbon remediation.

This manual was intended for use within the United States where resources, such as county **Soil Surveys** and similar data, are readily available to the user. However, the underlying principals of salt remediation make this manual applicable worldwide, with the possible exceptions of predominantly frozen soils, organic soils, and certain soils formed primarily from volcanic ash.

In contrast to **mineral soils** which are composed of inorganic **sand**, **silt**, and **clay** particles, organic soils are composed primarily of decayed vegetation which accumulates in saturated conditions. Although this manual pertains to many soils of volcanic origin, it does not address volcanic soils which contain a predominance of **allophanes**, due to their unusual physical and chemical properties.

Organization

This manual is organized into seven sections. Section 1 provides an introduction and overview. Section 2 addresses non-soil-related issues which may be considered when setting goals for the remediation effort. Section 3 reviews basic environmental factors for which the user should develop some familiarity prior to initiating remediation. Section 4 examines the effect of salt spills on various soils. Section 5 provides an overview of remediation option categories and a Decision Tree to assist in selecting an appropriate remediation option. Section 6 is a guide to site

assessment activities. Section 7 provides details of remediation activities, and Section 8 outlines post-remediation monitoring and project termination.

Appendices are included to expand on information provided within this manual. Each appendix is designed to be a self-contained module. Use of the Decision Tree presented in Section 5 will lead to one or more appendices which provide information for making specific determinations or performing certain actions. The following appendices are included:

- Appendix A contains tools for preparing an abbreviated field manual and the general procedures to follow for small, uncomplicated spills in adequate, marginal, and inadequate rainfall areas.
- Appendix B provides blank forms and worksheets for documenting and tracking the assessment, decision making, and remediation/disposition phases associated with each identified spill site.
- Appendix C lists state-specific regulatory agencies.
- Appendix D consists of a comprehensive glossary including acronyms. For the convenience of the user, technical terms and/or acronyms which are defined in Appendix D will appear in **bold type** the first time they appear in Sections 1–7. A number of technical words which do not appear in Sections 1–7 but which the user is likely to encounter during data gathering, are also included in Appendix D.
- Appendix E includes details pertaining to drainage problems and remediation procedures.
- Appendix F provides information on revegetation materials, including use of halophytic vegetation.
- Appendix G contains information regarding site delineation and field sampling.
- Appendix H provides details and procedures for using mechanical remediation technologies.
- Appendix I includes annual precipitation and evaporation quantity maps.
- Appendix J contains information regarding selection of a suitable analytical laboratory, data validation aids, and a list of analytical procedures.
- Appendix K lists and describes chemical amendments and application procedures.
- Appendix L discusses common types and use of mulching materials.

Use of this manual can be optimized by compiling and organizing available soil, climatological, and produced water information for the oil and gas fields in which the user operates. Gathering this information proactively may reduce response time when a spill occurs. This manual has also

been designed to minimize the amount of time and data required to select a suitable remedial alternative. With practice, the user should be able to move rapidly through the processes described within this manual.

REMEDATION GOALS

Setting reasonable objectives for the remediation effort is critical to developing a viable remediation plan. In some cases, the objectives may be established by legal, regulatory, or lease constraints. In other situations, the objectives may be based on more flexible criteria. It is advisable to, at a minimum, review the following factors prior to initiating any remediation effort:

- Lease requirements
- Regulatory constraints
- Corporate policies
- Environmental conditions

The user is cautioned to question whether remediation goals are realistic in situations where physical or climatic factors may be severe. A primary focus of this manual is to help the user assess the physical and chemical limitations of the site to be remediated. For instance, it may not be feasible to attempt to recondition a soil for growing crops if it was not suited for such a function before the spill occurred. Recognition of the fact that time will be required to remediate most spills is also important. It may take several years to return an area to productive use, especially if the spill was large or soil or climate characteristics are unfavorable.

One objective of this manual is to encourage wise utilization of human and physical resources. All actions taken should result in some tangible improvement to the environment. Overzealous goals and excessive attention to poor candidates for remediation often waste valuable resources (which may be more effectively utilized elsewhere), and may even further damage the affected or surrounding area.

Unless eclipsed by regulatory or legal issues, returning a salt-affected area to sustainable productivity with no offsite migration of salts is a commendable remediation objective.

Minimal regulatory or other guidance exists regarding criteria for a successful remediation effort for salt-affected soils. Due to the variety of natural landscapes, it would be difficult to establish any uniform criteria. In general, successful remediation suggests a landscape and ecosystem which have recovered sufficiently to support healthy and self-sustaining plant and animal growth, minimal **erosion**, and negligible long-term impact on usable surface or subsurface water. To the

degree feasible, successful remediation should also be consistent with the landowner's intended land use. These indicators of success must also be consistent with any regulatory criteria for salt-affected areas.

This manual attempts to address all of the above considerations. Actions suggested are intended to be practical; protective of health and the environment; cost-effective; and sensitive to various regulatory, legal, and public interests.

REVIEW OF SECTION 1

- This manual is designed to assist E&P personnel in remediating typical salt-affected soils.
- Remediation objectives should be selected only after considering all pertinent factors, including lease requirements, regulatory constraints, corporate policies, and environmental conditions.
- A commendable remediation goal is to return the land to reasonable and sustainable productivity with no offsite migration of salts.

Section 2

FACTORS INFLUENCING THE REMEDIATION OF SALTWATER SPILLS

Remediation of saltwater spills can be conducted for a number of reasons. Landowner claims; lease agreements; federal, state, and local regulations; reduction of long-term liabilities, company policies; and protection of usable water resources may be the driving forces behind a remediation project. These factors should be considered in addition to science and engineering issues when selecting the remediation goals and techniques.

LANDOWNER CONSIDERATIONS

Initiating remediation options should not be undertaken without consulting the landowner. In some cases, the lease agreement specifies the landowner's desires. Landowners will often have opinions on various remediation options.

In rarer cases, the landowner may want no remedial action taken at all. Some landowners prefer that any monies which would have been spent on remediation be paid to them in land damages. Before choosing this option, the operator should be aware that unremediated sites have been the subject of litigation even when damage payments were made and releases were signed by the landowner. The operator should also ensure that remediation is consistent with any applicable regulatory requirements.

Cooperation with landowners should be a high priority. Landowners can often provide suggestions and assistance which can substantially improve or decrease the cost of a remediation effort. A dissatisfied landowner may be in a position to complicate resolution of a spill condition. In any event, operators should be aware of his/her legal standing regarding interactions with affected landowners.

REGULATORY REQUIREMENTS

Federal, state, and local regulations may pertain to various aspects of remediation of produced water spills, including spill response, vegetation, vadose zone, groundwater or surface water impacts, and possibly air emissions. All potentially applicable regulations should be reviewed and documented in appropriate data collection sheets, such as those provided in Appendix B, prior to initiation of a project.

Regulations may influence the choice of remediation technology and the associated costs. A technology which may be suitable for certain conditions in one state may not be well received in an adjoining state. Furthermore, several regulatory authorities with competing criteria may have jurisdiction over the same spill site. For example, in some western states a sovereign Native American nation, a local Native American community, the Bureau of Indian Affairs, the Bureau of Land Management (**BLM**), the U.S. Army Corps of Engineers (**COE**) (e.g., regarding **wet-lands**), and other organizations may all have regulations pertaining to a single affected site.

Where they exist, water rights pertaining to interception, withdrawal, addition, and quality and quantity of groundwater and/or surface water may be factors in remediation. Special attention should be given to potential for salt migration into drinking or other potentially usable water.

Regulations in some jurisdictions may be very specific regarding the types of vegetation which may be introduced if revegetation is part of the remediation strategy. Other regulations may address disposition of saltwater, soil, surface water, or groundwater at a salt-affected site.

Some states have specific regulatory requirements. Appendix C contains a list of regulatory agencies and telephone numbers that are current as of the approximate date of this manual. As noted, more than one organization may have some jurisdiction over various aspects related to a remediation effort. Users of this manual should verify the accuracy of the information provided in Appendix C before performing remediation activities at a site.

PUBLICLY SUPPORTED ASSISTANCE AND INVOLVEMENT OF QUASI-REGULATORY ORGANIZATIONS

In addition to those exercising regulatory control, several publicly supported organizations may be in a position to assist with remediation, or to become otherwise involved in resolution of a spill condition. Depending on the circumstances, some of these organizations may have jurisdiction over spill disposition and remediation efforts. Examples include state and federal forestry, soil, water, and wildlife organizations.

A number of individuals in these organizations are well trained technically and are in a position to provide valuable technical insight. The county agriculture extension agent is typically an excellent source of information on vegetative recovery expectations and remediation techniques that have been successfully used in the past.

CORPORATE POLICIES

Corporate policies may include certain specific or general protocols and criteria for addressing a spill. Users of this manual should incorporate these policies into the framework of this manual, or request adjustments to the policies in consideration of new information provided by this manual or other reputable sources.

COMMUNITY CONSIDERATIONS

Local citizens and community organizations may seek input into spill remediation efforts. Concerns may be expressed regarding surface water, groundwater, or aesthetics of sites visible from public areas. The value of public relations and proposed alternative remediation technologies should be considered when local citizens and/or community organizations become interested in spills.

From one perspective, community and environmental proponent groups may provide an opportunity to enhance public relations by joining in public-spirited or “grassroots” remediation projects. Such actions are also being viewed very favorably by regulatory authorities who are making substantial concessions to facilitate such cooperative efforts.

REVIEW OF SECTION 2

Cultural factors provide guidance for remediating salt-affected soils. An understanding of remediation nontechnical factors is as important to the potential success of the remediation effort as are the technical considerations.

- Nontechnical issues that must be addressed when selecting a remediation alternative include landowner considerations, regulatory requirements, publicly supported assistance, corporate policies, and community considerations.
- To be deemed completely successful, a remediation project will prove acceptable to each of the above interests.

Section 3

BASIC ENVIRONMENTAL FACTORS

The natural capability of a land for various uses, its soil, climate, and water are environmental factors that influence the success of a saltwater spill remediation. This section reviews soil science fundamentals that are relevant to the fate and transport of salts after a spill and during remedial efforts. Technical terms and acronyms are defined in the glossary provided in Appendix D.

SOIL

The soil is where most remediation efforts are directed. Remediation efforts require a basic knowledge of soil physical components, **texture**, **layers (horizons)**, **slope** and erosion characteristics, drainage, and chemistry.

Physical Components

Soil has four physical components: inorganic solids, organic matter, water, and air (Figure 3-1). A typical soil consists of about 45% inorganic solids, 5% organic matter, 25% water, and 25% air. Thus, about 50% of a soil is **pore space** which is occupied by water and air. **Soil pores** can be full of water, but rarely contain less than 10% water, even when quite dry.

Texture (Particle Size Distribution)

Inorganic soil solids are a mixture of various-sized particles. Table 3-1 summarizes the characteristics of the particle size ranges: sand, silt, and clay.

Table 3-1. Characteristics of Sand, Silt, and Clay.

Size Name	Particle Diameter Range (mm)	Particle Appearance	Particle Feel	Chemical Activity ^a	Approximate Surface Area (sq ft/g)
Sand	2–0.05	Visible	Gritty	Inactive	0.05
Silt	0.05–0.002	Microscopic	Silky	Inactive	5
Clay	less than 0.002	Submicroscopic	Waxy	Active	5,000

^a Chemical activity refers to relative influence on dissolved constituents. For instance, soil clays commonly act as strong catalysts and enzymes to inorganic and organic chemical transformations, whereas the influence of soil silts and sands is much less pronounced in this regard.

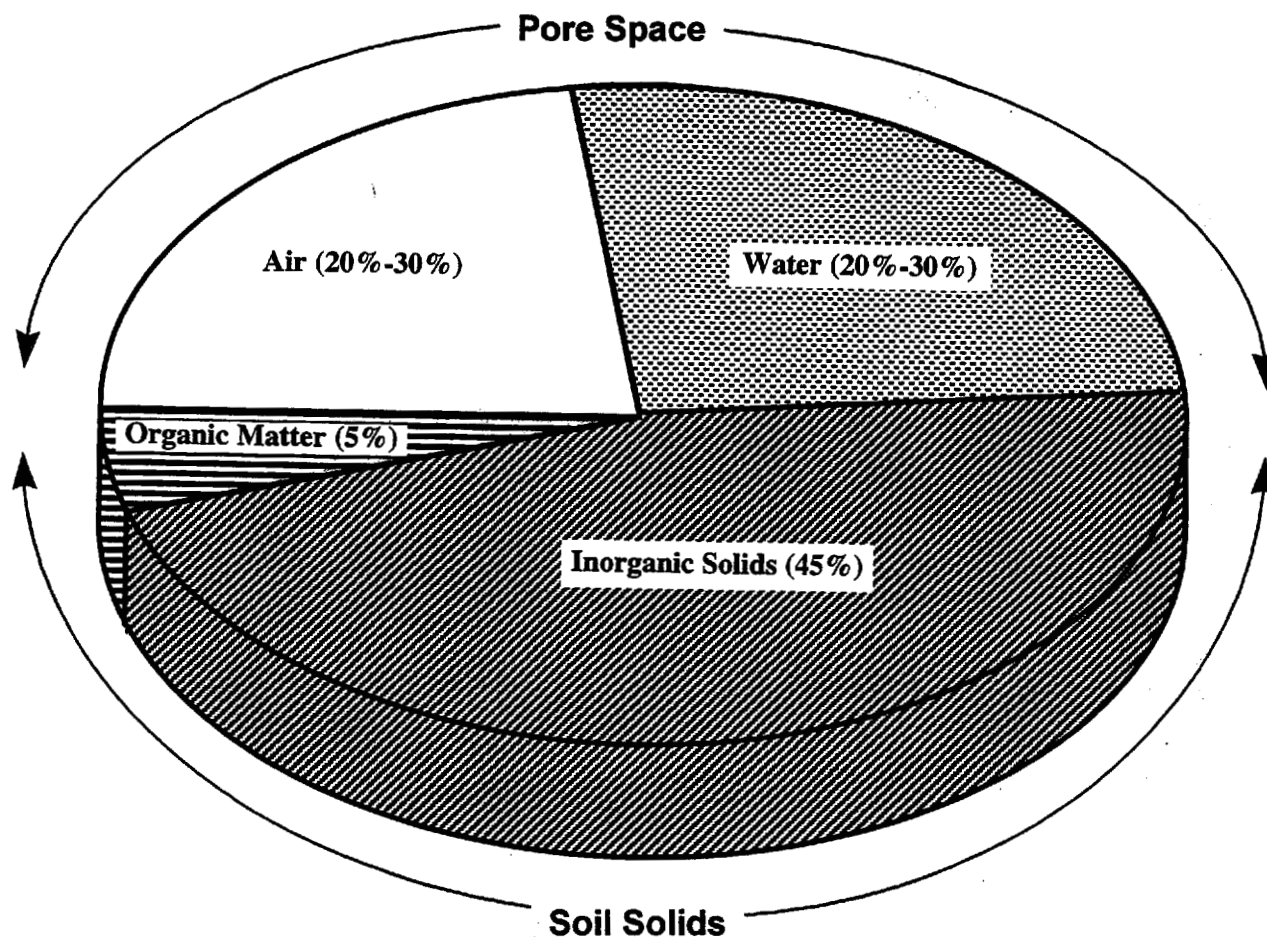


Figure 3-1. Physical Components of a Soil (adapted from Brady, 1984).

Larger-sized particles (greater than 2-mm diameter), such as gravel and **stones**, while occupying volume, are not considered an integral component of soil. Sand and silt also perform primarily a physical function in soil. As discussed in the subsection Chemistry (page 3-9), the high degree of chemical reactivity inherent in clays and organic matter makes them the most important components in determining soil behavior.

Figure 3-2 illustrates the relationships in terminology and units of measure among several particle size classification systems. The terminology associated with specific particle size ranges used in this manual follows the U.S. Department of Agriculture (**USDA**) system at the top of Figure 3-2.

USDA	CLAY	SILT		SAND					GRAVEL			COB- BLES	STONES	
		fl.	co.	v.fl.	fl.	med.	co.	v.co.	fl.	med.	co.			
		.002			.05					2			76mm	250mm

INTER- NATIONAL	CLAY	SILT	SAND			GRAVEL	STONES				
			fl.	co.							
		.002			.02			2			20mm

UNIFIED	SILT OR CLAY		SAND			GRAVEL		COBBLES		
			fl.	med.	co.	fl.	co.			
				.074			4.76			76mm

AASHO	CLAY	SILT	SAND		GRAVEL OR STONES			BOULDERS			
			fl.	co.	fl.	med.	co.				
		.005			.074			2			76mm

PHI SCALE																			
		.00195	.0078	.031	.125	.5	2	8	32	128	512mm								

v.fi. = very fine
fi. = fine
med. = medium
co. = coarse
v.co. = very coarse

USDA = U.S. Department of Agriculture (used by soil scientists and agronomists)
INTERNATIONAL = International Society of Soil Science
UNIFIED = Used by many agricultural and civil engineers
AASHO = American Association of State Highway Officials

Figure 3-2. Particle Size Classes of Five Different Systems
(adapted from USDA, Soil Survey Division Staff, 1993).

The proportion of sand, silt, and clay particles in a soil can be divided into twelve categories called textural classes (Figure 3-3). Soil within each textural class tends to exhibit distinct characteristics unique to that class.

Once the percent of sand, silt, and clay is known, the precise textural class can be determined using the textural triangle as shown in Figure 3-3. In this manual, soil textures have been further condensed from the twelve textural classes into only three groups (Figure 3-4): (1) **coarse**, (2) **medium**, and (3) **fine**.

The chemical and physical composition of different soils is extremely variable and is dependent on the parent rock material, the landscape position, biological interactions, and the amount of time exposed to climatic interactions. Common crystalline clay minerals include **kaolinite**, **illite**, **montmorillonite** (or **smectite**), and **vermiculite**. Although often coalesced into very hard **ag-**

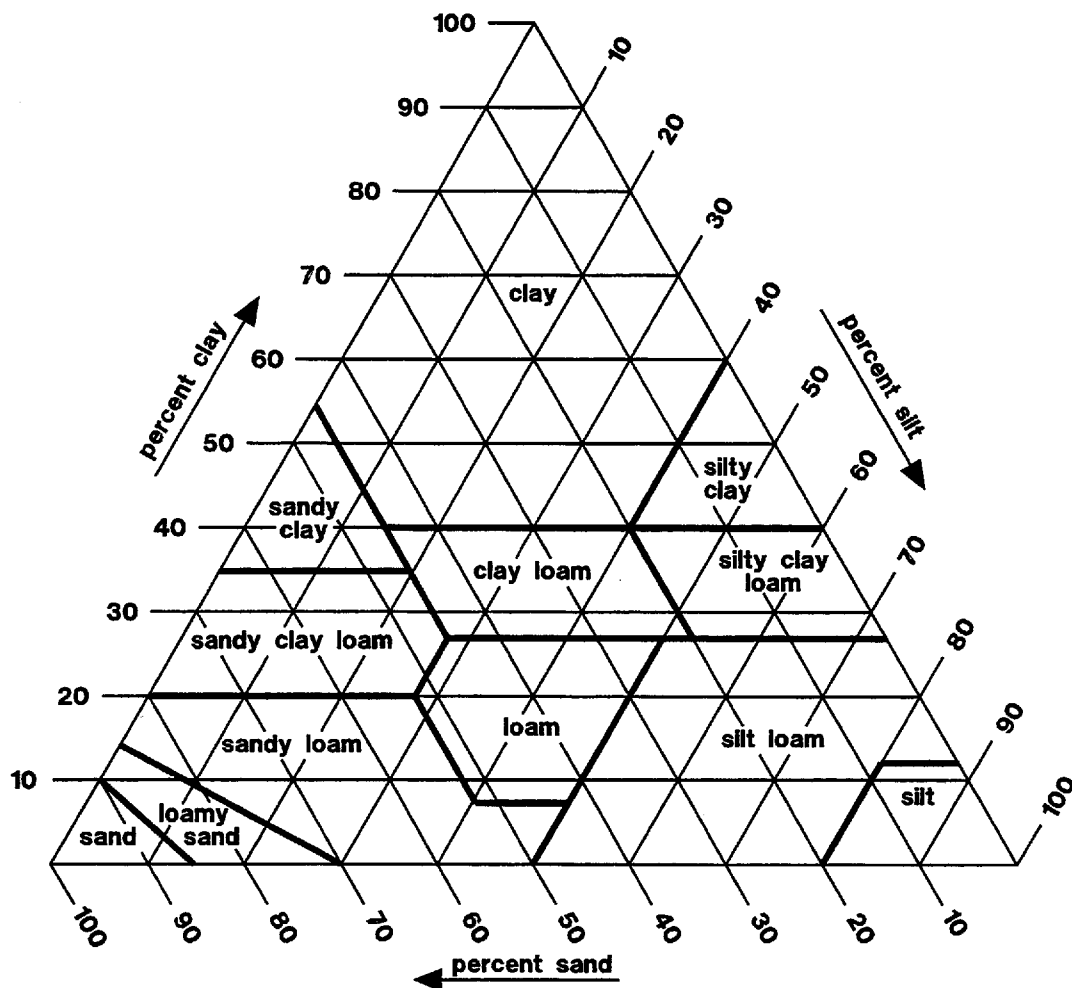


Figure 3-3. Soil Textural Triangle
(adapted from USDA, Soil Survey Division Staff, 1993).

gregates of gravel size or larger, individual particles of iron and **aluminum oxides** actually fall within the particle size range of clay minerals. Sand and silt grains typically consist of minerals such as quartz, mica, and feldspars. Relatively soluble constituents, such as carbonates and gypsum, are not typically included in particle size determinations. Soils with **parent material** of volcanic origins often contain somewhat amorphous clay minerals called allophanes. Another minor physical component found in mineral soils is organic matter. Organic matter is typically not included in particle size determinations.

The vast majority of soils are mineral soils which commonly contain up to about 5% organic matter. However, there is a special category of naturally occurring soils which consist primarily of organic matter. These soils are called "organic" soils. Organic soils do not develop from

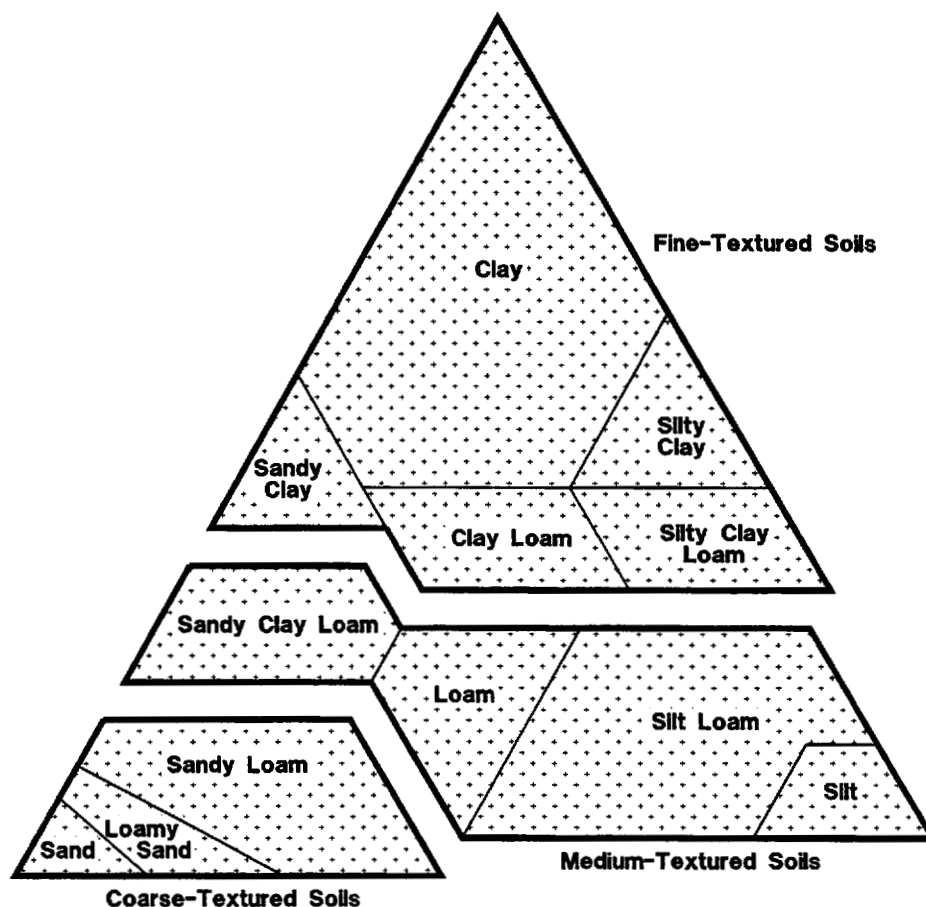


Figure 3-4. Soil Texture Groups (Plaster, 1985).
(Reproduced by permission. Soil Science and Management, By Plaster. Delmar Publishers, Albany, New York, © 1985)

geologic materials, but from decomposing plant materials. Other names for organic soils are "muskeg" soils and "muck" soils. Organic soils may form in environments dominated by fresh-water, brackish water, or saltwater.

Although organic soils are almost always located in very wet areas, they should not be confused with "hydric" soils. Hydric soils are located in very wet areas and are important regarding wetlands determinations. However, hydric soils are very often mineral soils.

Layers (Horizons)

Examination of a typical vertical section of soil to about a 6-ft depth reveals that it is segregated into layers. These layers are called horizons (Figure 3-5). Three major layers (A, B, and C horizons) are found in most soils.

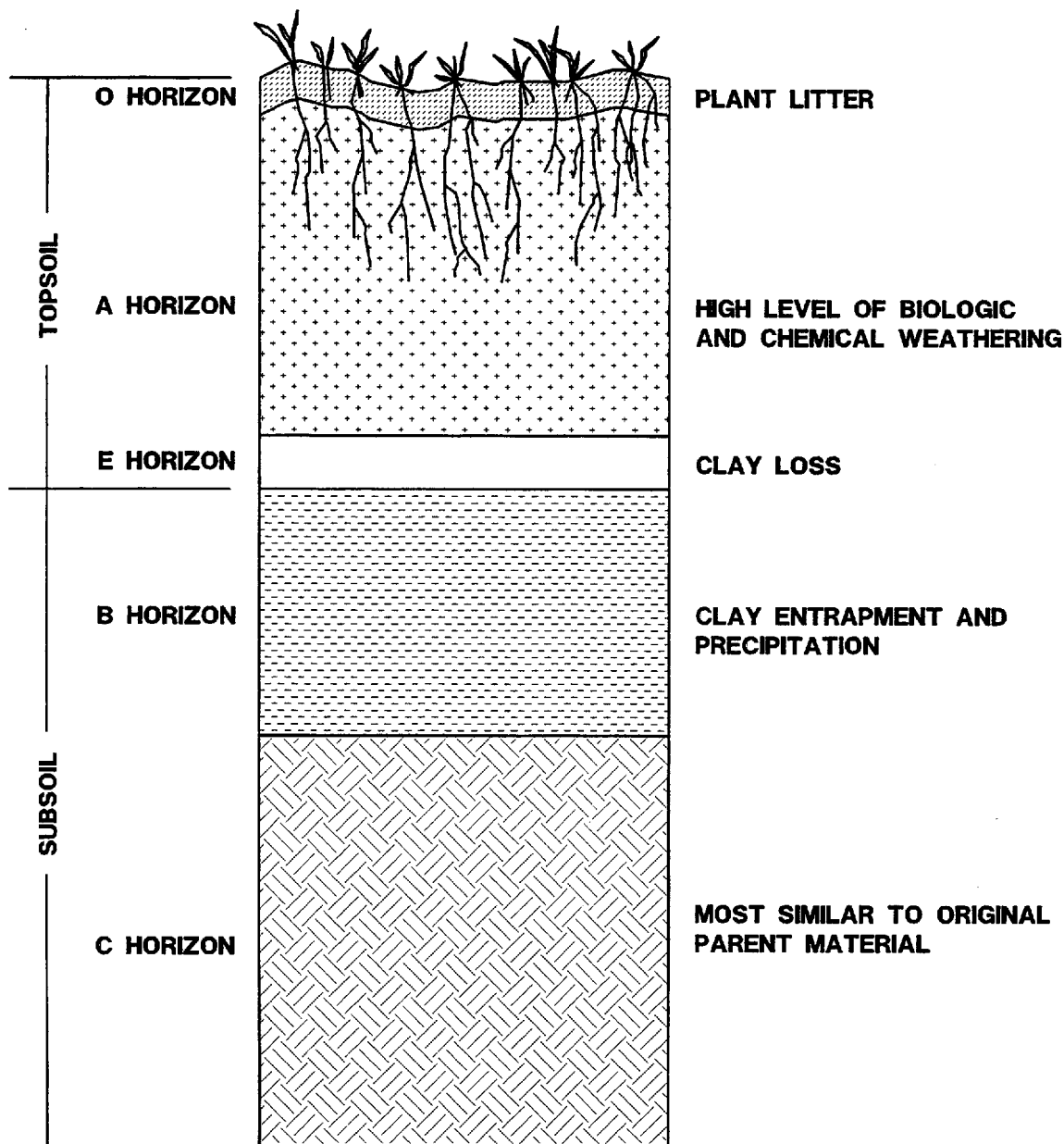


Figure 3-5. Soil Profile and Horizons.

The A horizon can be considered the topsoil or the primary root zone. This is the most intensely weathered portion of the soil **profile**. It is also the site with the greatest biological activity, and is the richest in plant nutrients as a result of decaying leaf litter or fertilization by humans. An O horizon can be designated above the A horizon if the weight percentage of organic matter at the soil surface is >50%. A light-colored and typically sandy E horizon can be designated at the bottom of an A horizon if most of the clay has leached downward into the subsoil.

One important aspect of the A horizon is that internal biotic activities, including plant growth, help bind soil particles together into stable structural units called aggregates. Soil particles bound in stable aggregates are resistant to erosion and indicative of relatively large and beneficial (macro) pores in the soil. These macropores help the soil efficiently take in rainwater and air which are essential to the survival of most plants and animals.

The B and C horizons constitute the subsoil. These horizons have little organic matter, fewer plant roots, and much less biological activity than the topsoil. The B horizon usually has the highest proportion of clay of any horizon in the soil, and this often greatly restricts the downward migration of water. The C horizon contains essentially no organic matter or buildup of migratory clay from above. However, original parent material in the C horizon has been subjected to chemical **weathering** by water percolating through the soil. Soil salts, carbonates, and reprecipitated silicates often concentrate and sometimes become cemented in the B and C horizons, further decreasing **porosity**. The consolidated or unconsolidated geologic material below the C horizon is often designated R for **regolith**, but is not considered to have been sufficiently weathered to be described as part of the soil.

Slope and Erosion Susceptibility

Different soils have different susceptibilities to erosion. Erosion is related to **slope steepness** and length, plant cover, rainfall, and the texture and aggregate stability of the soil. Erosion is accelerated by raindrop impact and wind, both of which are able to dislodge soil particles.

Erosion can be minimized by good management practices, such as interrupting the slope with small berms, controlling runoff, assuring good vegetative cover, and maintaining aggregate stability with good fertility and organic matter content. Factors which cannot easily be controlled are rainfall and soil texture.

Erosion causes several problems. First, it causes a loss of topsoil which contains most of the organic matter and biota, fertility, and seeds for plant regeneration. Second, eroded soil particles which are suspended in runoff water act in a scouring manner on downgradient soils, and eventually settle in waterways.

When subsoil is exposed, it is often even more susceptible to erosion than topsoil. Exposed subsoil is also unprotected by vegetative cover.

Although erosion occurs on all soils which are not flat, soil with slopes of greater than 8% (8 ft of fall over a 100-ft distance) are especially prone to erosion and require special consideration during any type of surface work. As discussed in Section 6, soil impacted by salt spills is also especially prone to erosion.

Drainage

The ability of a soil to drain is a very important feature of any soil, particularly with regard to salt remediation. In addition to initial moisture content, surface slope, depth to **water table**, and the thickness of soil above **bedrock**, soil internal drainage is affected by soil texture, pore size distribution, and low **permeability** layers.

In recognition of the interactions of various drainage factors, drainage categories were created by the USDA Natural Resources Conservation Service (**USDA-NRCS**, formerly the Soil Conservation Service, **USDA-SCS**). More detailed USDA-NRCS categories with attendant data and interpretations are given in USDA, Soil Survey Division Staff (1993). Some of this information is provided in Appendices D and E. For the purpose of this manual, soil drainage (before a spill) can be categorized as:

- **Excessively Drained.** In an excessively drained soil, water drains so rapidly that the soil retains relatively little water and plants are frequently in drought stress. Wetness is rarely a growth-limiting factor for mesophytic plants (plants which require a moderate amount of water). One or more of the following factors are usually present: minimal rainfall, steep slope, very deep water table, or coarse soil texture. A thin soil (minimum volume for holding water) above bedrock can also be excessively drained.
- **Well Drained.** A well-drained soil drains readily but not rapidly. Sufficient water is available to mesophytic plants during most of the growing season and excessive wetness is seldom a growth-limiting factor.
- **Moderately Drained.** In a moderately drained soil, water is removed somewhat slowly during some periods of the year. Growth of mesophytic plants is limited by excess water for only short periods during the growing season.
- **Poorly Drained.** In a poorly drained soil, water is removed very slowly and the soil is usually wet. Without drainage enhancements, excessive wetness is growth limiting to mesophytic plants. One or more of the following factors are usually present: substantial rainfall, minimal slope or depressional area, very high water table, fine soil texture or low permeability layer, or minimal macropores (large pores). In very poorly drained soils, the water table commonly remains at or very near the surface for long periods of time.

The movement of water and salts in soils is very complex. Under very dry conditions, swelling clay soils (which greatly inhibit **infiltration** and permeability when wet) may develop many large

(greater than 1-inch across) and deep (greater than 3 ft) cracks when dry. When it rains after a dry period, rainwater will move readily into these large cracks. Thus, when dry, some clayey soils can have both much larger and much smaller pores than sandy soils.

Coping with poor internal soil drainage presents a major obstacle for remediation of salt-affected soils. Salts must be able to move out of the soil root zone in order to remediate the soil.

Because they move only as dissolved ions in water, salts are able to move out of the soil only to the extent that water can flow through the soil. Low permeability layers, including impermeable bedrock or a near-surface water table, effectively prevent the removal of salts by stopping flow. Drainage is discussed in more detail in Appendix E.

Chemistry

Chemical reactivity in a soil can be generally correlated with particle size. Sand and silt particles are relatively large with a small surface area to weight ratio and consist of minerals with a minimal functional electrical charge. As a result, sand and silt particles are relatively inert chemically. In contrast, organic matter (relatively stable decomposed organic matter called **humus**) and inorganic soil clays have a much larger specific surface and functional electrical charge, and are thus considered very reactive chemically.

Reactive Clay Minerals. Of the two chemically reactive materials, clay minerals are the focal point in most discussions about soil chemistry because they are much more abundant than organic matter in most soils. In this manual, chemical reactivity refers primarily to the magnitude and variety of chemical interactions between clay minerals and dissolved ions in the **soil solution**. A wide variety of clay particles with very different characteristics are found in soil. In increasing order of chemical reactivity, the crystalline clay minerals are kaolinite, iron and aluminum oxides, illite, montmorillonite (or smectite), vermiculite, and allophanes.

Highly reactive clay minerals, such as allophanes, montmorillonite, and vermiculite, have both a high negative electrical charge and substantial interior and exterior surface area. A teaspoonful of some soil clay minerals can have a surface area as large as one-fourth of a football field, whereas the surface area of the same volume of sand may equal only a few square feet. As a result, clay minerals are capable of attracting and retaining a very high number of dissolved cations (positively charged ions such as calcium, magnesium, potassium, sodium, aluminum, and hydrogen). In contrast, kaolinite clay has a very low negative charge and a much lower

surface area to weight ratio, but even in kaolinite these features are much greater than in sand minerals. With respect to its own weight, the most reactive component in any soil is organic matter, but organic matter usually constitutes less than 3% of the entire weight of most surface soils.

During their formation, clay particles developed missing some positive electrical charges. Thus, clay particles have a net negative charge. Some clays, such as kaolinite, have a relatively small negative charge [~ 5 milliequivalents per 100 grams (meq/100 g) of clay, see **equivalent weight** in Appendix D]. Other clays, such as montmorillonite (80 meq/100 g) and vermiculite (110 meq/100 g), have a very large negative charge. Organic humus has the highest negative charge (generally calculated as 200 meq/100 g).

Dissolved Cations. Negative charges inherent in the solid clay particles are balanced at all times by positively charged ions (cations) which are dissolved in the soil-pore water (also referred to as soil water) and move very close to the solid clay surface. The most common of these cations in the soil are sodium (Na^+) in very **alkaline soils**; then calcium (Ca^{++}), magnesium (Mg^{++}), and potassium (K^+) in soils with a more balanced pH; and aluminum (Al^{+++}) and hydrogen (H^+) in very **acid soils**. Of these cations, only calcium, magnesium, and potassium are essential plant nutrients. Sodium is notably absent from the group of essential plant nutrients. The negatively charged clays must always be closely surrounded by an equal number of positive charges from dissolved cations.

The dissolved cations, which are very close to the clay minerals and actively balance the negative charges of the clay minerals, exist in dynamic equilibrium (exchanging interaction) with other similar dissolved cations, which are not actively balancing the negative charges of the clay. With the negative charges of the clay particles satisfied by the "adsorbed" cations, the unadsorbed cations are free to migrate in the soil solution (soil liquid water phase). Because free and adsorbed cations continually replace one another at the clay surface, they are called **exchangeable cations**.

The total number of **cation** charges which must remain adsorbed by the clay particles is called the **cation exchange capacity (CEC)**. Then, if the entire mass of a soil were composed completely of montmorillonite clay, it would have a CEC equal to that of montmorillonite clay (about 80 meq/100 g). However, whole soils rarely have a charge as high as their individual clay minerals or organic matter because some sand and silt are almost always present as well, and

these particles have no CEC. As a result, typical whole soils usually have a CEC ranging from 5 to 35 meq/100 g.

The exchangeable cations compete to a predictable extent to occupy "exchange sites" adjacent to the clay particles. Dissolved cations with the highest electrical charge and which are surrounded with the least number of water molecules have the highest charge density and are, therefore, best able to get close to the clay particles. Because of their high charge density, aluminum, calcium, and magnesium cations are the cations which typically spend the most time adsorbed on the cation exchange sites.

Sodium cations have the opposite characteristics. Because it has a single positive charge, and tends to be surrounded with a substantial amount of water, sodium can be competitive only if it can overwhelm the other adsorbed cations by sheer numbers. In most cases, a saltwater spill is easily capable of providing such overwhelming numbers of sodium cations.

Because of its low **adsorption** strength, sodium is also the cation most easily displaced from cation exchange sites by other types of cations. For the same reason, sodium is also the most mobile cation in soil water and can move almost as fast as the water itself.

Anions. **Anions** (negatively charged particles) also exist in the soil solution. Examples are chloride (Cl^-), sulfate (SO_4^{--}), bicarbonate (HCO_3^-), carbonate (CO_3^{--}), and nitrate (NO_3^-). Soils have a modest **anion exchange capacity** compared to the CEC. As a result, these anions are very mobile in the soil and like sodium can move almost as fast as soil water can move.

pH. The degree of soil acidity (pH) controls many functions in the soil. The lower the pH, the greater the acidity, or concentration of hydrogen ions (H^+). Because pH is a logarithmic expression, each pH unit represents a change of an order of magnitude (factor of 10). For example, a soil with a pH of 6 has ten times the concentration of hydrogen ions as a soil with a pH of 7. In terms of pH, the corollary to acidity is alkalinity which represents the concentration of hydroxide ions (OH^-), although alkalinity is also used to relate to the acid neutralizing capacity of bicarbonate and carbonate ions. In similar manner, dissolved aluminum also contributes to acidity. Aluminum, which begins to appreciably dissolve at a pH less than 5.5, is sufficiently strong that each aluminum cation (Al^{+++}) can split three water molecules (process of hydrolysis) into three hydrogen ions (H^+) and three hydroxide (or hydroxyl) ions (OH^-). Over time, each aluminum ion can then combine with the three hydroxyl ions leaving the three remaining hydrogen ions to

further decrease the pH of the soil solution. Aluminum toxicity which is caused by this process is a major problem in many soils in humid climates.

The pH of most soil ranges from about 5 to 8, but the pH of some soils is as low as 2 or as high as 11. The pH of a traditional healthy soil ranges from 5.5 to 8.5.

Plant Nutrients. The soil solution (liquid phase of a soil) dissolves and allows other plant nutrients to move toward plant roots. In order for a plant to survive it must have an appropriate amount of each of the plant nutrients listed in Table 3-2. All plant nutrients taken up by plant roots are either cations or anions. The overwhelming numbers of sodium and chloride ions present, and the **leaching** effect of the liquid spilled, often result in deficiencies and/or imbalance of nutrients. For some plant nutrients there is a fine line between too much (toxicity) and too little (deficiency) (Figure 3-6). The **micronutrient** boron (B) is of particular interest in remediating produced water spills. Although a minor constituent in both produced waters and natural soils, boron may be present in sufficient quantities in produced water to create boron toxicity conditions in soil after a spill. Because of the control it exerts on solubility, the availability of many of these nutrients, including boron, is determined by the pH of the soil (Figure 3-7).

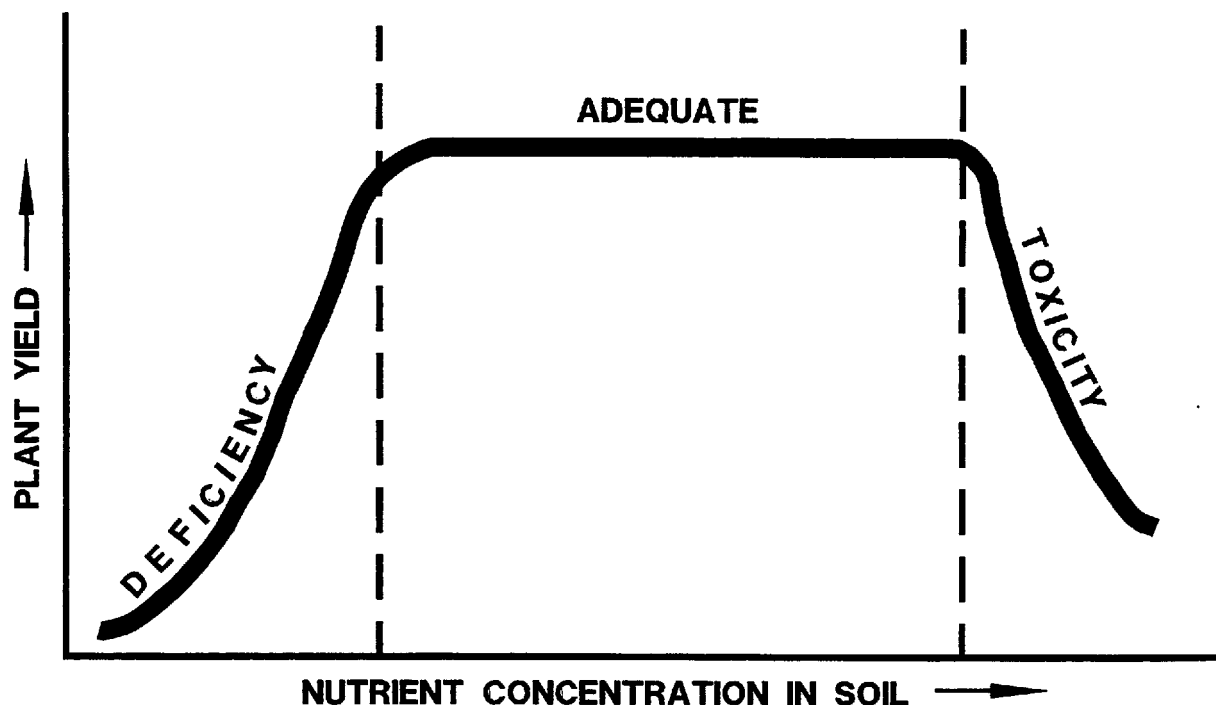
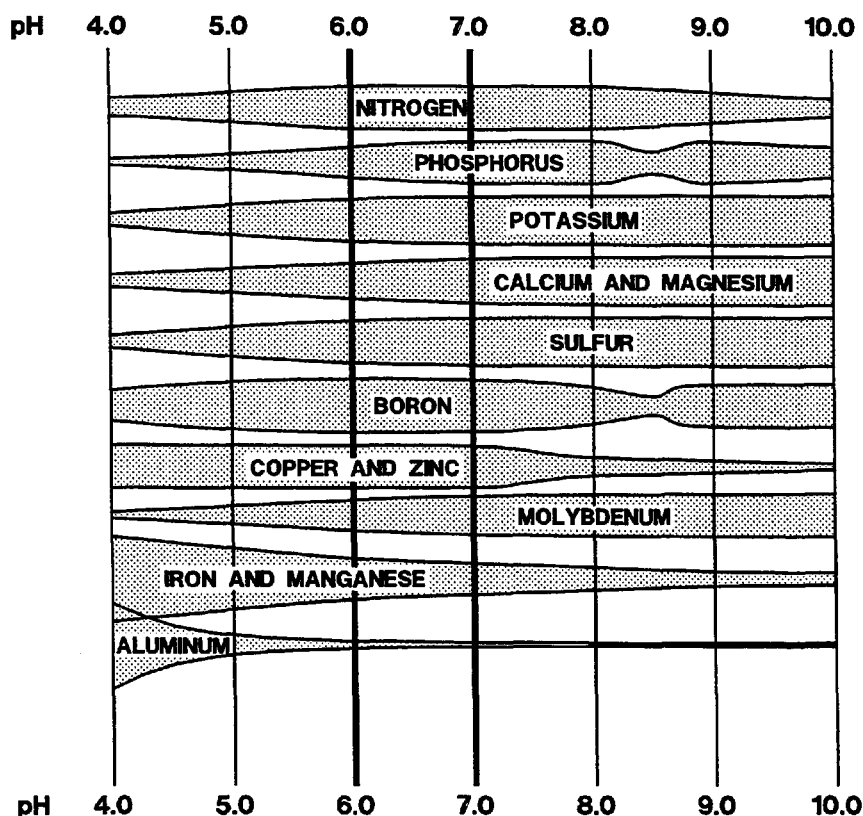


Figure 3-6. Relationship of Nutrient Concentrations, Deficiencies, and Toxicities in Plants.



NOTE: Aluminum is not a plant nutrient

Figure 3-7. Effect of Soil pH on Plant Nutrient Availability (Plaster, 1985).
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CLIMATE

To a great extent, climate determines the type of soil present. Climate dictates the frequency, duration, and quantity of precipitation and evaporation, as well as extremes and duration of temperature and wind.

These factors have a major impact on the fate and transport of salts in the soil. Most chemical **reactions** in the soil occur at a faster rate with increasing temperature. After a rainfall, a portion of the rainwater percolates downward through the soil dissolving and carrying soluble salts with it. During evaporative periods, soil-pore water reverses course and moves back upward through the soil bringing dissolved salts back to the surface. Since salts do not evaporate, they continue to concentrate at the soil surface during evaporation of soil water.

Table 3-2. Plant Nutrients.

Name	Symbol	Nutrient Form	Ion Name
Carbon	C	—	—
Hydrogen	H	H ⁺ (not used by plants in this form)	—
Oxygen	O	—	—
<i>Primary Macronutrients</i>			
Nitrogen	N	NO ₃ ⁻ , NH ₄ ⁺	Nitrate, ammonium
Phosphorus	P	HPO ₄ ⁻² , H ₂ PO ₄ ⁻	Orthophosphates
Potassium	K	K ⁺	—
<i>Secondary Macronutrients</i>			
Calcium	Ca	Ca ⁺²	—
Magnesium	Mg	Mg ⁺²	—
Sulfur	S	SO ₄ ⁻²	Sulfate
<i>Micronutrients</i>			
Boron	B	H ₃ BO ₃ , B(OH) ₄	Boric acid, hydrated borate
Copper	Cu	Cu ⁺²	—
Chlorine	Cl	Cl ⁻	Chloride
Iron	Fe	Fe ⁺² , Fe ⁺³	Ferrous, ferric
Manganese	Mn	Mn ⁺²	Manganous
Molybdenum	Mo	MoO ₄ ⁻²	Molybdate
Zinc	Zn	Zn ⁺²	—

After a spill, climatic factors will influence the selection of a remediation technology, including the types of vegetation which can be established and maintained.

WATER

A basic understanding of water is a prerequisite for understanding the fate and transport of salts in the soil. Water that infiltrates the ground or rises from the water table (due to capillary forces) provides soil moisture. The types of water most important to salt mobility and remediation are applied surface water, groundwater, and soil-pore water.

After a rainfall or irrigation event, water moves downward through the soil and displaces some of the air in the soil pores. With sufficient applied water, soil pores can become saturated with water. Water movement in a soil saturated with water is called saturated flow.

The main impediments to saturated flow are the size of pores, the total cross sectional area of pores through which the water can move, and the circuitous route the water must take around physical obstacles such as sand, silt, clay particles, and organic matter. In addition to gravity, saturated flow water moves in response to additional positive pressure from an applied hydraulic head (e.g., water ponded over a soil).

Gravity is typically effective in moving soil water only within a few days of saturation. After that time, gravity will have drained as much water as possible from the soil. The remainder is retained in the soil due to capillary action. This moist-but-not-saturated condition is called **field capacity** and represents the greatest amount of plant-available water the soil can retain. At field capacity, water is held in pores at about 0.3 atmospheres of tension (a very slightly negative pressure). This moisture content is called field capacity because: (1) gravity drainage has ceased, and (2) most plants cannot take up water from the soil unless there is also some air in the soil pores.

When some soil pores contain air, the soil is said to be in an unsaturated moisture condition, and water moves in accordance with different forces. In a dry soil, water moves toward and is retained in the smallest and driest capillary pores because they exert the most capillary tension. This is an extremely strong force and dominates all other forces acting on soil water. When very dry and very small, capillary pores and bare soil particle surfaces can exert tension on water which is more than 10,000 times greater than atmospheric pressure. This hygroscopic water is bound so tightly that it cannot move. When slightly more moist, water is still very closely drawn toward particle surfaces and capillary pores and the water is capable of moving very slowly. As the soil becomes increasingly moist, soil water will try to distribute itself in the soil such that there is equal tension in all directions.

Other factors also influence the movement of soil water in unsaturated conditions. Evaporation which is also operative in saturated conditions after a rain, **transpiration** (water uptake and release to the atmosphere by plants), and **osmotic** forces exerted by dissolved constituents (including salts) will begin to influence noticeably the **unsaturated flow** of water after the strongest capillary forces are satisfied. In order to overcome the osmotic force that draws water toward salts, a plant must devote a greater proportion of energy to creating its own internal counteracting osmotic potential.

As evaporation removes water from soil pores near the soil surface, water carrying dissolved constituents migrates upward to replace the evaporated water. As salts concentrate near the soil surface, the osmotic potential further increases and exerts even more force on water to move upward. This is especially problematic if the water table is within about 6 ft of the surface because this represents an unlimited supply of water which can carry salts upward with it during evaporative periods.

Most plants are able to pull water out of the soil with as much as 15 atmospheres of tension. When all soil water is held beyond a tension of 15 atmospheres (the permanent **wilting point**), most plants begin to die due to drought stress. However, the soil still contains substantial water at the permanent wilting point—it is just held so tightly that plants are unable to extract it. Because plants are utilizing internal osmotic pressure to draw water into roots, they must also work against the increased salt concentrations in the soil solution. As a result, plants can experience drought stress at soil **moisture tensions** much less than 15 atmospheres in salty soils.

The relationship among moisture saturation, field capacity, wilt point, and dryness are illustrated in Figure 3-8. This figure shows that after a soaking rain, loam, silt loam, and clay loam soils will have the greatest plant-available moisture (between 0.3 and 15 atmospheres of tension), clays and sandy loam soils will have a moderate amount of moisture, and sands will have the least amount of moisture.

Loam and silt loam soils tend to have the best distribution of pore sizes (ranging from micro- to macropores) between particles and aggregates. Clay soils often have an abundance of micropores but minimal macropores. As a result, clay soils often retain a substantial amount of water, but much of it is held under too much tension for plants to utilize. Most pores in very sandy soils are so large that very little water is retained in the soil after a rain, and most of it quickly drains away before plants can utilize it. Maintaining an effective pore size distribution or improving a detrimental pore size distribution is a primary objective in remediating salt-affected soils. It is much easier and less costly to maintain an effective pore size distribution than to attempt to alter a detrimental pore size distribution.

The typical moisture zones that occur in soil are shown in Figure 3-9. The vadose zone is where air and water occur simultaneously below the soil surface. Only water actually below the water table (within the saturated zone after gravity drainage) is called groundwater, by convention. Water above this zone is called vadose water or **unsaturated zone water**. Capillary pores

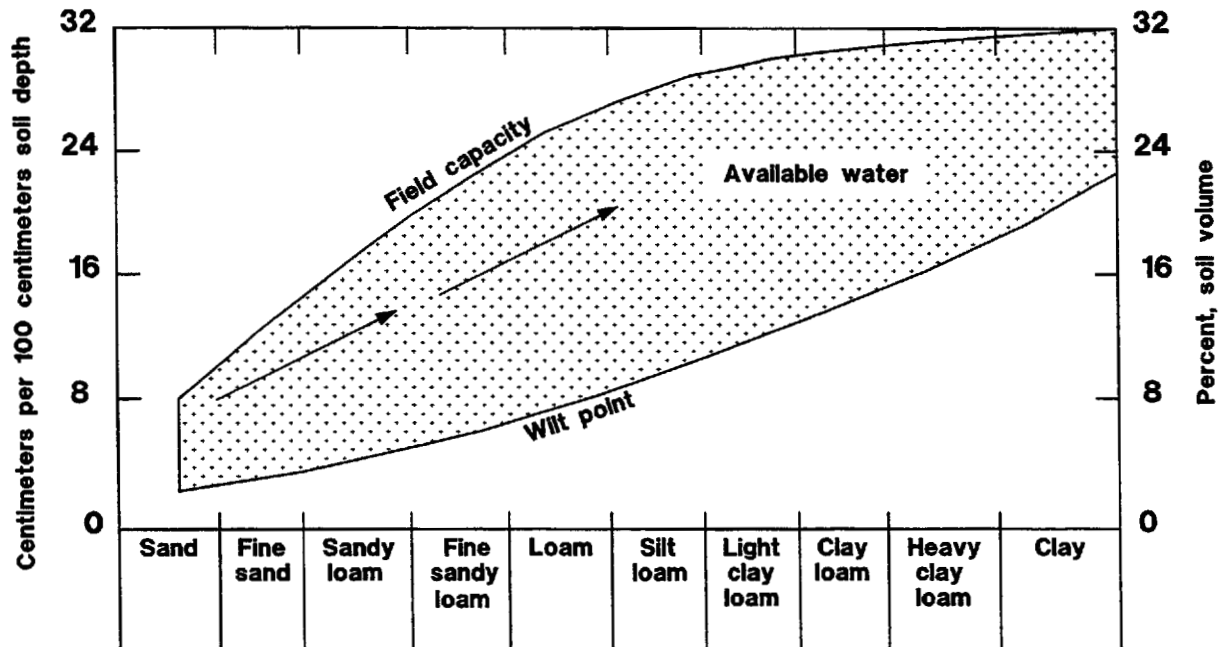


Figure 3-8. Soil Moisture Relationships (Foth, 1984).
(FUNDAMENTALS OF SOIL SCIENCE, H. D. Foth, 1984.
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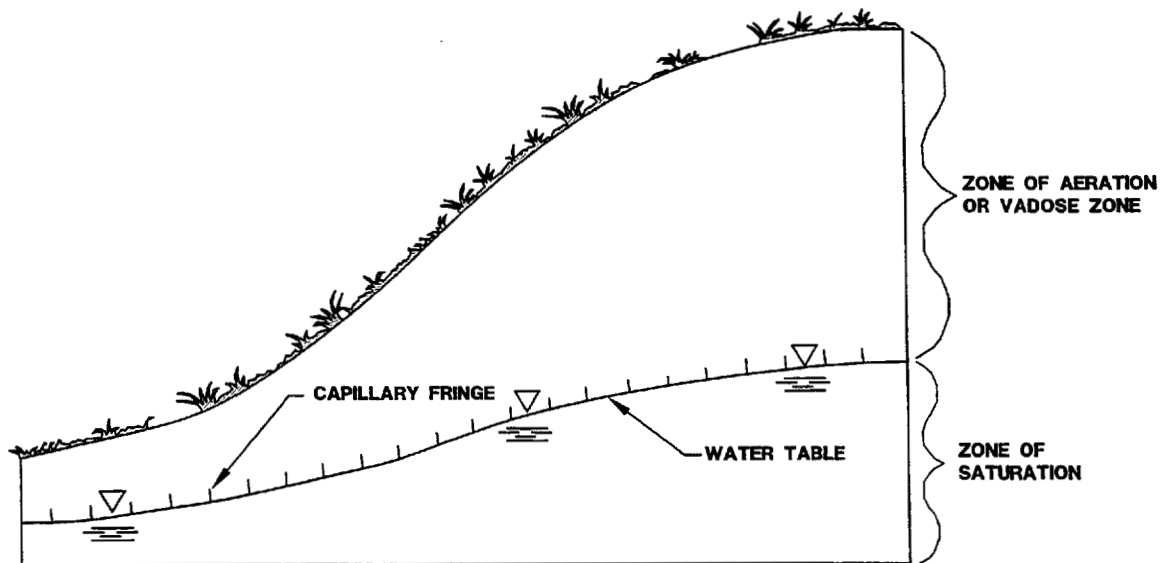


Figure 3-9. Soil Moisture Zones.

exerting tension near the bottom of the vadose zone can pull water from the groundwater to about 1 to 2 ft above the actual water table into a zone called the **capillary fringe**.

Where saltwater spills occur, efforts should be made to minimize surface migration of salts toward surface water and subsurface migration into nearby sediments. Except in very porous soils, surface water generally flows more rapidly than groundwater.

Flow rates of surface water are variable and often dependent on natural or manmade settings. Surface runoff, direct flow into streams, and even dry creek beds and ditches may become avenues for rapid movement of salts.

Groundwater typically moves much slower than surface water because it must continuously pass through a porous media. However, groundwater moves quickly through fractured bedrock and sandy and gravelly media. Groundwater can move to some extent in silty zones, and it barely moves at all in clayey materials. However, even clay is a slightly porous media and over time, water will migrate through it.

LAND USE CAPABILITY

Each soil and type of terrain has a natural capability to serve certain uses. As noted above, the variety of soils on which spills can occur is substantial. Even without a spill, some soils would have substantial land use limitations due to natural factors.

Land capability classifications were developed by the USDA-NRCS to show the ways in which a soil could be acceptably used, and to alert landowners about uses which were impractical due to soil limitations. Climate, erosion potential, slope, and drainage are important factors in land use classifications. The eight land use capability classifications are described in Table 3-3 and portrayed in Figure 3-10.

Land resources can be further categorized by site index. Categories include saltwater wetlands, brackish-water wetlands, freshwater wetlands, uplands, and mountains. Subcategories of uplands may include woodland, prairie, farmland, residential, industrial, and recreational. These categories have important implications regarding the successful remediation of salts and hydrocarbons.

Table 3-3. Land Capability Classification.

Land Capability Class	General Description and Limitations
<i>Suited for Cultivation</i>	
I	Few limitations that restrict its use; no subclasses
II	Some limitations that reduce the choice of plants or require moderate conservation practices
III	Severe limitations that reduce the choice of plants or require special conservation practices, or both
IV	Very severe limitations that restrict the choice of plants or require very careful management, or both
<i>Not Suited for Cultivation (except by costly reclamation)</i>	
V	Little or no erosion hazard but has other limitations (impractical to remove) that restrict its use largely to pastureland, rangeland, woodland, or wildlife habitat
VI	Severe limitations that make it generally unsuited to cultivation and restrict its use largely to pastureland, rangeland, woodland, or wildlife habitat
VII	Very severe limitations that make it unsuited to cultivation and restrict its use largely to grazing, woodland, or wildlife habitat
VIII	Limitations that preclude its use for commercial plant production and restrict its use to recreation, wildlife habitat, water supply, or aesthetic purposes

Source: Klingebiel and Montgomery, 1966.

Note: Except for Class I land, the following subclasses are recognized in which the dominant limitations for agricultural use are the result of soil or climate: (e) *erosion*, based on susceptibility to erosion or past damage; (w) *excess water*, based on poor soil drainage, wetness, high water table, or overflow; (s) *soil limitations within the rooting zone*, based on shallowness, stones, low water-holding capacity, low fertility, salinity, or sodium; and (c) *climate*, based on temperature extremes or lack of water.



Land Capability Classes			
Suitable for Cultivation		No Cultivation - Pasture, Hay, Woodland, and Wildlife	
I	Required good soil management practices only	V	No restrictions in use
II	Moderate conservation practices necessary	VI	Moderate restrictions in use
III	Intensive conservation practices necessary	VII	Severe restrictions in use
IV	Perennial vegetation - infrequent cultivation	VIII	Best suited for wildlife and recreation

Figure 3-10. Land Capability Classes (Courtesy USDA).

REVIEW OF SECTION 3

- Environmental factors of importance to the remediation of a salt spill include soil physical, chemical, and biotic components; climate, especially rainfall and evaporation conditions; water movement in a soil, including the unsaturated zone and depth to the water table; and land use capability which provides a gross evaluation of the potential productivity of a soil and its ability to respond to remediation treatments.
- The four physical components of soil are solid inorganic particles, organic material, air, and water. These components, respectively, occupy about 45%, 5%, 25%, and 25% of the volume of a typical soil.

- Soil texture is the distribution of sand, silt, and clay. Various combinations of sand, silt, and clay result in 12 textural classes which can be simplified to coarse, medium, and fine textural groups.
- The most chemically reactive components in a soil are clays and organic matter. These solid materials have a net negative charge which is balanced by dissolved cations, primarily calcium, magnesium, sodium, and potassium.
- The CEC is a measure of the total number of negative charges in the solid phase of a soil. Organic matter and some soil clays (smectite and vermiculite) have a very high CEC, while others (kaolinite and illite) have a much lower CEC.
- The three most common soil horizons and their typical features are:

- Horizon A	Topsoil	Most biotically active
- Horizon B	Upper subsoil	Most clay
- Horizon C	Lower subsoil	Least developed; most like parent material
- Excessive erosion results in loss of topsoil, the possible need to reshape land, and the possible need to import or rebuild topsoil.
- The ability of a soil to drain internally depends on the amount of water present, the thickness of soil above bedrock, soil texture, pore size distribution, the depth of the water table, soil chemical factors, and the presence of low permeability layers of soil.