# Understanding Soil Risks and Hazards

## Using Soil Survey to Identify Areas With Risks and Hazards to Human Life and Property

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# Contents



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**Cover pictures:**

***Upper left*.—A large boulder that has crushed a building in Zion National Park. (National Park Service photo.)**

***Upper right*.—Landslides are hazardous. (Photo by Chuck Gordon, USDA, NRCS.)**

***Lower left*.—Crop damage resulting from saline seepage. (Oklahoma NRCS photo.)**

***Lower right*.—Damage caused by soil liquifaction during a major earthquake. (NRCS photo.)**

# Preface

This publication is an introduction to soil conditions that can be risks or hazards for many land uses. Local knowledge and experience were used to develop this publication. Discussions of 26 soil-related concerns were developed by authors within the National Cooperative Soil Survey. In my opinion, each of the authors is an expert. The intent of this publication is to expand awareness of various soil risks and hazards to human life and property and encourage city and county officials, planners, developers, and others to consider the soil in their land use decisions. Thanks to all the contributors, authors, photographers, and reviewers.

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# Introduction

Soil surveys have been completed for most parts of the United States. This inventory of soil resources had as its foundation an orientation to agricultural management and assessment of the potential for agriculture. Soil survey work reflected this focus until 1966, when legislated authorities were expanded to include a wide variety of concerns, including urban development. Soil surveys have been issued since 1900 generally as county-based publications and as cooperative efforts of the Natural Resources Conservation Service (formerly the Soil Conservation Service), University Cooperative Experiment Stations, and various Federal, State, county, parish, or tribal partners. The delivery of soil survey information has expanded from paper printed copies to the Web (http://soils.usda.gov/survey/ and http://soildatamart.nrcs.usda.gov).

Knowledge of soil landscapes, soil formation, and the various soil properties and functions has expanded with a classification system oriented to the interpretation of the soil survey. Various divisions and subdivisions of the basic system of classification called soil taxonomy provide a basis for application of the information to engineering and agricultural uses of the soil. Information about soil properties provides a basis for assessing risks and hazards to buildings and other structures of human populations.

Additionally, during the soil inventory process, we have ascertained the relationship of various landscape features to soil geography. Identifying and mapping soil-landscape relationships strengthen soil interpretations and the associated intrepretations involving hydrology and landscape stability. The separation of geology and soils is not a clear division, so this report describes several risks and hazards commonly referred to in geologic reports. It is not the intent to delve into another scientific field but to enhance the delivery of information about the risks and hazards to the public through the connection of soils to the landscape and the corresponding geology. For example, sinkholes develop in specific geologic formations but manifest themselves as surface features. The same applies to landslides, which are not solely dependent on soil properties or surface features but are aggravated by natural or human disturbances.

The intent of this publication is to create a public awareness of soil-related risks and hazards that may not be readily apparent. The description of risks and hazards in this publication is not intended to be complete and comprehensive, nor are the prescriptions for design and construction of specific projects. However, an awareness will lead readers to further investigation of the risks and hazards in their area of interest, such as a site for a home, community road, or school. Locating facilities in areas with excessive risks contributes to loss of life, health, and property. The soil survey does not answer or address all of the concerns discussed in this report, but it does address many of them or can lead to an understanding of the relationships. Many Web sites address risks and hazards, and these are mentioned where they are known to provide additional material for those wanting more information. One site of particular merit is the hazards site of the USGS (http://geology.usgs.gov/realtime.shtml).

## Limitations of Soil Surveys

Soil surveys are not designed for site-specific evaluations. Each survey uses a minimum size of delineation, which may be several acres in size. Problem soils or risks and hazards in areas smaller than the scale of mapping cannot be delineated on soil maps; however, they may be mentioned in soil map unit descriptions.

Soil surveys are limited by the chemical and physical data that are collected. Samples for analysis may or may not have been completed for soils located within a soil survey area. Information learned in one area is extrapolated to other areas. Soil tests are not done for such items as chemical applications and toxic spills.

Soil surveys represent landscapes and soils as they were at the time of mapping. More recent changes related to land shaping, mining, or other human activities or to natural events are not reflected in the imagery or soil information.

Soil surveys today generally describe the soils only to a depth of 2 meters, or about 80 inches. Earlier surveys described the soils to a shallower depth. Many of the risks described in this publication are related to earthy materials that are below the depth of soil survey investigations. We have tried to describe these limitations within the discussion of the risk. There are many other sources of information about the risks described. This set of descriptions does not include all known soil risks, nor is it in any way the final authority concerning the risks. The risks and hazards are presented in alphabetical order, so their position within the text carries no connotation about their prevalence or relative importance.

# Acid Sulfate Soils

By Delvin S. Fanning, Emeritus Professor of Soil Science, University of Maryland, and Gary B. Muckel, Soil Scientist, USDA, NRCS.

Acid sulfate soils are derived from sediments containing iron sulfides, commonly in tidal margins along seacoasts. If exposed to air, sulfides oxidize and produce sulfuric acid. Iron and other metals are released into the environment. Aluminum and other elements may enter soil solutions. These processes have extremely adverse effects on plant growth and animal life, both in the soils and in waters that come from the soils. Engineering structures may be drastically affected. Sulfuric acid and associated acid-forming salts rapidly corrode metals and concrete in buildings, channels, pipelines, and roads. The corrosion can weaken the structures and greatly reduce their expected lifespan.

*Soil Taxonomy* refers to the unoxidized soil materials that have potential to become exceedingly acid as *sulfidic materials*. Soils that contain these materials, such as the soils in current and former tidal marshes, are potential acid sulfate soils. Oxidation of sulfidic materials typically produces a *sulfuric horizon,* according to *Soil Taxonomy*. These oxidized materials have a pH of 3.5 or less. When this horizon is at or near the ground surface, the soil is an active acid sulfate soil. When left undisturbed and saturated with water, sulfidic materials are relatively benign. When exposed to aerobic conditions by drainage, mining, excavation, or dredging, they create environmentally challenging problems.

## Occurrence and Identification

Acid sulfate materials are more commonly exposed today than in earlier times because modern land reshaping involves excavation to greater depths. Acid sulfate soil materials can appear dark to the point that they are sometimes mistaken for topsoil. Spread on the surface as if it were topsoil, the acid sulfate material is corrosive to concrete in direct contact. Runoff from the material commonly is equally corrosive and harmful to plants and soil organisms.

**Decomposition of a concrete channel caused by acidic runoff.**

When sulfide-bearing soil materials are encountered as soft sediments in tidal environments, dredged materials, some mine spoil, and other areas, engineers must deal with low soil bearing strength, uneven subsidence, and blockage of tile drains by precipitates. Destruction of vegetation along outflow channels accelerates erosion of streambanks. Some sulfides, called mono-sulfides, form on the bottom of streams that drain acid sulfate soils. When mixed and moved during periods of flooding, they rapidly oxidize and deplete dissolved oxygen from the waters, killing fish and other aquatic life. Fishkills and lesions on fish also may result from high levels of aluminum and iron in the highly acidic waters that come from active acid sulfate soils.

Sulfidic materials also are evident in the unoxidized (reduced) zone of soil-geologic columns in upland areas far from modern oceans or seas. Commonly, these upland sulfidic materials occur several meters below the natural soil surface, so they may not be recognized in soil surveys. If possible, sulfidic materials should be identified wherever they occur, regardless of depth, so they can then be avoided in mining or construction activities. If the materials must be disturbed, appropriate reclamation measures must be used.

State maps that show where sulfide-bearing geologic formations are likely are available for Maryland and Virginia. However, more information is needed, specifically on the depth at which sulfidic materials might be encountered. In limited areas where sulfidic materials may be evident, soil scientists are selectively examining some soils beyond the traditional 2 meter limit of U.S. soil surveys to better understand and predict the occurrence of these materials.

Iron sulfide minerals (e.g., pyrite) commonly form in anaerobic soils and sediments in estuarine environments and tidal marshes by a process called sulfidization. During the active process, hydrogen sulfide gas, $H_2S$, evolves. The rotten egg smell is positive identification in tidal environments. In geologic deposits on uplands, however, $H_2S$ is no longer evolved.

Sulfidic materials are typically dark gray to black (Munsell color chromas of 1 or less) prior to oxidation. Adding drops of 1N HCl commonly causes an immediate color change and evolution of $H_2S$. The pH is near neutral (7.0). Sulfidic materials may be identified by incubation under moist aerobic conditions. If the pH drops to about 3.5 within about 8 weeks, the material is considered to be sulfidic. When placed in hydrogen peroxide, such materials undergo a violent oxidation reaction with the release of much heat, rapidly consuming the peroxide.

Once sulfidic materials undergo oxidation under field conditions, the soils become active acid sulfate soils that typically have a pH of 3.5 or less. New colors commonly appear from the formation of the mineral jarosite and other iron oxides in cracks and crevices in the soil materials. Matrix colors commonly become lighter in color and slightly higher in chroma. Jarosite is a pale yellow sulfate mineral that has been used to identify such soils as *cat clays*. These soils are called *Kette Klei* in the Netherlands, where much early work on acid sulfate soils was done as the sea was pushed back behind dikes to form polders. The definition of a sulfuric horizon in *Soil Taxonomy* requires neither a specific color nor the presence of jarosite.

## Problem Areas

In many coastal areas of the United States, sulfidic materials are near the surface or at some depth where they are easily exposed during construction activities. Dredged materials from the San Francisco Bay of California, from the Baltimore Harbor in Maryland, and from the tidal Pocomoke River in Somerset County, Maryland, have all exhibited acid sulfate conditions.

Very severe acid sulfate soil problems arose from construction of a new airport in Stafford County, Virginia. Geologic sulfidic materials were disturbed over almost 2 square miles. Similar problems occur along many interstate highways where construction has carved deeply into soil-geologic columns, exposing sulfidic materials to oxidation. Acid sulfate problems commonly resulted from coal mining prior to the passage of the national Surface Mining Control and Regulations Act in 1977, which prohibited such acid-forming materials from being placed at the surface of newly constructed soils during mining operations.

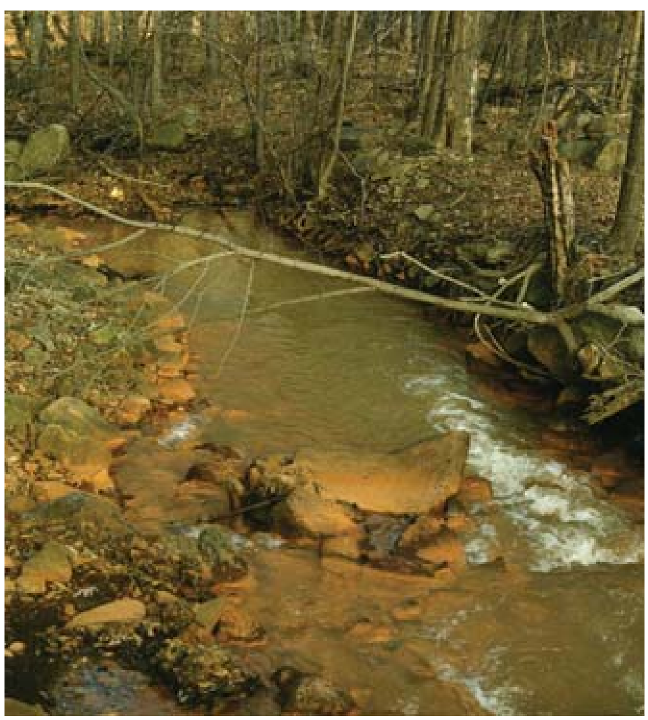
Many countries have similar experiences. The effects of acid sulfate soils had to be overcome on the site for the Olympic Stadium in Australia. Several highway projects in coastal areas of Australia have confronted these soil materials. West African countries (e.g., Senegal, Gambia and Guine' Bissau), Finland, China, Vietnam, Indonesia, Thailand, The Netherlands, and many other countries face the challenges that these soils present. Improper drainage of acid sulfate soils can, in effect, create an acid wasteland that is very difficult to reclaim. The soils commonly occur in low-lying, nearly level areas that are attractive sites for drainage and construction.

Probably the most severe problem of all involves the acid waters that enter waterways from areas where the materials are exposed or deposited. In Australia acid sulfate soils were recognized as a major environmental problem when fishkills occurred and were described by fishermen and environmentalists with little prior experience with acid sulfate soils.

## Management

The least expensive management alternative is learning to recognize sulfidic materials and avoiding their exposure and use as construction materials. Awareness of acid sulfate soils by governmental authorities, agencies, engineers, farmers, environmental regulators, and politicians is increasing. Acid sulfate soil problems are being brought under control, or avoided, in many places. There is a need to do a better job of educating local environmental authorities and engineers about acid sulfate soils.

Many different tactics have been attempted to ameliorate the effects of acid sulfate soils. Flooding, liming, leaching with fresh water, leaching with salt water, pyrite removal via hydraulic separation, and application of manganese dioxide, ferric hydroxide, calcium carbonate, phosphate, organic matter, and wood ash have all been attempted with varying degrees of success. Wick drains are used in some areas to improve the bearing capacity of soft sediments by removing water from the materials as the bearing load is increased. Treatments involving settling basins and applications of lime are used for the leachate from these soils.



**A rock stained red by the iron in the water from an acid sulfate area.**

Some plants in tropical areas have shown promise for channel stabilization. The best methods depend on the soil and the availability of resources.

Environmental impacts can be minimized when the possible hazards of acid sulfate soils are recognized prior to construction activities and measures are taken to deal with them,. Adequate planning should include implementation of a detailed acid sulfate management plan and the education of design and construction staff as well as consulting stakeholders and the community.

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# Chemical Heave and Expansive Salts

By Douglas Merkler, Soil Scientist, Las Vegas, Nevada, USDA, NRCS.

Chemical heave occurs when expansive anhydrous salts convert to their hydrated state. This mineral transition occurs with absorption of water and a consequent expansion. The reaction is stimulated by a drop in temperature, so an event can be sudden and extensive. Rapid expansion of such salt concentrations in soils can cause sudden cracking and even collapse of overlying structures unless precautions have been taken to mitigate the hazard.

## Areas Affected

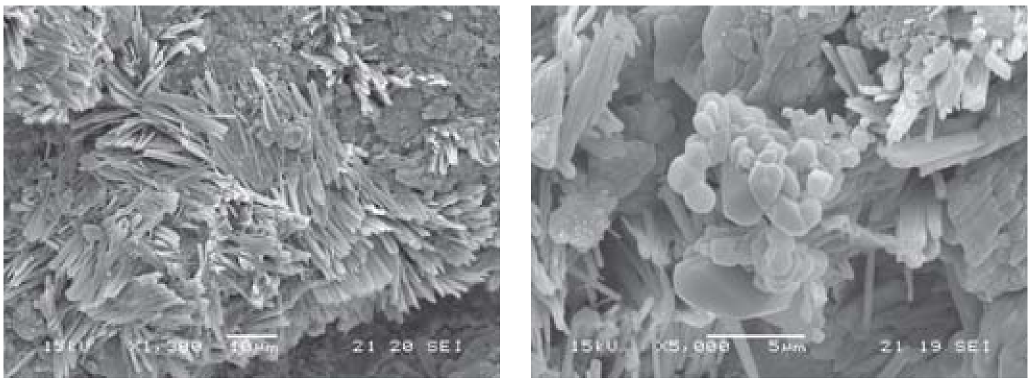
The Las Vegas Wash and associated flood plains east of Las Vegas, Nevada, have areas of soils that are heavily enriched with salts. These soils support a saline meadow ecological site dominated by inland saltgrass. They are in the Land series, classified as fine-silty, mixed, superactive, thermic Typic Aquisalids. The soils have a history of chemical heave. Many saline lakebeds in the arid West have similar chemistry. Soil survey reports identify soils with concentrations of salts.

**Urbanization in Las Vegas, Nevada. (NRCS photo.)**

Expansive, water-soluble salts cause several million dollars in property damage annually in the Las Vegas Valley. Similar problems have been reported in California, Texas, Kansas, and Utah but are less well documented. Most of the damage comes from hydration of anhydrous thenardite ($Na_2SO_4$) to mirabilite ($Na_2SO_4.10H_2O$). Both are highly soluble and easily transported in solution to low-lying, poorly drained areas where they crystallize as evaporites in the upper 6 to 12 inches of the soil.

## Chemical Action

Research has been limited. Sodium sulfate in water crystallizes to thenardite at temperatures above 90 degrees Fahrenheit (32 degrees Celsius). At cooler temperatures mirabilite is crystallized. Thus, the reaction takes place and expansion occurs as air temperature drops during the night. As the temperature drops below about 90 degrees Fahrenheit, the anhydrous thenardite absorbs up to 10 molecular weights of water as it hydrates to mirabilite. The molecular volume of mirabilite is 400 times its anhydrous form. The combination of crystallization and hydration commonly produces swelling pressures of 300 pounds per square foot within the soil matrix and can produce as much as 2,300 pounds per square foot.




**Scanning electron microscope images of the mineral thenardite (left) and mirabilite (right). (Images by John G. Van Hoesen and Dr. Brenda J. Buck, Department of Geoscience, University of Nevada, Las Vegas.)**

The use of lime treatment of sulfate-bearing clays in road construction is under study. It suspected that this treatment greatly contributes to chemical heaving.

## Problem Areas

A water source is required for the reaction to take place. Almost all observations have occurred near an obvious water source. In an urban setting, cracks in the streets adjoining filled utility ditches or areas adjacent to houses where landscaping water is added are ideal locations for water to enter the soil and become available in the soil pores for the reaction to take place. Typically, heave in streets parallels utility trenches backfilled with highly permeable material. Local areas of damage are often traced to specific houses in areas where water is channeled from roofs and yards to the street. Areas where storm water ponds are problem sites. In desert areas, storm-water drainage systems commonly are undersized and streets are designed to carry part of the storm-water volume. Cracks and other openings in the street provide the additional water access to the soil during storms.

## Recommendations

Onsite evaluation is needed to determine the presence of expansive water-soluble salts if structures are planned on the flood plain of the Las Vegas Wash or in similar areas in the arid regions of the U.S. Proper management of surface water can prevent accumulation within or adjacent to engineered structures and buildings. Accumulations of dry sodium sulfate salts should be removed by mechanical means, deep leaching, or chemical treatment. Local roads and streets may require a special base to prevent damage from expansion.

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# Compaction

Adapted from “Technical Note No. 17,” Soil Quality Institute, USDA, NRCS.

Compaction is important when soil material is prepared for construction, but it degrades soils for other important functions. It occurs when moist or wet soil particles are pressed together and the pore spaces between them are reduced. Adequate pore space is essential for the movement of water, air, and soil fauna through the soil. Restricted infiltration results in excessive runoff, erosion, nutrient loss, and potential water-quality problems. Compaction restricts penetration by plant roots and thus inhibits plant growth. Also, it can significantly reduce the rate of rainwater infiltration in urban areas, thus increasing the volume of storm-water runoff.

## Susceptible Areas

Soils in all regions of the United States are susceptible to compaction. Compaction affects cropland, pasture, rangeland, forestland, gardens, lawns, and recreational areas.

## Cause

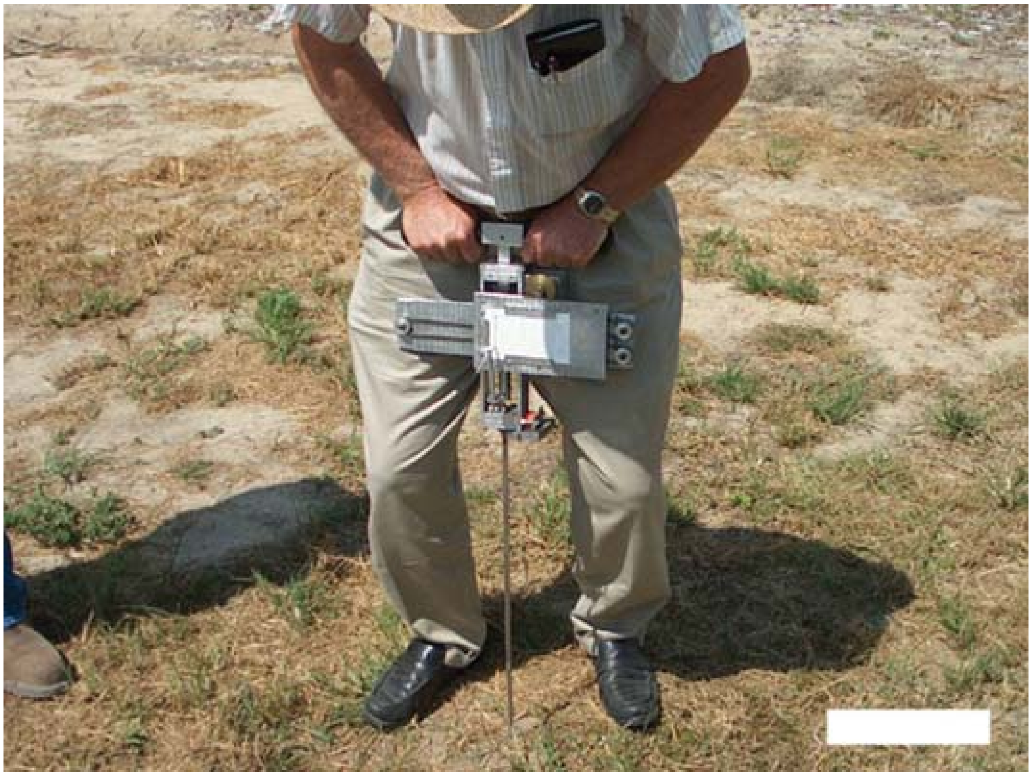
Compaction is a familiar sight in areas of road construction. Heavy equipment with plain or sheep-foot rollers drives over well watered surfaces, creating maximum density in the soil material and thus increasing the bearing strength of the road.

Compaction in areas of other land uses occurs in a similar manner. This unintentional compaction is caused primarily by wheel traffic, but it also can be caused by animal or human foot traffic or sometimes by natural processes. Soil is especially susceptible to compaction when it is moist or wet. A low content of organic matter, poor aggregate stability, and moist or wet conditions increase the likelihood of compaction. Moldboard plowing and excessive tillage break down soil aggregates. After aggregates are broken down and the surface is bare of vegetative residue, the soil is more likely to be compacted by the excessive vehicle passes common in conventional tillage systems. Excessive traffic during thinning and harvesting activities in forests can cause compaction that will be detrimental to the next crop of trees. Grazing on wet soils in a confined area can create compacted layers. Foot traffic compacts the soils on trails and in other highly used areas in parks, on lawns, or in forests. This compaction affects the vegetation underfoot and in areas adjacent to the traffic zone.

## Recognizing Compaction

Generally, compaction is a problem within the top 24 inches of the soil. There are several signs of compaction. Discolored or poor plant growth, especially in very wet or very dry years, may reflect the poor soil-plant-water relationships of compacted soils. Excessive runoff on sloping land and ponding on nearly level land are common in compacted areas because water does not infiltrate into the soil. Penetration resistance of the soil to a firm wire (survey flag) or stake increases in compacted areas. A shallow hole may reveal lateral root growth with little, if any, penetration of roots into compacted layers. Platy, blocky, dense, or massive layers may indicate compaction.

Quantitative methods of detecting compaction include measuring penetration resistance with a commercially available cone penetrometer and measuring soil bulk density by other methods. Soil texture must be considered in evaluating bulk density values. For example, a bulk density of 1.50 g/cc is root limiting for soils with a high percentage of clay, but very sandy soils are not root limiting below a bulk density of 1.85 g/cc. Soil moisture content significantly impacts the readings of a penetrometer. Data must be evaluated in respect to moisture content and type of penetrometer with attention to the size and shape of the penetrometer tip.



**Using a penetrometer to check compaction.**

## Preventing Soil Compaction

Preventing soil compaction is important because all compaction is expensive to treat and deep compaction may have permanent, untreatable effects on plant growth. Certain strategies can minimize compaction. A controlled traffic system can separate traffic zones from planting zones within a management area. Traffic is restricted to controlled zones between the rows. “Traffic” can include people in parks and cattle in pastures as well as tractors in fields and trucks on construction sites. The soil should not be subject to traffic when it is wet. If necessary and permitted, measures that improve drainage should be applied. Decreasing tire pressure or using duals or triples to replace singles can minimize compaction, but these measures increase the area affected by compaction. Maximizing the number of axles decreases the axle load per tire. The use of vehicles with high inflation pressure and small footprints should be minimized. Frequently emptying carry carts minimizes field traffic and high axle loads. Applying a system of conservation tillage, increasing the content of organic matter in the soil, and minimizing tillage, which breaks down aggregates and destroys soil structure, help to prevent compaction.

## Alleviating Soil Compaction

Shallow soil compaction generally can be alleviated by chisel plowing at shallow depths. Deep compaction requires subsoiling, which refers to tillage at a depth of at least 14 inches. Inserting any narrow tool to a lesser depth is considered chisel plowing.

Chiseling and subsoiling are expensive, and their benefits are generally not long lasting if traffic continues. Before these methods are implemented, the depth and extent of the compaction problem should be determined. Subsoiling should occur when the soil is dry enough for the equipment to fracture the compaction zone properly but moist enough for the equipment to pull the shank. Subsoiling when the soil is too dry will disturb more surface soil, and subsoiling when it is too wet will not fracture the compacted layer. A good compromise is the moisture content near the wilting point of plants. After the soil is examined for a determination of variations in the depth of the compacted layer, subsoiling or chiseling should extend into or through the compacted layer, or about 1 inch below the compacted zone. The proper spacing, such as in-row versus complete field disruption, should be selected. Timing is important. Subsoiling after field operations in the fall allows water to infiltrate during winter. On the Southeast Coastal Plain, spring subsoiling is preferable because compacted layers will normally reconsolidate during winter. In areas with a permanent cover of vegetation, such as grazing lands, orchards, lawns, parks, and forests, subsoiling may be needed prior to or during planting. Deep-rooted perennials should be considered where compaction is not too severe and mechanical subsoiling is not practical. As a last resort, pastures can be renovated with bent-leg subsoilers. Damage to actively growing roots can be reduced by subsoiling during winter or dormancy periods. Rotational grazing and properly planned watering facilities and permanent lanes can minimize compaction on grazing lands.

## Summary

Soil compaction restricts infiltration, deep rooting, and the amount of available water and thus inhibits plant growth. Measures that prevent compaction are recommended. These measures include deferring surface traffic when the soil is very moist or wet, increasing the content of organic matter, controlling the traffic pattern.

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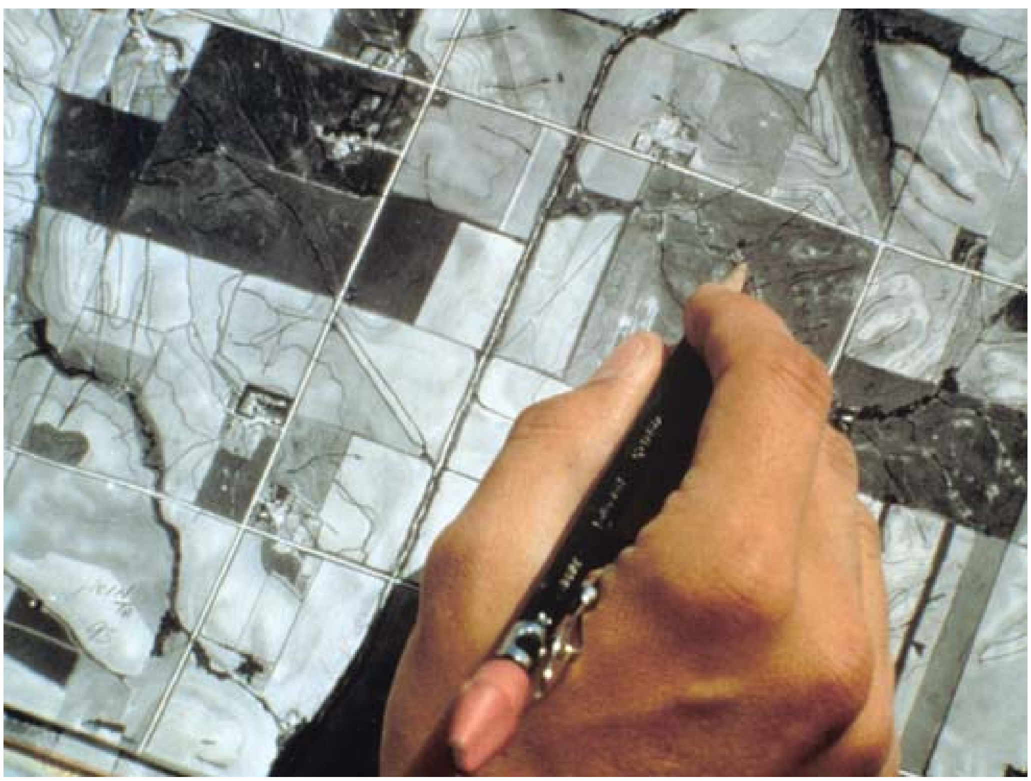
# Contamination by Metals

Adapted from "Urban Technical Note No. 3," Soil Quality Institute, USDA, NRCS, and "Minimizing Health Risks from Lead Contaminated Soil," Fact Sheet 336, Rutgers State University Cooperative Extension.

Metallic chemical elements that have a relatively high density and are toxic or poisonous at low concentrations in some formulations are a human concern where they contaminate soils. Mining, manufacturing, and the spreading or disposing of synthetic products (e.g., pesticides, paints, batteries, industrial waste, industrial sludge, and domestic biosolids) can result in metal contamination of urban and agricultural soils. Metals also occur naturally, but rarely at toxic levels. Potentially contaminated soils may occur at old landfill sites (particularly those where industrial waste was applied), in old orchards and livestock dipping vats where pesticides containing arsenic were used, in fields where waste water or municipal sludge was applied in the past, in areas in or around mining waste piles and tailings, near smelters, in industrial areas where chemicals were dumped on the ground, or in areas downwind from industrial sites.

Contaminants are generally not identified in soil survey reports. These reports can be helpful, however, in locating land uses that may be associated with contaminants. They include aerial photographs or satellite imagery as base maps. Photo interpretation techniques can help to ascertain the extent and location of specific land uses, depending on what surface features or land uses were evident at the time of the photography.



**By showing land use, aerial imagery used as background for soil surveys can help soil scientists to identify areas of possible contamination. (NRCS photo.)**

Some soils were polluted long ago. Tetraethyl lead was an antiknock agent in leaded gasoline for many years until it was prohibited in the United States in 1986. Lead passed through car exhaust systems was deposited along streets and highways. Lead tends to bind to soil particles and remains near the soil surface, unless the soil is disturbed.

Soils around older homes and other buildings are often contaminated by lead-based paints.

U.S. Government regulations began to restrict the concentration of lead in paint in the 1960s and finally banned lead-containing residential paints in 1978. Paint used before the 1950s may have as much as 50 percent lead. Remodeling of older houses and other buildings has brought lead poisoning to the attention of people at all income levels.

Lead arsenate and other lead compounds were applied as pesticides in fruit orchards and on other crops until the 1950s. New houses are sometimes constructed on this contaminated farmland.

As a soil contaminant in Florida and other Southern States, arsenic can often be traced to the extensive use of cattle dipping vats to eradicate ticks. In Florida the problem with tick infestation became so widespread that in 1926 Georgia built a 240-mile fence along the Florida border to prevent the movement of tick-infested cattle. From 1907 to 1960, the use of arsenic to control ticks was a USDA-approved method.

## Managing the Uptake of Metals by Plants

A common concern about metals in the soil is their uptake by plants that humans or livestock consume. The following soil and crop management practices can help to reduce uptake by plants:

- Alter the soil pH. Mercury, cadmium, lead, nickel, copper, zinc, chromium, and manganese are more soluble at the lower (more acid) pH levels, so increasing the pH makes them less available to plants and less likely to be ingested by humans. Raising the pH has the opposite effect on arsenic, molybdenum, selenium, and boron.
- Drain wet soils where drainage systems are permitted. Drainage improves soil aeration and allows metals to oxidize, making them less soluble and less available. The opposite is true for chromium. Active organic matter is effective in reducing the availability of chromium.
- Apply phosphate. Heavy phosphate applications reduce the availability of mercury, cadmium, lead, nickel, copper, zinc, chromium, and manganese, but they have the opposite effect on arsenic, molybdenum, selenium, and boron. Use care; high levels of phosphorus in the soil can result in water pollution.
- Carefully select plants for use on metal-contaminated soils. Plants translocate larger quantities of metals to their leaves than to their fruits or seeds. The greatest risk of food-chain contamination is in leafy vegetables, such as lettuce and spinach, or in forage eaten by livestock.

Plants are sometimes used to remove soil contaminates. This process is called phytoextraction. Plants absorb and move metals into their above-ground parts, which are later removed and discarded. Several crop growth cycles may be needed. Plants are not useful for phytoextraction of lead under natural conditions. A chelator has to be added to the soil. For people who consume vegetables from home gardens, it is fortunate that plants do not accumulate lead. Risks result, however, from direct contact with the lead.

## Soil Testing

If it is suspected that the soils around a home have high levels of metals, a soil test is needed to determine if the soils are actually contaminated. Soil tests for metals are different from standard soil fertility tests, though both are needed to give clues on how to address contamination. Environmental and some agricultural laboratories perform soil tests for metals. Procedures for collecting a soil sample and explanation of test results can be obtained from the laboratory used. Metal levels are not the sole factor affecting human concerns about metal contamination. Element origin, concentration, and chemical form, as well as other important soil properties, control the complex reactions and transformation of element species, affecting the fate, bioavailability, and transport of trace elements in soils.

**Laboratory analysis.**

## Contact With Contaminated Soil

Gardening or playing where soils are contaminated can endanger human health. Metals can be inhaled as soil dust or directly ingested. If the soil is the source, soil removal may be too expensive. Access and contact in the garden or play areas can be minimized by the following strategies:

- Plant shrubbery or sod along the walls of older homes and along the street.
- Grow only flowers, ornamental plants, or turf grass on soils that have high metal levels. Wear gloves while working in these soils.
- Cover play areas and any bare spots with turf grass, woodchips, mulch, or clean sand to prevent direct contact and to prevent problems with dust.
- Replace old sand in the sandbox.
- Use an uncontaminated site, or use raised beds filled with uncontaminated soil.
- Keep dust at a minimum by maintaining a moist soil and using mulch in the garden.
- Wash vegetables carefully to remove soil and dust deposits, and peel all root crops.

## Summary

Metals from past uses remain in some soils and are impacting the health of humans where they are at toxic concentrations and formulations. Appropriate actions can eliminate the negative impacts of metal-contaminated soils on human health.

## References for Further Reading

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# Corrosion

Adapted from the “National Soil Survey Handbook,” USDA, NRCS.

Corrosion of various metals and concrete is a common problem in some soils. Corrosion affects materials both on the surface and within the soil to various degrees. Soil survey reports provide corrosivity ratings for uncoated steel and for concrete.

Concrete and uncoated steel are used extensively. Streets, highways, sidewalks, houses, and pipelines for gas, sewage, and water are a few examples of the structures and facilities that are exposed to corrosion.

Selecting the wrong pipe material or failing to protect pipe can greatly shorten the lifespan of sewer and water lines. Corrosion affects both main lines buried under streets and smaller lines that connect to homes and businesses. Line maintenance of facilities may be continuous and costly where the conduit materials are not suited to the soil.

The risk of corrosion is rated in soil survey reports as low, moderate, or high.

Soils are rated for corrosivity in a natural condition or the condition evident during a soil survey. Local soil conditions, such as excess moisture and alterations of the landscape, can accelerate corrosion. Also, fertilizer and industrial wastes can alter soil conditions and thus increase corrosivity.

## Corrosion of Uncoated Steel

Soil moisture, texture, acidity, and soluble salts (electrical resistivity at field capacity or electrical conductivity of the saturated extract of the soil) are soil factors that relate to corrosion classes used in soil survey reports. Soil reaction (pH) over its complete range of values correlates poorly with the risk of corrosion; however, a pH of 4.0 or less almost always indicates a high risk of corrosion. The likelihood of corrosion is greater in extensive installations that intersect soil boundaries or soil horizons than in installations that are in one kind of soil or in one soil horizon.

In the “Guide for Estimating the Risk of Corrosion of Uncoated Steel,” soils are assigned to corrosion risk classes on the basis of selected soil properties, but the actual risk should be tempered by knowledge of other properties that affect corrosion. A study of soil properties in relation to local experiences with corrosion helps soil scientists and engineers to make soil interpretations. Special attention is given to those soil properties that affect the access of oxygen and moisture to the metal, the electrolyte, the chemical reaction in the electrolyte, and the flow of current through the electrolyte. Sulfides or other sulfur minerals, such as pyrite, can be weathered readily and cause a high degree of corrosion in metals because of very low pH.

Using interpretations for corrosion without considering the size of the metallic structure or the differential effects of using different metals may lead to wrong conclusions. Construction, paving, filling, compacting, surface additions, and other activities that alter the soil can increase the risk of corrosion by creating an oxidation cell. Mechanical agitation or excavation that results in increased aeration and in a discontinuous mixing of soil horizons also can increase the risk of corrosion.

Cathodic protection is a common technique used to address corrosion of metal pipes. These protection devices require maintenance and occasional replacement. Several types of pipe coverings also are available. Careful selection of the materials used to surround pipe and backfill helps to prevent abrasions of the pipe. Scratches on or wear of the pipe may allow a point of entry for corrosion. Often times, it may be better to use an unwrapped pipe and thus expose the whole surface to corrosion instead of exposing small points.

## Corrosion of Concrete

Corrosion of concrete results from soil-induced chemical reactions between a base (the concrete) and a weak acid (the soil solution). The rate of deterioration depends on (1) soil

**Guide for Estimating the Risk of Corrosion of Uncoated Steel [1]**

| Property | Limits | | |
|---|---|---|---|
| | **Low** | **Moderate** | **High** |
| **Drainage class and texture** | Excessively drained, coarse textured soils; well drained, coarse textured to medium textured soils; moderately well drained, coarse textured soils; or somewhat poorly drained, coarse textured soils | Well drained, moderately fine textured soils; moderately well drained, medium textured soils; somewhat poorly drained, moderately coarse textured soils; or very poorly drained soils with a stable high water table | Well drained, fine textured or stratified soils; moderately well drained, fine textured and moderately fine textured or stratified soils; somewhat poorly drained, medium textured to fine textured or stratified soils; or poorly drained soils with a fluctuating water table |
| **Total acidity (meq/100g)** | <8 | 8-12 | ≥12 |
| **Resistivity at saturation (ohm/cm)** | ≥5,000 | 2,000-5,000 | <2,000 |
| **Conductivity of saturated extract ($dSm^{-1}$)** | <0.3 | 0.3-0.8 | ≥0.8 |

[1] Based on “Underground Corrosion,” Circular 579, U.S. Department of Commerce, National Bureau of Standards.

**Guide for Estimating the Risk of Corrosion of Concrete [1]**

| Property | Limits | | |
|---|---|---|---|
| | **Low** | **Moderate** | **High** |
| **Texture and reaction** | Sandy and organic soils with pH of >6.5 or medium and fine textured soils with pH of >6.0 | Sandy and organic soils with pH of 5.5-6.5 or medium textured and fine textured soils with pH of 5.0 to 6.0 | Sandy and organic soils with pH of <5.5 or medium textured and fine textured soils with pH of <5.0 |
| **Na and/or Mg sulfate (ppm) in soil** | Less than 1,000 | 1,000 to 7,000 | More than 7,000 |
| **NaCl (ppm) in soil** | Less than 2,000 | 2,000 to 10,000 | More than 10,000 |

[1] Based on data in “National Conservation Practice Standards,” Standard 606, Subsurface Drain.

texture and acidity, (2) the amount of sodium or magnesium sulfate in the soil, and (3) the amount of sodium chloride (NaCl) in the soil. The presence of NaCl is one of the factors evaluated not because it is corrosive to cement but because it is commonly associated with sulfates, which are one of the principal corrosive agents.

Special cements and methods of manufacturing may be used to reduce the rate of deterioration in soils that have a high risk of corrosion. A soil that has gypsum requires special cement. The sulfate ions in gypsum react with the cement and weaken the concrete.

The "Guide for Estimating the Risk of Corrosion of Concrete" shows the relationship of soil texture, soil acidity, sulfates, and NaCl to corrosion classes.

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# Drought

By Henry Mount, Gary Muckel, and Sharon Waltman, National Soil Survey Center, USDA, NRCS.

One of the greatest risk factors in growing plants is insufficient or infrequent soil moisture. Drought is a condition of unusual dryness. Soil survey reports include climate tables and information about soil-water relationships. This information can be used to reduce the impact of drought and can provide an understanding of the soil properties that make a soil susceptible to the stresses of drought.

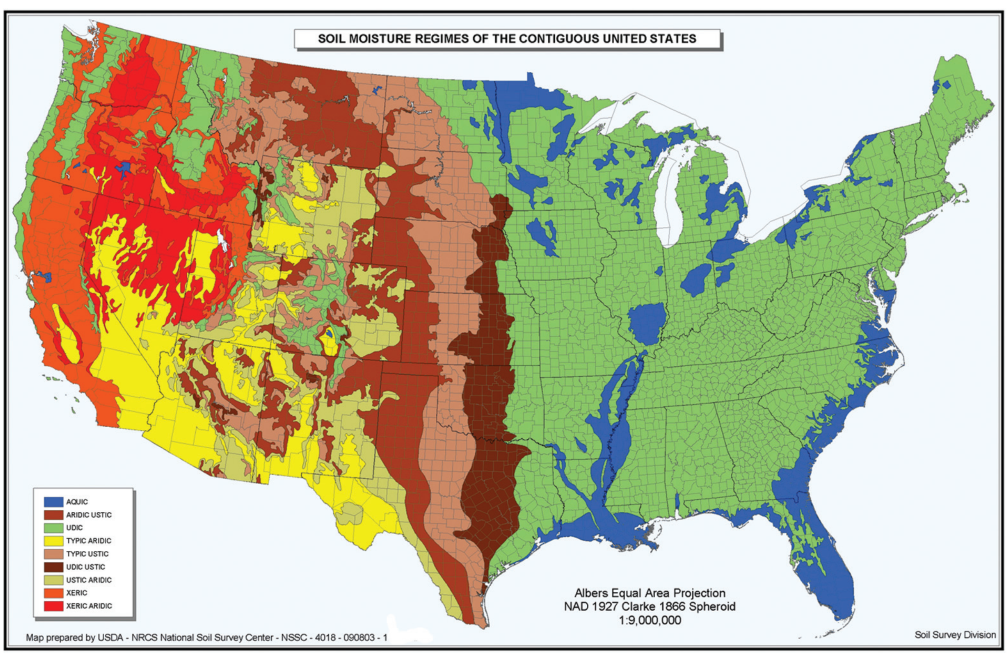
The capacity of soils to store and slowly provide moisture to plants allows plant growth between periods of precipitation or between irrigation runs. The risk of desiccation from drought is lower in soils with a higher available water capacity (AWC) than in soils that cannot store as much water. Available water capacity is important for irrigation scheduling and water conservation. It is shown as a physical soil property in soil survey reports.

## Soil Climate Regimes

Soils in deserts of the Southwest U.S. are perennially dry because of a low amount of rainfall, infrequent rainfall, and high evaporation rates. Soils in areas with nearly continuous precipitation and low evaporation rates are perennially moist. While these general statements are true when similar soils are compared, there are soil properties, landscape influences, and surface covers that greatly influence the effect of precipitation on the moisture within the soil. Soil climate regimes that indicate the internal moisture conditions of the soil are used to overcome the limitations of grouping soils by climate zones.

The U.S. system of soil classification in *Soil Taxonomy* groups soils by soil moisture regimes. These regimes are based on the presence or absence of plant-available moisture within the soil during the growing season. They are affected by the weather and by soil properties and landscape features.

Desert soils have an aridic moisture regime. They lack available moisture for more than half of the cumulative days a year that are warm enough to sustain plant growth. Soils with a




**General areas of soils with similar soil moisture regimes in the United States.**

xeric or ustic moisture regime are dry for 3 or more months during each year. Soils with a xeric moisture regime have moisture in winter or when they are cool, and soils in an ustic moisture regime have moisture during the summer. Soils with an aridic, xeric, or ustic regime generally require irrigation if they are to sustain most viable agricultural crops during the summer. Irrigation is commonly practiced on soils with these regimes. Irrigation water satisfies the moisture requirements of plants during periods when no moisture is otherwise received. A shortage of irrigation water, which can occur in droughty years, results in lower crop production. Much of the irrigation water comes from storage reservoirs supplied from winter precipitation. Rangeland in these areas can normally be quite productive, but forage production is significantly reduced during dry years.

Soils with a udic soil moisture regime are not dry for as long as 90 cumulative days in normal years. Generally, these soils receive moisture from summer rainfall that is adequate to keep them moist during the period of crop growth.

## Relation of Topography and Soil to Susceptibility to Drought

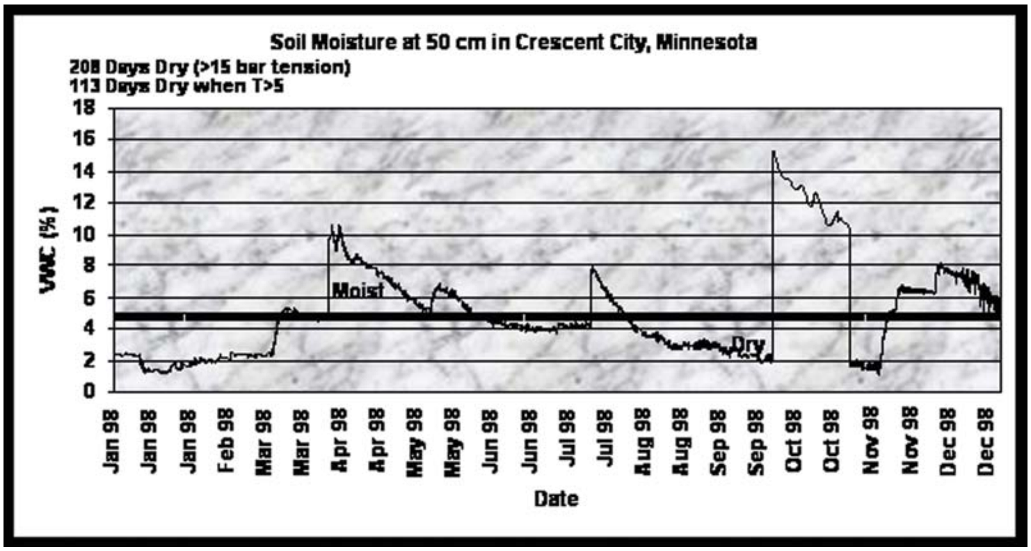
Soils within the same general climate zone that receive at their surface the same amount of precipitation may have different soil moisture regimes because of the condition of the surface soil and subsoil. Soils on steep slopes commonly lose more water through surface runoff than soils in level areas. Soils at the bottom of a hill commonly receive additional water as runoff from adjacent areas. Internal soil properties also affect the soil moisture regime. Soils vary in their capacity to hold moisture available to plants. The capacity of the soil to hold and release moisture is called the available water capacity. In physical properties tables, soil survey reports show, for each soil layer, the AWC in terms of inches of available water per inch of soil. To determine the total available water capacity, the reported AWC must be multiplied by the depth of the soil layer down to the rooting depth of concern or to a root-limiting barrier. Sandy soils, gravelly or stony soils, soils that are shallow to bedrock or to other root-limiting layers, and saline soils have a low AWC. Saline soils may hold water, but plants cannot absorb the water, so these soils have a low AWC assigned to them.

Organic matter, soil structure, and compaction are affected by management. Soils that have been compacted have layers that restrict water entry as much as bedrock in shallow soils. Soils with good soil structure and with more organic matter than the amount shown in the soil survey report hold more water and allow more water to penetrate the surface. Soils that are allowed to erode have less organic matter and a lower rate of water infiltration than the soil survey report generally shows and have a lower available water capacity. Excessive tillage can break down soil structure and reduce the infiltration rate and the amount of available water. These are use-dependent conditions that can be changed with proper soil management. The land manager should consider the status and management of organic matter, soil structure, and compaction from the perspective of soil moisture management and the need to minimize the impact of drought.

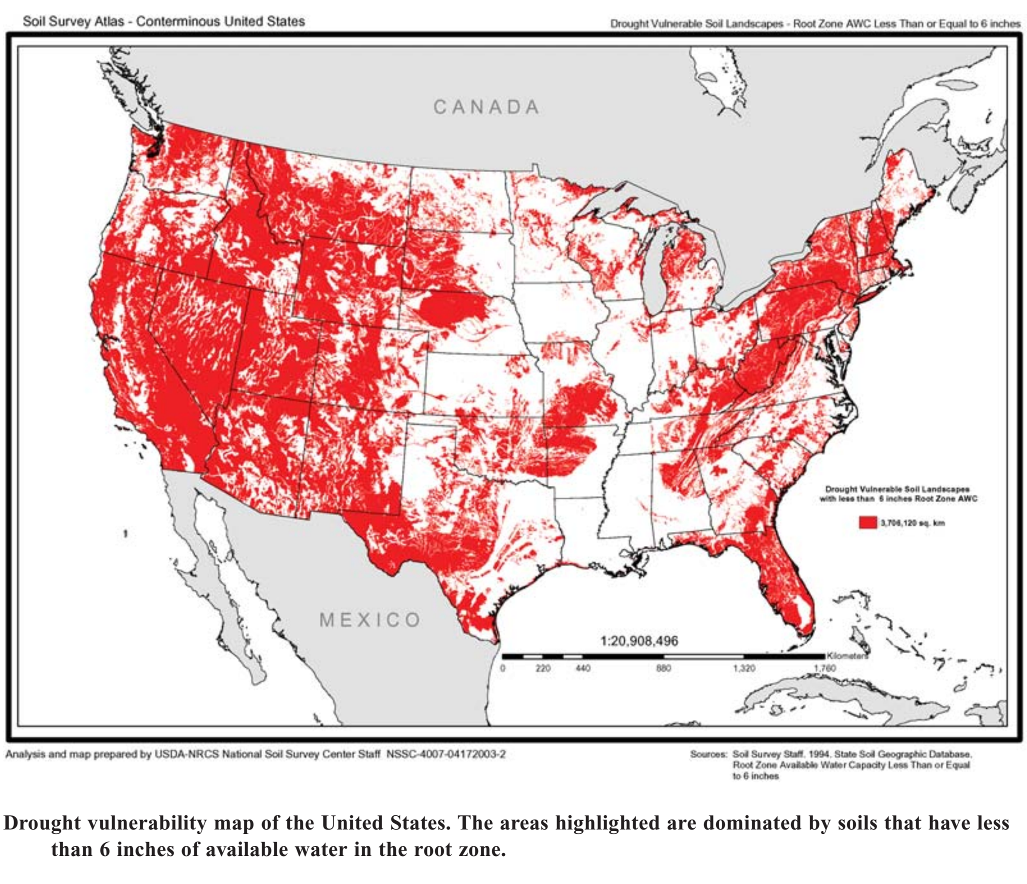
The graph on page 26 depicts a sandy soil in Minnesota as dry for more than 3 months in the summer of 1998. Crops on the adjacent soils with a higher AWC did not exhibit moisture stress. Agricultural viability is sharply reduced without irrigation on this sandy soil. Sandy soils have a low AWC, and their moisture must be replenished frequently if they are to maintain crops. Even in areas where rainfall totals remain constant, soils with a low available water capacity show signs of drought when the interval between rains lengthens.

## Management Decisions That Minimize the Impact of Drought

By understanding soil properties related to soil moisture, land managers are better equipped to manage their land and make informed decisions. The critical time for knowing the actual soil moisture condition or the availability of irrigation water is shortly before planting time, when land managers decide what crop to plant or whether to plant. It is inefficient to try to add to stored soil moisture with a fallow system when soil moisture is at capacity. For many




**Susceptibility of a sandy soil in Minnesota to drought.**




**Drought vulnerability map of the United States. The areas highlighted are dominated by soils that have less than 6 inches of available water in the root zone.**

crops, planting during periods of inadequate soil moisture is highly risky. Farm-operation decisions made at other times can significantly affect the actual soil moisture. These are decisions to contribute plant residue to the soil and thus increase the supply of organic matter and decisions to incorporate practices that lessen compaction. These decisions are important to soil moisture management and affect the risk of drought. In irrigated areas the land manager has additional considerations. It is wasteful to apply more water than the soil can hold and inefficient to frequently apply too little. Decisions on the amount of water to be applied and the frequency of irrigation are equally important to all water users, whether on the farm or in the city. Understanding soils can help the manager to make good decisions.

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# Dust

By Gary Muckel, Soil Scientist, National Soil Survey Center, USDA, NRCS.

Dust in the air is a hazard to humans for many reasons. As fine particles, dust can have a direct adverse effect on human and animal health. Dust may contain pesticides, pollen, fungi, and other irritants to the lungs and eyes of humans. Dust can affect visibility. Traffic accidents involving up to 100 cars and trucks have occurred at times when dust obscured stopped vehicles on highways. Probably the greatest economic impact of dust is the cost of filters and of wear and tear on vehicles and on mechanical appliances, such as air conditioners. Dust is never appreciated when it enters the home. Soils contribute dust to the atmosphere from natural forces, such as the wind, and from human activities, such as driving vehicles on dirt roads, cultivating fields, and shaping land.

## Areas of Concern

Fugitive dust in farming areas with Mediterranean climates is of special concern. Because most precipitation falls in winter, these areas are dry during the summer, when many construction and farming practices are conducted. Both paved and unpaved roads contribute a large amount of dust, particularly with high vehicle speeds. Farming also contributes a large amount of dust. Farming practices performed during periods when the soils are moist contribute little fugitive dust. Ripping and land leveling contribute more fugitive dust than most farming practices. To be effective, these practices require low soil moisture.

## Airborne Dust and Human Health

Dust can have a direct impact on human health. Dust particles, 2.5 microns or smaller, are of special concern. While most particles of windblown soils are large and fall from the air quickly, the smaller particles (referred to as $PM_{2.5}$) can enter the natural defense mechanism of the human respiratory tract. They can penetrate deep into the lungs, where they can become lodged and cannot be easily, if ever, expelled. The smaller the particle, the deeper it can penetrate into the lungs. Consequently, $PM_{2.5}$ can cause a wide variety of health problems, especially in children, the elderly, and people with preexisting respiratory or cardiovascular disease. Dust also contributes to skin problems and irritation of the eyes. Dust may stimulate asthma. Very fine dust, such as smoke particles, stays in suspension for long periods, affecting visibility, and it is commonly seen as haze in the western sky, where it contributes to colorful sunsets. To protect public health, the U.S. Environmental Protection Agency has established National Ambient Air Quality standards for $PM_{2.5}$. Atmospheric dust provides a mechanism for the transport of fungal spores, pollen, and bacteria. Fungal spores attached to the dust particles are a source for soil-borne diseases, such as Histoplasmosis and Valley Fever. Pesticides and herbicides also can attach to dust particles.

Dust can travel a long distance once it reaches the upper atmosphere. Some dust may circle the earth. Rain droplets form around dust particles, and dust returns to the earth in this fashion as well as falling directly from the sky when the wind no longer holds it in suspension.

## $PM_{2.5}$ and Soils

The potential for soil to release dust into the atmosphere depends largely on the moisture status of the soil, the kind and size of the soil particle, and the condition of the soil surface. Particles in the $PM_{2.5}$ size range are often bonded to larger particles, making large aggregates. Energy (usually in the form of increased windspeed and/or traffic over the soil surface) is needed to break the aggregates into smaller particles. Destruction of the aggregates can result in the generation of fugitive dust. $PM_{2.5}$ can be suspended, while larger particles rarely stay in suspension because they are too heavy. Soil particles that are moist or wet stick together and

Land leveling and other machinery operations can add dust to the air.

The Dust Bowl years in the 1930s drew attention to the severe loss of soil and poor soil management.

are not carried by wind. It is only when the soil surface is dry and bare and without a crust that very small soil particles are susceptible to blowing.

$PM_{2.5}$ particles approximate the soil particle size of very fine silt and clay. Mica, kaolinite, and silica are common minerals in inhalable dust. These are common minerals in soils. Soils high in content of serpentine minerals might be of special concern because of their relation to asbestos.

Dust is common in the drier parts of the Western United States. It is also common in other dry parts of the world where the plant cover is minimal and the soils are in a condition that allows them to be blown by strong winds or to become airborne by mechanical means. Wind erosion degrades the soil resource and contributes to airborne dust. Some soils contribute very little dust to the air. Sands, for example, move across the soil surface with blowing winds, but the particles are too large to stay in suspension. Drained organic soils (Histosols) produce dust, whereas undrained organic soils do not.

## Recommendations

The amount of dust can be reduced during many soil-disturbing operations by lower vehicle speed. Confining tillage operations to times of the day when solar radiation is lowest and the wind is calm also can reduce the amount of dust. Irrigation is usually practiced in areas of Mediterranean climates. It may offer ways to reduce surface dust production.

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Other references available on the Web:

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http://www.oznet.ksu.edu/wdl/climate/cok/index.asp?page=271)
http://www.ranchwest.com/egan.html
http://www.cahe.wsu.edu/~cp3/erosion/erosion.htm
http://www.weru.ksu.edu/pics/dust_storms/index0.1.html

# Earth Collapse of Soil Pits and Trench Excavations

By Larry K. Johnson; adapted from material previously prepared for the National Society for Consulting Soil Scientists.

The people who die from earth collapse each year include construction workers, agricultural workers, homeowners, inspectors, professional consultants, and children. Approximately 100 construction workers are killed each year in the United States. Workers' compensation claims indicate that excavation cave-ins cause approximately 1,000 work-related injuries each year. It is estimated that cave-ins kill at least 12 children in the United States each year.

Almost all fatalities and serious injuries occur where human activities have created unstable earth conditions and where escape is difficult. Young adults and children have been killed while excavating holes in sand along beaches or streambanks. The causes of death and injuries include suffocation, severe internal injuries, and debilitating spinal fractures. The trenches were reported to range from 4 to 25 feet in depth. One fatality occurred in a 4-foot trench after a worker sat down and was crushed by falling earth.

## What Causes Earth Collapse?

Soil weighs approximately 3,000 pounds per cubic yard, the approximate weight of a small automobile. This weight puts a tremendous pressure on the walls of a trench. The stability of trench or excavation walls is dependent on many factors. These include the soil type, natural fissures and zones of weakness within the soil, the water content of the soil, weather conditions, the depth of the excavation, previous disturbance of the soil, surcharge loads next to the trench, and vibrations caused by equipment.

**Fissures developed in a trench wall along natural zones of weakness in the soil profile. Note hand pick for scale.**

A proper assessment of soil stability at a project site requires an accurate characterization of the soils, ground water, and site conditions. Because of layering, fissuring, and a constantly changing moisture content, soils almost never have uniform properties. Published soil survey reports and soil scientists can be helpful in identifying local soil and ground-water conditions but cannot provide a definitive basis for decisions. Properly trained contractors and engineers can use soil information to design and install protective measures, such as shoring, installing trench boxes, and properly sloping the excavations.

## Warning Signs of Trench Instability

- Tension cracks forming near and parallel to the edges or on the sides of the excavation.
- Subsidence of the soils at the top edge of the excavation.
- Surface soil falling into the excavation or soil particles becoming dislodged from the sides of the excavation.
- Saturated soils occurring on the sides or bottom of the excavation, water seeping from the sides of the excavation, or ground water rising into the excavation.
- Surface water entering the pit or excavation or standing on the bottom for an extended period.
- The sides of the excavation bulging outward or the bottom of the excavation beginning to uplift.
- The sides and top of the excavation being undercut by excavation equipment or falling soils.
- Lateral movement of existing protective shoring.
- Instability in areas where the pit or trench is excavated in previously excavated ground (fill).

**Tension cracks forming parallel to a trench excavation.**

**An adequately sloped trench.**

## What Are the Safety Requirements?

In general, rules of the Occupational Safety and Health Administration (OSHA) require that trench faces exceeding a height of 5 feet must be stabilized either by sloping the face of the wall back to a stable slope or by shoring. If the walls of a trench are less than 5 feet high and the soils are soft or unstable, however, either a sloping or shoring system may also be required. If the soil cannot be classified for stability purposes because no information about the excavation site is available, then the steepest permissible slope is $1^1/_2$ horizontal to 1 vertical.

## Safety Considerations

It is the responsibility of professionals who are involved in potentially dangerous earth-related activities to know the law and recognize potentially unsafe conditions. Safety issues should be discussed with the equipment operator, co-workers, and observers. These issues include a safe stand-back distance from the front and rear of excavating equipment. All equipment is to be completely turned off, and the boom and bucket are to be removed from the excavation before personnel enter the excavation for observation and sampling. Under no circumstances are personnel to enter or exit the excavation by riding the backhoe bucket.

The entire excavation site should be observed, including the soil adjacent to the site and the soil being excavated. Careful visual inspection of the conditions in and around an excavation, prior to and during the work, is the primary and most prudent approach to hazard identification and control. An earthen embankment may fail with little advance warning; however, danger signs often occur before a collapse.

Where soils are configured in *layers*, the soil must be classified as Type A, B, or C on the basis of the weakest soil layer. Each layer may be classified individually if a more stable layer lies below a less stable layer, i.e., where a Type C soil rests on top of stable rock.

**Type A soils** are the most stable. They are cohesive soils with an unconfined compressive strength of 1.5 tons or more per square foot. Examples of Type A cohesive soils are commonly those with a texture of clay, silty clay, sandy clay, clay loam, or, in some cases, silty clay loam or sandy clay loam. No soil is Type A if it is fissured, is subject to vibration of any type, has previously been disturbed, is part of a sloped, layered system where the layers dip into the excavation on a slope of 4 horizontal to 1 or more vertical, has seeping water, or is a Vertisol.

**Type B soils** are moderately stable. They are cohesive soils with an unconfined compressive strength of more than 0.5 ton per square foot but less than 1.5 tons per square foot. Examples of other Type B soils are those with angular gravel, those with a texture of silt or silt loam, previously disturbed soils unless otherwise classified as Type C, soils that meet the unconfined compressive strength or cementation requirements of Type A soils but are fissured or subject to vibration, soils with dry unstable rock, and soils with layered systems sloping into the trench at a slope of less than 4 horizontal to 1 vertical (only if the material would be classified as a Type B soil).

**Type C soils** are the least stable. They are cohesive soils with an unconfined compressive strength of 0.5 ton or less per square foot. Other Type C soils include granular soils, such as those with gravel or sand or loamy sand, submerged soils, soils from which water is freely seeping, and soils with submerged rock that is not stable. Also included in this classification are Vertisols and material in a sloped, layered system where the layers dip into the excavation or have a slope of 4 horizontal to 1 or more vertical.

| **Safety Checklist for Pit and Trench Excavations** | **Check** |
|---|---|
| A competent person is onsite and supervising the investigation. | |
| Underground utility lines have been marked, and excavations are offset properly. | |
| No personnel are in an unsupported trench more than 5 feet deep or in a trench less than 5 feet deep if the soils are soft or unstable. | |
| The maximum allowable slopes in unshored trenches do not exceed the following: **Type A soils**, 3/4H:1V (53 degrees) (from horizontal); **Type B soils**, 1H:1V (45 degrees); **Type C soils**, $1^1/_2$H:1V (34 degrees); **Stable rock**, vertical. Stable rock is rock that is not fractured, fissured, or foliated. Trenches more than 20 feet deep require a professional engineer. | |
| Warning signs of potential trench instability have been reviewed and either present no problems or are considered in trench configuration. (See "Warning Signs of Trench Instability.") | |
| The trench is properly stepped, or ladders are provided and used for entry to and exit from the trench if the trench is more than 4 feet deep. | |
| The excavating equipment and other machinery are positioned properly and located an adequate distance from the edge of the trench so that the trench remains stable and a collapse of the excavation walls is not initiated. | |
| All spoil material, tools, or other hazardous objects are located more than 2 feet from the edge of an unsupported trench, and spoil materials are placed at an angle of 45 degrees or less. | |
| If the trench is located next to a surcharge load, such as a building foundation, adequate structural safeguards are implemented. | |
| Vibrating equipment, such as vibratory rollers, and heavy machinery are not operating in the vicinity of the excavation during the investigation. | |
| No personnel are sitting down in a potentially unsafe trench, and all personnel are able to escape readily from the excavation. | |
| No personnel (especially groups) are standing on the edge of the excavation or climbing on the sidewalls of the trench. | |
| No personnel are working outside of any installed shoring or protected areas. | |
| A contingency emergency rescue plan is in place, including telephone access to rescue and medical personnel in case of a cave-in or other accident. | |
| The test pit or trench is completely backfilled after completion of the exploration. If multiple deep test pits are opened, each excavation is closed before the next one is opened. | |

## References for Further Reading

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# Erosion by Water and Wind

By Gary B. Muckel, Soil Scientist, National Soil Survey Center, USDA, NRCS.

Soil erosion is the removal of material from the surface soil, which is the part of the soil having an abundance of nutrients and organic matter vital to plant growth. The most common forces causing soil erosion are water and wind. Water and wind erosion can be very slow and even hard to detect, or it can be rapid and very apparent. Left without protection, the surface soil is exposed to the full force of wind and water and can be eroded in a short time.

## Processes

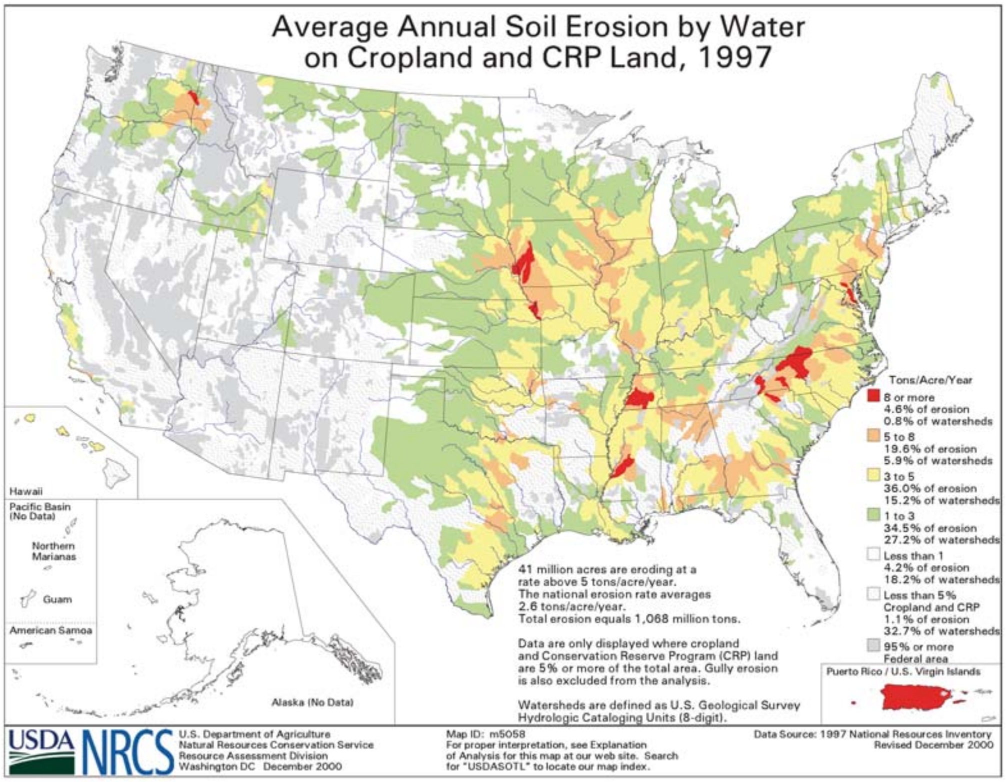
Erosion processes involve detachment and short transport of particles from the soil surface. Deposition is the process by which the soil particles come to rest. Soil particles are detached in two ways by water. Raindrops impacting an exposed soil surface exert a tremendous force that can dislodge soil particles. The dislodged particles are suspended by the raindrop splash and are moved away from the point of impact by sheet flow of water on the soil surface. The second way that soil particles are detached is by the adhesive friction of concentrated flow in a rill. Once soil particles are detached, they can be transported a short distance by the flow of water until the flow velocity decreases because of reduced slope gradient or flow blockage. Soil deposition occurs on the footslope or toeslope of a hillslope where the velocity of flow lessens. Slope is required to generate flow velocity, so less water erosion occurs in the flatter areas. Sheet and rill erosion can be invisible to erosion rates of up to 10 tons per acre. When rills are visible, the rate of erosion is at least 12 tons per acre. If rills are deep (up to 1 foot) or closely spaced, erosion rates may be 25 or more tons per acre. Ephemeral gullies, which are often filled in by equipment, can indicate erosion rates of 40 or more tons per acre.

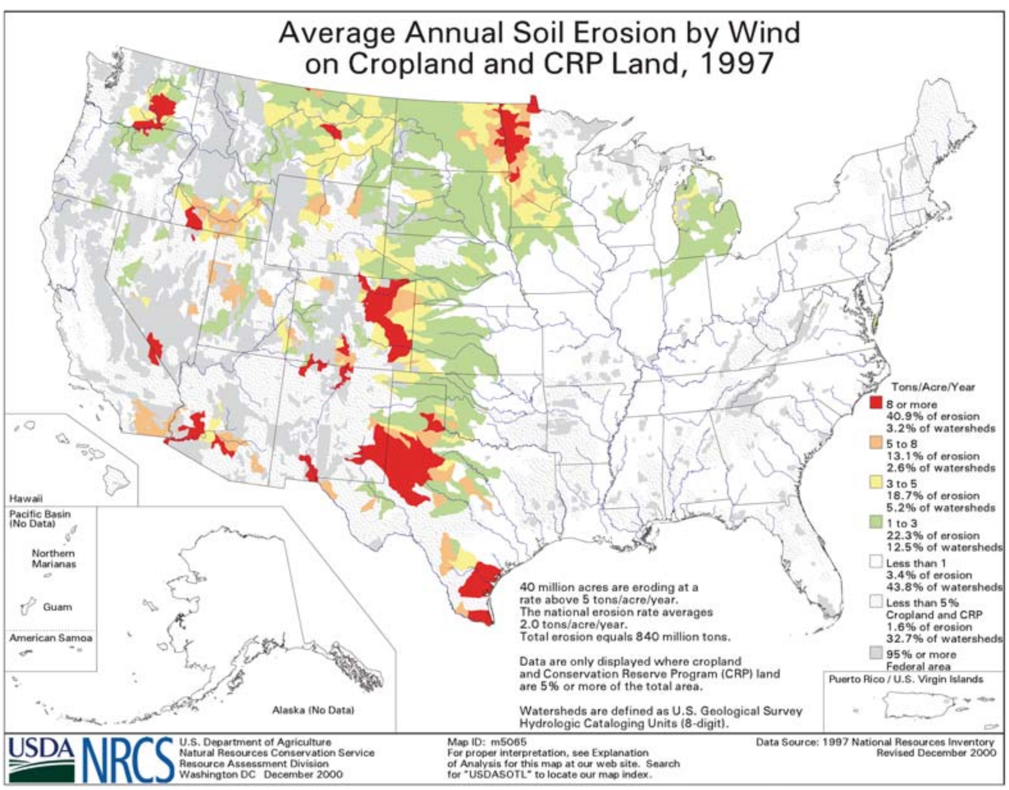
Together, erosion and deposition represent the dynamic processes of cutting and filling. These processes are natural sequences. Soil parent materials evolve from erosional deposition. Deep soils are in areas where the soil materials were deposited by wind or water. The soil material (parent material) was removed from areas near or far. The process may have occurred a long time ago or quite recently. Erosion tends to move particles from states of high energy to states of low energy and generally results in leveling. Needless acceleration of the process, however, is a concern related to the basics of food production and sustainability. Loss of the most productive layer of the soil (the surface soil) at a rate that is faster than that of soil development (deposition and weathering) is called accelerated erosion. Accelerated erosion and slow accumulation of organic matter have a destabilizing effect on our ability to grow crops economically. Accelerated erosion also contributes excess sediment to streams, lakes, and estuaries. It is typically caused by human activities.

The dynamic swings in nature can occur at intervals beyond our comprehension. As changes take place in a natural system, a new level of stability must be established. Balancing crop production with natural forces requires a set of conservation measures. Effectively applying these measures requires a good knowledge of the soil and how our actions as humans affect the ability of the soil to stay in place.

## Water Erosion

Most water erosion prediction equations are based on the amount and intensity of rainfall and on four additional factors. These factors are the ability of the soil to hold together, the surface cover (which provides protection from the forces of erosion), the distance for action (slope length), and the slope gradient. Almost all management solutions to erosion address one or more of these factors. Soil survey reports provide information about water erosion, including erosivity (K factor), soil loss tolerance (T factor), and slope gradient. The technical guides used by NRCS offices include detailed information concerning soil properties, climatic factors, and conservation practices. A general recommendation is to build organic matter in


Average Annual Soil Erosion by Water
on Cropland and CRP Land, 1997
Tons/Acre/Year
8 or more
4.6% of erosion
0.8% of watersheds
5 to 8
19.6% of erosion
5.9% of watersheds
3 to 5
36.0% of erosion
15.2% of watersheds
1 to 3
34.5% of erosion
27.2% of watersheds
Less than 1
4.2% of erosion
18.2% of watersheds
Less than 5%
Cropland and CRP
1.1% of erosion
32.7% of watersheds
95% or more
Federal area
Puerto Rico / U.S. Virgin Islands
Hawaii
Pacific Basin (No Data)
Northern Marianas
Guam
American Samoa
Alaska (No Data)
41 million acres are eroding at a rate above 5 tons/acre/year.
The national erosion rate averages 2.6 tons/acre/year.
Total erosion equals 1,068 million tons.
Data are only displayed where cropland and Conservation Reserve Program (CRP) land are 5% or more of the total area. Gully erosion is also excluded from the analysis.
Watersheds are defined as U.S. Geological Survey Hydrologic Cataloging Units (8-digit).
U.S. Department of Agriculture
Natural Resources Conservation Service
Resource Assessment Division
Washington DC December 2000
Map ID: m5058
For proper interpretation, see Explanation of Analysis for this map at our web site. Search for "USDASOTL" to locate our map index.
Data Source: 1997 National Resources Inventory
Revised December 2000


Average Annual Soil Erosion by Wind
on Cropland and CRP Land, 1997
Tons/Acre/Year
8 or more
40.9% of erosion
3.2% of watersheds
5 to 8
13.1% of erosion
2.6% of watersheds
3 to 5
18.7% of erosion
5.2% of watersheds
1 to 3
22.3% of erosion
12.5% of watersheds
Less than 1
3.4% of erosion
43.8% of watersheds
Less than 5%
Cropland and CRP
1.6% of erosion
32.7% of watersheds
95% or more
Federal area
Puerto Rico / U.S. Virgin Islands
Hawaii
Pacific Basin (No Data)
Northern Marianas
Guam
American Samoa
Alaska (No Data)
40 million acres are eroding at a rate above 5 tons/acre/year.
The national erosion rate averages 2.0 tons/acre/year.
Total erosion equals 840 million tons.
Data are only displayed where cropland and Conservation Reserve Program (CRP) land are 5% or more of the total area.
Watersheds are defined as U.S. Geological Survey Hydrologic Cataloging Units (8-digit).
U.S. Department of Agriculture
Natural Resources Conservation Service
Resource Assessment Division
Washington DC December 2000
Map ID: m5065
For proper interpretation, see Explanation of Analysis for this map at our web site. Search for "USDASOTL" to locate our map index.
Data Source: 1997 National Resources Inventory
Revised December 2000

the surface soil. Building organic matter increases the ability of the soil to hold together for better aggregation and water infiltration. The movement of water into the soil lessens the amount of water that runs across the soil surface. The cover provided by crops or grass, crop residue, or temporary artificial means, such as straw, protects the surface from the impact of raindrops and slows the movement of surface water. Minimum tillage or no-till systems maintain the surface cover and tend to increase the amount of organic matter. Contour tillage, terraces, and check dams shorten the erosive distance of the flow and slow waterflow. These practices also lower the effective slope gradient.

**An Iowa field from which topsoil has been removed by sheet and rill erosion.**

## Wind Erosion

When bare, soils are subject to wind erosion. The shear force of wind detaches particles protruding from the soil surface, and these detached particles then strike other particles on the surface as they bounce along the surface. This process is called saltation and is the most noted transport mechanism for sand-sized particles. Soil survey reports rate the susceptibility of bare soil surfaces to wind erosion by assigning the soils to wind erodibility groups. These groups are shown in the tables of soil survey publications covering areas that are subject to wind erosion. The groups are based on soil texture, content of organic matter, effervescence of carbonates, content of rock fragments, and mineralogy. Also considered are soil moisture, surface cover, soil surface roughness, wind velocity and direction, and the length of unsheltered distance. Conservation practices focus on maintaining a surface cover and reducing the length of the unsheltered distance with windbreaks or strips of wind-resistant plantings. The Field Office Technical Guides of NRCS offices include wind erosion prediction tools and additional solutions.

**A sandy area in Iowa where topsoil has been blown off the tops of knobs.**

Soil survey information is used to assess the hazard of wind and water erosion, to evaluate the erosion rate, to estimate the soil loss tolerance, and to aid in the design of erosion-control practices.

## References for Further Reading

United States Department of Agriculture, Natural Resources Conservation Service. Electronic field office technical guides. Web accessible (http://www.nrcs.usda.gov/technical/efotg).

United States Department of Agriculture, Natural Resources Conservation Service. National conservation practice standards. Web accessible (http://www.nrcs.usda.gov/technical/Standards/nhcp.html).

United States Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, part 618.72 and exhibit 618.16. Web accessible (http://soils.usda.gov/technical/handbook/contents/part618p7.html#ex16).

United States Department of Agriculture, Natural Resources Conservation Service. State of the land national resources inventory maps/soil erosion. Web accessible (http://www.nrcs.usda.gov/technical/land/erosion.html).

# Erosion and Sedimentation on Construction Sites

Adapted from "Urban Technical Note No. 1," Soil Quality Institute, USDA, NRCS.

Soil is important but is often an overlooked component of our urban infrastructure. It is especially important in regulating runoff of storm water and in supporting trees, shrubs, lawns, and gardens. Soil erosion during construction commonly is a serious problem. Information about many erosion-control practices is available in local soil and water conservation district offices. Preventing soil-related problems is easier and more cost effective than correcting them later. Communities need to work with developers, contractors, and local governments to limit compaction and soil loss during construction operations. The result is a soil functioning properly on the urban landscape.

Although construction activities may affect only a relatively small acreage of land in a watershed, they can be a major source of sediment and increased water runoff. Construction activities often leave the soil disturbed, bare, and exposed to the abrasive action of wind and water. These conditions greatly accelerate erosion, which produces large amounts of sediment. The sediment is unsightly in the local area, clogs storm-water drains, reduces the capacity of reservoirs, and adds nutrients and sediment to streams. Erosion on construction sites is commonly 100 times greater than that on agricultural land. Adequate measures are available to prevent onsite and offsite damage.

## Onsite Impacts

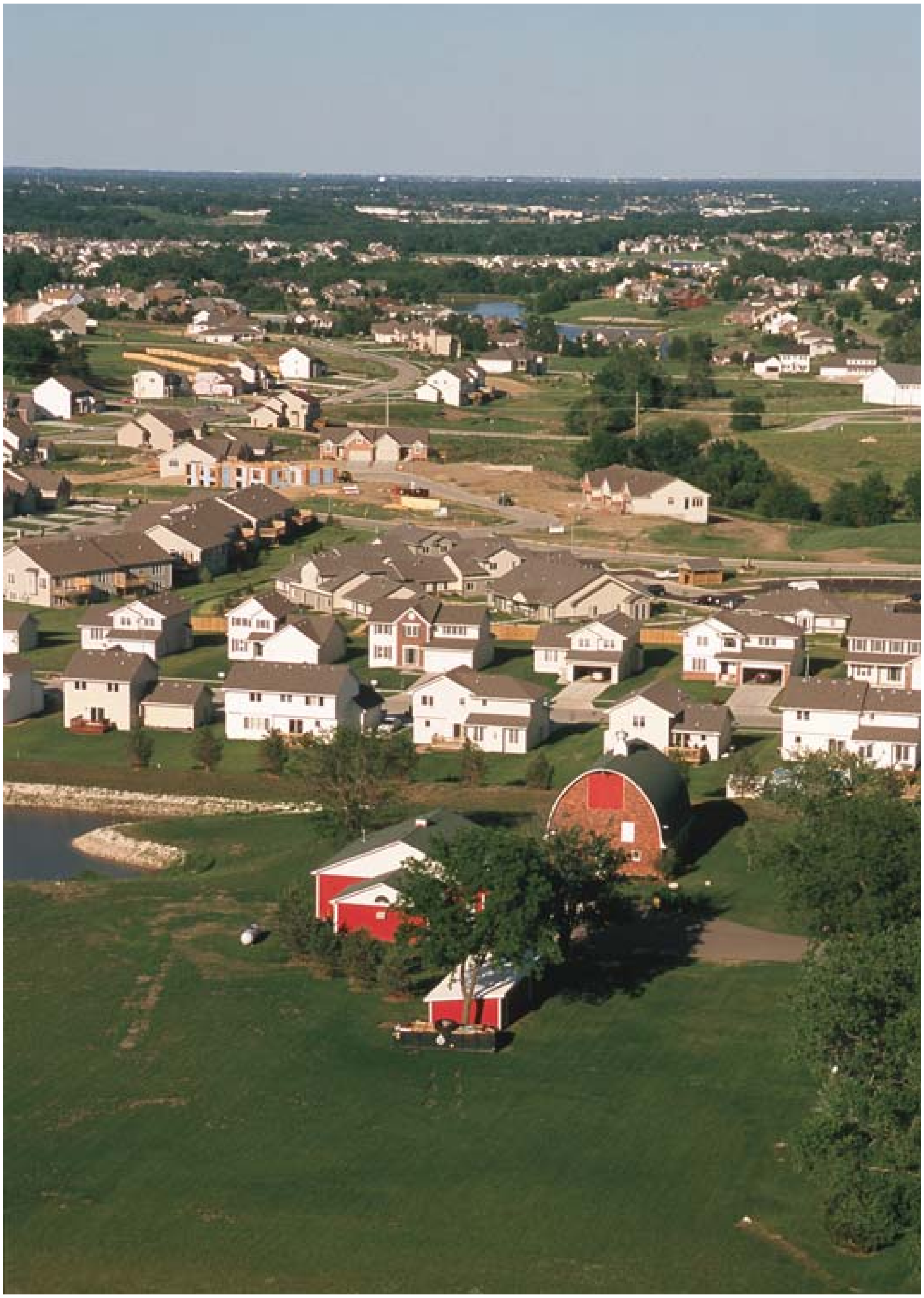
Construction activities can have serious detrimental effects on the soil on construction sites. Topsoil removal, grading, and filling drastically reduce soil quality on these sites, resulting in long-term adverse impacts on plant growth and runoff. Removal of topsoil inhibits biological activity and reduces the supply of organic matter and plant nutrients. These properties are important to plant nutrition, water infiltration, resistance to compaction and erosion, and control of pests and disease.

Another poor construction practice is allowing heavy equipment and even smaller construction vehicles to drive or park on the site. These vehicles track large quantities of mud onto the street, and the mud enters the storm sewer. Also, the traffic of the vehicles further compacts the soil. Compaction lowers the rate of water infiltration and reduces the available water-holding capacity. As a result, plant growth is restricted, droughtiness is increased and the soil requires more frequent watering, and more rainfall runs off the surface, straining storm-water facilities. Because of the restricted rate of water infiltration, fertilizer and pesticides are carried to offsite areas and into nearby lakes and streams rather than entering the soil.

Washing cement trucks onsite or dumping the remains on the soil contributes to onsite and offsite problems. Even diluted cement clogs soil pores, decreases the rate of water infiltration, restricts root penetration, and increases storm-water runoff. Waste cement that is dumped onsite becomes a concrete barrier under the soil surface. Placing sod on a compacted soil or in an area with cement waste leaves a very shallow root zone, causing a long-term problem for the landowner and the watershed. A seedbed should be prepared before the sod is placed on the soil.

## Offsite Impacts

Erosion from construction sites has offsite environmental and economic impacts. Erosion creates two major water-quality problems in surface waters and drainageways—excess nutrients and excess sediment. Both impacts create unwanted biological growth and turbidity that degrades the habitat for fish and other aquatic organisms. Sediment can accumulate in stream channels, lowering the flow capacity and causing more frequent flooding in areas that were never flooded or were only rarely flooded in the past. In flood-prone areas levees may



**An area where new homes were built on farmland in Dallas County, Iowa, in the suburbs of Des Moines.**

need to be built or enlarged to better protect public safety. Sediment can accumulate on public roads and in road ditches, culverts, and streams.

Many local governments enforce regulations intended to control or prevent erosion on construction sites. State and local laws and the Clean Water Act of 1992 may require contractors to develop detailed erosion- and sediment-control plans before beginning construction projects more than approximately 2.5 acres in size.

## Management Practices

Adding mulch, seeding, and providing sod protect the soil from erosion. Straw bales, silt fences, gravel bags, narrow grass strips or buffers, vegetative barriers, and terraces and diversions catch sediment and shorten the length of the erosive surface. Combinations of cover and structural practices help to control erosion and sedimentation and improve soil quality. Some temporary measures, such as a silt fence at the base of the slope, do not reduce the hazard of erosion on the slope but trap some of the sediment leaving the slope.

Following are some basic principles of erosion control on construction sites:

- Divide the project into smaller phases, clearing smaller areas of vegetation.
- Schedule excavation during low-rainfall periods when possible.
- Fit development to the terrain.
- Excavate immediately before construction instead of exposing the soil for months or years.
- Cover disturbed soils with vegetation or mulch as soon as possible and thus reduce the hazard of erosion.
- Divert water from disturbed areas.
- Control concentrated flow and runoff, thus reducing the volume and velocity of water from work sites and preventing the formation of rills and gullies.
- Minimize the length and gradient of slopes (e.g., use bench terraces).
- Prevent the movement of sediment to offsite areas.
- Inspect and maintain all structural control measures.
- Install windbreaks to control wind erosion.
- Avoid soil compaction by restricting the use of trucks and heavy equipment to limited areas.
- Break up or till compacted soils prior to vegetating or placing sod.
- Avoid dumping excess concrete or washing trucks onsite.

Soil will be exposed during construction. It is essential that the exposed area is minimized and that a protective cover is quickly established. Conservation practices that provide immediate permanent cover (sod) or provide intermittent cover (mulching and seeding) are very effective in controlling erosion and runoff. Other practices, such as diversions and terraces, also help to control erosion and runoff. They provide temporary protection until vegetation or sod become established, and they provide permanent protection for the site.

## Reference for Further Reading

United States Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute. 2000. Urban technical note no. 1. Web accessible (http://soils.usda.gov/sqi/files/u01d.pdf).

# Erosion of Streambanks

By Lyle Steffen, Geologist, National Soil Survey Center, USDA, NRCS.

Streambank erosion destroys land and cultural features of the land. It adds sediment to streams. High streambanks typically fail through mass wasting. Sudden mass movement of a high bank is a hazard.

**High streambank erosion along a Wisconsin stream.**

**A stable stream in western Montana.**

## Processes

Stable streams are said to be in dynamic equilibrium. The stream erodes and deposits sediment at slow average annual rates. Streambank erosion is a natural process. It occurs as soil particles are eroded from the bank by flowing water or by collapse or mass wasting. Often, the base of a bank is eroded by flowing water that over steepens or undercuts the bank, resulting in a collapse. Bank erosion typically occurs on the outside edge of a bend in a stream where much higher flow velocities occur. This nearly vertical, eroding surface is called the cut bank. Deposition typically occurs on the inside of a bend as point bar deposits in the more slowly moving water.

Stable streams laterally migrate across and down their valley while moving water and sediment from watersheds. The lateral migration is accomplished through bank erosion. As the stable stream laterally migrates, it maintains its width. The banks of a stable stream generally are low enough to allow floodwater to overflow the bank in approximately 2 out of every 3 years.

Bank erosion is a dynamic process that occurs during periods of high flow and continues for a period of time after the high flows have receded. During the periods of high flow, some bends are severely eroded and others undergo little or no erosion. Determining an average annual bank erosion rate is difficult. Geologic evidence indicates, however, that stable streams take many decades to centuries to migrate from one valley wall to the opposite valley wall across their flood plain. The low height of the banks and the root systems of riparian vegetation typically help to maintain very low annual bank erosion rates.

## Change in Equilibrium

When a disturbance is introduced into the watershed, the riparian corridor, or the stream itself, the equilibrium can be lost. Land use changes upstream, such as home building, poor grazing management, or diversions of water along highways, can cause additional water to be delivered to a stream and change the equilibrium. If more water is delivered to a stream more frequently, the alluvial channel will probably become larger in response to the increased flows. If the erosion resistance of the bank materials is greater than that of the bed materials, the stream may begin to downcut. In streams where the erosion resistance of the bank materials is similar to that of the bed materials, the stream may begin to erode its banks to accommodate the new flow regime.

These changes begin a cycle of channel evolution that results in accelerated bank erosion rates. Streams may laterally migrate across the valley floor in a few decades instead of centuries. Tremendous amounts of sediment stored in flood-plain deposits enter the stream during the erosion process. Less than half of this sediment is deposited directly downstream. The rest travels much farther downstream. The increased sediment loads typically create water-quality problems in downstream areas.

**An area where poor grazing management has changed the extent and distribution of grass species in the watershed, causing increased runoff. The changed runoff pattern caused the channel to downcut. The higher banks are sloughing into the channel as it attempts to widen following the downcutting. The headcuts will continue to migrate upstream, creating more instability.**

## Stabilization

Channel evolution continues until the stream reaches a new state of dynamic equilibrium. At this point, the channel has become large enough to allow sediment deposition to begin the process of stabilization. The channel evolution process is accelerated in zones with greater rainfall, especially in streams with erosive soils in their bed and on their banks. In Mississippi, for example, channel evolution processes run their course in 40 years or less.

In the glaciated regions of the upper Mississippi River basin, such as eastern Nebraska, channel evolution has remained in the enlarging phase for over 100 years, mainly because the streambank soils are more resistant to erosion.

A stablizing stream in Mississippi. The streambed downcut in the late 1950s in response to channel straightening and removal of the riparian forest. It widened and began to build anew by 1984.

An unstable stream in eastern Nebraska. It has downcut and is widening because of changes in runoff and sediment loads after land use changed from prairie to row crops in the late 1800s.

## Reference for Further Reading

United States Department of Agriculture, Natural Resources Conservation Service. 1998 (revised in 2001). Stream corridor restoration: Principles, processes, and practices. Web accessible (http://www.usda.gov/stream_restoration/).

# Expanding Soils and Shrink-Swell Potential

By Phil Camp, State Soil Scientist, Arizona, USDA, NRCS.

Homes built on expanding smectite clays without due precautions likely will be structurally damaged as the clay takes up water. Cracks will appear in walls and floors. Damage can be minor, but it also can be severe enough for the home to be structurally unsafe.

**Shrinking and swelling of expansive soils commonly result in serious cracking of homes and other structures.**

The American Society of Civil Engineers estimates that half of the homes in United States are built on expansive soils and half of these will have some damage. The group claims that these soils are responsible for more home damage every year than floods, tornadoes, and hurricanes combined.

Building contractors should take precautions to stabilize the structures. Studies in Waco, Texas, in the 1960s showed that reinforced concrete slabs would “float” on the soil and insulate a one-story structure from the stress of clay expansion and contraction. One solution is post-tensioned foundations for homes. Builders put cables in the concrete. Workers then stretch the cables to help hold the concrete together. The cables must be stretched several times after the slab is poured and must be properly sealed after the process of tensioning because some components could rust and fail. Other strategies are to buffer the foundation or slab with gravel, to use pilings, and to control runoff and landscaping moisture. The USDA Rural Development has printed construction guides for one-story buildings in some States. These guides are based on soil survey information. Larger structures should be engineered specifically for the site. The real trick on expansive soils is to minimize wetting and drying.

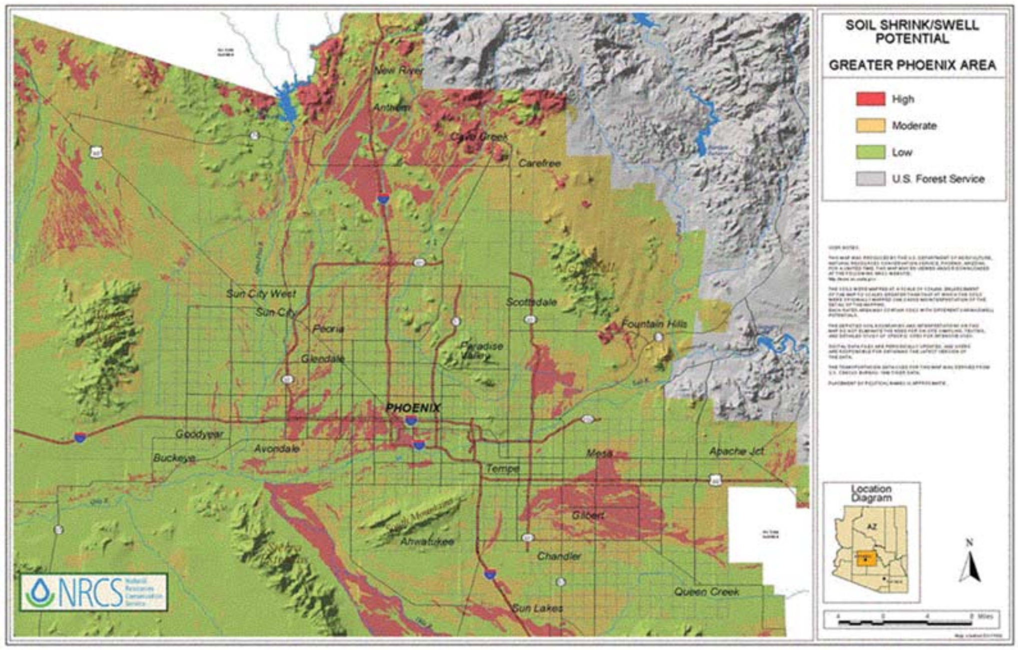
Information about shrink-swell classes and linear extensibility is available in NRCS soil survey reports. High numbers indicate that shrink-swell problems are likely. In some areas, such as the Front Range of Colorado, soft sedimentary rocks may include seams of bentonite (highly expandable smectite), less than a foot wide, that are exposed in excavations intersecting nearly vertical, upturned geologic strata.

## Precautions on Expansive Soils

The following precautions should be taken when a home or commercial structure is bought or built in areas of expansive soils.

FOR A NEW HOME:

- Ask the builder for the subdivision public report. The report should indicate if expansive soils are present and what the builder has done to minimize their effects. NRCS soil survey reports can also help to determine the presence and location of expansive soils.




**Shrink-swell potential map of Phoenix, Arizona.**

- If there are expansive soils, look into the cost of a stronger foundation, such as one reinforced by a post-tension system.
- Make sure that water drains away from the house on all sides and that builders, landscapers, and pool companies do nothing to hinder that drainage.
- Minor cracks are common in a new home as it settles but sometimes signal something more serious. To find out what is acceptable, check the minimum workmanship standards for licensed contractors in your area.
- If cracks develop in a new home, ask the builder to fix them. If they reappear, be persistent and get them fixed again.

FOR A USED HOME:

- Ask sellers if they have a copy of the subdivision public report, which should disclose the presence of expansive soils. If they do not have a copy, ask your local real estate department for one. Many departments file these reports under the subdivision name and keep them for years.
- As you examine the home, look for cracks in interior walls, especially around windows and doors and where walls meet other walls, ceilings, or doors. Look for variations in texture or paint that could indicate where cracks have been fixed. Ensure that doors and windows open and close properly. Cracks may indicate normal settling or structural problems. If you have doubts, hire a structural engineer.
- If cracks and gaps develop and your home is past warranty, hire a structural engineer to determine what is wrong and how it can be fixed.

## Landscaping on Expansive Soils

The potential for structural damage often can be minimized or the damage avoided altogether by following certain landscaping practices. On expansive soils, the main landscaping goal is to minimize fluctuations in soil water content. Proper surface drainage, plant choices, sprinkling practices, and long-term maintenance are all important. In areas that are constantly moist, the soil should be kept in that condition during extended dry periods. In the more arid areas, excess moisture and landscaping should be kept several feet away from the foundation. Surface drainage and downspout outlets should be maintained away from the foundation. Trees should be planted no closer than 15 feet from foundations. A distance of 25 to 30 feet is best. Tree roots withdraw sufficient water from soils to cause drying and cracking. Expansive soils do not swell and shrink if the moisture content remains constant. Sprinkler lines should be installed away from the house. Applying water selectively near the foundation walls helps to maintain a consistent moisture condition.

## References for Further Reading

Colorado State University Cooperative Extension. Landscaping on expansive soils. Colorado State University Cooperative Extension Bulletin 7.236. Web accessible (http://www.ext.colostate.edu/pubs/garden/07236.html).

United States Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, part 618.37, Linear extensibility percent. Web accessible (http://soils.usda.gov/technical/handbook/contents/part618p2.html#37).

# Falling Rock

By Gary B. Muckel, Soil Scientist, National Soil Survey Center, USDA, NRCS.

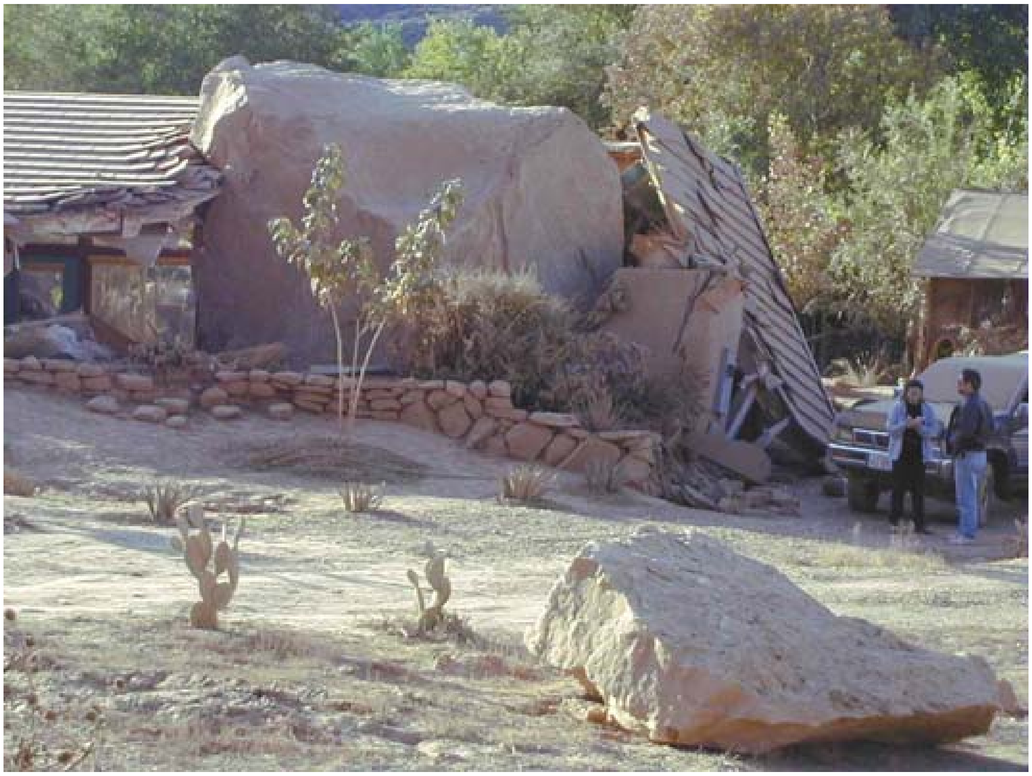
Building on mountain slopes involves various hazards. The slopes provide a scenic view of the valleys below, but there may be hazards on the hillslopes above. The hazards include landslides, which are described separately in this publication. Hillslopes provide a natural pathway for rocks and boulders to move downslope. Houses and people in this pathway can be victims of the great energy generated by the falling mass of rolling rocks or by the falling of a single rock.

## Warnings

Highway signs, such as “Falling Rock,” “Fallen Rock,” or “Rockslide Area,” are plentiful in mountain areas of the U.S. and other countries, warning us of the hazard of rocks either on the road or falling onto the road from above.


**A common warning sign along roads.**

Falling rock is one of the common dangers of mountaineering, especially in the spring and summer. This problem is so common that some mountaineering guidebooks advise against certain climbs unless hard freeze conditions will last for the duration of the climb. Even small rocks can kill, attaining a high speed as they bound down the slope. Some give a warning sound and can be avoided (dodged), while others are silent killers. When houses are built in the hills, these same warnings are sometimes forgotten. Crushed houses and vehicles are not unusual in mountainous areas.



**A large boulder that has crushed a building in Zion National Park. (National Park Service photo.)**

## Cause

Stones and boulders naturally reach lower energy levels or lower positions on the landscape. Thawing in the spring and early summer promotes detachment of the stones and boulders from the ground. The rocks then roll or drop down the hill. Rainfall also causes the release of stones and boulders. Human or animal activities upslope can jar loose rocks and boulders. Earthquakes cause boulders and rocks to give way and move down the slope.

## Recommendations

Be aware of the land around you. Building in areas with potential for rockfall is dangerous. Look at the property proposed for the building. If large rocks are on the soil surface, question the origin of the rocks and boulders. If they came from slopes above, there may be more above waiting to come down the hill. Check with the state geological survey and local county planning authorities for local information that may be available.

In some areas known for rockslides, such as Yosemite National Park, special seismometers are being installed to provide warning. Several people have been killed by rockfalls in Yosemite since the area became a park. In theory, if the cliff cracks or moves, the machines record an increase in activity and the chances of a rockfall escalate. Predicting when and where all rockfalls take place is not expected, but it is hoped that sensors will record an increased activity so officials can close areas to recreationists and evacuate adjacent villages.

Specialized engineering companies can assess the potential danger of sites, reduce the hazard, and clean up after a rockfall. Barriers are sometimes constructed, and rock bolting, wire mesh, rock fences, application of gunite on facades, and benching are techniques used to resolve specific kinds of problems.

## Reference for Further Reading

United States Department of the Interior, National Park Service. Geologic hazards. Web accessible (http://www2.nature.nps.gov/geology/hazards/).

# Floods

Adapted from Federal Emergency Management Agency Web-based information sources.

Floods are the most common and widespread of all natural disasters, except for fire. Most communities in the United States can experience some kind of flooding after spring rains, heavy thunderstorms, or winter snow thaws. Floods can be slow or fast rising, but they generally develop over a period of days. Dam failures potentially result in the worst flooding. A dam failure is usually the result of neglect, poor design, or structural damage caused by a major event, such as an earthquake. When a dam fails, a gigantic quantity of water is suddenly released, causing massive destruction.

## Emergency Information

1. Floodwaters are extremely dangerous. The force of 6 inches of swiftly moving water can knock people off their feet. The best protection during a flood is to leave the area and seek shelter on higher ground.
2. Water from flash floods moves at very fast speeds and can roll boulders, tear out trees, destroy buildings, and obliterate bridges. Walls of water can reach heights of 10 to 20 feet and generally are accompanied by a deadly cargo of debris. The best response to any signs of flash flooding is to move immediately and quickly to higher ground.
3. Cars can be easily swept away by just 2 feet of moving water. If floodwaters rise around a car, passengers should abandon the car and climb to higher ground.

## Danger Zones

Flash floods and other floods occur within all 50 States. Communities particularly at risk are those located in low-lying areas, near water, or downstream from a dam.


**Flooding in Fort Worth during the "Dust Bowl" days.**

**Rocks and debris litter a roadway after a flash flood in Weber City, Utah. (NRCS photo.)**

## What Is a Flash Flood?

Flash floods usually occur when intense storms drop large amounts of rain within a brief period. They occur with little or no warning and can reach full peak in only a few minutes.

## Flooding Facts

- Individuals and business owners can protect themselves from flood losses by purchasing flood insurance through the National Flood Insurance Program. Homeowner's policies do not cover flood damage. Information is available through local insurance agents and emergency management offices.
- Flooding has caused the deaths of more than 10,000 people since 1900. Property damage from flooding now totals over $1 billion each year in the United States.
- More than 2,200 lives were lost as a result of the Johnstown, Pennsylvania, flood of 1889. This flood was caused by an upstream dam failure.
- On July 31, 1976, the Big Thompson River near Denver overflowed after an extremely heavy storm. A wall of water 19 feet high roared down the Big Thompson Canyon, where many people were camping. A total of 140 people perished, and millions of dollars of property were lost.

## Flood-Prone Areas

Soils that are subject to flooding are indicated in the tables of soil survey reports. Soils are rated for the frequency, duration, and most likely period of flooding. In communities, more detailed maps are developed and maintained by city and county officials. The Federal Insurance and Mitigation Administration's Hazard Mapping Division maintains and updates National Flood Insurance Program maps (http://www.fema.gov/fhm/).

Building in flood-prone areas is generally poor land use management. Most communities have building codes that restrict building on flood plains. Relocation is often a recommended solution in areas that are repeatedly flooded. Elevating homes is another option in some areas. Flood insurance can be costly. Destruction of property by flooding costs the National Flood Insurance Program hundreds of millions of dollars a year. Homeowners share the responsibility and consequences of their choice to live in high risk areas. The hazard of flooding should be ascertained before a building is constructed on a particular site.

## References for Further Reading

Federal Emergency Management Agency. Hazards. Web accessible (http://www.fema.gov/hazards/floods/flood.shtm).
Federal Emergency Management Agency. Homepage (http://www.fema.gov/).
Federal Emergency Management Agency. National Flood Insurance Program. Web accessible (http://www.fema.gov/fima/nfip.shtm).

# Frost Action

By Henry Mount and Gary B. Muckel, Soil Scientists, National Soil Survey Center, USDA, NRCS.

In the northern latitudes and at high elevations in the mid latitudes of the United States, the ground freezes during winter months unless it is covered by snow. The depth of freezing ranges from a few centimeters in mild areas to 2 or more meters in colder regions. Such ground freezing can lead to frost action, causing the heaving of buildings, frozen water and sewer lines, and breakup of road surfaces (especially with alternate freezing and thawing).

## Basic Conditions for Frost Action

Three basic conditions must exist for frost action to occur:

- The soil must be susceptible to frost;
- Water must be available in sufficient quantities; and
- Temperatures must be cold enough to cause soil and water to freeze.

Without all three conditions, frost action and heaving cannot occur.

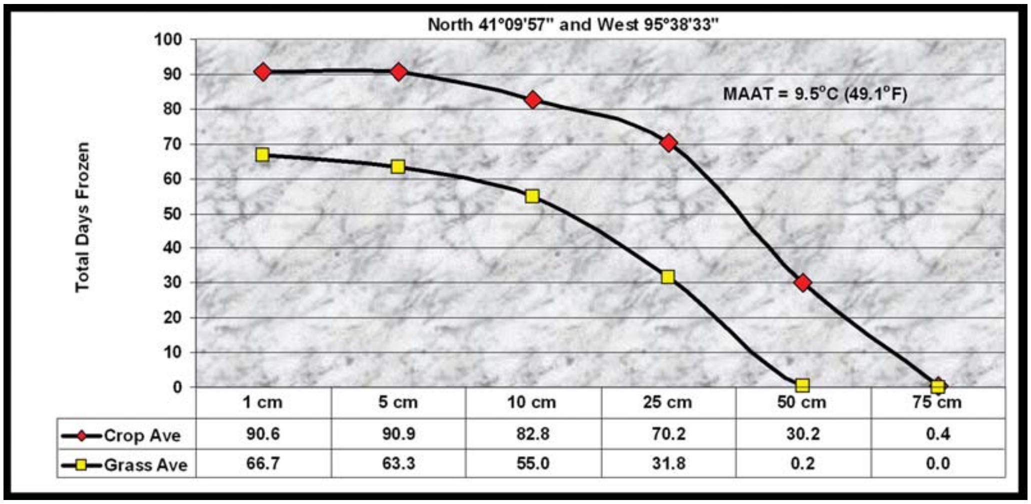
Susceptibility to frost is related to the size distribution of soil particles and the size and continuity of small voids between the soil particles. In general, free draining, coarse grained soils, such as sands and gravel, are not susceptible to frost, whereas clays, silts, and very fine sands even in small proportions support the formation of ice lenses. If frost-susceptible soils near foundations can be removed and replaced by coarser textured material, frost heaving will not occur.

Water moves from unfrozen areas to the front where water freezes and forms ice lenses. Water must be available in the unfrozen soil. A high ground-water table or wet soil conditions therefore favor frost action when soil temperatures are very cold. The high water table and wet soil conditions may inhibit frost penetration in the soils that are less cold because saturated soils have a higher specific heat than unsaturated soils. If permitted, a proper drainage system can help to keep water from reaching the freezing zone in frost-susceptible soils. Even soils with a water content well below saturation, however, can heave substantially if unsaturated flow through the soils is favorable. A barrier to waterflow in the soil reduces the potential for frost action. The process of forming ice lenses draws an excess of soil water to the freezing front. When it thaws in the spring, the soil becomes supersaturated with the excess water. This excess water liquefies the soil, causing a loss of strength. Expansion during the freezing cycle and loss of strength during the thawing cycle cause failure of road surfaces, resulting in dips and potholes.

## Depth of Freezing

Depth of freezing is largely determined by the rate of heat loss from the soil surface. Besides the thermal properties of the soil, this heat loss depends on such climatic variables as solar radiation, snow cover, wind, and air temperature (the most significant variable). If loss of heat can be prevented or reduced, frost-susceptible soils may not have freezing soil temperatures. Soil temperature studies throughout the U.S. have shown that soils in areas of woodland rarely freeze, even near the surface. Snow and leaf litter act as thermal blankets that keep these soils from freezing even in areas of extreme winter cold. Roads, however, are cleared of snow and are susceptible to freezing and thawing.

The depth of soil freezing is important for homeowners. Some soils may freeze for only a few days from a depth of 1 to 5 centimeters. Other soils can freeze to a depth of 75 or more centimeters, depending on air temperature and ground cover. The following graph shows the impact of freezing at the Deep Loess Station, Agricultural Research Service, in Treynor, Iowa (1995-2001 data), and the relation to two different kinds of surface cover, crops and grass.




**Frost penetration and duration in Treynor, Iowa.**

## Prevention of Frost Damage

The conventional approach to foundation design is to prevent frost damage by ensuring that the foundation footing is placed beyond the depth of expected maximum frost penetration, so that the soil beneath the footing will not freeze. This measure alone, however, does not necessarily prevent frost damage. The depths at which foundation footings should be placed are normally determined by local experience, as incorporated in local building codes.

Where possible, it is a good practice to remove frost-susceptible soil and replace it with coarse granular material that provides a barrier to unsaturated flow. Good drainage practices also should be followed, including the installation of drainage tile around the perimeter of the foundation. In recent years lightweight plastic insulation has been used extensively to reduce ground heat loss and hence the depth of frost penetration in very cold regions.

Other concerns in frost-prone areas are water and sewer lines and septic systems. Following local codes helps to ensure that the lines are buried below the depth of frost. Sprinkler lines, which typically are near the soil surface, should be drained before the soil freezes. Water lines buried under driveways and walkways are more susceptible to freezing because snow is removed from these areas and frost penetrates deeper into the soil.

Good road surface drainage is important. Filling cracks in roads helps to keep water from entering into or under the pavement.

## Potential for Frost Action

Soil survey reports indicate the potential for frost action in those areas where frost action occurs. The terms describing the potential are:

- *Low.*—Soils are rarely susceptible to the formation of ice lenses.
- *Moderate.*—Soils are susceptible to the formation of ice lenses, which results in frost heave and subsequent loss of soil strength.
- *High.*—Soils are highly susceptible to the formation of ice lenses, which results in frost heave and subsequent loss of soil strength.

## Reference for Further Reading

United States Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, part 618.29, Frost action potential. Web accessible (http://soils.usda.gov/technical/handbook/contents/part618p2.html#29).

# Gypsum in Excess

By Gary B. Muckel, Soil Scientist, National Soil Survey Center, USDA, NRCS.

Gypsum is the most common sulfate mineral in soils in the Western United States. Gypsum in soils generally is an evaporite. It is mobile when dissolved in water and deposited in the soil or on the soil as the water evaporates.

## Occurrence

Gypsum primarily occurs in soils of the arid parts of the world. In the United States, it occurs primarily in closed basins in New Mexico, Texas, Utah, Arizona, Nevada, Wyoming, and California. To a lesser degree, some soils in North Dakota, Montana, Oklahoma, and South Dakota also have gypsum. These soils generally are in areas where the parent material is high in content of sulfates.

In some areas, such as the Alamogordo area of southern New Mexico, gypsum dominates the soil. The White Sands National Monument is probably the most familiar location. The gypsum there occurs as sand-size particles. Gypsum can occur as particles of other sizes but is less common in the finer particle-size fractions.

**White Sands National Monument. (National Park Service photo.)**

## Limiting Properties of Gypsum

Gypsum is somewhat soluble, so it has several undesirable effects. Excess water, such as runoff water from a roof eave, can dissolve soil around the base of a house. Irrigation in areas with gypsum also can result in dissolution. The material goes into solution or easily erodes and forms solution cavities, pipes, and gullies. Generally, maintenance and leveling costs are high where soils containing gypsum are used for irrigated crops. Gypsum can go into solution and then reprecipitate. When this process occurs around a root, further water and nutrient uptake can be restricted. As a calcium-based mineral, gypsum inhibits the uptake of zinc, magnesium, iron, copper, and phosphorus in plants, resulting in nutrient deficiencies. The cation-exchange capacity is reduced, and thus the level of fertility is lowered. Reprecipitation of gypsum can result in root and water restrictions in the soil and can cause increased salinity above a gypsum pan. The somewhat high solubility of gypsum increases the osmotic potential of the material. As a result, the availability of water to plants can be decreased.

Gypsum is corrosive to concrete. Soils high in content of gypsum require special cement, special treatment, or density enhancement. The ions in gypsum react with the cement and weaken the concrete. Associated sulfates, such as sodium sulfate and magnesium sulfate, also contribute to the deterioration of concrete. Corrosion of concrete is most likely to occur in soils that have more than about 1 percent gypsum and are in areas where wetting and drying occur.

Soils with more than 10 percent gypsum may collapse if the gypsum is removed by percolating water. Even areas of low rainfall can receive enough extra water to cause problems in these soils. Diverting surface water away from the house and roof gutters and piping runoff away can help to alleviate the problems.

## Information Sources

Soil survey reports identify soils that contain gypsum. The tables showing soil properties indicate the percentage of gypsum in the soils. Some areas with gypsum have been identified as miscellaneous land types, such as Badlands. These areas are unsuited to agriculture. The information in soil survey reports may not be adequate for an evaluation of all the concerns associated with gypsum.

As a soil mineral, gypsum is so significant that it is recognized at various levels of the U.S. soil classification system, or soil taxonomy. The soils that contain gypsum can be identified in the official soil series descriptions (http://soils.usda.gov/technical/classification/osd/index.html). Use the query option for "gyp*" at the suborder level and for the mineralogy class.

## References for Further Reading

Corrosion-Doctors Web site: http://www.corrosion-doctors.org/Concrete/Portland.htm.

United States Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, part 618. 30, Gypsum. Web accessible (http://soils.usda.gov/technical/handbook/contents/part618p2.html#30).

United States Department of Agriculture, Natural Resources Conservation Service. Official soil series descriptions. Web accessible (http://soils.usda.gov/technical/classification/osd/index.html).

# Hydro-Compactible Soils

By Kenneth F. Scheffe, State Soil Scientist, and Stephen L. Lacy, Geomorphologist, New Mexico, USDA, NRCS.

## Introduction

A collapsible soil is one that undergoes appreciable loss of volume upon wetting, load application, or both. These soils are also referred to as hydro-compactible soils or low-density soils. The amount of collapse can reach nearly 20 percent of the soil's original volume. In many circumstances, settlement of hydro-compactible soils can be relatively rapid and have devastating effects on structures and facilities.

Collapsible soils are relatively stable until runoff is concentrated in areas where land use changes introduce homes, other structures, roads, irrigation, septic systems, or leaking water lines. The original European settlements in the arid Southwest have expanded from the stream valleys and low terraces onto nearby alluvial fans, which may have collapsible soils. Special attention and care are needed when these areas are developed. It is far easier and cheaper to avoid collapsible soils than to remediate them. Local soil survey publications can help users to identify hydro-compactible soils.

## Occurrence

Collapsible soils occur throughout the world but are primarily in arid and semiarid areas, including Arizona, California, Nevada, Colorado, Utah, and New Mexico.


**Concentric cracks caused by soil collapse near abandoned buildings in New Mexico. (NRCS photos.)**

A common characteristic of these soils is recent and rapid deposition, usually during floods of short duration but high intensity. This deposition results in an inherently unstable internal soil structure. The generally dry conditions of the area cause these deposits to desiccate quickly in their original condition, without the benefit of further reworking or packing of the sediment grains by water.

Alluvial fans in areas with as much as 20 inches of annual precipitation in the Southwestern United States commonly form along the flanks of hills and mountain ranges. During periods of significant, usually intense precipitation, soil and rock material in the form of fan alluvium, debris flow, or mud flow can move rapidly downslope. These flows move in mass with little mixing and stop only where channels open into less sloping areas, allowing the flow to become wide and then shallow. When the material stops moving, water drains from the flow, leaving the soil body intact. Voids, which contained water during periods of flow, are replaced by air. The resulting soil mass has high porosity and a high ratio of voids to soil (a high void ratio).

**Alluvial fan prone to soil collapse. (NRCS photo.)**

**A channel cut with loose packing of the alluvial material.**

The final strength of the soil is sufficient to maintain the soil's own weight. Subsequent deposits on top of this porous soil do not wet the soil sufficiently to induce collapse. As the deposit builds, less and less water from the sporadic and episodic deposition above reaches the collapsible soil and consequently does not induce collapse. The soil supports considerable overburden weight. Collapsible soils generally have a maximum thickness of about 60 to 80 feet.

## Identifying Properties

The following characteristics seem to be common among hydro-compactible soils:

- A high void ratio—a loose honeycomb of silt and sand particles coated and held together with clay or other cementing agents, such as salts and carbonates.
- Low bulk density, generally 1.1 to 1.4 grams per cubic centimeter.
- Geologically young age.
- A clay content of less than 30 percent and most commonly 10 to 15 percent.
- Less than 10 percent moisture content (far less than saturation).
- A large percentage of pore space, in the range of 40 to 60 percent.
- Most commonly, an arid or semiarid climate.

Application of experience with and knowledge of collapsible soils in similar geomorphic positions may be the best indicator of the potential for collapse.

Features to look for in developed areas include:

- Ponding and poor surface drainage.
- Concentric or curving cracks in soil or asphalt.
- Tilted structures.
- Misaligned, cracked, or separated joints in concrete slabs and curbs.
- Evidence that cracks in structures or roads have been repaired.

In undeveloped areas detection is more difficult. Small depressions in areas of fan deposits not associated with grading or removal of material should be suspect, as should "sinks" created where human activities have concentrated or impounded runoff, especially where soil and parent materials are not soluble and subject to solution subsidence.

## Mechanisms of Collapse

The mechanism of collapse is quite simple. Collapse occurs as water enters the pores between the individual sand and silt grains and weakens the "bonding" of the clays or other binding agents. Overburden or applied weight causes soil particles to slide across one another (shear), filling voids and resulting in a reduction in the overall volume of the soil. Collapse in any part of the profile causes the collapse of the entire profile, and whatever sits on the soil moves with the collapsed soil, either intact or in pieces.

## Inducing Collapse Prior to Construction

When a sufficient amount of water can be supplied to a site, ponding or injection of water into collapsible soil is often used as a means to induce collapse before construction. Another method is to excavate the soil material and repack. Some choose to excavate the collapsible soil and replace it with compacted gravel beneath the footing. An excessive load of fill may be piled on the collapsible soil to induce collapse. After the collapse, the fill is removed back to the grade level. Dropping a very heavy weight on the soil (dynamic compaction) may induce the collapse. This treatment can be used during dry conditions.

**Low water-use landscaping and drainage away from buildings help to prevent soil collapse. (NRCS photo.)**

## Stabilization

On sites that support structures, stabilization techniques are applied to prevent collapse and consequent damage. Russian engineers have experimented with injecting hot gasses (more than 900 degrees C) into the soil to “fire” the soil clays into a ceramic state. Other methods include injection of ammonia gas, sodium silicate, lime, or Portland cement to stabilize the clay or cause cementation. These methods are not the most effective ways to deal with collapsible soils, but they may be the only options in some cases.

## Practices That Minimize the Risk of Collapse

- Reduce the load per unit area; however, collapsible soils can fail under their own weight when wetted.
- Build large structures on floating foundations or with piles driven below the collapsing soil depth.
- Convey surface waters from streets, gutters, roofs, and parking lots to offsite or noncollapsible areas.
- Restrict the use of septic systems or locate septic systems away from homes.
- Waterproof sewer and street drains to prevent seepage.
- Seal surface soil layers with liners or cement.
- Avoid building on collapsible soils.

## References for Further Reading

Love, D.W. 2001. What decision makers should know about collapsible soils in New Mexico. New Mexico Decision-Makers Field Guide, New Mexico Bureau of Mines and Mineral Resources.

Pawlak, S.L. 2002. Evaluation, design and mitigation of project sites in collapsible soil areas in western Colorado. Hepworth-Pawlak Geotechnical.

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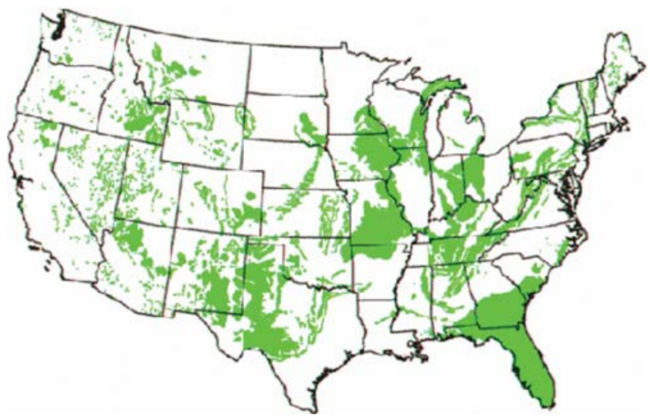
# Karst Landscapes

By Darwin L. Newton, State Soil Scientist, Tennessee, USDA, NRCS.

Karst landscapes present risks to many types of land use, including agriculture, houses and business structures, roads, and dams. Areas of karst landscapes demonstrate differential settlement and subsidence, which cause increased costs of construction and delays in construction. Evaluation of construction sites and specially designed measures are necessary.

Karst topography, which includes such features as sinkholes, caves, springs, disappearing streams, and uneven surfaces, is exhibited in many areas of the United States. The term "karst" has its origin in the region of Trieste, Italy, and adjacent Slovenia, which is characterized by a well developed sinkhole plain.

Karst features in the United States are in areas where carbonate and other soluble rocks have dissolved. Karst topography is most notable in the Midwest and South, in Iowa, Missouri, Indiana, Kentucky, Tennessee, Arkansas, Georgia, and Florida.



**Areas of karst in the U.S. (National karst map, USGS.)**

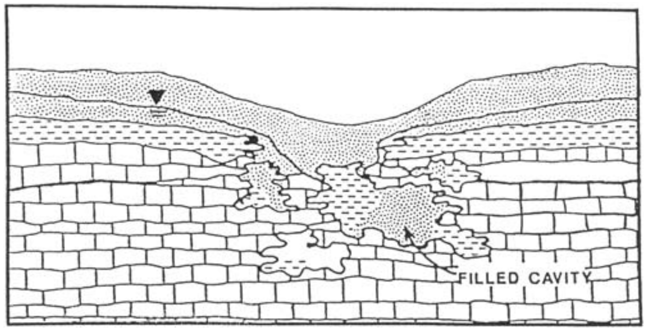
Urban sprawl in the United States continues at a rapid rate as suburbs grow from major cities. In some areas the sprawl encompasses large areas on karst plains. Development on these plains involves risk to human life and property. Before development is undertaken, risk assessment is necessary to ensure maximum utilization of an area while minimizing the risk to life and property. Extensive studies using dye trace and geotechnical studies have developed risk-assessment criteria and models. Assessments address nonpoint and point source contaminates of ground water, sinkhole flooding, and sinkhole collapse. Even with evaluation, risks remain.

## Geologic Characteristics

Although not unique to limestone, karst is primarily identified with limestone dissolution and the resulting sinkhole features. Limestone has more than 50 percent carbonate minerals.

The formation of karst is more likely in areas of rocks with a higher content of carbonate minerals than in areas of rocks with a lower content of these minerals. Karst also depends on the porosity of the limestone and the abundance of water.

Sinkholes and a landscape with no noticeable surface streams characterize karst areas. These areas have extensive underground drainage systems. Three types of sinkholes have been defined. These are solution sinkholes, collapse sinkholes, and subsidence sinkholes. Solution sinkholes result from surface dissolution of bedrock. Collapse sinkholes result from bedrock




**Solution sinkhole. (Destephen  and Wargo, 1992.)**

collapse through subsurface dissolution, and subsidence sinkholes result from environmental disturbance (ground-water change, loading, etc.).

Karst areas pose a hazard to life and the well-being of our environment. Cars can drive into sinkholes, livestock can fall into the sinkholes, and wells and ground water can be contaminated. In the age of environmental awareness, risk assessment in these areas is necessary to minimize the loss of life and degradation of the environment.

Soil survey reports generally indicate the presence of sinkholes in the map unit descriptions and commonly indicate known sinkholes on the detailed soil maps through delineation of large areas and use of an open diamond as a standard landform feature symbol.

**Sinkholes indicated by diamond-shaped symbols.**

**Sinkholes in Boone County, Missouri.**

## References for Further Reading

Beck, B.F. 1984. Sinkhole terminology. *In* Proceedings of the First Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Florida Sinkhole Research Institute, Orlando, Florida.

Destephen, R.A., and R.H. Wargo. 1992. Foundation design in karst terrain. Bulletin of the Association of Engineering Geologists 29:165-173.

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U.S. Geological Survey. Karst Interest Group Proceedings, 2002. Web accessible (http://water.usgs.gov/ogw/karst/kig2002/jbe_map.html).

U.S. Geological Survey. Land subsidence in the U.S. USGS Fact Sheet-165-00, December 2000. Web accessible (http://water.usgs.gov/ogw/pubs/fs00165/).

# Landslides

By Chuck Gordon, State Soil Scientist, Montana, USDA, NRCS.

The word "landslide" is a general term for most types of mass-movement landforms and processes involving the downslope movement of soil and rock materials. Although landslides have many causes, most involve earth materials with low shear strength, ground-water saturation of materials, an interruption of the slope by natural causes or human activities, or a combination of these.

## Cause and Location

There are two primary causes for slope failure or landslides. One involves an uneven distribution of weight on a slope. Adding weight to the top of a slope (fill, a structure, tall trees, soil saturation, etc.) or removing weight at the toe of a slope (excavation, erosion, drainage, landslide, etc.) causes the weight on the slope to be uneven and thus often results in slope failure. The second cause of slope failure is typically the wetting of a weak layer that is inclined at the same angle as the ground surface. Water can reduce the strength of the weak layer and lubricate the layer, allowing the upper block of wet soil to slide down the slope. A variation of this cause is the accumulation of water on a soil or rock layer with a low permeability rate. The water can saturate the layers above the water restriction, adding weight to the upper layers. The water on top of the restrictive layer can also reduce the shear strength of the soil and lubricate any failure planes, causing a slope failure.

Large landslides are most common in areas of shale and other soft sedimentary material. Landslide deposits commonly have many seeps, springs, and depressions that have small ponds or bogs.

Landslides are hazardous to life and property both in the landslide itself and in the areas where the landslide material is deposited. Some landslides are stable and unlikely to move again; others remain unstable and can be reactivated by basal undercutting, such as that caused by stream erosion or by excavation. Movement can also recur because of increased ground-water pressure, such as that induced by the removal of forest cover or the diversion of drainage water to unusual slope positions. Landslides can by reactivated by some management practices, such as excavation. Excavation for road construction can be particularly hazardous.

Landslides constitute a major geologic hazard because they are widespread, occurring in all 50 States, and cause $1 to 2 billion in damage and more than 25 fatalities on average each year. Landslides pose serious threats to highways and structures that support fisheries, tourism, timber harvesting, mining, and energy production as well as general transportation. Landslides commonly accompany other major natural disasters, such as earthquakes and floods, that exacerbate relief and reconstruction efforts, and expanded development and similar kinds of land use have increased the incidence of landslide disasters.

Landslides are common throughout the Appalachian region and New England. The greatest hazard in these areas is from sliding of clay-rich soils. Related damages in urban areas, such as Pittsburgh, Pennsylvania, and Cincinnati, Ohio, are among the most serious in the United States. Landslides also occur across the Great Plains and into the mountain areas of the Western United States, in areas of weathered shale and other clay-rich rocks, particularly in areas of steep slopes, periodic heavy rains, and vegetation loss after wildfires. Earthquakes and volcanoes also cause landslides. The catastrophic 1980 eruption of Mount St. Helens in Washington was preceded by the development of a large landslide on the north side of the volcano. In 1994, the Northridge earthquake in the San Fernando Valley triggered thousands of landslides in the Santa Susanna Mountains north of the epicenter.

Landslides are hazardous. (Photo by Chuck Gordon, USDA, NRCS.)

Soil debris from a landslide. (NRCS photo.)

## Landslide-Prone Areas

The following locations are generally prone to landslides—existing old landslides, steep slopes or the base of slopes, areas in or at the base of minor drainage hollows, the base or top of an old fill slope or steep cut slope, areas where part of the natural slope is interrupted, and developed hillsides where leach field septic systems are used.

## Features Prior to Major Landslides

- Springs, seeps, or saturated ground in areas that have not typically been wet before.
- New cracks or unusual bulges in the ground, street pavements, or sidewalks.
- Soil moving away from foundations.
- Ancillary structures, such as decks and patios, tilting and/or moving relative to the main house.
- Tilting or cracking of concrete floors and foundations.
- Broken water lines and other underground utilities.
- Leaning or offset telephone poles, trees, retaining walls, or fences.
- Sunken or down-dropped roadbeds.
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content).
- Sudden decrease in creek water levels though rain is still falling or just recently stopped.
- Sticking doors and windows and visible open spaces indicating jambs and frames out of plumb.

## Minimizing the Risk of Landslides

The risk of landslides can be minimized in a number of ways.

First, avoid steep slopes or areas with noticeable mass movement when choosing a building site. Avoid disturbing the natural land surface in areas of shale and other soft sedimentary material.

Be leery of naturally wet areas with seeps and springs that might indicate water problems. Slope stability decreases as water moves into the soil. Do not allow surface waters to saturate a sloping soil. Springs, seeps, roof runoff, gutter downspouts, septic systems, and poorly graded sites, all of which can result in ponding or surface runoff, are sources of water that often increase the risk of landslides. Properly locate diversion channels to help redirect runoff away from areas disturbed during construction. Runoff should be channeled and water from roofs and downspouts piped to stable areas at the bottom of the slope. Seek professional assistance in selecting the appropriate type and location of a septic system. Septic systems located in fill material can saturate soil and increase the risk of landslides.

Note unusual cracks or bulges at the soil surface. These might be typical signs of soil movement that may lead to slope failure. Alter the natural slope of the building site as little as possible during construction. Never remove soil from the toe or bottom of the slope or add soil to the top of the slope. Landslides are less likely to occur on sites where disturbance has been minimized. Seek professional assistance before earth-moving begins.

Remove as few trees and other vegetation as possible. Trees develop extensive root systems that are very useful in slope stabilization. Trees also remove large amounts of ground water. Trees and other kinds of permanent plant cover should be established as rapidly as possible and maintained to reduce the risks of erosion and landslides.

## Repairing a Landslide

Geotechnical engineers should usually be brought in to remediate a slope failure. Slope failures are both dangerous and complex, and any remediation work should involve skilled and experienced geologists and engineers.

## Additional Information and Sources

Contact the local city or county planning commission, local insurance agencies, local offices of the Natural Resources Conservation Service, the local conservation district, professional geotechnical engineers, or geological survey professionals for information about the stability of the slopes in the area of concern.

United States Department of Agriculture, Natural Resources Conservation Service. Landslide prevention in eastern Kentucky. A brochure by RC&D Councils of eastern Kentucky.

United States Geological Survey (http://landslides.usgs.gov and http://landslides.usgs.gov/html_files/landslides/newsinfo.html).

# Liquefaction of Soils by Earthquakes

Adapted from the USGS Hazards Web site.

While not a soil risk, the hazard of earthquakes sometimes relates to soils. Soil survey reports can be used to assess the damage that might result from soil liquefaction during an earthquake.

## Soil Type and Shaking Hazard

Ground shaking is the primary cause of earthquake damage to human-made structures. Seismic shaking is stronger in some areas than in others because the soil or geologic material amplifies ground shaking. The strongest amplification of shaking includes water-saturated soil and artificial fill. Loose or uncompacted fill is more susceptible to shaking than well compacted fill. The shaking often causes liquefaction of fine textured, saturated soils.

Other factors influence the strength of earthquake shaking at a site, including the earthquake's magnitude and the site's proximity to the fault. These factors vary from earthquake to earthquake. In contrast, water-saturated earthen materials and soils always amplify shear waves. If an earthquake is strong enough and close enough to cause damage, the damage will usually be more severe in areas of these materials.

## Soil Liquefaction

Liquefaction is a phenomenon in which the strength and stiffness of a soil are reduced by earthquake shaking or other rapid loading. Liquefaction and related phenomena have been responsible for tremendous amounts of earthquake damage around the world.

Liquefaction occurs in soils at or near saturation, especially the finer textured soils. The water must nearly fill the space between the particles. The water exerts pressure on the soil particles that influences how tightly the particles are pressed together. Prior to an earthquake,

**Highway offset by an earthquake fault in east-central Idaho. (Photo by Karl Hipple, USDA, NRCS.)**

**Severe road damage caused by an earthquake in east-central Idaho. (Photo by Karl Hipple, USDA, NRCS.)**

**California earthquake of 1994. (USGS photo.)**

**Damage caused by soil liquifaction during a major earthquake. (NRCS photos.)**

the water pressure is relatively low. Earthquake shaking can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other. When liquefaction occurs, the strength of the soil decreases and the ability of the soil to support building foundations and bridges is reduced.

Liquefied soil exerts higher pressure on retaining walls, causing them to tilt or slide. This movement can cause settlement of the retained soil and destruction of structures on the ground surface. Increased water pressure can also trigger landslides and cause the collapse of dams. If a hillside starts to slide, the soil loses its strength and flows away like a liquid. Roads may crack and split as subgrade materials liquefy. Because liquefaction primarily occurs in saturated or nearly saturated soils, its effects are most commonly observed in low-lying areas near bodies of water, such as rivers, lakes, bays, and oceans. Upland soils that have a large percentage of silt and substantial moisture but are not saturated also can liquefy.

## Strategies That Reduce the Hazard of Liquefaction

Three strategies can reduce the hazard of liquefaction when new buildings, bridges, tunnels, or roads are designed and constructed:

- Avoid construction on soils that are susceptible to liquefaction. By characterizing the soil at a particular building site, one can decide if the site is susceptible to liquefaction and therefore unsuitable for the desired structure.
- If it is necessary to build on liquefaction-susceptible soils because of space restrictions, a favorable location, or other factors, it may be possible to design the foundation elements so that the structure can resist the effects of liquefaction.
- Mitigate the hazard of liquefaction by improving the strength, density, and/or drainage characteristics of the soil.

These strategies apply to the upper 100 feet or so of the earth's surface, which is far beyond the normal range of the soil descriptions in soil survey reports. Standard soil surveys generally address only the upper 2 meters of the earth's surface.

## References for Further Reading

http://www.ce.washington.edu/%7Eliquefaction/html/main.html
http://earthquake.usgs.gov/
http://quake.wr.usgs.gov/prepare/hazards.html

# Permafrost-Affected Soils

By Joe Moore, State Soil Scientist Alaska, USDA, NRCS.

Permafrost-affected soils are subject to various hazards when disturbed. They require special management.

## Types of Permafrost

Permafrost takes many different forms in soils. Thin ice lenses are disseminated throughout some soils. Other soils, especially old soils that have fine grained textures and are on high terraces or on footslopes, have massive ice in the form of large blocks and wedges.

## Reaction to Disturbance

Permafrost in many soils of Alaska is relatively warm, just below 32 degrees F. These soils are insulated by a cover of vegetation. If the vegetative cover is disturbed by wildfire or cultural practices, insulation is lost and the permafrost will begin to melt. If a soil contains large amounts of sand and gravel, there will be no change in the strength or stability of the soil as the permafrost thaws. The stability of the soil is nearly the same, whether frozen or thawed. If a soil has finer textures (silt and clay) and disseminated ice, the soil can become supersaturated and liquefy as the permafrost thaws. Such a soil will lose all strength and stability unless the meltwater eventually drains off. If the soil has large blocks and wedges of ice, large voids and pits will appear in the soil as the blocks of ice melt. The resulting pitted landscape is known as *thermokarst* and is very disruptive to almost all land uses.

**Massive ice in the form of a wedge buried in a permafrost-affected soil. The wedge-shaped feature is relatively pure ice. The surface is dirty because the fine materials melted out of the overlying soil. (Photo by Joe Moore, USDA, NRCS.)**

Wildfires disturb or destroy the insulating vegetative cover on permafrost-affected soils. Within a year, the permafrost will begin to thaw and meltwater will be released. The intensity of the burn determines the amount of thawing. (Photo by Mark Clark, USDA, NRCS.)

An agricultural field with a large pit, or thermokarst, resulting from the melting of massive ice several feet below the soil surface. It may take many years after the surface is disturbed for the buried blocks of ice to melt. (Photo by Alaska NRCS staff.)

**Collapse of a section of the Alaska Highway in 1982 after massive ice under the roadbed melted. (Photo by Joe Moore, USDA, NRCS).**

**The result of building a conventional foundation on permafrost-affected soils containing massive ice. Heat transfer from the house resulted in melting of the ice and displacement of the foundation. (Photo by Alaska NRCS staff.)**

**Permafrost-affected soils with loamy textures become saturated and unstable if allowed to thaw. In areas of these soils, the trans-Alaska oil pipeline is elevated above the ground. (Photo by Alaska NRCS staff.)**

## Management

Permafrost-affected soils can be managed for many uses. An understanding of the properties of each soil is critical. In some cases it is desirable to maintain insulation and allow the soil to remain frozen and stable. Other soils, however, can be successfully thawed, allowed to drain naturally, and used for agriculture.

It is critical that those soils containing massive ice be identified before land use decisions are made. Conventional development on such soils is likely to end in failure as ice blocks eventually melt. Well designed engineering practices that keep the soils insulated allow successful development. Onsite drilling is often necessary to identify the location of individual ice blocks.

## References for Further Reading

Soil survey reports in Alaska identify permafrost as a limiting feature in interpretation tables and as a soil property in the tables on engineering properties. Permafrost-affected soils are in the soil order Gelisols.

Additional information is available at http://soils.ag.uidaho.edu/soilorders/gelisols.htm.

# Postfire Runoff

By Chuck Gordon, State Soil Scientist, Montana, USDA, NRCS.

Wildfires are an integral part of nature. They can have many positive effects on plant ecology and wildlife habitat but also can have devastating effects on life and property. Besides the direct effect of the fire itself, postfire runoff problems can occur. Slopes left denuded by forest or range fires are susceptible to accelerated erosion, flash flooding, and debris flows because of the scarcity of vegetation and roots that bind the soil and chemical changes in the soil that prevent water absorption.

## Hydrophobicity

Fires of very high temperature can result in hydrophobicity of the soil surface. When the surface becomes hydrophobic, a drop of water placed on the soil will remain intact and does not spread out and enter the soil. Plant leaves, twigs, branches, and needles normally form a layer of litter and duff on the forest floor and under chaparral and shrubs. After intense heating, a waxy substance derived from burned plant material coats the soil particles in a thin layer of soil at or below the mineral soil surface. The waxy substance penetrates the soil as a gas and solidifies as it cools, forming a waxy coating around soil particles. The layer appears similar to nonhydrophobic layers. During the interval between fires, hydrophobic substances accumulate in this layer. During an intense fire, these substances move into the mineral soil. Some soil fungi excrete substances that make the litter and surface layer repel water.

## Effects of Hydrophobicity

Fire-induced water repellency affects both the soil and the watershed, as follows:

- Repellency changes the distribution of water; less water enters the soil as the amount of runoff increases.

**Wildfire. (Photo by National Interagency Fire Center.)**

**An area affected by rapid runoff following a fire. (NRCS photo.)**

**An area where barriers to runoff have been installed.**

- Increased runoff can cause damaging flows in stream channels.
- Increased runoff results in more erosion and loss of fertile topsoil.
- Increased erosion contributes sediment to the lower areas, clogging stream channels and lowering water quality.
- Depending on the intensity of the fire, hydrophobic layers can persist for a number of years, especially if they are relatively thick. A smaller amount of water penetrating the soil means less water available for plant growth.

## Recovery Techniques

Several recovery techniques can reduce the hazards associated with postfire runoff. The amount of remaining vegetative cover, woody material, soil texture, soil crusting, surface rocks, and slope of the land should be considered in any rehabilitation work, in addition to the extent and thickness of any hydrophobic layer. Revegetation and structural practices assist in the recovery from the aftermath of a wildfire. Vegetation is one of the most important factors influencing erosion if the soil can allow adequate moisture entry. The vegetation helps to control erosion by shielding the soil from the impact of raindrops, by maintaining a soil surface capable of absorbing water, and by slowing the amount and velocity of runoff. A few of the structural practices that aid in the recovery process are straw wattles, which stabilize slopes; contour tree felling; mulching; temporary check dams; concrete barriers; and rock-lined channels.

## References for Further Reading

California Geological Survey. Hazards from mudslides in wildfire areas. Web accessible (ftp://ftp-fc.sc.egov.usda.gov/CA/programs/EWP/MudslideHazards.pdf).

United States Department of Agriculture, Natural Resources Conservation Service. California postfire recovery emergency watershed protection. Web accessible (http://www.ca.nrcs.usda.gov/programs/ewp/).

United States Department of Agriculture, Natural Resources Conservation Service. Wildfire risk reduction and recovery tips for homeowners. Web accessible (ftp://ftp-fc.sc.egov.usda.gov/CA/programs/EWP/azpmsarwldfrrecovery.pdf).

United States Department of Agriculture, Natural Resources Conservation Service, Soil Quality Institute. 2000. Soil quality resource concerns: Hydrophobicity. Web accessible (http://soils.usda.gov/sqi/files/SQIShydrophob.pdf).

# Radon Potential

Adapted from the USGS Web site.

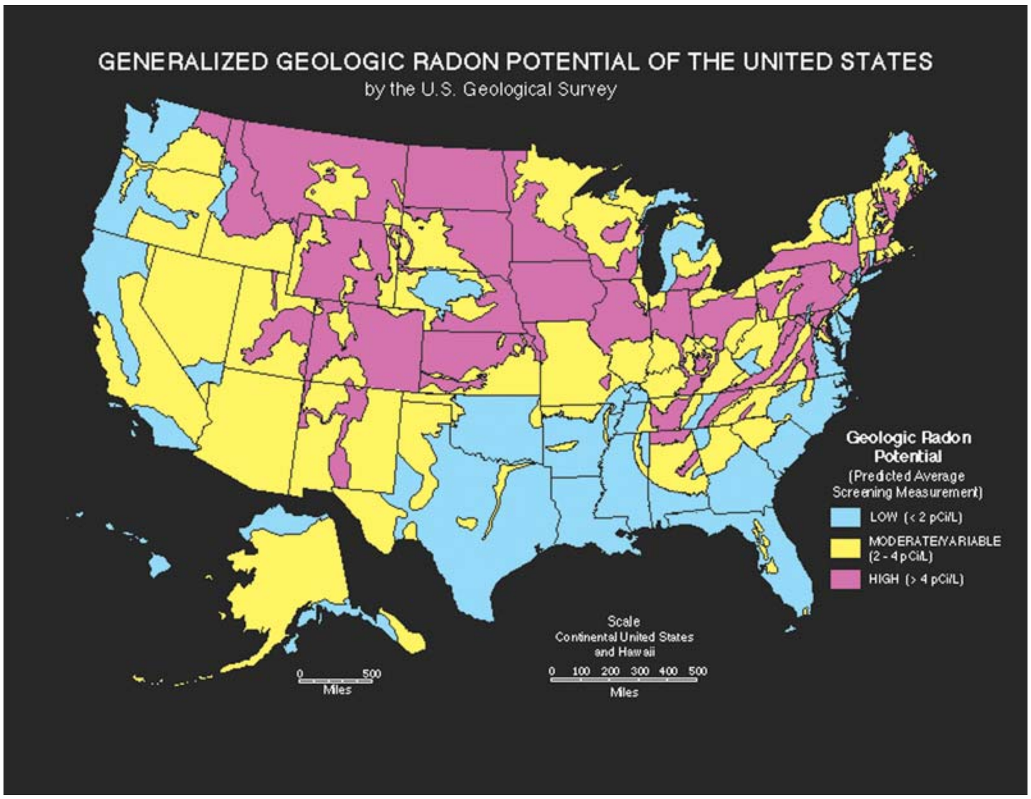
Radon derived from decay of uranium is a naturally occurring, colorless, odorless gas that is soluble in water. It is radioactive, which means that it breaks down, or "decays," and forms other isotopes. As it decays, radon releases an alpha particle that impinges on tissue, causing structural damage and possible genetic change. The rate of radon's radioactive decay is defined by its half-life, which is the time required for one-half of any amount of the radioactive isotope to decay into other isotopes. The half-life of radon is 3.8 days.

## Health Risk of Radon

Exposure to radon has been recognized as a health risk, primarily as a cause of lung cancer. Most research is focused on the dangers of inhaling radon gas and its related alpha particles.

## Radon Gas in the Home

Radon gas commonly enters the air in homes through basement foundation cracks. Ground water can carry additional radon into homes and other buildings. Dissolved radon is easily released into the air when water is used for showering, cleaning, and other everyday purposes. Water-borne radon is commonly a concern only for those who use wells for their water supply. Because of its short half-life, radon in public water supplies usually decays to low concentrations before the water is delivered to users, especially if the water has been treated. A tightly sealed dwelling may have a lower air pressure than the areas outside the home because of air escaping the vents for water heaters, furnaces, exhaust fans, clothes dryers, etc.




**Radon potential in the United States. (USGS map.)**

This lower air pressure may increase the diffusion of radon through the foundation and basement walls, and radon may become concentrated to dangerous levels in the indoor air.

## Location and Source

The source of radon is the radioactive decay of uranium. Therefore, higher radon amounts are commonly detected in areas underlain by granite and similar rocks that generally contain more uranium than other rock types. Glacial till from multiple sources is a candidate for high amounts of radon. Radon moves from its source in rocks and soils through voids and fractures. Scientists evaluate the radon potential of an area and create a radon potential map by using a variety of data. These include the uranium or radium content of the soils and underlying rocks and the permeability and moisture content of the soils. Generally, locally applicable maps are not available, and other indirect sources of information about these factors, such as geologic maps, maps of surface radioactivity, and soil maps, are used.

Scientists can measure radon in local soil air. Existing indoor radon data for homes also are useful. Data from homes are the most direct sources of information about the indoor radon potential, even though the houses that have been sampled may not be typical for the area and exact location information about the measured houses is seldom available.

A geologic map shows the type of rocks and geologic structures in a specific area. Because different types of rocks have different amounts of uranium, a geologic map can indicate the general level of uranium or radium to be expected in the rocks and soils of the area. Such maps are especially important in showing where rocks with high levels of uranium occur.

Because radon that enters buildings usually comes from the upper several feet of the earth's surface, knowing the radon levels of near-surface (surficial) materials is important. Surficial geologic and engineering maps show and describe these surface materials for many parts of the United States. Soil survey reports include descriptions and maps of the soils in the areas described. These reports provide information about the physical properties of materials at the surface, such as permeability, but they are generally not useful for determining what the uranium concentrations in the surficial materials might be.

## References for Further Reading

U.S. Geological Survey. The geology of radon. Web accessible (http://energy.cr.usgs.gov/radon/georadon/4.html).

U.S. Geological Survey. Radon potential of the Upper Midwest. Web accessible (http://energy.cr.usgs.gov/radon/midwest3/html).

# Saline Seeps

By Jimmy Ford, State Soil Scientist, Oklahoma, USDA, NRCS.

A saline seep results from a salinization process accelerated by dryland farming practices. It is an intermittent or continuous saline water discharge, at or near the soil surface, downslope from recharge areas under dryland conditions. A saline seep inhibits or eliminates crop growth in the affected area because of increased soluble salt concentrations in the root zone of the soil. Saline seeps are differentiated from other saline soil conditions by their recent and local origin, saturated root zone, shallow water table, and sensitivity to precipitation and cropping systems.

## Adverse Effects of Saline Conditions

Salts depress plant growth in one of three ways: first, prevention of soil water uptake by plant roots because of increased osmotic tension; second, disruption of the nutritional and metabolic processes of plants; and third, alteration of soil structure, permeability, and aeration. Plants vary in their tolerance to salts. Electrical conductivity (EC) is proportional to the salt content of a soil and is the most common indicator of salinity. When the EC of the soil water reaches 4 mmhos per cm, the growth of many plants is restricted. Salt-sensitive plants are affected at 2 mmhos per cm, and highly tolerant plants can withstand 8 or more mmhos per cm.

## Causes of Saline Seeps

Several types of dryland saline seeps occur throughout the northern Great Plains and in parts of the southern Great Plains. The main causes of all types of saline seeps are the geology of the region, high precipitation periods, and farming practices that allow water to move beyond the root zone and into the subsoil in areas of saline geologic formations.

In areas of native prairie vegetation, grasses and forbs use most of the precipitation and little moisture percolates below the root zone. When permanent vegetation is removed and

**Salts at the surface of a soil in Oklahoma. (Oklahoma NRCS photo.)**

replaced with crops that do not use water as efficiently, the quantity of water in the subsoil increases. Before 1940, storing soil water by using a crop fallow system was somewhat inefficient. Frequently, tillage tools provided less than optimum weed control, tractor power was minimal, and land fallowing was not timely. After 1940, more effective tillage tools became available, tractor power was adequate, and fallowing became timely. The widespread use of effective herbicides reduced weed populations during periods when crops were grown and during subsequent fallow periods. These factors increased the amount of water stored in the soil. Water in excess of plant needs contributed to saline-seep outbreaks. These outbreaks began in the 1940s and continue to the present.

The formation of saline seeps begins with a root zone filled to its water-holding capacity. With a management change from maintaining a permanent cover of grasses to growing cultivated crops or other practices that decrease water use, more water moves into the soil. Once the soil is filled to field capacity, any additional water that moves through the root zone may contribute to saline seepage. Water percolating through salt-laden strata dissolves salts and eventually forms a saline water table above an impermeable or slowly permeable layer. Underground saline water moves downslope and dissolves more salts until it eventually discharges at the soil surface. The discharge water evaporates, concentrating salts on or near the soil surface. As a result, crop growth in the affected area is restricted or eliminated and the soil is too wet to be farmed.

## Identifying Saline Seeps

Kochia (*Kochia scoparia* L.) is an important indicator plant on cultivated land. After a grain harvest, the soil is normally too dry to support weed growth. Kochia growing vigorously in small areas after a grain harvest is a good indicator. Also, scattered salt crystals on a dry soil surface may indicate saline conditions. Salt crystals form on the soil surface as the discharge area dries. Prolonged soil surface wetness in small areas following a substantial rain may indicate areas of limited drainage that may become saline seeps. Tractor wheel slippage or tractor bog-down in certain areas and water seepage into wheel tracks are good indicators

**Kochia and bare areas in a saline seep. (Oklahoma NRCS photo.)**

**Crop damage resulting from saline seepage. (Oklahoma NRCS photo.)**

of increased wetness. Rank wheat, barley, or other crops and growth accompanied by lodging in local areas that produced normal growth in previous years indicate increasing wetness. Increasing infestations of the salt-tolerant foxtail barley (*Hordeumjubatum* L.) may be another warning sign. Other symptoms may be poor seed germination and abnormally flocculated, dark surface soil on the lower slopes. The dark color could be caused by dispersed lignite or organic matter mixed with the surface soil.

## Control Measures for Saline-Seep Problems

The first indications or symptoms of saline-seep development should trigger action or management change. The next step is to locate the recharge area. Most remedial treatments must be applied in the recharge areas, which will always be at a higher elevation than the discharge area.

Since seeps are caused by water moving below the root zone in the recharge area, there is no permanent solution to saline-seep problems unless control measures are applied to the recharge area. In general, two procedures are used for managing seeps: first, agronomically using the water before it percolates below the root zone and second, mechanically draining ponded water where possible before it infiltrates or intercepting laterally flowing subsurface water before it reaches the discharge area. A subsurface drainage system is generally not satisfactory. The water is contaminated by salts, and disposal without downstream pollution of surface or ground water is difficult because of physical and legal constraints.

Agronomic control is generally the most feasible management measure. Seeding a perennial crop, such as alfalfa or grasses, in the recharge area of a saline seep is commonly the quickest, most effective way to dry the deep subsoil and stop waterflow to the saline seep. Concurrent with the application of control measures to the recharge area, the seep area and the area surrounding the seep may be seeded to an alfalfa-grass mixture. Establishing crops in discharge areas will be difficult unless the flow of ground water to the seep is reduced. The choice of seed mixture, seeding rate, and planting frequency is at the discretion of the land manager.

## Reference for Further Reading

United States Department of Agriculture, Agriculture Research Service. 1954. Diagnosis and improvement of saline and alkali soils. United States Salinity Laboratory, Riverside, California.

# Subsidence of Organic Soils

By Gary Muckel, Soil Scientist, National Soil Survey Center, USDA, NRCS.

The word “subsidence” is a general term for a lowering of the ground surface that can result from changes in soil or geologic conditions. Subsidence of organic soils is a specific concern if the soils are drained for cultivation or urban development.

## Organic Soils

Organic soils include Histosols and their “histic” suborders, as they are classified by the USDA system of soil taxonomy. These soils have more than 30 percent organic matter. They are commonly called peats or mucks. They formed in bogs or fens of northern latitudes; in flat, deltaic areas, such as those along lower Mississippi River and those in the Sacramento and San Joaquin Valleys in California; and on coastal plains marginal to oceans. Source materials include reeds, sedges, and grasses in marsh fens, such as those in the Florida Everglades; woody remains in swamps, such as those in Louisiana; and mosses, mostly sphagnum, in areas of cool climates. Organic soils generally form under saturated conditions in areas where oxidation of the organic matter is limited and organic matter subsequently accumulates. Some thick layers of organic material are buried by sediments so thick that the organic layers are not apparent after normal construction excavations.

## Mechanism of Subsidence

Subsidence occurs when wet organic materials are drained and exposed to air. Initial subsidence occurs when the water table is lowered, usually by pumping. This subsidence generally takes as much as 3 years. Long-term subsidence results from oxidation and

**Reeds and sedges in an area of organic soils. (NRCS photo.)**

**Lotus plants in a Maryland wetland that has organic soils. (NRCS photo.)**

dissipation of the organic material. Subsidence rates commonly range from 1 to 3 cm per year. Keeping the water table as high as practical for as much of the year as possible is the best way to minimize subsidence. When the California delta was first farmed around 1900, a common practice was to kill weeds by burning the peat and then put out the fire by raising the water table. As a result, today the land level is 15 to 20 feet below the water level in the adjacent Sacramento River. When conditions favor oxidation, the soils are more susceptible to wind erosion. On one occasion, prevailing westerly winds, often strong, through a river gap blew so much organic dust into Stockton that a legislative mandate dictated erosion-control measures.

Under natural conditions, most organic soils are hydric. Keeping the soils wet reduces the potentials for oxidation, decomposition, and wind erosion.

## Subsidence in Soil Survey Reports

Subsidence of organic materials is indicated in the "Soil Features" tables of soil survey reports. As used in soil surveys, subsidence is the decrease in surface elevation resulting from the drainage of wet soils that have organic layers or semifluid, mineral layers. Initial subsidence generally is about half of the depth to the lowered water table or to mineral soil, whichever is shallower. It occurs within about 3 years after drainage. Total subsidence is the decrease in elevation if all organic materials are dissipated. It is particularly relevant in shallow Histosols in areas of warm climates, such as the border of Lake Pontchartrain in Louisiana. Subsidence of cultivated Histosols is estimated from the ratio of the current bulk density to average bulk densities measured in soils cultivated for a long period of years.

## Significance

The susceptibility of soils to subsidence is an important consideration in areas of organic soils that are drained. If these soils are drained for community development, special foundations are needed for buildings. New Orleans was first settled on a natural levee along the Mississippi River, but with time the city extended into marshy and swampy areas. Today, homes in such areas are on pilings, and utility lines and sewer lines are similarly supported. Sidewalks, driveways, and roads, however, are not supported. The original garages are now extra rooms, and sidewalks have predictable humps. Facilities that lack special foundations may settle at different rates. This differential settling causes breakage, high maintenance costs, and inconvenience. If the soils are drained for farming, the long-term effects of subsidence, the possible destruction of land, and the possible legal implications of wetlands must be considered.

## Cause and Rate of Subsidence of Organic Materials

Subsidence resulting from drainage is attributed to (1) shrinkage as the material dries, (2) consolidation because of the loss of ground-water buoyancy, (3) compaction from tillage or manipulation, (4) wind erosion, (5) burning, and (6) oxidation. The first three factors are responsible for initial subsidence, which occurs rapidly, within about 3 years after the water table is lowered. After the initial rapid subsidence, the rate of subsidence decreases significantly to a lower steady rate. Oxidation and subsidence continue at this lower rate until stopped by the water table or underlying mineral material. The rate of subsidence depends on (1) ground-water depth, (2) the amount of organic matter, (3) the kind of organic matter, (4) soil temperature, (5) reaction, and (6) biochemical activity. The rate of subsidence decreases with shallow ground-water depth and higher amounts of organic matter. Coarse particles (woody materials) oxidize more slowly than fine particles (from grasses). High soil temperatures and increased biological activity accelerate subsidence.

After organic soils have been drained and cultivated for a number of years, they reach a nearly steady rate of subsidence that is reflected by the rather stable bulk density. Unpublished studies by the National Soil Survey Laboratory have shown that the bulk density of the organic component (mineral material calculated out) stabilizes at around 0.27 g/cc for surface layers and 0.18 g/cc for subsurface layers.

## Reference for Further Reading

United States Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, part 618.60, Subsidence of organic materials. Web accessible (http://soils.usda.gov/technical/handbook/contents/part618p4.html#60).

# Water-Saturated Soils

By Gary Muckel, Soil Scientist, National Soil Survey Center, USDA, NRCS.

Soils that are saturated with water or that have a water table near the surface are significantly limited for most construction purposes. Excess water in a soil affects nearly all soil survey interpretations for rural and other land uses. Naturally wet areas have special value as catchments and as wetland habitat.

## Identifying Areas With Water-Saturated Soils

Soil survey reports provide information about soil moisture status or depth to the water table. The soil moisture status "wet" is equivalent to soil saturation and a water table. A zone of saturation that extends far below the usual soil survey mapping depth of 2 meters is considered an "apparent" water table. The saturated zones may vary in depth during the year, depending on the source of water. Zones of saturation that are above unsaturated soil layers with restricted permeability are termed "perched."

For jurisdictional determination of wetlands, three components are required—hydric soils, hydrophytic vegetation, and wetland hydrology. Hydric soils are defined as soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (Federal Register, July 13, 1994). The definition and investigation of hydric soils have clarified the morphological soil characteristics that indicate wetness. In some soils that are not considered hydric, wetness can cause construction and performance problems.

Soils with water-saturated zones are not necessarily wet all the time. Saturation may occur only during certain periods of the year. Nearly all wet soils, however, exhibit characteristic morphologies that result from repeated periods of saturation, inundation, or both, for more than a few days. When combined with microbial activity, saturation or inundation in the soil causes a depletion of oxygen. This anaerobiosis promotes biogeochemical processes, such as the accumulation of organic matter and the reduction, translocation, and/or accumulation of iron and other reducible elements. These processes result in characteristic morphologies that persist in the soils during both wet and dry periods.

The indicators of wetness are referred to as redoximorphic features because of their origin in the reduction or oxidation of soil minerals. The indicators are mainly accumulations or losses of iron, manganese, sulfur, or carbon compounds. These features allow a soil scientist to assess wetness.

## Historical Drainage

Drainage of potential agricultural lands was quite common as agriculture moved into wet forests and tall grass prairies. Tile lines and open drains were installed to remove excess water. Unfortunately, wetlands also were drained, and today major concerns have been expressed for restoring former wetlands for environmental and wildlife purposes.

## Significance of Water Saturation to Various Land Uses

Zones of water saturation affect land use when they are close to the soil surface or within the depth of construction. High water tables, whether apparent or perched, often cause wetness in basements and disfunctional septic tank absorption fields. The excess wetness restricts the growth of most landscaping plants and trees around houses. When surface ponding occurs, mosquitoes cause aggravation and disease.

**Surface and subsurface drains require an outlet. (NRCS photo.)**

**Wet soils may have many limitations if they are used as sites for buildings. (NRCS photo.)**

**Foundation failure caused by excess water. (Photo by Pennsylvania NRCS.)**

## Correcting Problems of Excess Water

Controlling surface runoff generally is the first means of correcting problems associated with excess water. Offsite water can often be intercepted and diverted to other locations, especially if surface water movement is involved. The source of excess water can be removed. The downspouts of houses can cause local zones of saturation. Extending the downspout farther away from the house and its foundation can often remove excess water. Sloping the soil surface away from the house also is an early remedy when runoff from adjacent areas is the cause of excessive wetness.

Subsurface water presents different challenges. There are two primary ways to reduce saturation in a soil—intercepting the water and draining the water. Surface or subsurface water can be intercepted and diverted to other locations. The water is caught as it flows on or within the soil. Diversion of the excess water may be lateral or downward. An impermeable barrier is used. Drainage tile or other channels can be installed on or within the soil if a suitable outlet is available. Alternatively, the excess water can be pumped from the soil if a collection point and submersible pump are used.

## Check First Before Building

When locating sites for homes or other buildings or for installations, such as septic tanks and filter fields, it is best to check the soil for indicators of wetness. Avoiding wet soils or designing for them is cheaper than trying to resolve drainage problems later.

## References for Further Reading

Hurt, G.W., P.M. Whited, and R.F Pringle, editors. Version 5.01, 2003. Field indicators of hydric soils in the United States. United States Department of Agriculture, Natural Resources Conservation Service. Web accessible (ftp://ftp-fc.sc.egov.usda.gov/NSSC/Hydric_Soils/FieldIndicators_v5_01.pdf).

United States Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, part 618.57, Soil moisture status. Web accessible (http://soils.usda.gov/technical/handbook/contents/part618p4.html#57).

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