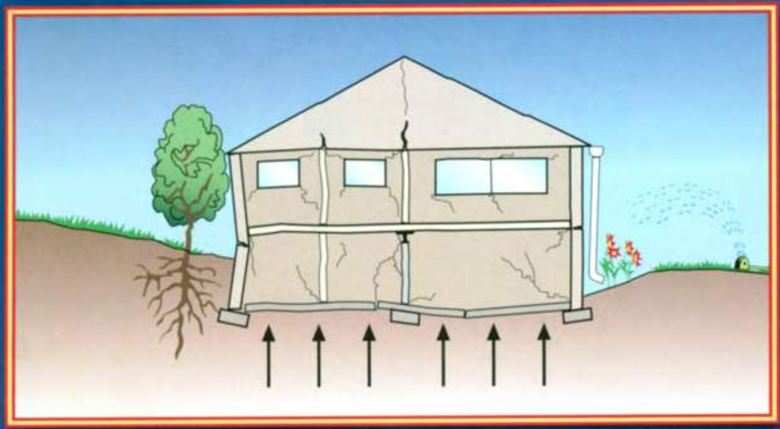
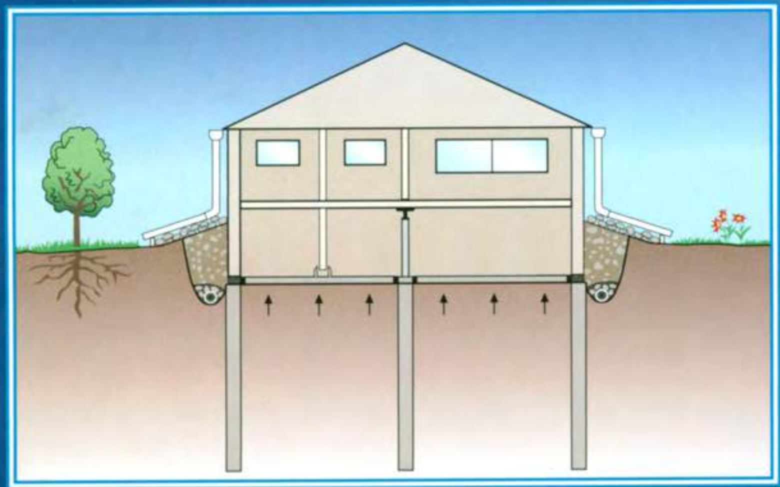


Don't let this happen to you!



Protect your investment!

A Guide to Swelling Soil for Colorado Homebuyers and Homeowners

Second Edition Revised and Updated by David C. Noe, 2007

Colorado Geological Survey Special Publication 43

Special Publication 43

A Guide to Swelling Soil for Colorado Homebuyers and Homeowners

Second Edition

By David C. Noe, Candace L. Jochim, and William P. Rogers

Second Edition Revised and Updated by David C. Noe, 2007

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SWELLING SOIL—
COLORADO'S SILENT DESTROYER

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Severe foundation damage

Repair costs

Cracked walls and ceilings

Piles of concrete

Settlements and lawsuits

Broken pipes and water lines

Homes for sale

WHY SHOULD YOU CARE ABOUT SWELLING SOIL?

Swelling soil is a common and sometimes serious problem in Colorado. This geologic hazard is capable of causing severe damage to houses. The damage may occur slowly over time, and houses in a neighborhood may be affected at different times.

Colorado's semi-arid climate and geology combine to make it one of the most severely affected areas in the USA. Many thousands of houses are built on swelling soil here every year. A prominent engineer, Fu Hua Chen, once estimated that 1 out of every 3 houses built along the Front Range urban corridor will be built upon swelling soil.

Repairs to damaged foundations typically cost $30,000 to $70,000, but may cost up to $400,000 or more for very large houses. Over 15,000 Denver-area homeowners were involved in litigation involving swelling soil during the 1990s. Nationwide, the cost of repairing swelling soil damage amounts to several billions of dollars yearly.

Special insurance or federal emergency funds typically do not exist for swelling soil damage. Builder's and homeowner's warranties may be available but the coverage they offer is usually limited in scope, amount, and duration. In general, owners of older homes will be solely responsible for the cost of repairing damages.

DON'T LET THIS HAPPEN TO YOU!

Many Colorado families have suffered distress from swelling soil damage. However, with the right knowledge and actions, you can do something to avoid or at least reduce this damage and distress. Given the high cost of repairs, the proper construction and maintenance of a property may save tens of thousands of dollars.

A SHARED RESPONSIBILITY

Homeowners, homebuilders, and engineers have shared responsibilities for reducing swelling soil damage. For satisfactory performance, a house needs to be designed and built properly and then maintained properly through time.

If you are thinking of buying or building a home on swelling soil, or if you already own a home that may be affected by swelling soil, you need to have a basic knowledge about these things:

- What swelling soils are and how they behave
- How moisture in the soil contributes to shrinking, swelling, and damage
- How homes can be designed and built to resist damage from swelling soil
- How to properly landscape and maintain a home site to reduce damage
- What risks a homebuyer must accept when purchasing a home on swelling soil
- How to recognize swelling soil damage

WHY YOU SHOULD READ THIS BOOK

The purpose of this book is to assist Colorado homebuyers and homeowners in reducing damage caused by swelling soil. It was written to satisfy part of the disclosure requirements of the State of Colorado for new houses built on swelling soil, and as a guidance manual for longer-term home care.

In particular, we have written this book to inform you about what your builder can do to design a house for swelling soil conditions. We want you to know how to avoid buying a damaged house, how to recognize damage that has occurred or is occurring, and who to call if your home is undergoing damage from ground movement.

Most importantly, we want you to be aware that risks from swelling soil cannot be completely eliminated. These risks, however, can be significantly reduced through proper site-investigation, design, construction, landscaping and maintenance practices.

HOW TO USE THIS BOOK

This book is divided into three parts. The first part is a **Quick-Start Summary of Key Points** that outlines important facts that homebuyers and homeowners should know about swelling soil, according to Colorado law and disclosure requirements.

The second part is a more extensive **Guide to Swelling Soil**, which is divided into six chapters that provide detailed descriptions and illustrations about the topics that were introduced in the Quick-Start section.

The third part consists of several **Appendices** that address specific topics such as swelling soil geology, construction details, inspecting a house for swelling soil damage, and listings of helpful reading and information resources.

Prospective homebuyers are encouraged to use this book to better understand the potential risks involved with buying a house built on swelling soil. Homeowners can use all parts of the book to help maintain the long-term integrity of their home and protect their investment.

Important terms are highlighted in **boldface** type. These terms are used by professional geologists, engineers, and homebuilders, and may be unfamiliar to the first-time reader. However, you may find an understanding of them to be extremely useful when you are dealing with swelling soil or with housing and construction in general.

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NATIONAL AWARDS FOR THE FIRST EDITION

The John C. Frye Memorial Award in Environmental Geology, 1998—*Awarded by the Geological Society of America and Association of American State Geologists for outstanding publication concerning Environmental Geology*

The E. B. Burwell, Jr., Memorial Award in Engineering Geology, 2001—*Awarded by the Geological Society of America, Engineering Geology Division, for outstanding publication concerning Engineering Geology*

QUICK-START SUMMARY OF KEY POINTS

SWELLING SOIL (Summary of Chapter 1)

- Swelling soil contains clay minerals that attract and absorb water. It swells in volume when it gets wet and shrinks when it dries.
- Other names for this geologic hazard include "shrink–swell soil," "expansive soil," and "bentonite." These terms may refer to both soil and bedrock that contain swelling clay.
- Swelling soil may be found throughout Colorado, with the general exception of the highest mountain areas
- The swell potential of soil beneath a particular property depends on the local geology. Subsurface sampling and laboratory testing are necessary to evaluate the swell potential of soil or bedrock layers at different depths.
- Layers of swelling claystone bedrock that dip (tilt) into the ground at steep angles constitute a distinct geological hazard called "heaving bedrock." Jefferson and Douglas counties have adopted regulations to address this hazard.
- ***See Chapter 1 and Appendix A to learn more about swelling soil.***

SUBSURFACE MOISTURE (Summary of Chapter 2)

- The increase or decrease in subsurface moisture has a major effect on swelling soil behavior. An increase in moisture will result in swelling, while a decrease will result in shrinking.
- Under natural conditions, shallow soil just beneath the ground surface will alternately become wetter and drier as a result of seasonal moisture and temperature changes.
- Urbanization and land development significantly increase the amount of moisture in the ground, and can result in deeper subsurface wetting.
- The increase in soil moisture following land development often triggers soil swelling, and may cause ground heaving and significant damage.
- One of the most important means of mitigating swelling soil damage is reducing the accumulation of subsurface moisture.
- ***See Chapter 2 to learn more about how subsurface moisture affects swelling soil.***

CONSTRUCTION AND DRAINAGE (Summary of Chapter 3)

- Designs for houses should be based on the potential severity of swelling soil. The design of a house should be specifically tailored to the amount of uplift or heave that is expected due to soil swelling.
- Special designs and construction methods have been developed for grading and ground preparation, foundations, floors, building interiors, exterior flatwork, and surface and subsurface drainage systems for sites where swelling soil is present.
- These designs work in a number of different ways. They may be geared toward reducing the swell potential, isolating or concentrating the load of the house, letting parts of the structure heave and move relative to other parts with minimal damage, and/or reducing the amount of water that infiltrates into the ground next to the foundation.
- Proper surface drainage is critical, and involves directing water away from the foundation by means of downspouts, splashblocks, earthen berms and swales.
- Swelling soil may or may not be the primary consideration in many of the decisions made by the builder. Specific swelling soil designs should be implemented at sites with a higher swell potential.
- Quality control during construction is the key to the success of any design used to mitigate swelling soil. Poor construction quality can add significantly to swelling soil damage to a house.
- ***See Chapter 3 and Appendix B to learn more about construction designs for swelling soil.***

LANDSCAPING ON SWELLING SOIL (Summary of Chapter 4)

- Many conventional landscaping practices (such as planting bluegrass lawns, trees, and gardens near foundations) are not recommended for areas of swelling soil because they contribute excess water to the soil.
- There are some simple landscaping guidelines that should be followed in order to reduce swelling soil problems. The sloped area immediately adjacent to the house is an especially critical area for landscaping.
- Irrigation should be limited to the amount necessary to maintain vegetation. Excessive watering, even with good drainage, drives water into the soil and increases the likelihood of swelling soil problems.
- Xeriscape™ landscaping, which makes use of many types of water-wise plants, rocks, and organic mulches, is an attractive and cost-effective way to conserve water and reduce swelling soil activity. Other advantages include lower maintenance and less mowing.
- ***See Chapter 4 to learn more about landscaping on swelling soil.***

HOME MAINTENANCE ON SWELLING SOIL (Summary of Chapter 5)

- Homeowners should routinely inspect and maintain all of the different systems that were designed to protect the house from swelling soil damage, including slabs, walls, subsurface and surface drainage, slopes and landscaping.
- Proper maintenance and irrigation practices are absolutely necessary to help prevent a house from being damaged by swelling soil and reduce potentially costly repairs.
- The lack of proper maintenance and irrigation practices can contribute significantly to conditions that cause swelling soil damage.
- ***This is one of the most important chapters if you are a homeowner. See Chapter 5 to learn more about home maintenance on swelling soil.***

SWELLING SOIL AND HOMEOWNER RISK (Summary of Chapter 6)

- Colorado Senate Bill 13 (1984), C.R.S. 6-6.5-101, is a law that requires the builder of a new home to disclose evidence of swelling soil to a potential buyer.
- SB-13 requires that the builder provide a summary of a site-specific soil report, which should include soil observations and swell potential, engineering data and determinations, and building design recommendations.
- During resale of an existing house, the homeowner and the real estate broker must provide disclosure of pertinent soil conditions as well as any known damage or repairs. However, buyers should not rely solely on this information.
- Swelling soil should be considered seriously in balance with location, cost and resale when you are thinking of buying a house.
- Find out everything you can about a particular new or resale house, especially how it was actually constructed with regard to the soil conditions. Look for signs of damage or repairs, poor landscaping and maintenance practices, and ask for owner or inspection records that may indicate soil problems.
- The final decision to purchase a house on swelling soils is yours. It should reflect a knowledge and acceptance of the risks involved. It may be extremely useful to hire a professional house inspector or engineer to help you with your decision.
- ***See Chapter 6 to learn more about swelling soil and homeowner risk. See Appendix C for information about how to check a new or resale property for swelling soil.***

CHAPTER 1

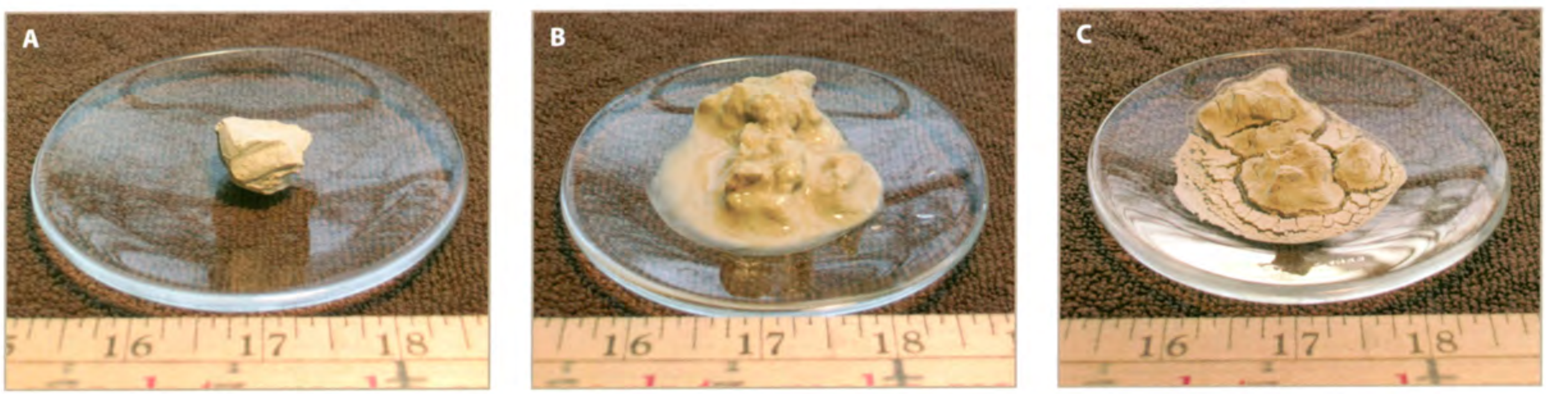
SWELLING SOIL

SWELLING AND SHRINKING BEHAVIOR

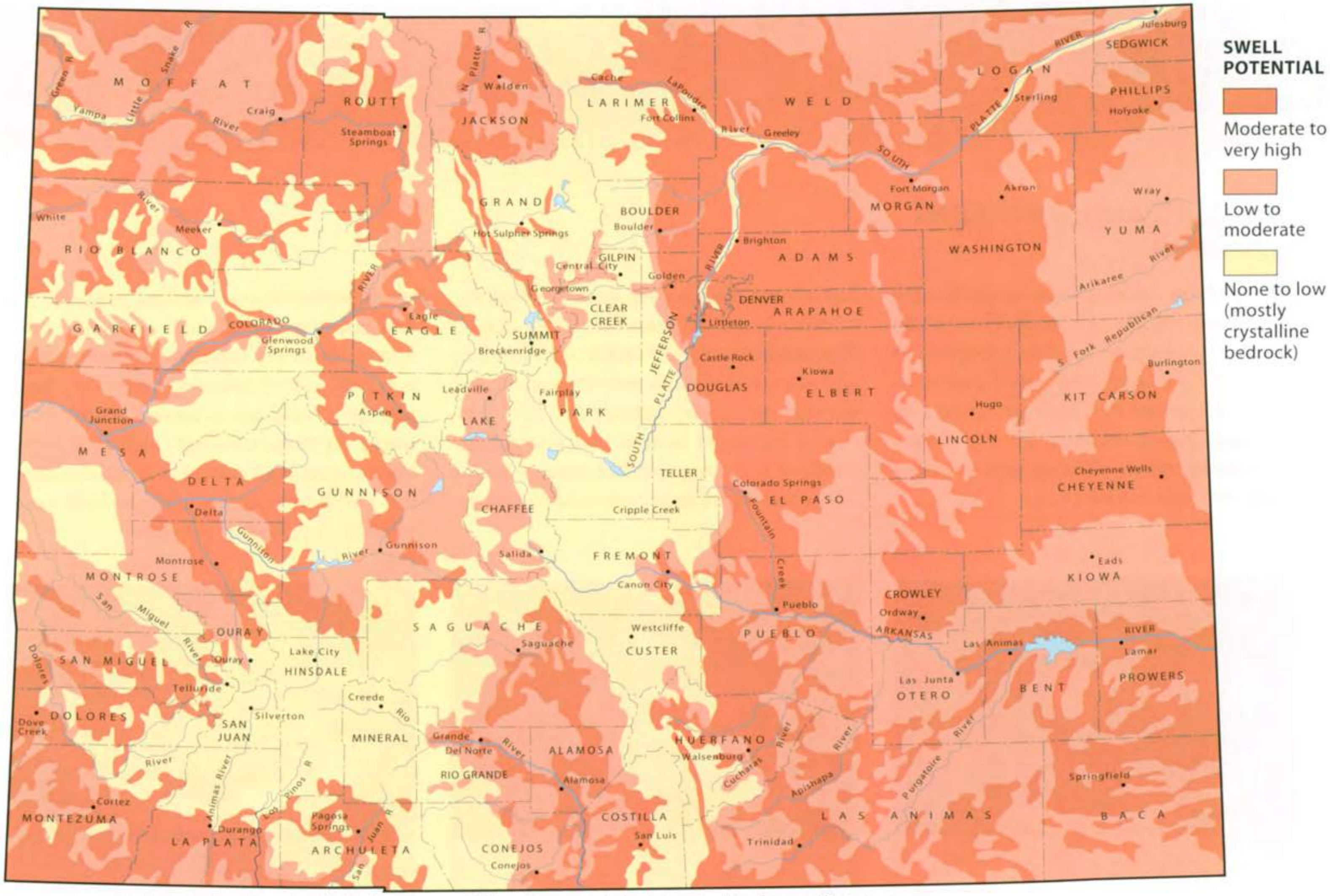
Damage from swelling soil occurs when the soil changes volume as a result of a moisture change. **Swelling** occurs when moisture is added. It can cause high swell pressures and/or an increase of volume within the soil. Swelling and associated ground heave accounts for much of the damage to structures and roads in Colorado.

Shrinking, the opposite effect of swelling, occurs when a soil dries out. It can cause a decrease in volume within the soil. Shrinking and associated ground settlement can cause damage during dry periods and droughts. There are many factors that control the swelling and shrinking behavior of a soil. These factors are discussed in Appendix A.

Swell potential and **swelling pressure** are two measurements of a soil's ability to expand under laboratory conditions. A soil sample is typically rated as having either very high, high, moderate, low or no swell potential. A soil having moderate to very high swell potential and swelling pressure is capable of causing uplift to concrete slabs, which exert relatively low loading pressures.



A piece of highly expansive claystone (A) before addition of water. One hour after adding water (B), the claystone has swelled and its volume has almost tripled. Forty-eight hours later (C), it is drying out and has begun shrinking and cracking.



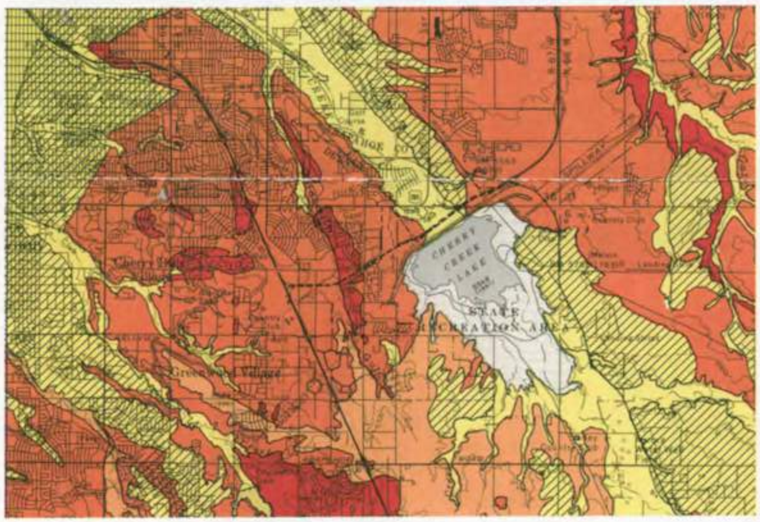
This is a generalized map. The swell potential of soils at any specific location can only be determined by site-specific testing.
Map modified from "Shrink–Swell Potential" map, Colorado Land Use Commision, 1973.

Generalized distribution of swelling soil and bedrock in Colorado.

OCCURRENCE OF SWELLING SOIL IN COLORADO

Swelling soil and bedrock is widespread throughout Colorado. It covers broad areas of the eastern plains and is found mainly in valleys and on mesa slopes in western Colorado. A majority of the state's major population centers are located in areas of potentially swelling soil and bedrock.

On a smaller scale, however, individual sites within these areas may not have swelling soil beneath them because of localized geological variations. Because the soils in an area can have different origins, properties, and thickness, it is necessary to evaluate the subsurface conditions for each property or building site.



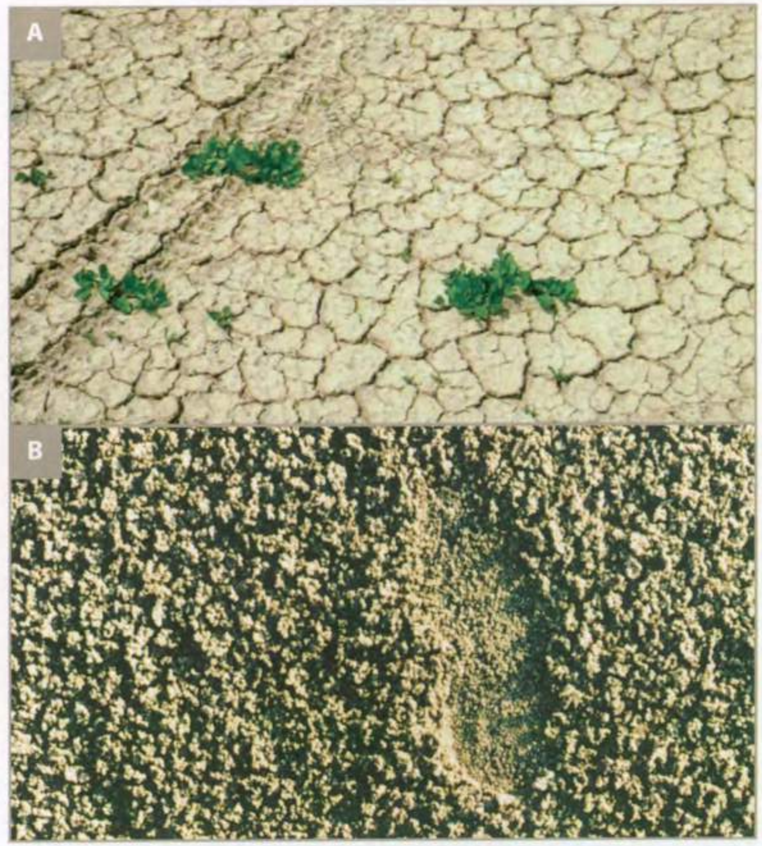
Swell Potential

Very high | High | Moderate | Low

Example of a map showing local distribution of swelling soil. Maps of this type are available from the Colorado Geological Survey for the Front Range Urban Corridor area, from Pueblo to Fort Collins. From publication EG-7 by Hart (1974).

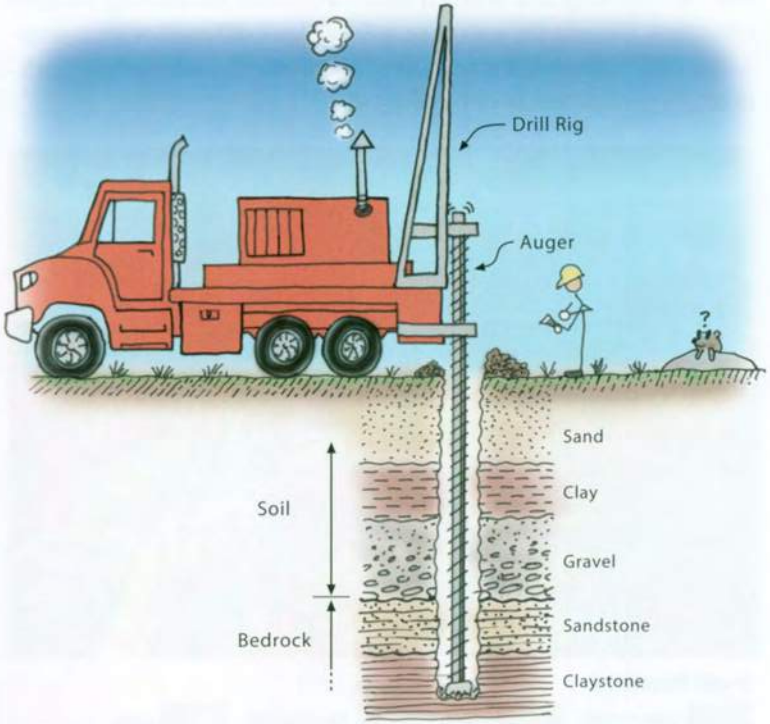
HOW TO RECOGNIZE SWELLING SOIL

One way to find out if swelling soil is present is by simply looking at the ground surface. Soil containing swelling clay will be very sticky when wet, and may display **desiccation cracks** or a puffy **"popcorn" texture** when dry. Heat and evaporation may cause larger cracks to open up into the ground, on the order of several feet deep and up to an inch wide.



Evidence of swelling soil at the ground surface. A) Small-scale desiccation cracks, with tire tracks for scale. B) "Popcorn" texture, with footprint for scale.

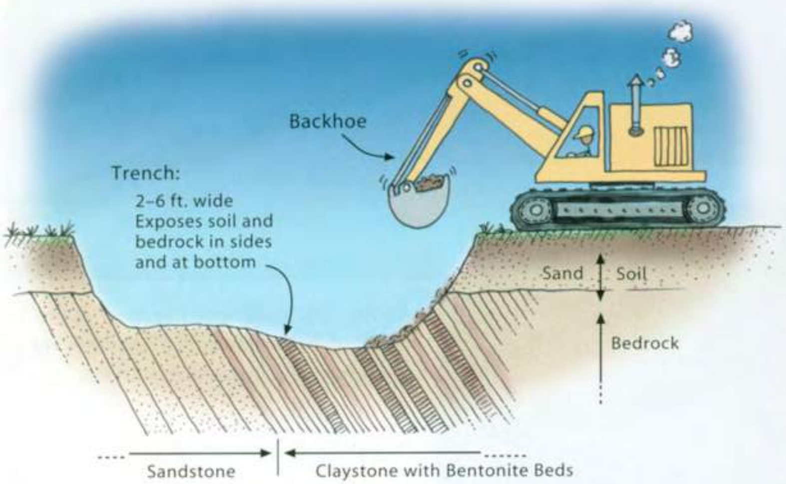
It is important to identify whether deeper layers or lenses of swelling soil are present beneath a property. **Drilling** is effective for relatively flat-lying soil and bedrock because it allows for inspection and sampling of successively deeper layers.



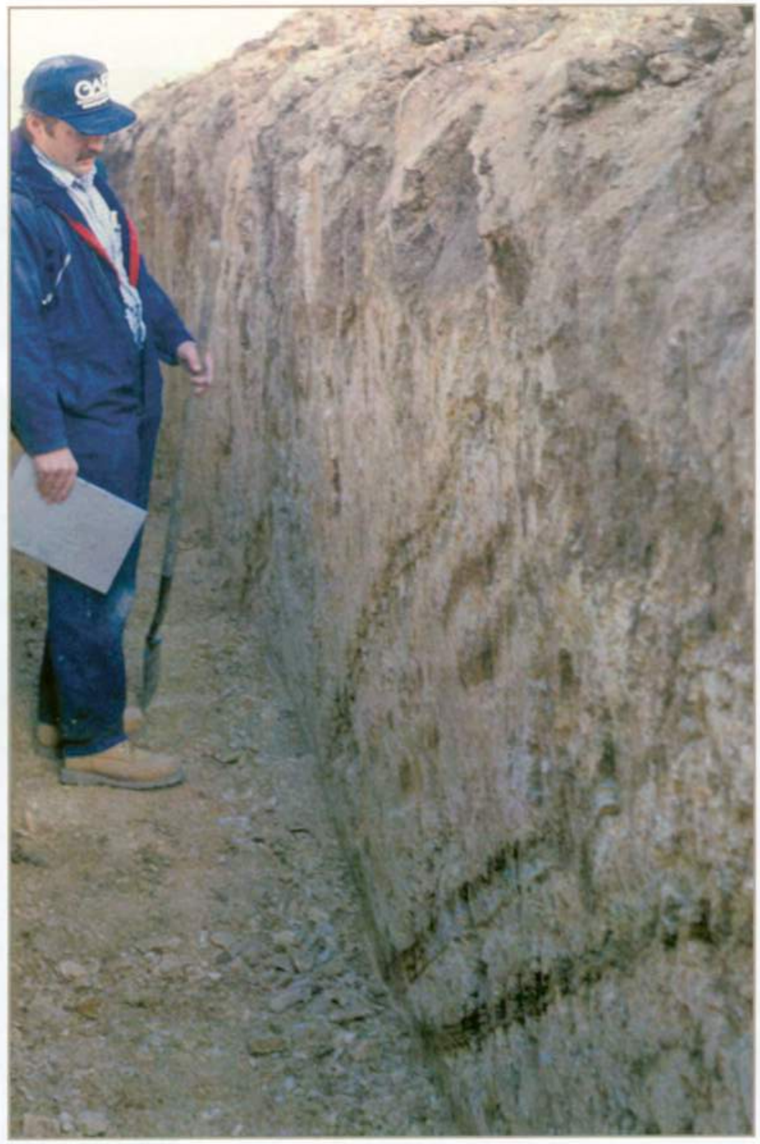
Drilling exploration used to identify and test flat-lying soil and bedrock layers for swell potential and other engineering properties.

Trenching is effective in areas underlain by steeply dipping bedrock because it exposes many near-surface bedrock layers for inspection and sampling.

Samples taken from test holes or trenches are tested for swell potential and swelling pressure in a laboratory. This information is used to design foundations for buildings. Such evaluations are a required practice in many areas of Colorado where swelling soil is anticipated.



Trenching exploration used to identify and test steeply dipping bedrock layers for swell potential and other engineering properties.



STEEPLY DIPPING BEDROCK AREAS

Heaving bedrock, also known as **expansive, steeply dipping bedrock**, is a distinct geological hazard in certain areas of Colorado where the sedimentary bedrock layers just beneath the ground surface are steeply dipping (upturned and tilted). The bedrock layers may swell unevenly to form linear heave features along the ground surface. Houses built over such heave features may be subjected to extreme amounts of vertical and lateral stress. The resulting damage can be severe and costly to repair.

Jefferson and Douglas counties now require detailed site investigation and specialized building techniques in areas defined by overlay maps that show the extent of potentially heaving bedrock. Houses in the overlay areas constructed before 1995 may not have been built with current state-of-the-art construction practices. Heaving bedrock may occur at other locations along the Front Range foothills and on the Western Slope of Colorado. These other areas do not have requirements for specialized practices, and caution is advised in those areas. See Appendix A for more on heaving bedrock hazards.

Above: This "roller-coaster road" is the result of uneven swelling and heaving of steeply dipping bedrock layers.

Left: Layers of steeply dipping claystone exposed in a road cut.

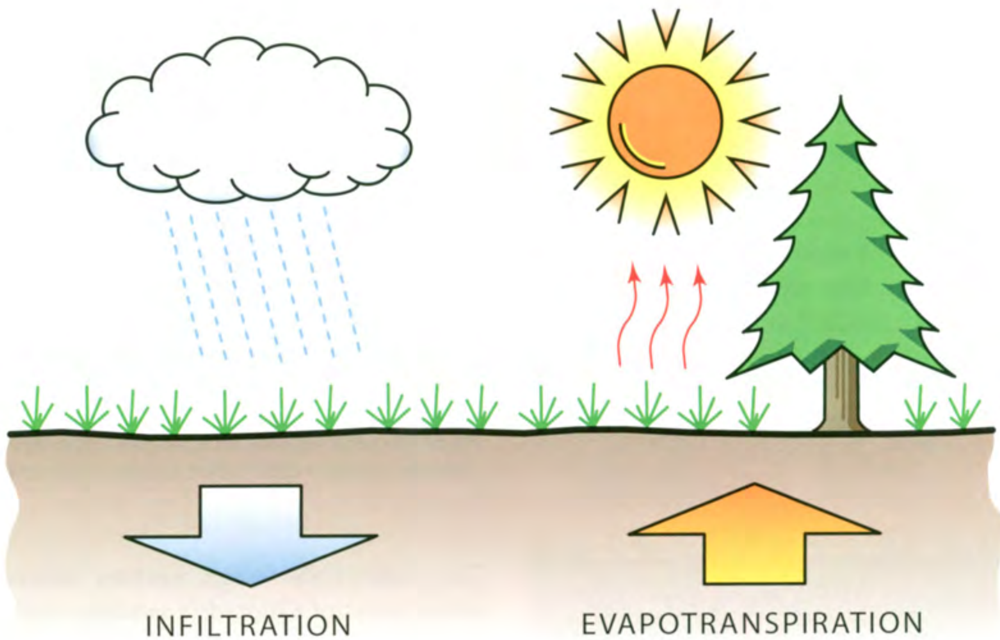
CHAPTER 2

SUBSURFACE MOISTURE

In most cases where significant swelling soil damage occurs, the damage is triggered by an increase in subsurface moisture. Colorado soils tend to become wetter after subdivisions are built because additional sources of water are activated.

TYPES OF SUBSURFACE MOISTURE

Water exists beneath the ground surface as **ground water** where the soil is saturated, and as **ground moisture** where the soil is unsaturated. Water enters the ground through **infiltration**. Natural sources of infiltration include rainfall, snowmelt and seepage from lakes and streams. Man-made sources include lawn and crop irrigation, and seepage from man-made ponds, ditches, and buried water and sewer lines. Water can leave the ground by vaporizing due to heating and drying (evaporation) or by being used by green plants (transpiration); the cumulative effect is called **evapotranspiration**.

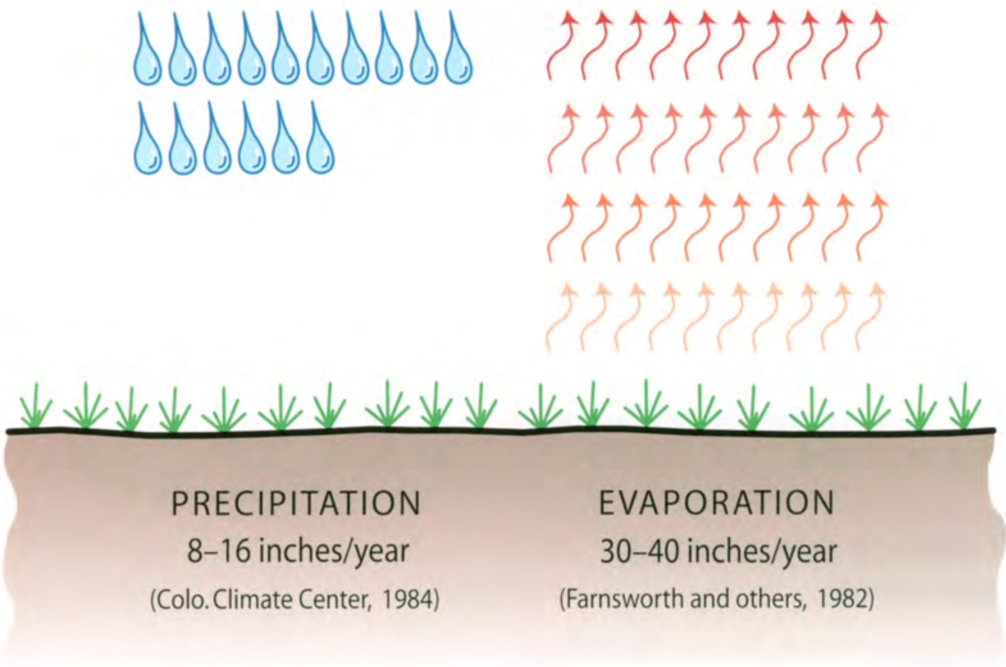


Water moves into the ground by infiltration, and leaves the ground by evapotranspiration.

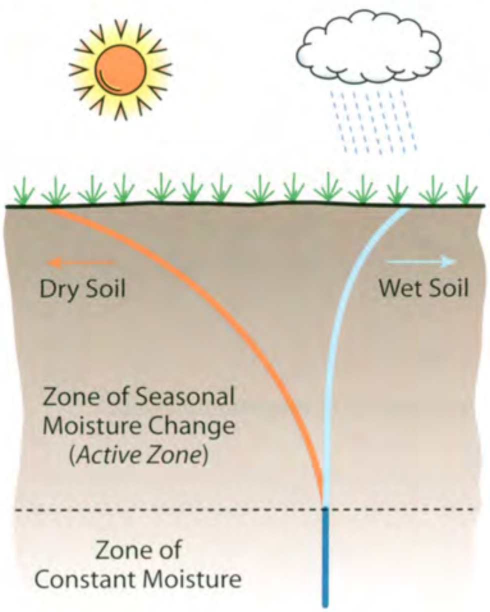
NATURAL SUBSURFACE MOISTURE CONDITIONS

The amount of subsurface moisture varies seasonally under natural conditions. In Colorado, soil moisture tends to increase during the late winter and spring when rates of precipitation and infiltration are high. During the dry season it may decrease again. Similarly, the water table may rise during wet periods and fall during dry periods.

These wetting and drying cycles cause swelling soil to swell and shrink. The depth below the ground surface where the soil undergoes seasonal wetting and drying is called the **active zone** or **zone of moisture change**. The natural active zone along Colorado's eastern plains is typically 7 to 10 feet deep.



An example of natural precipitation vs. evaporation for Colorado's major population centers, showing a water deficit that results in dry soil.



The eastern plains and western valleys, where most of Colorado's swelling soil is found, receive less precipitation, and are hotter and have high evapotranspiration. These areas have an overall deficit of water during much of the year, and the near-surface soil is typically dry. The mountainous areas of Colorado usually have a surplus of subsurface water as a result of high rates of precipitation and a cool climate, and soil in these areas tends to be wet or moist.

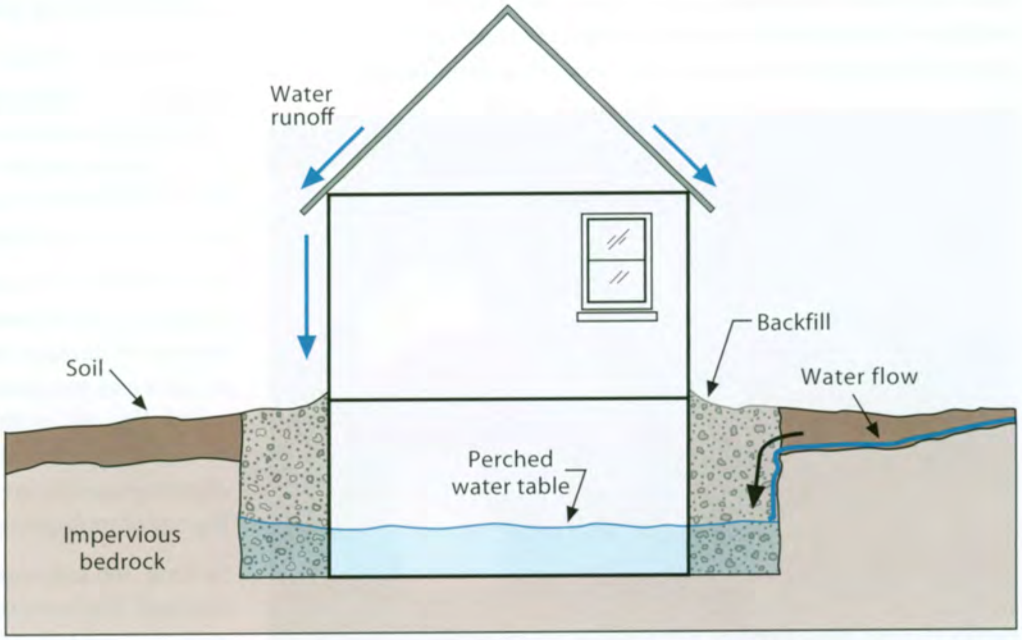
Left: Diagram showing the active zone, where near surface soil undergoes seasonal moisture change. These changes become smaller with depth until a zone of constant moisture is reached.

HOW SUBSURFACE WETTING AFFECTS SWELLING SOIL

Urbanization and land development can significantly alter the moisture content of the soil. More water infiltrates into the ground due to irrigation of lawns and gardens and, in some cases, leakage from septic systems and water or sewer pipes. Evaporation out of the ground is reduced by impervious roadways, parking lots, driveways, sidewalks, and buildings. Off-site water may migrate into an area through backfilled trenches and gravel bedding. A **perched water table** may develop on top of impervious soil or bedrock.

As we have learned, swelling soil may expand or shrink in response to moisture changes. If newly introduced subsurface water comes into contact with potentially swelling soil beneath a house, the soil may expand and cause damage. Houses built during a dry period may be more susceptible to wetting and may show more heave.

Subsurface wetting occurs within the active zone after a house is built and lawn irrigation begins. In some cases the wetting may extend deeper than the active zone after many years. This is a topic of controversy among geotechnical engineers. The post-construction wetting typically increases to depths of 15 to 20 feet or more along Colorado's eastern plains. In areas of steeply dipping bedrock, the zone of wetting may increase to depths of 35 feet or more after a subdivision is built.



Perched water table in a house excavation dug into impervious bedrock. This is an unwanted situation because runoff water is flooding the basement and slowly infiltrating into the bedrock.

DROUGHT AND SHRINKING SOILS

Colorado is subject to occasional periods of **drought**. During a drought, soil will dry out in developed areas where watering restrictions are enacted. If swelling clay is present in the active zone, it will undergo volume **shrinkage**. Soil shrinkage may reverse heaving of house foundations, porches, and concrete slabs, and it may cause additional damage due to **ground settlement**. Such movements may affect a house that has been relatively stable for years or even decades.

Large desiccation cracks, with depths of up to several feet, may form during extended dry periods. This is an adverse situation because the open cracks may allow deep penetration of water during subsequent wet periods.

Certain types of trees and plants will pull large amounts of moisture out of the soil through rootlets during drought periods.

This may cause deep drying and localized soil shrinkage and ground settling in the immediate area of the tree. Damage to structures may occur if the tree is located too close to a house foundation.

This large desiccation crack is the result of drying and shrinkage of swelling soil.

ONSET AND DURATION OF DAMAGE

Each house will have its own history of movement and damage. In a nutshell, the timing and severity of these movements depends on the subsurface moisture changes that are occurring in the soil. The severity of damage may be manifested as **cosmetic damage**, which is visually unattractive, or as **structural damage**, which affects safety or basic living conditions for occupants.

The onset and duration of damage from swelling soil is extremely variable. In some cases, there is immediate evidence of ground movements and damage. In other cases, the movements and damage may be slow and progressive, or there may be seasonal periods of heave and settlement, or there may be long periods of inactivity separated by sudden movements. The rapid changes may result from long-term changing conditions and a build-up of stresses. Many houses have a history of multiple movements and repairs.

In time, the soil may stabilize as a new, higher level of moisture is reached. But even then, future changes in the soil moisture could cause renewed movement and damage. Because swelling soil is never truly stable, new designs and remedial repairs need to consider the expected range of future wetting and drying. For example, a house that is repaired for acute drought settling may become damaged again when the longer-term wetting and heaving of the soil resumes.

One of the most important means of reducing the risk of swelling soil damage is to control the amount of moisture that infiltrates the soil. Chapters 3, 4, and 5 contain successful design, construction, landscaping, and maintenance practices for reducing the effects of subsurface water.

CHAPTER 3

CONSTRUCTION AND DRAINAGE

In this chapter, we will look at basic construction considerations for houses built on swelling soil. Detailed designs, and their advantages and disadvantages, are found in Appendix B.

The design and construction of a house and its individual elements should ideally reflect the condition of the soil beneath it. The designs are usually chosen by the homebuilder after considering recommendations from engineers and taking other factors, such as house affordability, into account.

Swelling soil conditions warrant special designs for ground preparation and site grading, foundations, interior and exterior elements. The designs should be specifically tailored to the potential severity of swelling soil at the building site in order to reduce, counteract, or absorb the amount of uplift and heave that is expected.

These designs work in a number of different ways, and are often used in combination. They may be geared toward reducing the swell potential, isolating or reducing the load of the house, letting parts of the structure heave and move relative to other parts with minimal damage, and/or reducing the amount of water that infiltrates into the ground next to the foundation.

Houses must be designed and constructed appropriately for the soil conditions.

We encourage homebuyers to learn about the designs that were or will be used to build a house in which you are interested in buying. Use the information in this chapter and Appendix B to ask the builder or owner questions about the house design, to assess whether its construction is appropriate for the soil conditions. Homeowners may use this same information to understand and manage the effects of soil movements upon a home.

GROUND PREPARATION AND GRADING

Before any houses can be built in a new subdivision, the site is usually graded and utilities and roads are installed. This may involve **cutting** away topographically high hills and **filling** in lower areas. Swelling soil or bedrock may be exposed or brought nearer to the surface in cuts, and it may make up a sizable portion of the materials used to construct fill pads for houses and roads. There are several methods of site preparation available to reduce the potential swelling of fills and natural soil, depending on the site conditions.

SHALLOW AND DEEP FOUNDATIONS

House foundations must be properly engineered to account for geological conditions at any given homesite. Depending on the site's swell potential, swelling soil may or may not be a primary consideration. Several different types of foundations are commonly used in areas of swelling soil in Colorado. They are termed **"shallow"** or **"deep,"** depending on the design of their basal elements. The actual choice of a foundation type depends on numerous geologic and non-geologic factors, and may reflect common regional practices and individual preferences of foundation engineers.

LATERAL SUPPORT FOR FOUNDATION WALLS

Foundation walls require reinforcement or additional supports to resist **lateral pressures** exerted on the outside surface by the adjacent soils and backfill. This is especially true when the soils and backfill are composed of swell-prone clay. The exact design depends on the length, height and general configuration of the walls, as well as soil and subsurface water conditions.

FLOOR CONSTRUCTION

There are two primary types of floors used in Colorado when swelling soil is present, **floating slab** and **structural** floors. These floor systems are used for basements in many areas, especially in the Front Range urban corridor, but may be used for at-grade construction in cases where basements are not used. It is important to understand how these floor systems work, because they both have specific strengths and limitations.

Learn everything you can about how your house was built to reduce the effects of swelling soil.

Quality control is a key part of construction.

INTERIOR CONSTRUCTION

Special interior construction is necessary for any house built on swelling soil. The actual designs may vary depending on the type of foundation and flooring, as well as the soil's swell potential. The basic considerations are the same regardless of whether or not the house has a basement. Many of these designs were developed for use with floating slab floors, where it is assumed that the floor will undergo some heave or settlement. We have included designs for interior walls, stairs, doors and windows, utility pipes, and furnaces in Appendix B.

EXTERIOR FLATWORK

Concrete driveways, sidewalks, patios and porches cannot be designed to resist vertical heaving because uplift pressures exerted by swelling soil can greatly exceed the weight of the slab. Homeowners in Colorado should accept the fact that **exterior flatwork** is likely to undergo some heaving and cracking in areas of swelling soil. Long-term flatwork repair and replacement is not guaranteed under the provisions of most builder's and structural homeowner's warranties. It is essential to minimize potential flatwork damage through proper engineering design and construction. Homebuyers should ask the builder what precautions were taken and should verify that no "corner-cutting" was done against flatwork design, reinforcement and thickness specifications. See Chapter 6 and Appendix C for more information.

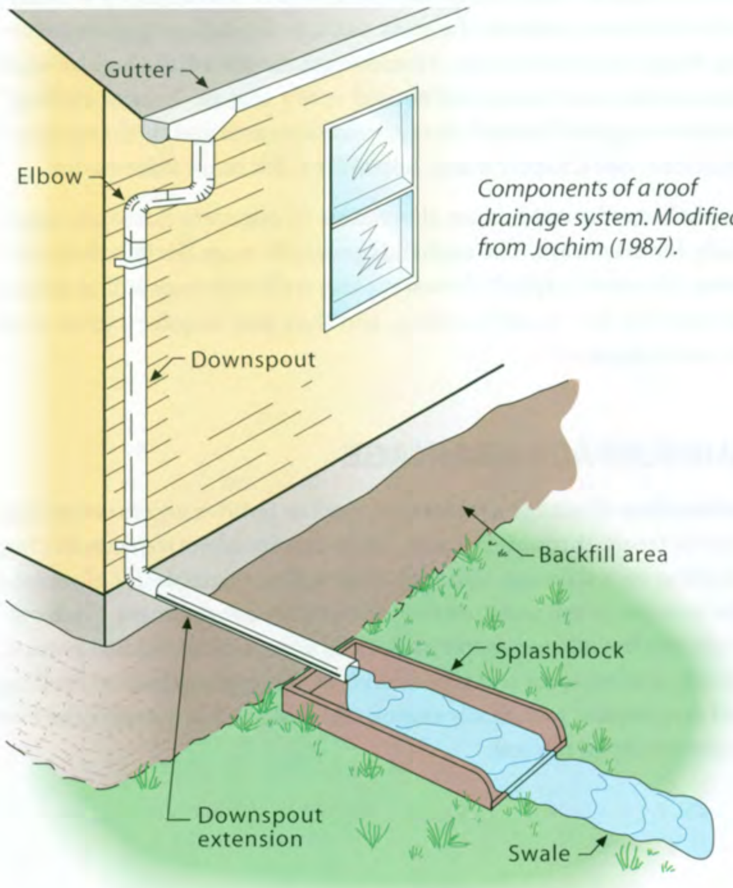
Asphalt can be used as an alternative to concrete flatwork, especially for driveways. The asphalt is generally more flexible than concrete. However, asphalt driveways and walkways may still be prone to cracking due to soil swelling, and they may require a great deal of maintenance.

SUBSURFACE DRAINAGE

Subsurface drainage systems are used to remove excess water that moves freely through the soil. They can be effective in reducing swelling soils damage, although they will not completely eliminate the increase in soil moisture that occurs after development. Such systems may include perimeter drains and sumps for individual houses, as well as interceptor and area drains. Septic systems sited on swelling soil may require specifically engineered designs that consider the low permeability of the soil.

SURFACE DRAINAGE

Proper **surface drainage** is critical for houses built on swelling soil. Water from rainfall, snowmelt, and irrigation must not be allowed to pond and infiltrate into the soil near foundations or flatwork. Instead, it must be collected, directed into drainage swales and carried away from the house by means of ditches, street gutters or storm drains.



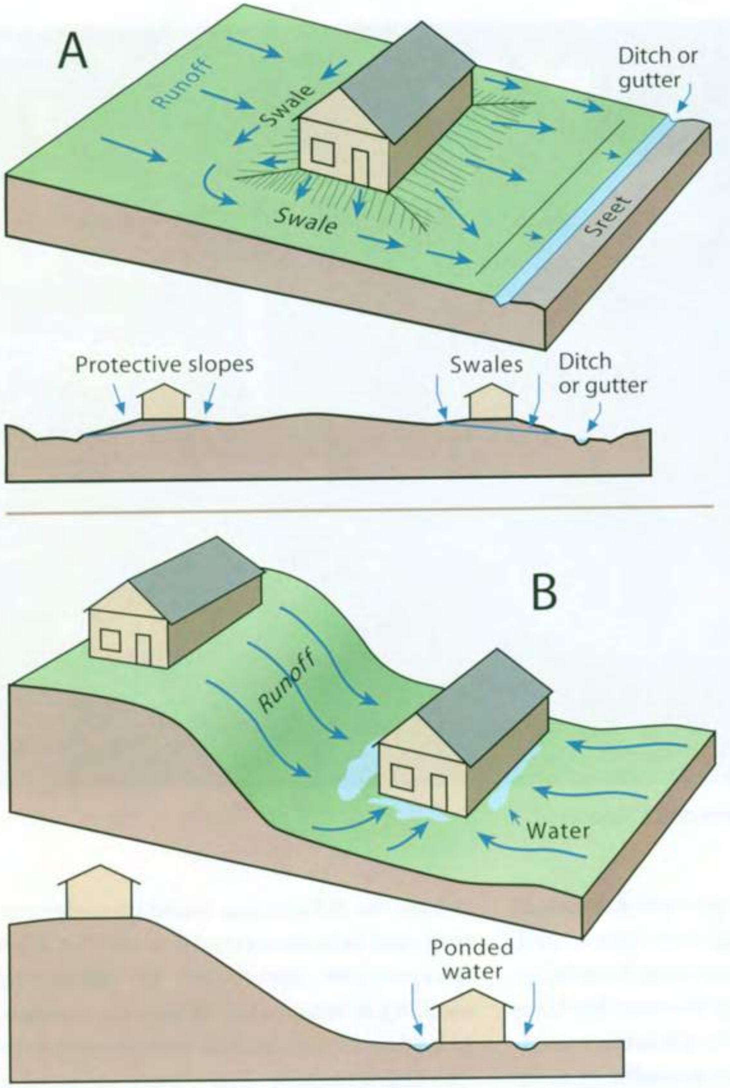
Components of a roof drainage system. Modified from Jochim (1987).

Roof drainage. The roof drainage system is composed of gutters, downspouts and splashblocks. Its purpose is to keep rainwater and snowmelt from pouring or dripping over the eaves and falling next to the foundation. Fixed **downspout extensions** and **splash blocks** are two acceptable means of carrying water away from the house beyond the backfill area. A swale should be provided in the yard at the end of the downspout extension or splash block to allow water to flow even further away from the house, preferably to a street or ditch. It is essential that all roof runoff should be carried at least 5 feet, and preferably 10 feet, away from the building.

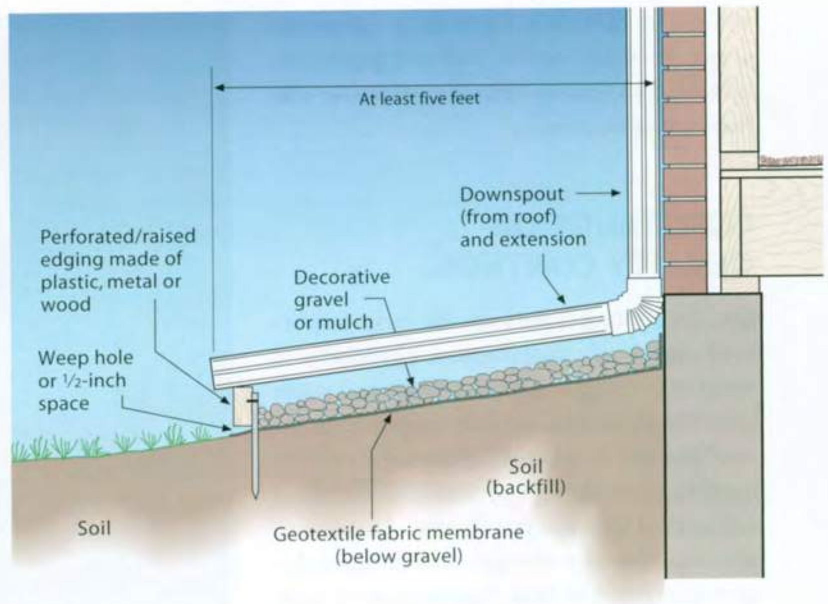
Slope drainage. A properly designed and maintained slope next to the house is a critical aspect of surface drainage. When houses are built, the slope and adjacent ditches and swales should be graded according to the specifications of a qualified engineer. The main purpose of **lot grading** is to provide positive drainage away from the house. If the lot is sloping and well drained, precipitation will run off and reduce infiltration near the house. However, if the lot is not properly graded, the water may pond and infiltrate the soil, and swelling soil damage may result.

The **minimum slope** or fall necessary within 10 feet of a building depends upon the type of surface and/or landscaping. Paved areas should maintain a minimum slope of 1 percent (1 inch of vertical fall for 10 feet of horizontal distance). A greater initial slope of 2 to 5 percent is desirable, however, since even a small amount of settling can reverse such a small slope and cause water to pond.

Landscaped areas next to a house should consist of a **runoff slope** or dirt-cored berm that extends 10 feet outward from the foundation into the yard, where possible. The fall of the slope should be at least 5 to 10 percent (6 inches to 1 foot of vertical fall for every 10 feet of horizontal distance). Many newer houses built on small lots have slopes as steep as 33 percent. Where houses are closer than 20 feet apart, the slopes should direct runoff water to a low swale between the houses and away from the area. All slopes should be



Carefully planned and maintained slopes (A) provide positive drainage and prevent water from ponding on the property, whereas poorly planned and maintained slopes (B) allow water to pond around the foundation and infiltrate into the soil. Modified from Jochim (1987).



Properly designed runoff slope next to a house foundation. Note that roof drainage is carried by a downspout extension to a point beyond the slope. Modified from Holtz and Hart (1978).

properly landscaped with rocks or other mulches (see Chapter 4) to prevent erosion. Soil beneath the slope surface should be well compacted and fine-grained so that water will not easily infiltrate into the backfill.

Ditches and swales. Runoff water from roof and slope drainage systems can be collected and carried away from the house by ditches and swales. These are simply shallow trenches (ditches) or depressions (swales) in the yard that are graded to collect, direct, and convey rainwater, snow melt and excess irrigation water away from the house and off the property. Care must be taken to ensure that the diverted water is not directed toward neighboring structures. Ditches and swales may drain into commonly shared concrete gutters, storm sewers, or detention ponds in suburban areas. In many areas, **culvert pipes** are installed so that so that runoff water can flow under roadways.

CONSTRUCTION QUALITY CONTROL

Quality control is perhaps the most important aspect of construction, especially in areas of swelling soil. Even though soil water conditions may be initially responsible for swelling soil movement, poor construction quality can add significantly to the total amount of damage to a house. Any one of the construction designs and methodologies described in this chapter may be rendered useless unless it is done carefully and correctly.

Appendix C at the end of this book will show you how to look for house damage that may have been caused by swelling soil and/or poor design or construction, as well as how to obtain professional assistance to assess a house for damage or repairs.

REMODELING AND ADDITIONS

Major remodeling projects or additions to existing building may require special considerations, especially when the site is underlain by swelling soil. Soil conditions, including the swell potential, may change over time due to increased moisture and perched subsurface water. Designs may change over time as well. As a result, the original soil and foundation reports typically cannot be used for later remodeling projects. New subsurface engineering investigations are advisable in order to assess and design for changed conditions.

Culvert and drainage swale along a rural road.

The design of an addition needs to consider potential detrimental impacts to both the existing structure and the addition. In particular, the old and new foundation elements may need to be connected in a way that allows independent movement in differential swelling is anticipated. It may be necessary to bridge the soft backfill soil adjacent to the existing structure. The construction of an addition may offer opportunities to improve earlier design oversights and site drainage to reduce local soil movements.

CHAPTER 4

LANDSCAPING ON SWELLING SOIL

Much of the damage that could be caused by swelling soil can be reduced by proper landscaping. As a homeowner, you can be creative about vegetation choice and layout as a means of protecting your property against swelling soil damage.

EFFECTS OF LANDSCAPING ON SWELLING SOIL

The landscaping conventionally used in Colorado consists of luxuriant bluegrass lawns, showy gardens and large shade trees. Many of these plants originated in more temperate climates and have water requirements that cannot be satisfied by rainfall alone. As a result, we augment nature's precipitation by **irrigating** with large amounts of water.

Swelling and shrinking soil behavior is affected by conventional landscaping practices. A significant amount of irrigation water meant for plants **infiltrates** deeply into the ground. **Impervious covers** such as concrete walkways and porches cut off evaporation that would normally remove moisture from the soil to the atmosphere. Trees and shrubs can **transpire** large amounts of water out of the soil around their root systems.

As a result of these practices, the soil beneath a property usually takes on additional or **excess water** after the property is developed. If the soil contains swelling clay, damage to houses may occur for as long as the soil continues to take on water. Most geologists and engineers who work with soil in Colorado agree that ***excess water is the most significant and direct cause of swelling soil damage***.

*An example of how **not** to landscape for swelling soil conditions. A garden has been planted next to the foundation, and the downspout extension has been removed.*

The planting of trees, flowers, and other water-dependent vegetation close to houses should be avoided in areas of swelling soil, where the primary concern is to keep excess moisture away from the foundation. Trees and large shrubs pose a potential problem because they may cause soil shrinkage and foundation settling during droughts as their root systems pull moisture from the soil.

Excess water generated by irrigation often infiltrates downward to a **perched water table**. The water may flow laterally through the soil to other locations, causing soil to swell beneath nearby houses or roads. Swelling soil will draw available moisture toward foundations, much like a sponge. It is imperative to control irrigation in all parts of the yard to reduce damages caused by swelling soil.

GUIDELINES FOR LANDSCAPING

Landscaping on swelling soil should be geared toward reducing the amount of excess water that infiltrates into the ground, especially in the immediate area around the house foundation. Here are some basic guidelines:

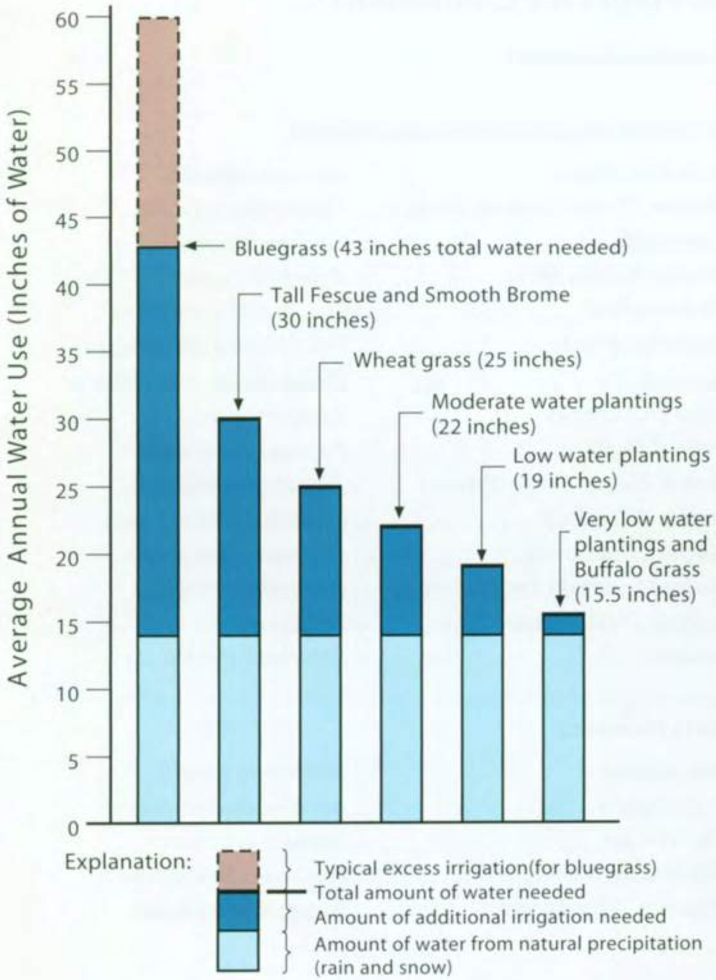
- Do not plant flowers or shrubs closer than 5 feet from the foundation, unless they have very low water requirements and are hand- or drip-line watered
- Plantings near the foundation should not disturb the runoff slope around the house
- Trees should not be planted closer than 15 feet from the foundation, 20 feet for large tree types
- Trees with high water requirements or with extensively wide, shallow root systems (such as willows or poplars) should be avoided
- Sprinkler systems should not spray water any closer than 5 feet from the foundation
- Automated sprinkler systems with rain sensors can be adjusted to the monthly water requirements for various plants
- Use low-water vegetation throughout your property, including gardens and lawns
- Group plants according to similar water needs so that different areas of vegetation can be irrigated in a water-wise manner

Central lawn area accented by gravel edging.

- Irrigation should be limited to the amount necessary to keep plants healthy, and overwatering should be avoided
- Be sure to deep-water existing trees during long, dry periods to keep them from drawing water from the surrounding soil
- Poor-quality, "heavy" clay soil should be improved and conditioned by mixing in organic material to improve its fertility and air and water circulation

XERISCAPE: A PRACTICAL ALTERNATIVE

Landscaping conditions in Colorado are different from most other parts of the country and are typified by high elevation, semi-arid climate, a short growing season, low precipitation and occasional droughts. The swelling clay soils tend to be alkaline, calcium- or sodium-rich, and have poor aeration (air circulation) and drainage.



Average water usage for different types of plants for an area having 14 inches of natural precipitation. The native grasses require less additional irrigation than bluegrass lawns. Modified from Xeriscape Colorado, Inc.

Water availability is also a serious constraint on landscaping in Colorado. More than half of residential water use typically goes to outdoor landscape watering. Water used by Coloradans comes from streams and wells. These supplies are being stressed because of the rapidly increasing population. Water rationing during the summer months has become a common practice in many communities.

Xeriscape™ is a practical solution to landscaping under these seemingly unfavorable conditions. Pronounced "Zeer'-is-scape," the term was coined by Denver Water and means "water-wise landscaping" (from "xeros," the Greek word for dry). Xeriscaping is a process aimed at conserving water, based on proper planning and design, use of mulches and/or turf alternatives, zoning of plants, soil improvements, efficient irrigation, and appropriate maintenance (Xeriscape Colorado, Inc.).

Buffalograss lawn with a walkway made of slabs of Lyons Sandstone.

A Listing of Some Water-Wise Plants for Coloradans

Common and Scientific Name by Category

Deciduous Trees

Bigtooth Maple	*Acer grandidentatum*
Bur Oak	*Quercus macrocarpa*
Flowering Crabapple	*Malus sp.*
Gambel (Scrub) Oak	*Quercus gambelli*
Hackberry	*Celtis occidentalis*
Thornless Honey Locust	*Gleditsia triacanthos inermis*
Western Catalpa	*Catalpa speciosa*
White Ash	*Fraxinus americana*

Evergreen Trees

Douglas Fir	*Pseudotsuga menziesii*
Eastern Red Cedar	*Juniperus virginiana*
Piñon Pine	*Pinus cembroides edulis*
Ponderosa Pine	*Pinus ponderosa*
Rocky Mountain Juniper	*Juniperus scopulorum*

Shrubs

Althea (Rose of Sharon)	*Hibiscus syriacus*
Buffalo Juniper	*Juniperus sabina*
Chokecherry	*Prunus virginiana*
Creeping Oregon Grape Holly	*Mahonia repens*
Common Lilac	*Syringa vulgaris*
Fernbush	*Chamaebatiaria millefolium*
Golden Currant	*Ribes aureum*
Mountain sumac	*Rhus glabra cismontana*
Thimbleberry	*Rubus deliciosus*
Yucca	*Yucca sp.*

Perennial Flowers and Ground Covers

Basket-of-Gold	*Aurinia saxatilis*
Blanket Flower (Indian Blanket)	*Gaillardia aristata*
Coreopsis	*Coreopsis tinctoria*
Double Bubble Mint	*Agastache cana*
Globemallow	*Sphaeralcea coccinea*
Hardy Ice Plant	*Delosperma nubigenum*
Harebell	*Campanula rotundiflora*
Hens and Chicks	*Sempervivum sp.*
Iceland Poppy	*Papaver nudicaule*
Prairie Zinnia (Paperflower)	*Zinnia grandiflora*
Prairie Wine Cup	*Callirhoe involucrata*
Purple Coneflower	*Echinacea purpurea*
Rocky Mountain Penstemon	*Penstemon strictus*
Sedums (various types)	*Sedum sp.*
Yarrow	*Achillea millefolium*

Turfs (Grasses)

Blue Grama	*Bouteloua gracilis*
Buffalograss	*Buchloe dactyloides*
Fine Fescue	*Festuca cultivars*
Tall Fescue (turf-type)	*Festuca arundinacea*
Western Wheatgrass	*Pascopyrum smithii*

(Sources: Jochim, 1987; City of Aurora; Denver Water; Xeriscape Colorado)

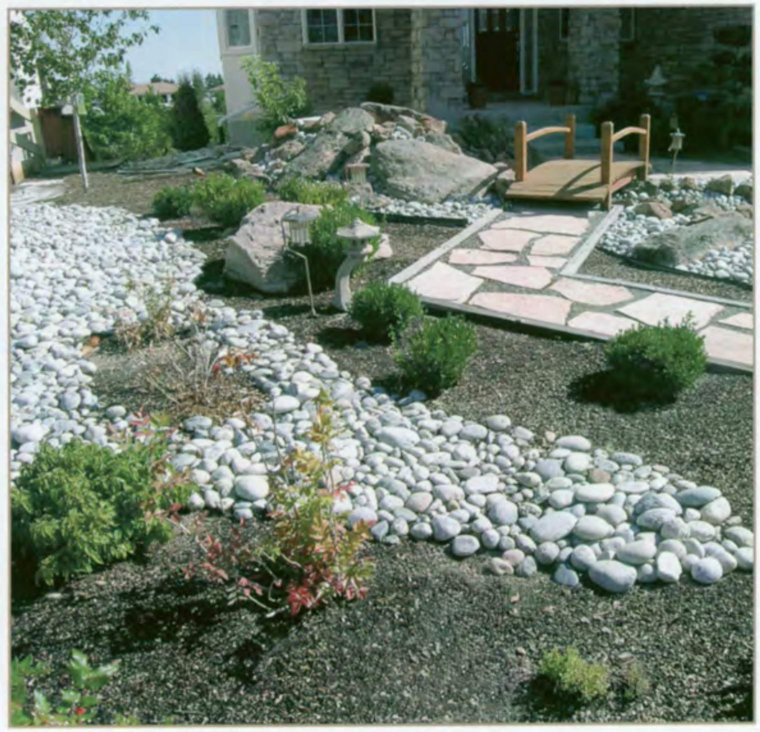
Mulch edging accented by decorative wildflowers, grasses and shrubs.

A low-water landscape requires less intensive maintenance after it is established. There is a dramatic difference in the water demands of a conventional bluegrass lawn versus Xeriscape plantings. Colorado homeowners have been able to reduce their total household water use by as much as 50 percent, and have saved as much as 30 percent on the cost of their annual water bills by installing water-wise landscaping (Denver Water Department, 1988). ***An important benefit of Xeriscaping is that it can help to reduce swelling soil damage to a home.***

Xeriscape landscaping can be used creatively to suit a homeowner's needs. The results can be practical, colorful, and appealing. Numerous plants, both native and introduced, are well adapted to Colorado's climate and soil. The facing table lists several of these trees, shrubs, perennial flowers, ground covers and turf grasses (which often come in multi-species mixes). There are several excellent resources available to homeowners who are looking for information and ideas about Xeriscaping and water conservation, several of which are listed at the end of this book.

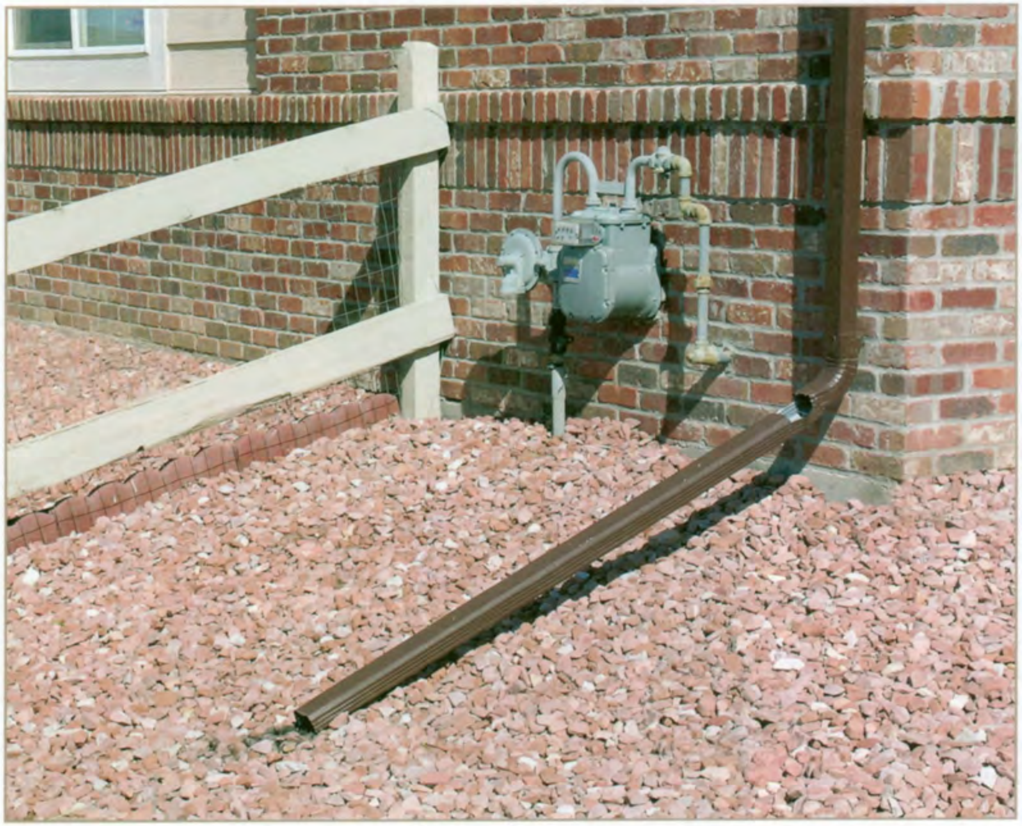
LANDSCAPING WITH MULCHES

An important component of Xeriscaping, especially for areas of swelling soils, is using **mulch** as a cover in selected areas of the yard. Mulches can be **organic** (bark, wood chips, etc.) or **inorganic** (boulders, cobbles, gravel, or crushed rock). These materials may be underlain by a **geotextile fabric** base that controls weeds and retards infiltration, but still permits evaporation. The use of impermeable plastic sheeting is discouraged because it prevents normal evaporation from occurring. An attractive, relatively low-maintenance landscape can be created by using **gravel edgings**, **rock gardens**, low-water ground cover and, perhaps, a limited central area of lawn.



Rock garden with islands of low-water vegetation.

One of the most effective ways to reduce infiltration of water next to a house foundation is to construct a **runoff slope** and cover it with a mulch landscape. When used for this purpose, the slope should extend at least 5 feet out from the house. A perforated border or **edging** should be used to hold the outer edge of the liner in place, and to allow passage of free water away from the mulch area.



A gravel-covered runoff slope with a downspout extension to carry water away from the foundation.

Just remember, you still have to maintain good surface drainage and irrigation control, and not plant trees or shrubs too close to the foundation.

Replacing a lawn or garden with an organic or inorganic mulch landscape has some disadvantages. The most significant ones are listed as follows:

- Trees or islands of vegetation planted within gravel mulches will need to be tolerant of radiated solar heat and resistant to sunscald
- Increased surface runoff away from the house must be properly drained through a system of slopes, swales, or ditches (see Chapter 3)
- Heavier gravel and cobbles should be used to cover a steep slope, as light-weight organic and gravel mulches may wash away during a hard rainfall
- Walking on areas of crushed rock may damage the fabric liner; this is remedied by providing adequate pathways made of concrete or flat stones
- The geotextile fabric will eventually deteriorate over time and allow unwanted weed growth and water infiltration if the fabric is not replaced
- Organic mulches will decompose naturally, adding nutrients to the soil but necessitating adding new material at periodic intervals

These inherent disadvantages can be controlled through proper planning and maintenance of the landscaped areas. The bottom line for mulch covers, and Xeriscaping in general, is that the potential benefits far outweigh the problems, especially when it comes to reducing swelling soil damage.

CHAPTER 5

HOME MAINTENANCE ON SWELLING SOIL

The lack of timely maintenance to critical slope, drainage, and landscape areas around a house is another important factor that can contribute significantly to swelling soil damage. Severe problems may result from poor maintenance practices such as:

- neglecting to maintain adequate runoff drainage slopes
- neglecting to clean gutters and downspouts
- overwatering lawns and gardens
- neglecting to adjust and maintain sprinkler systems
- planting trees, shrubs, and flowers too close to the foundation
- constructing patios, fences, or other obstructions that dam and pond water
- neglecting to seal old construction joints and cracks that develop over time.

It is essential that the homeowner understands how to check and maintain all of the different systems that were designed to protect a house against swelling soil damage. The following sections describe typical types of periodic maintenance that should be conducted if your house is built on swelling soil. (For more details on the design considerations for these systems, see Chapter 3 and Appendix B).

CONCRETE FLOOR AND WALL MAINTENANCE

Every homeowner should conduct a yearly inspection of **concrete slabs and walls**, both inside and outside of the house. This is especially important during the first 5 years after a new house is built because this is usually when the greatest adjustment occurs between the house and its environment.

Some **cracking** will occur in virtually all new concrete slabs and walls, but it tends to be more common and more severe in areas of swelling soils. Cracks should be sealed as soon as possible using a quality exterior acrylic caulking compound or equivalent products manufactured for this purpose.

Cracks should be regularly monitored by measuring the width of a number of cracks at a designated spot along each crack. Note whether the cracks stay the same width, steadily increase in size over time, or expand and contract with the seasons. This can be helpful information in the event that a professional damage-and-repair consultant needs to be called.

Furnace boots and the built-in gaps in the top or base of interior walls should be monitored annually. Collapse of these gaps may indicate that the concrete floor is heaving.

It is typical for small cracks to form in concrete due to curing and temperature and humidity changes. Look for larger cracks that may indicate swelling soil movements.

STRUCTURAL FLOOR SYSTEM MAINTENANCE

Homeowners should be familiar with any maintenance and special requirements of structural floors and any attendant systems. Passive or active **ventilation systems**, floor grates, and polyethylene **vapor barriers** should be maintained to prevent moisture and humidity build-up beneath the floor. Mold issues are important, but are beyond the scope of this guide. Call your county health department if you have concerns about mold growing in your subfloor space.

Monitor subfloor soil conditions periodically by entering the crawl space (if possible) or by peering through door hatches in the floor. Take care to notice extreme wetting or upward movement of the soil surface. If the soil has risen and come into contact with the floor joists, structural problems could ensue. It may be necessary to call for professional help if the floor begins to move or buckle.

SUBSURFACE DRAINAGE MAINTENANCE

Subsurface drains should require little maintenance if they were correctly installed. For gravity-discharge drain systems, it is extremely important to avoid obstructing the drain at the point where it discharges. It may occasionally be necessary to clean out roots, nests or other debris from the end of the pipe. If the subsurface drainage system is not working, it may have been broken, installed incorrectly, or even not installed at all. Older houses may have drain tiles that could break over time. In any of these cases, it will probably be necessary to dig up the drain in order to diagnose the problem and make the appropriate repairs.

If an **area drain** is installed in a subdivision, the homeowners association should be aware of its location and should have the system maintained and cleaned out regularly.

Sump systems require regular periodic inspections and, if water has entered, cleaning of the sump pit and maintenance of the submersible sump pump. Constant standing or running water in the sump may indicate a larger subsurface drainage problem.

SURFACE DRAINAGE MAINTENANCE

Roof gutters should be inspected at least twice a year, in the spring and fall. All debris should be cleaned out and metal gutters checked for rust. Check the slope of the gutters. If the slope is too low, water will accumulate in low spots, building up debris and accelerating rusting. Use a garden hose or pour a bucket of water into the gutter at its high end, and note if the water flows out smoothly or ponds in low spots. The gutters should be adjusted to remove any high or low spots.

Downspouts should be checked for clogging at the same time the gutters are checked. Clogging often occurs at the elbow where the downspout and gutter meet. The elbow can be removed for cleaning but it may be necessary to use a plumber's snake to clean the downspout. A leaf strainer or leaf guard should be installed at the top of the downspout if there is a problem with leaves. Flexible **downspout extensions** elbows should be bent back into their "down" position at all times.

Drainage swales should be regularly maintained. The best time to check their condition is immediately after a period of rainfall or snowmelt. Make sure that there are no obstructions caused by fences or walls.

Sprinkler systems, both manual and automatic, should be checked and maintained often to prevent leakage into the ground from cracks in hoses and loose-fitting joints. Watering schedules should be adjusted according to the season and types of vegetation present. Denver Water distributes a pamphlet called "Great Timing" that tells how to time watering in order to reduce outdoor water consumption (see "Information Sources," at end of book).

SLOPE MAINTENANCE

The most critical aspect of slope maintenance is maintaining a positive slope over the **backfill** area next to the house (see "Surface Drainage" in Chapter 3). Backfill material may settle enough to reverse or flatten the runoff

Settling of the backfill material has caused this sidewalk slab to settle and crack, resulting in reverse drainage and ponding next to the foundation. From Jochim (1987).

slope. **Reverse or negative drainage** will cause ponding, allowing water to infiltrate into the ground next to the foundation.

To maintain the runoff slope around a house, the homeowner should periodically compact the soil at the surface of the slope by tamping it down with a heavy piece of wood and adding new fill material as needed. Additional soil should be added and compacted as is necessary to maintain a **positive slope** away from the foundation. Easy directions for determining and correcting slope are found at the end of this chapter.

Settling of concrete sidewalks and porches next to the foundation may necessitate removal and replacement of these elements if it results in reverse drainage. Additional soil should be placed to create proper drainage, and a new concrete section should be installed. If the existing slab still has a positive slope of at least 1 percent, it is only necessary to seal the cracks.

LANDSCAPING MAINTENANCE

It may be prudent to delay installing any landscaping adjacent to the foundation until the backfill has had a chance to settle. Otherwise, it may be costly and time-consuming to remove existing landscaping over a backfill area that has settled.

During dry periods, check the lawn and backfill areas for vertical desiccation cracks. These cracks may be filled with loose native soil.

Low-water **Xeriscapes** require greater amounts of watering and maintenance for the first few years after planting than is required thereafter. Periodic maintenance is still needed after the Xeriscape is established to keep weeds out and to ensure the performance of the plants and mulches.

The topic of landscape maintenance is much too broad to be covered completely in this guide. The benefits of wise landscaping include swelling soil mitigation, water conservation and cost savings and much more. Homeowners are advised to call one of the agencies listed in the "Information Sources" at the end of this book for more information.

AN EASY METHOD FOR DETERMINING SLOPE

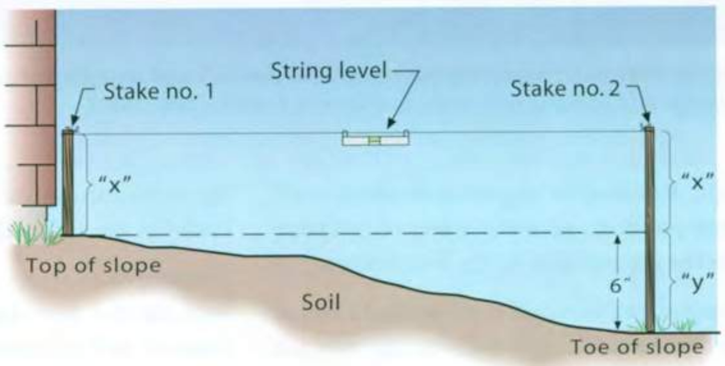
Here is an easy way to determine slope for the purpose of maintaining proper surface drainage away from a house. The only materials required are a string level or line level (available at most hardware stores), two 3-foot long wood stakes, 12 feet of string, a marking pen, a measuring tape or yardstick, and a hammer.

1) Hammer one stake into the ground next to the foundation.
2) Tie one end of the string to this stake.
3) Measure off 10 feet, or 120 inches, of string away from the stake. Mark that spot on the string.
4) Tie the loose end of the string to the second stake. Be sure to leave exactly 10 feet of string between the stakes.
5) Push the second stake into the ground after stretching the string straight out from the building.
6) Attach the string level to the middle of the string.
7) Hammer the second stake into the ground until the string level indicates that the string is level. Your setup should look like the drawing.
8) Measure the distance, in inches, between the string and the ground on stake number one. Call this distance "x."
9) On stake number two, mark the distance "x" below the string.
10) Now measure the left-over distance between "x" and the ground on stake number two, in inches. This distance is called "y."
11) Determine the slope by using "y" in this equation: Slope = "y" ÷ 120 x 100.

EXAMPLE:

Looking at the drawing, the distance "y" = 6 inches. Therefore: Slope = 6 ÷ 120 x 100 = 5.0 percent.

To correct an existing slope that is too flat, first determine what the slope should be. We suggest a 5 to 10 percent slope, or greater. To get a 10 percent slope (1 foot of fall within 10 feet from the foundation), the distance "y" in the drawing should equal 1 foot, or 12 inches. This slope can be attained by raising the slope until 12 inches can be measured below "x" on the stake, either adding dirt at the top next to the house, or removing dirt beyond the slope toe to create a swale. Remember to tamp the dirt where it has been added to achieve proper compaction.



Drawing: slope determination setup

CHAPTER 6

SWELLING SOIL AND HOMEOWNER RISK

Ultimately, there are few easy or clear-cut decisions when it comes to swelling soil. We strongly advocate an informed decision on the part of a potential buyer of a new or resale home or a present owner considering improvements or repairs to a home.

An informed decision involves knowing the potential severity of swelling soil beneath the house in balance with other important considerations such as location, lifestyle and affordability. It involves a realization and acceptance of the risks that are inherent in owning a home built on swelling soil.

DISCLOSURE FOR NEW HOMES

For **new homes**, Colorado Senate Bill 13 (1984), C.R.S. 6-6.5-101, describes the responsibility of a builder of a new home to **disclose** evidence of any significant soil hazards, including swelling (expansive) soil, to a potential buyer. This guide is designed to satisfy the disclosure requirements in Part 1 of the statute:

> *At least fourteen days prior to closing the sale of any new residence for human habitation, every developer or builder or their representatives shall provide the purchaser with a copy of a summary report of the analysis and the site recommendations. For sites in which significant potential for expansive soils is recognized, the builder or his representative shall supply each buyer with a copy of a publication detailing the problems associated with such soils, the building methods to address these problems during construction, and suggestions for care and maintenance to address such problems.*

In practice, the provisions of this statute should be followed when the project geotechnical engineer recommends using certain construction methods and designs specifically to reduce the effects of swelling soil.

This information should be included in a summary **soil report** for each lot or for a larger project area. The report should include soil descriptions and observations and an assessment of the swell potential, using the most specific information available for the subject site. It should include the engineering recommendations used by the builder or developer in determining the site's building designs.

If you are considering purchasing a new home and have received this book as part of the Senate Bill 13 disclosure requirements prior to closing, it is most likely that the home was built on swelling soil. You may now be facing a decision on whether to go ahead with the purchase or to look elsewhere for a home that may be less affected by swelling soil (Some steps that may help you with this decision are listed in Appendix C).

DISCLOSURE FOR RESALE HOMES

Buyers of **resale homes** in Colorado are also protected by disclosure legislation. Real estate brokers are required to disclose all adverse material facts under the provisions of Senate Bill 223 (1993), C.R.S. 12-61-801 et seq. The presence of swelling soil, although not specifically named, may be considered an **adverse material fact**, because it can affect the physical condition of or cause defects in the property.

A violation of disclosure requirements by the real estate broker may be investigated by the Colorado Real Estate Commission under C.R.S. 12-61-113(1).

The seller of a resale home should be asked to fill out form SPD19-10-06, Seller's Property Disclosure, which specifically lists the presence of expansive soil as a hazardous condition. This form is supplied by the real estate broker. Both the buyer and the seller sign the form as part of the property sale. **Non-disclosure** of adverse material facts by the seller may constitute misrepresentation or fraud, and is covered by common law.

As a homebuyer, you should not rely solely on disclosure information for a variety of reasons. For example, the present homeowner may not understand or have any knowledge of swelling soil and may attribute structural movements to settling or poor construction alone. They may be genuinely unaware of previous problems or repairs if the home has had multiple owners. In any case, make sure that you ask the homeowner specific questions about the property's soil conditions as well as existing and past damage and repairs.

It may be possible to determine if swelling soil has affected a resale home by looking for telltale signs of **damage** and/or **repairs** (Appendix C tells how to inspect a resale home for swelling soil damage). In addition, it may be advisable to hire a structural engineer to assess the physical condition of the home, the soil report, and the foundation design.

REDUCTION OF RISKS

Swelling soil is widespread in Colorado and is not easily avoided. However, the mere **presence** of swelling soil beneath a property gives no definitive indication of the potential **severity** of the swelling hazard. You should be more concerned about the soil's swell potential (Is it non-swelling, low, moderate, high, or very high?) and how the home was designed and built with regard to those actual soil conditions.

The potential severity of damage due to swelling soils can be significantly reduced if steps are taken to recognize the problem and then design, construct, landscape, and maintain the home in a responsible manner. Leaving out or cutting corners on any one of these steps can lead to dramatic and devastating results. The risks associated with swelling soils and bedrock can be reduced, but not eliminated, by careful design and construction procedures.

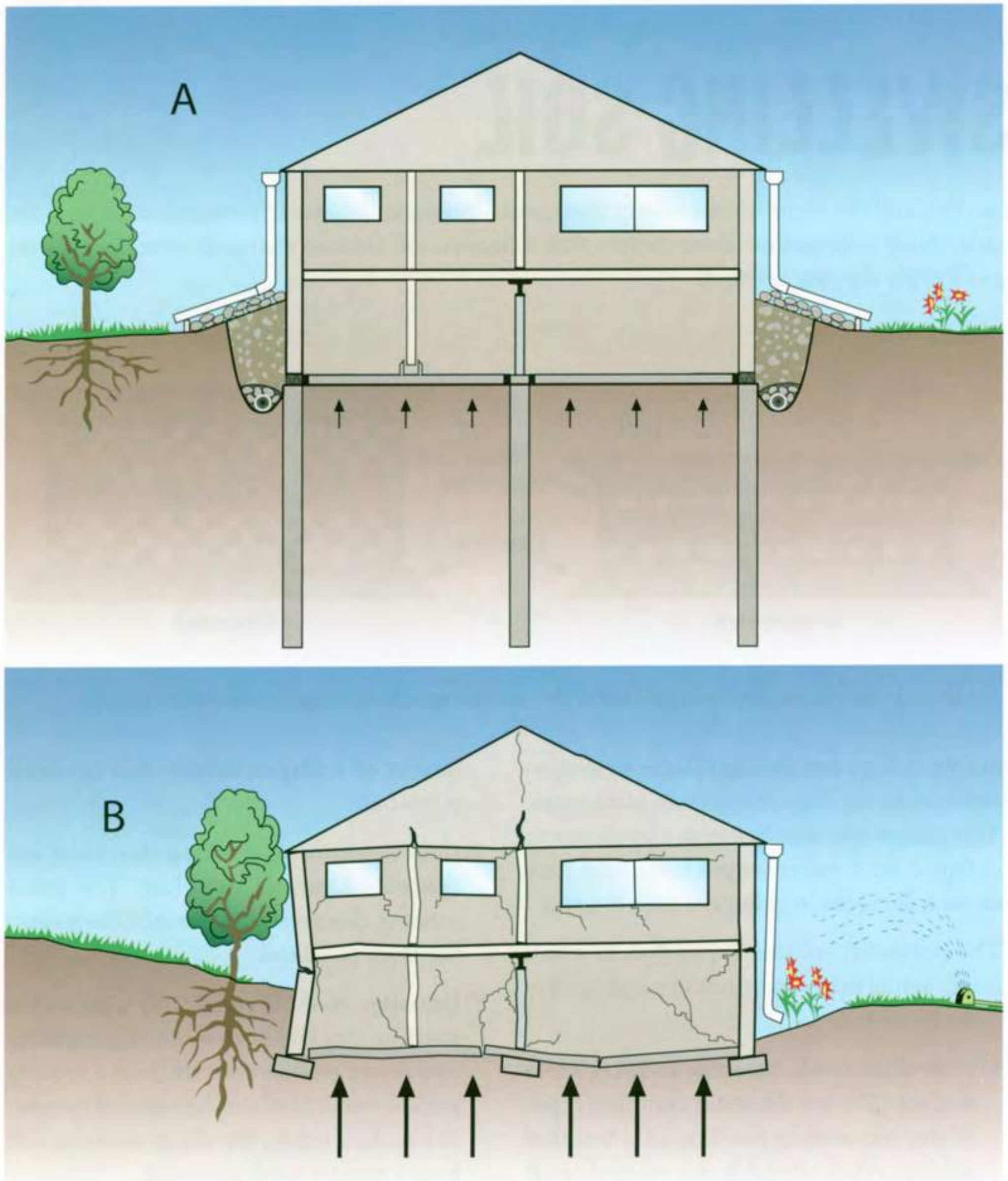
BALANCING OTHER BUYER CONSIDERATIONS

Swelling soil will not be your only consideration when it comes to house-hunting in Colorado. There are many other important factors to consider including the location of the home or property with respect to work, schools, parks, recreational facilities, and views. The cost of the home or property will also be of great importance to you.

Modern technology and construction practices have improved performance of new houses built on swelling soil. However, one should expect that swelling soil will expand and heave to some degree in response to development and irrigation. Any corner-cutting in the proper design, construction, landscaping and maintenance that results in an initial savings to a homebuyer could be negated by the cost of repairs many years later.

We hope that this will convince you to consider swelling soil seriously, and balance the consideration of swelling soil risks along with the other decision factors that are important to you.

Right: The results of proper (A) versus improper (B) design, construction, landscaping, and homeowner maintenance for homes built on swelling soil. Modified from Holtz and Hart (1978).



THE FINAL DECISION

The final decision to purchase—or to not purchase—a particular house on swelling soil is yours, and yours alone.

We encourage you to find out all you can about the geology beneath the house and how the house foundation was built. If you have been furnished a written warranty, read it carefully. Damage from swelling soil can occur even if the home is new, and you should be aware of what your builder may or may not be responsible for repairing. You may wish to hire a professional engineer to assist you with your decision (as explained in Appendix C).

Your choice will ultimately rest on your own judgment of performance expectations and tolerance of risk. Many people will understand and accept the risk of living on swelling soil, while others may choose to look for a home on non-swelling soil.

If you choose to buy a house on swelling soil, we sincerely hope that you will use the information in this guide to help maintain your property and protect it against this potentially powerful geological hazard.

A

APPENDIX A

MORE ABOUT SWELLING SOIL

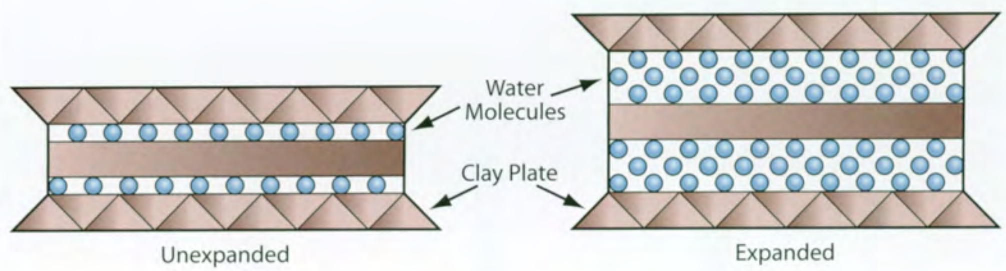
Soils can have different origins and physical properties, and the deposits can vary in thickness. Understanding these factors is important for making design decisions. This section contains additional information about factors that influence soil volume changes, laboratory determinations of a soil's swell potential, and heaving of steeply dipping bedrock.

FACTORS THAT INFLUENCE SWELLING AND SHRINKING

Smectite (montmorillonite) is the clay mineral responsible for most swelling soil and bedrock damage in Colorado. **Bentonite** is a special type of smectite that was originally deposited as ash from ancient volcanoes, and which may have especially high swelling characteristics. **Illite** and **mixed illite-smectite** are common clay minerals that may swell, but to a lesser degree than smectite.

Swelling occurs when moisture is added. Certain clay minerals such as smectite may exert a chemical and physical attraction on moisture, pulling layers of water molecules into microscopic areas between the flat clay plates. The clay plates are pushed farther apart as more water layers are pulled in. This pushing apart (swelling) can cause high swell pressures and/or an increase of volume within the soil.

Shrinkage, the opposite effect of swelling, occurs when the soil dries out. As drying occurs, layers of water molecules are pulled out from between the clay plates by evaporation or by capillary forces from plant roots. This causes the area between clay plates to collapse on a microscopic level, and may cause a decrease in volume within the soil.



Expanding clay plates; view is magnified from a microscopic level. Modified from Hart (1974).

The potential volume expansion of a soil under actual field conditions depends on five main factors:

1) **Type of minerals.** Smectite and (to a lesser degree) illite are the most common types of clay minerals in swelling soil. Soil that contains relatively stable clay minerals such as kaolinite, or non-clay minerals such as quartz or feldspar, usually has no swell potential.

2) **Concentration of swelling clay.** Most soil contains a mix of minerals. The more swelling clay present in the mix, the greater the swell potential.

3) **Density.** A dense material containing swelling clay will have more clay particles and fewer air-filled voids than a loosely packed material of similar mineral composition. As a result, the dense material will have a greater swell potential.

4) **Moisture change.** A dry soil has the potential to absorb more moisture than a wet soil, and can subsequently undergo a greater amount of volume expansion. This is why homes built during dry periods may experience greater heaving than those built when the soil is wet. The amount of moisture change that can occur in a soil is a function of the initial amount of moisture in the soil (natural moisture content), the ability of the clays in the soil to pull in additional moisture (swell potential), and the amount of free-draining water or water vapor available to the soil.

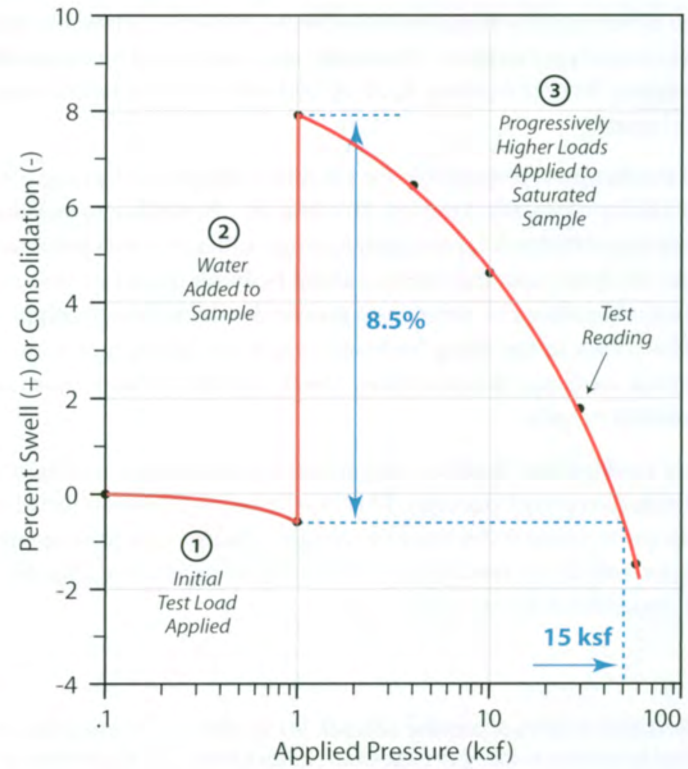
5) **Restraining pressure.** A layer of swelling soil that occurs near the ground surface may swell significantly and cause uplift and heaving because there is very little loading, or restraining pressure, to prevent it from swelling. However, the swell potential of a similar layer that occurs several feet below the surface is restrained by the weight of the surrounding and overlying soil **(overburden)**. If the overburden weight is greater than the soil's swelling pressure, then actual swelling and uplift are unlikely.

HOW TO READ A SWELL TEST

Swell potential and **swelling pressure** are two measurements of a soil's ability to expand against different restraining pressures under laboratory conditions. A soil sample is typically rated as having either very high, high, moderate, low, or no swell potential. Swelling pressure is the pressure exerted by the soil mass against a restraining force when it is wetted.

Typical swelling pressures for swelling soil in Colorado can reach 15,000 pounds per square foot, or even higher in some cases. Soil having such a high swelling pressure is capable of causing uplift to concrete slabs and footing-type foundations, which exert relatively low loading pressures.

The swell potential and swelling pressure are measured in a laboratory by means of a **swell-consolidation test**, where a sample of soil is confined in a tube and weighed down by a load that simulates overburden pressures. The sample is exposed to water and is allowed to swell, and the percentage of gain or loss in length is noted. This is the swell potential. Next, more weight is added until the sample is pressed to its original length. The pressure where this occurs is the swelling pressure. The results are plotted on a graph, such as shown in the example below.



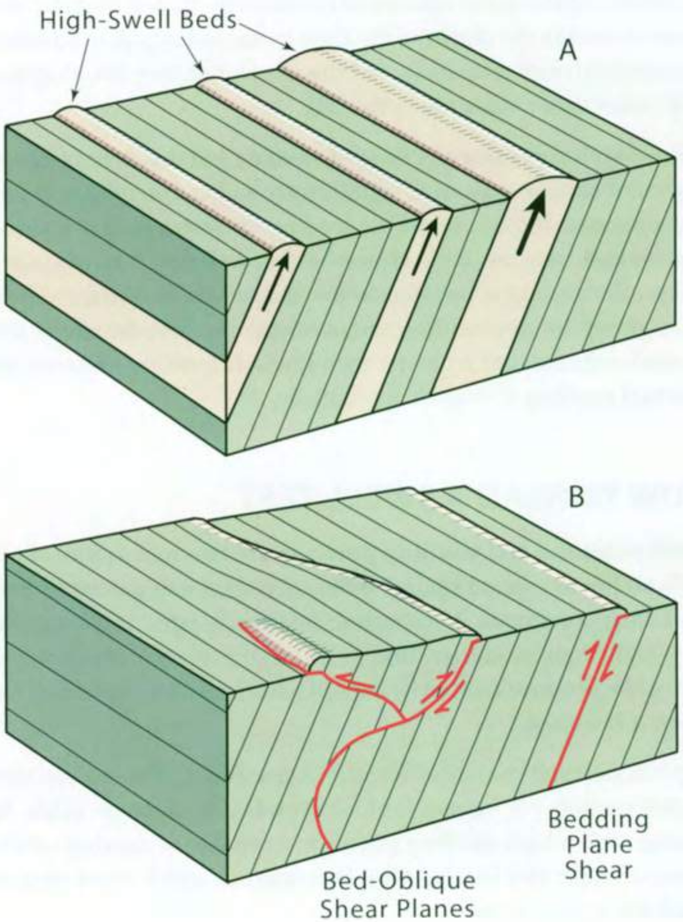
Graph of results for a swell-consolidation test. In this example, the swell potential is 8.5% and the swell pressure is 15,000 pounds per square foot (15 ksf).

HEAVING BEDROCK PROCESSES

Differences in thickness of soil or flat-lying bedrock layers can cause some differential swelling beneath a house. However, when swelling bedrock layers are inclined, differential movements can be extremely damaging. Steeply dipping, heaving bedrock is a very serious geologic hazard.

The mechanisms responsible for such movements in dipping rock layers are geologically complex. Heaving may occur due to swelling of individual bedrock layers, each having a different swell potential, or due to shear–slip movements along bedding planes or fracture surfaces. Moisture can penetrate a greater depth into steeply dipping bedrock than in flat-lying bedrock, resulting in a deeper zone of potential swelling. In some cases, these movements may continue for several decades.

Many swelling-soil building designs are ineffective against dipping bedrock movement damage. This is why some Colorado jurisdictions, particularly Jefferson and Douglas counties, require special designs such as overexcavation and fill replacement. See Chapter 1 and Appendix B for more information.



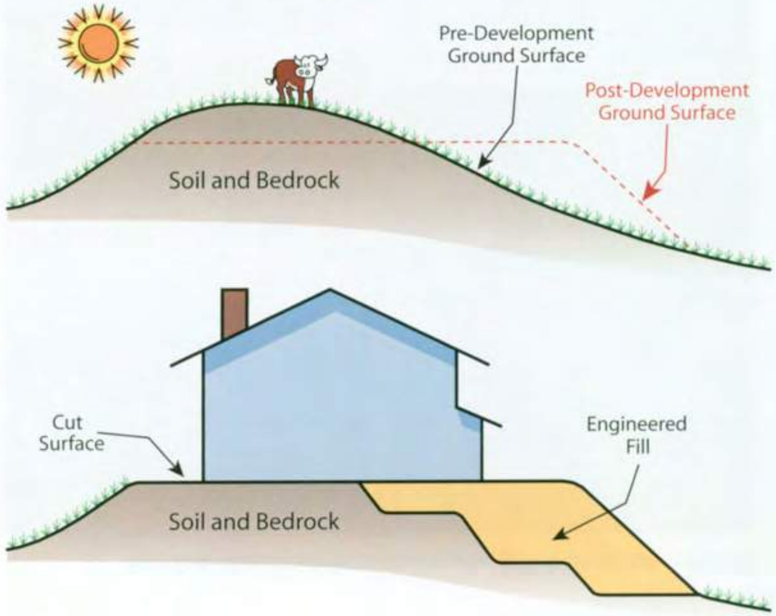
Right: Different types of heaving bedrock. (A) Symmetrical heave features caused by uneven swelling of individual bedrock layers. (B) Asymmetrical heave features caused by shear–slip movement along bedding planes and/or fracture surfaces. Modified from Noe and Dodson (1995).

APPENDIX B

CONSTRUCTION-DESIGN DETAILS

B

This appendix describes the advantages and some of the pitfalls of certain specialized designs used in ground preparation and house construction on swelling soil. Many variations of a design are possible, and the actual designs used for any particular house may differ to some degree from those shown. The following information is not intended to be a design standard for construction or grading and is not a substitute for building code requirements or on-site engineering practices.



Grading cut and fill areas.

GROUND PREPARATION AND GRADING

Cuts. Grading cuts are susceptible to swelling because the natural restraining loads have been removed, exposing soil or bedrock layers that have not previously swelled to their full potential. Such areas can dry out after grading, thereby increasing the swell potential. In some cases, grading exposes fractures or other water conduits that were not open to moisture intrusion prior to grading.

Fills. It is common engineering practice to reduce the swelling potential of graded fills by controlling their moisture and density. The fill soil is typically spread out in thin layers. Water is added to each new layer, and then the layer is compacted by machine to a recommended density. In Colorado, engineered fill is typically wetter and less swell prone than the natural, host soil. Construction of fills may involve mixing non-swelling sand or low-swell clay with higher-swell clay, which may effectively reduce the swell potential.

The **overexcavation and fill replacement** method (also called **subexcavation**) is becoming increasingly used in areas of swelling soil and bedrock. Overexcavations and deep fills may be recommended in certain Colorado counties where steeply dipping, heaving bedrock is encountered. The method involves cutting and removing the soils to a prescribed depth, usually 3 to 10 feet or more below the anticipated lowest foundation level. The cut is then filled with uniform layers of original or imported soil under controlled moisture and density conditions. This fill creates a buffer between the foundation and the underlying swelling soil.

An overexcavation and fill replacement construction operation.

Overexcavations vary in their extent and depth. Broadly extensive, area excavations constructed with large earth-moving equipment are the most common. Strip and individual-foundation excavations are less common, and demand very rigorous quality control. Problems arise from insufficient cut depth, moisture conditioning, compaction, or subsurface drainage. House footprints should lie well away from the edge of an overexcavation to avoid edge effects such as differential heaving or settling.

Water or chemical treatments. Another means of reducing swell potential is to inject water or a mix of water and chemicals into the soil. This is typically done after site grading. The addition of water will pre-swell the soil. Chemical treatments are specially formulated to change the clay chemistry and mineralogy so that the clay becomes less expansive. Such treatments are used mainly for roads and commercial buildings, and less commonly for single-family residential dwellings.

A main drawback of water or chemical treatments is that they may not penetrate very deeply or uniformly into swelling soil and bedrock due to the presence of fractures, low-permeability layers and other geological complexities. Another drawback is that the chemicals may be leached out of the soil over time.

Moisture injection operation.

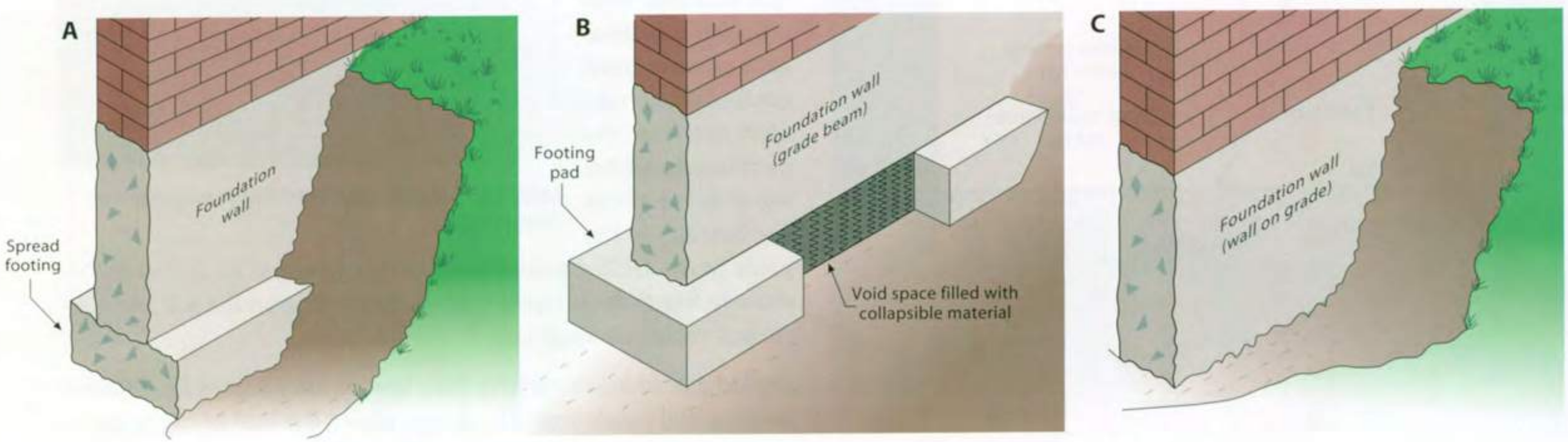
SHALLOW AND DEEP FOUNDATIONS

Shallow foundations have basal elements that are directly supported by soil, bedrock, or fill along the bottom of the foundation excavation. They are used in many areas of Colorado for low-swell soil, or in conjunction with overexcavated and replaced fills. The use of shallow foundations for moderate-swell soil is less common and should be subject to cautious professional judgment.

A **spread footing foundation** consists of a continuous strip of concrete, typically 16 inches wide but occasionally narrower or wider, upon which the foundation wall is placed. The footing has a relatively large bearing area (basal area) in contact with the ground, which spreads out rather than concentrates the weight of the house. This type of foundation works best in loose, non-swelling soil to reduce settlement.

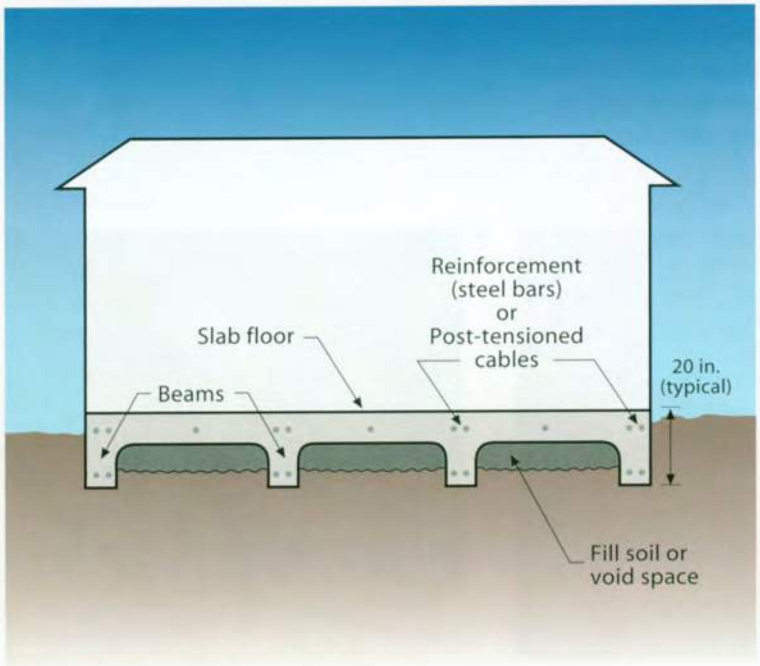
A **footing pad foundation** consists of discontinuous concrete pads. Between the pads are void spaces filled with a collapsible material, such as cardboard, that does not transmit loads. The pads and void spaces are spanned by a grade beam, a steel-reinforced foundation wall. The load of the house is supported by the grade beam and pads. This type of foundation may be appropriate for soil having very low to low swell potential.

A **wall-on-grade foundation** consists of a continuous foundation wall that rests directly on the soil. The wall exerts a moderate pressure on the soil due to its rather small bearing area. A voided wall-on-grade foundation contains rectangular void spaces in the bottom of the foundation wall at specified intervals. These types of foundations have been used in Colorado for soil having low to moderate swell potential, but are becoming less common in most areas of the state.



Spread footing (A), discontinuous footing pad (B), and wall-on-grade (C) foundations. Modified from Holtz and Hart (1978).

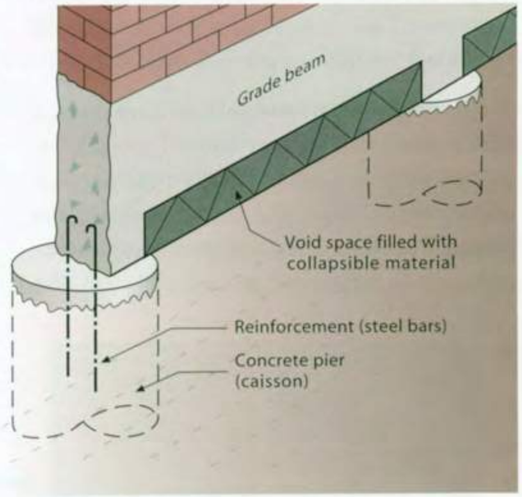
A **post-tensioned, slab-on-grade** foundation consists of a concrete element that has waffle-like vertical beams, or a thicker horizontal slab, and is smooth on the upper side. Strong steel cables, called tendons, cross through the slab. These tendons are tightened after the concrete is placed, so that the slab becomes stronger and more rigid as the concrete cures. The load-bearing walls of the building rest on the upper surface. Post-tensioned slabs may be uplifted by moderately to highly swelling soil. However, the rigidity of the slab may allow the building to move as a unit to reduce damage. This type of foundation is most often used in Colorado for commercial or multi-family buildings, and is increasingly being used for residential buildings without basements.



Post-tensioned, slab-on-grade foundation.

Deep foundations have basal elements that penetrate the soil or bedrock to some depth below the base of the foundation wall, essentially anchoring the foundation into the ground and transferring much of the load to deeper soil or rock layers.

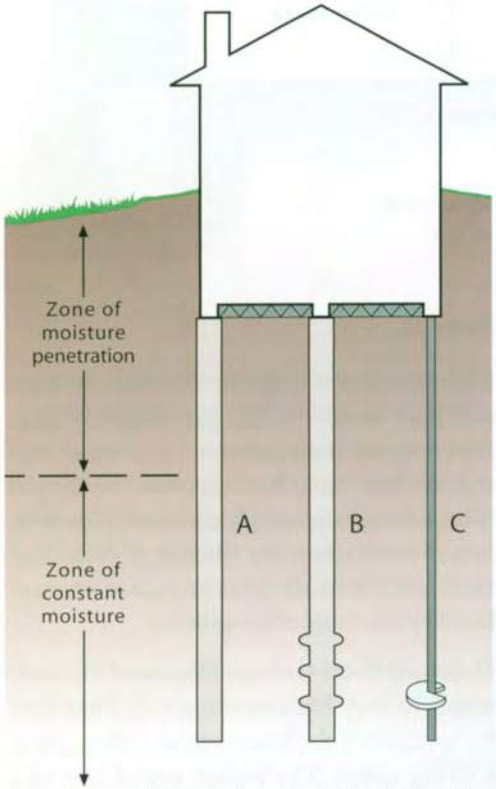
Drilled pier foundations are the deep foundation systems most often used in areas of moderately to very highly swelling soil in Colorado. Drilled piers for houses are typically constructed by drilling a geometric array of holes, usually 8 to 16 inches in diameter, into the ground. Steel reinforcement rods are lowered into the hole, after which the hole is filled with concrete. After the concrete hardens sufficiently, a grade beam is constructed over the piers to create a load-bearing span between them. Void spaces, filled with collapsible material such as corrugated cardboard, are created between the piers to separate the top of the soil from the bottom of the grade beam. Drilled piers typically range between 15 and 35 feet or more in length from top to bottom, depending on the soil and subsurface moisture conditions.



Drilled pier foundation. Modified from Holtz and Hart (1978).

Drilled pier foundations have been specifically adapted for different swelling soil conditions. The design allows the load of the house to be concentrated on a relatively small number of piers, to resist uplift pressures from swelling soil. The piers must be drilled to a depth below the zone of expected, long-term, post-construction moisture penetration, or else they may heave and damage the house.

Several types of drilled pier configurations are typically used in Colorado. They may be **straight-shafted** or may have grooves cut near the base. **End-bearing drilled piers** are drilled into bedrock, whereas **friction drilled piers** are drilled in thick soil deposits where the underlying bedrock is too deep to be reached. **Helical steel piers**, **mini piles**, and **push piles** are used in areas of Colorado as remedial installations to replace previously damaged foundation elements, and may be used for new construction in certain cases. Helical piers consist of a steel shaft with auger-like blades near the tip. The tip is advanced into the ground by rotation until it meets a prescribed torque resistance or depth. Mini piles and push piles consist of bladeless steel shafts.



Three types of drilled piers: straight-shafted (A) and grooved (B) concrete piers, and helical steel pier (C). All piers should extend well below the anticipated zone of moisture penetration.

Drilled pier foundations may reduce the effects of swelling soil when designed and constructed properly. There are certain geological situations in Colorado, however, where drilled piers may not be the most appropriate foundation design. In particular, pier foundations are largely ineffective in areas of steeply dipping bedrock, where the bedrock may be unstable to depths of more than 30 feet. In such areas, one method that may counteract the differential heaving is **overexcavation and fill replacement,** whereby a house is isolated from the heaving bedrock by a thick pad of engineered fill.

LATERAL SUPPORT FOR FOUNDATION WALLS

Reinforcement may be provided by steel bars or beams or by wing-like walls (**buttresses** or **counterforts**) that extend outward from the foundation wall at a right angle. An improperly designed wall is at risk of buckling or bowing inward when exposed to backfill soil that contains swelling clay. Many engineers in Colorado discourage the use of high-swell **backfill** soil along foundation walls. The walls of walk-out basements are susceptible to bowing because of differential loading along the length of the wall.

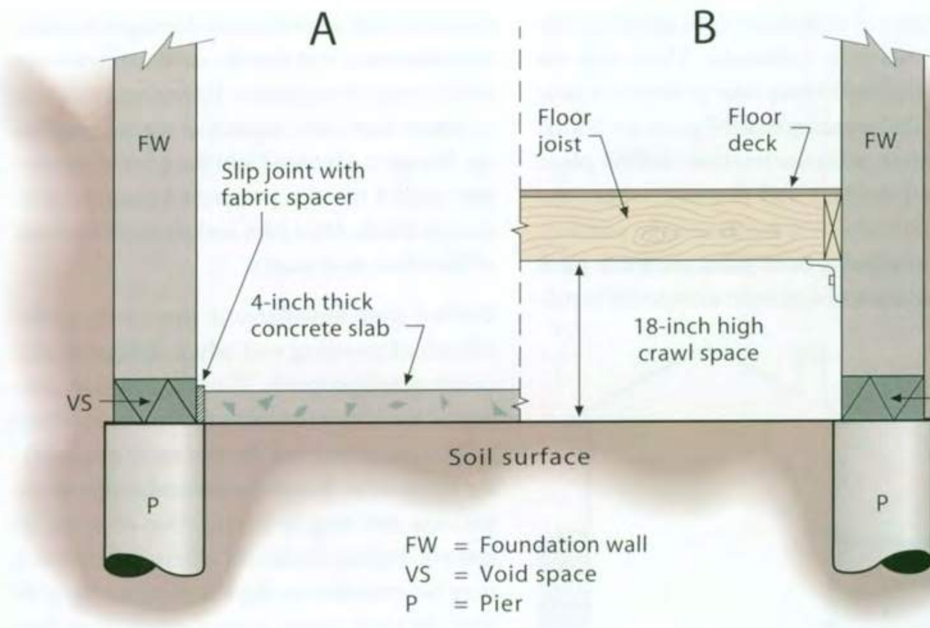
Concrete buttress installed along the outside of a foundation wall.

FLOOR CONSTRUCTION

Floating slab floors, also called **slab-on-grade floors**, consist of a non-reinforced concrete slab that rests directly on soil or fill. The slab is isolated from the outer foundation walls by a slip joint and can move up and down, or "float" independently from the foundation, as the soil below swells and shrinks. This design allows the floor to undergo 2 to 3 inches of vertical heaving without causing appreciable damage to the rest of the house. Special interior construction is necessary when floating slab floors are used (as explained in the next section).

Floating slab floors perform well for non- or low-swelling soil, and are commonly used in conjunction with overexcavations where non- to low-swelling fill has been placed below the slab. This design is not appropriate for highly swelling soil or steeply dipping bedrock, as the slab may undergo significant heaving, cracking, and buckling. Some builders use floating slab floors on moderately swelling soil, although there is a risk of movement and cracking. Concerned buyers may opt to pay more to have a structural floor installed instead.

Structural floors have been used increasingly in Colorado since the mid-1980s. The floor assembly is supported by the outer foundation walls and is suspended, effectively isolating the floor from the soil. The weight of the floor and all objects on the floor is transferred directly to the foundation, thus increasing the foundation's resistance to heaving. Older designs consisted of wood or composite decking supported on wood beams (floor joists). Many types of designs and materials are currently in use, including concrete decking and steel floor joists.



Floating slab floor (A) and structural floor and crawl space (B).

Wooden floor systems typically have an 18-inch high, sub-floor **crawl space** that allow owner access to inspect for ground heaving. These spaces may be difficult to ventilate, and wood rot and deterioration and mold growth have become serious structural and health issues in many cases. The newer, non-wood floor systems have reduced clearance beneath the floor joists (typically 6 inches) and the subfloor space is easier to ventilate to reduce sub-floor humidity. The installation of low-flow fans and floor grates to circulate air and polyethylene vapor barriers placed on the soil is becoming increasingly common. However, recommendations for the use of these features should be decided on a case-by-case basis by the builder's engineers.

Structural floors are most often used for moderate- to very-high-swelling soil. They may be specified if the basement is to be used as a living space. The higher initial cost of a structural floor may be offset by better long-term performance (as compared to floating slab floors) in those areas.

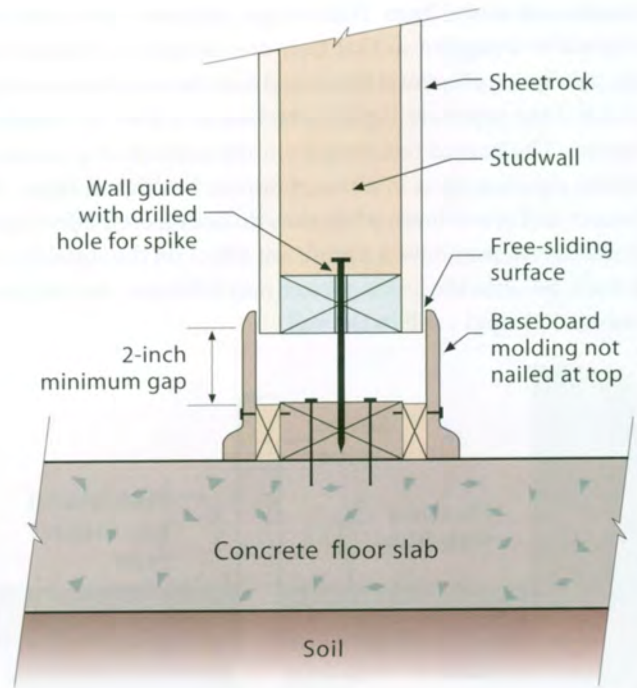
The homebuyer should refer to the **soil and foundation report** to determine the engineer's recommendations for the flooring in any new home. The risk of damage from swelling soil should be lessened considerably, although not eliminated, if the builder followed the engineer's recommendations. If the builder elected not to follow those recommendations, or if they assumed the higher-risk choice of flooring options, you should carefully weigh the initial cost savings against the possible consequences and costs of damage.

INTERIOR CONSTRUCTION

Interior walls. Some interior walls are designed to help support the weight of the roof and upper stories of a house (**load-bearing walls**), while others are used primarily as room partitions and support only their own weight (**non-load-bearing walls**). Load-bearing interior walls may be affected by heaving of the foundation or floors, and they may transmit deformation and damage to other parts of the house.

Non-load-bearing interior walls are used with floating slab floors. They commonly employ a gap or void constructed at the bottom of the wall so that it is suspended a specified distance above the floor slab. Extra-tall baseboard or headboard moldings are used to cover the void. Should the floor heave, the floor and interior wall will shift toward each other and reduce the void, but no damage should occur as long as some void remains. In cases where the void closes and the wall and floor slab come into direct contact, deformation and damage may be transmitted to the interior wall and other parts of the house.

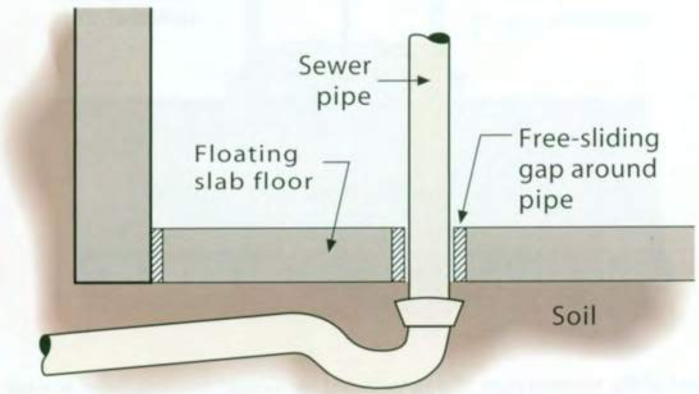
Stairs. Stairs supported on floating slab floors should not have fixed connections. An accepted design is to attach the top of the stairway to the house frame using a strap connection. The base of the stairway rests on the slab floor but is not connected to it. This design allows the stairway to rotate up or down to accommodate a certain amount of floor movement.



Detail of the bottom part of a suspended, non-load-bearing interior wall. Modified from Holtz and Hart (1978).

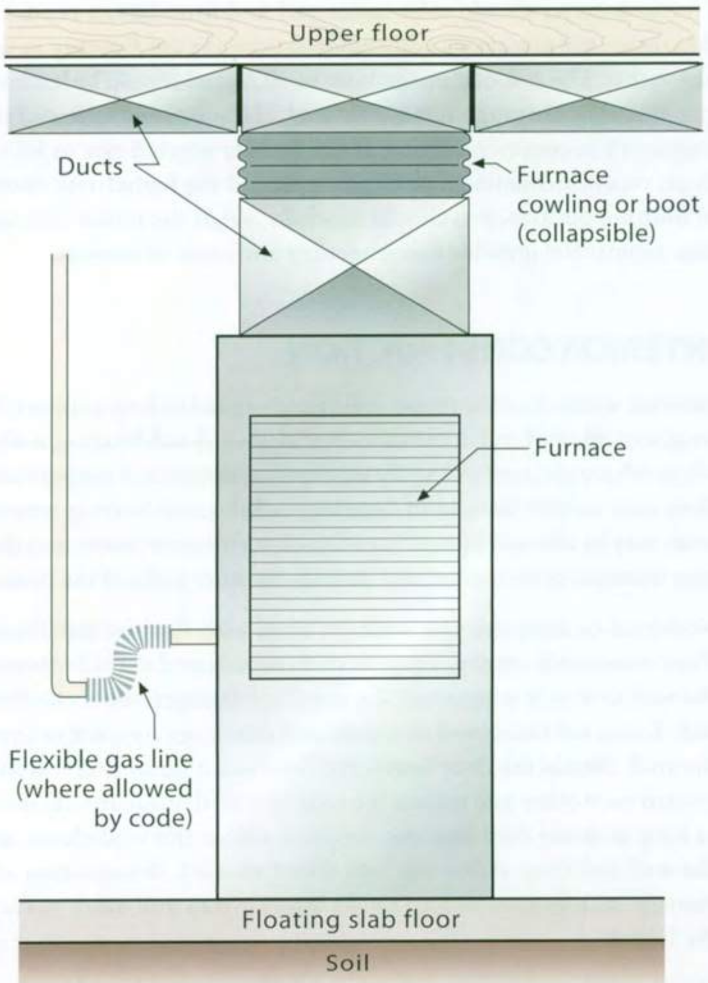
Doors and windows. Doors and windows may be significantly affected by swelling soil. Their frames may be deformed to a point where they bind and do not open easily, or they may be rendered totally inoperable. In other cases, they may be separated from their frames to the extent that they cannot be closed or latched. Windows may be stressed to a point where the glass breaks. Ideally, door frames resting on floating slab floors should be designed with some amount of void or head space to allow for adjustment in the event of heaving. This design will tolerate minor amounts of heaving, but large amounts of heaving will affect the frames.

Gas, water, and sewer lines. Natural gas, propane, water and sewer lines should be designed so that they are completely isolated from floating slab floors, structural floors and foundations. Ruptured pipes may result if the pipes are rigidly attached to a floor or foundation that heaves. The hazard resulting from the rupture of a natural gas or propane pipe is serious in terms of human health and safety. Ruptured water and sewer lines, while they do not directly affect human health and safety, may have a significant effect on the stability of the house itself, because the leaking water may infiltrate into the ground and cause additional swell in the soil.



Detail of a sewer line where it leaves a house. Modified from Holtz and Hart (1978).

Furnace. Furnaces mounted on floating slab floors may be crushed between the floor and ceiling framing in the event of heaving, unless special precautions are taken. A properly designed furnace in this case will have a flexible and collapsible cowling, or **boot**, in the ductwork at the top. If significant heave occurs, the boot will fold or shorten but the furnace system will remain operable. The cowling should be designed so that it can shorten or extend several inches in the event of heaving or settling.



Furnace cowling or boot. Modified from Holtz and Hart (1978).

EXTERIOR FLATWORK

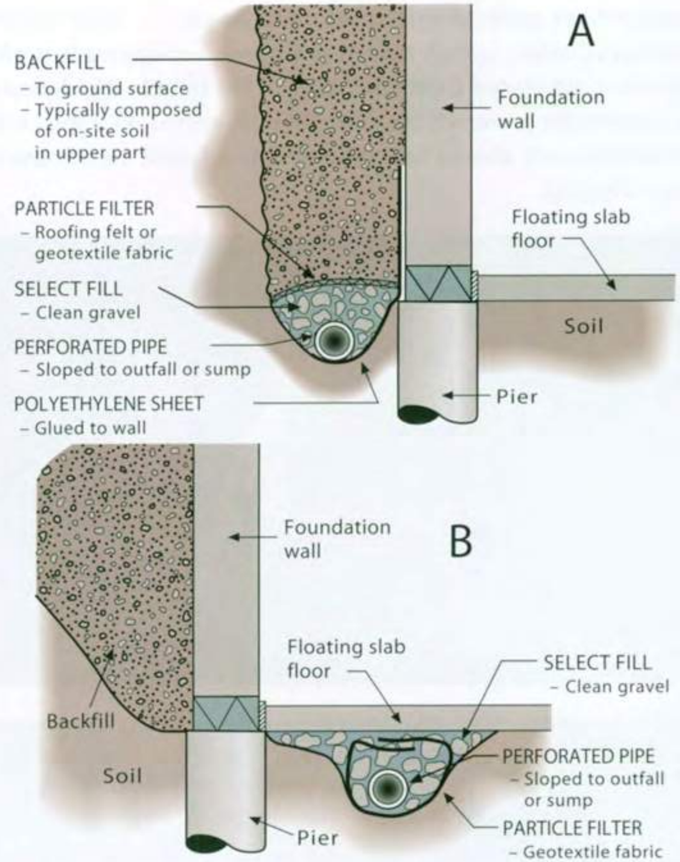
Most **exterior flatwork** (driveways, sidewalks, patios, and porches) has in the past been constructed with unreinforced concrete. However, flatwork on moderately to very highly swelling soil should be designed and constructed with adequate strength according to the site's soil characteristics. Steel reinforcement is now used in some cases. In some cases, the concrete must be formulated to resist corrosion and deterioration due to alkaline chemistry of the ground water and soil.

Steel rebar has been placed before pouring concrete for this reinforced slab.

Concrete porches and patios may require their own drilled pier foundations to avoid heaving, tipping,or settling. Porches supported directly on swelling soil may react seasonally, rising as the soils become wet during late winter and spring and sinking as the soils dry out later in the year. They are also susceptible to settling due to consolidation and settlement of the underlying backfill adjacent to the house foundation, and to frost heaving. Wood decks can be used in lieu of concrete patios and should be designed to allow for support post movements. Porches and patios should be isolated from the main structure in all cases to prevent more widespread damage should movement occur.

SUBSURFACE DRAINAGE

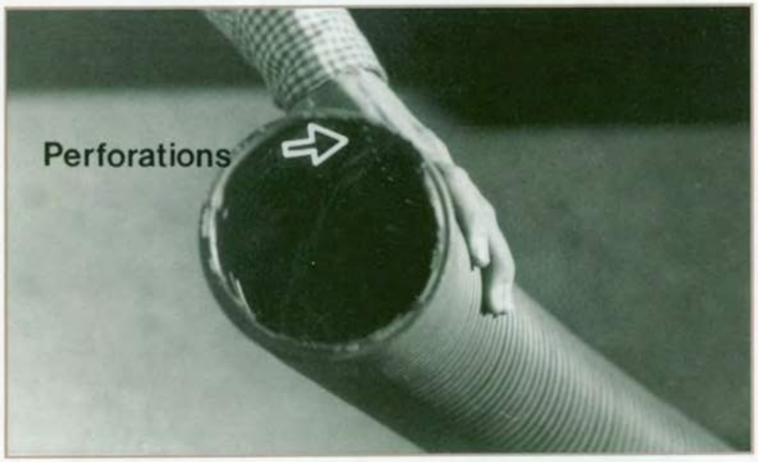
Perimeter drain. Subsurface drainage around the foundation is achieved by installing a perimeter drain near the base of the foundation. This system consists of a trench (either inside or outside of the foundation wall) that contains a drain pipe; coarse, clean gravel; a geotextile drainage fabric or perforated roofing felt as a particle filter; and backfill material.

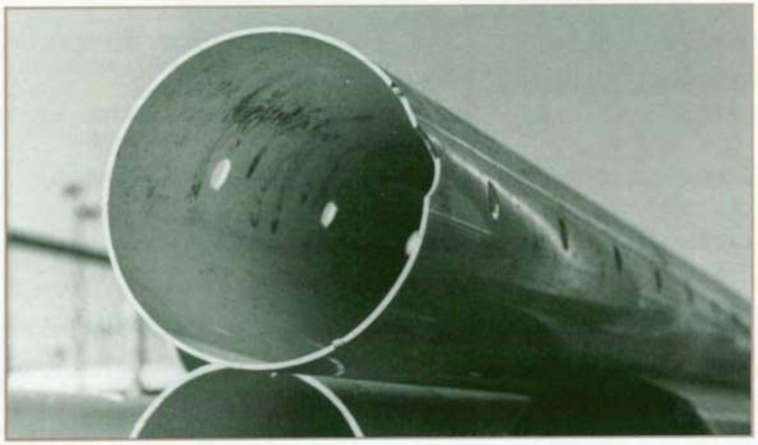


Components of a typical perimeter drain, exterior (A) and interior (B).

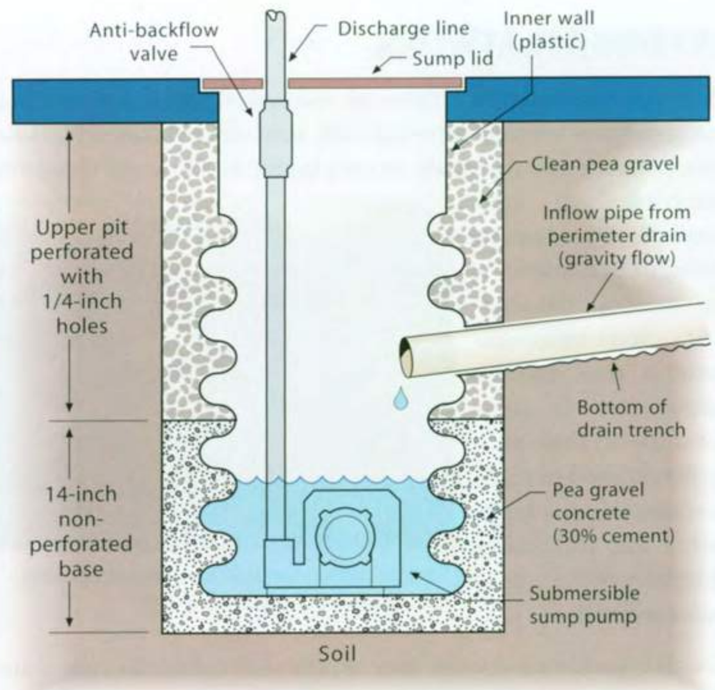
The highest level of the drain pipe should be several inches below the level of the floor slab and/or base of the foundation wall. Perimeter drains should be installed with a slope of ⅛–¼ inch per foot so that gravity will allow and control the flow of the water. The drain must discharge into a sump, an area underdrain, or a suitable gravity outlet.

Drain pipes are made of perforated metal or plastic. They may be slotted on all sides, or they may have two rows of opposing perforations that are placed facing the sides of the trench. Rigid plastic pipe is generally preferred because it resists corrosion. Pipes with large perforations should be wrapped with a fabric membrane to reduce clogging.





Two types of 4-inch-diameter plastic drain pipe: corrugated and slotted on all sides (A) and perforated on two opposing sides (B). From Jochim (1987).

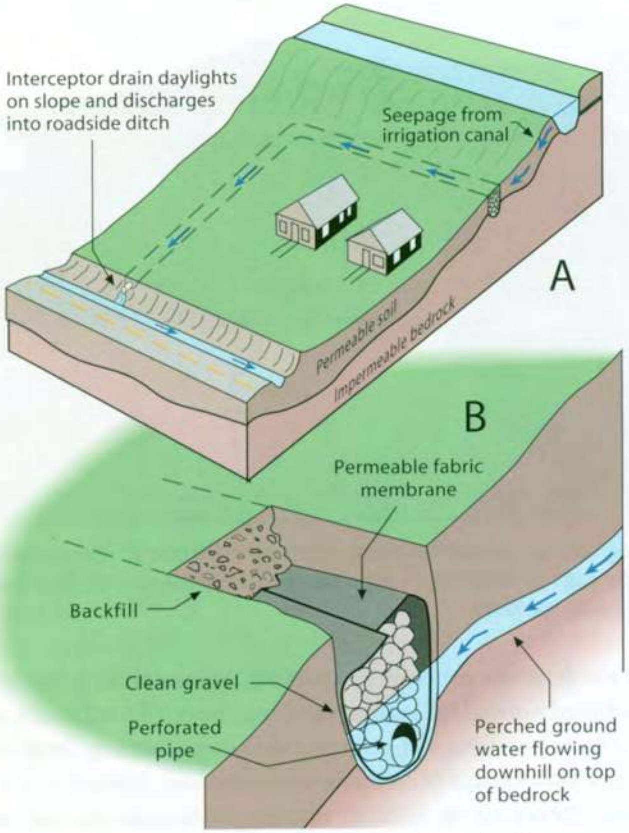


Sump system with a non-perforated base.

Sump system. A sump is an enclosed pit or low area that collects water. Water from the perimeter drain system flows into the sump by gravity drainage. When water collects in the sump, it should be removed by an automatic submersible pump and discharged into an acceptable area. Sump pits having non-perforated bases and sides are best for areas of swelling soil because they keep the water from entering the surrounding soil. Sumps are usually installed in a basement. As an alternative, they can be installed outside in the yard.

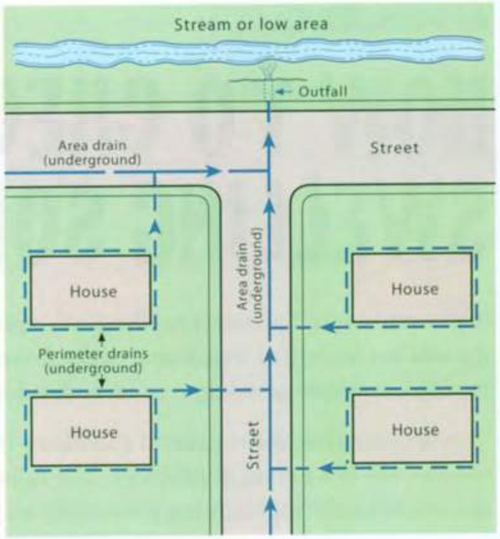
Sumps work most effectively in areas where the movement of water through the soil is slow, and are especially appropriate in clay soil and bedrock. A good-quality pump is required that removes even shallow water, in order to reduce infiltration and localized swelling and heaving of the soil. The effectiveness of the system may be reduced if larger amounts of water constantly flow into the sump.

Interceptor drain. Interceptor drains are used to collect subsurface water and divert it to an acceptable outfall. This type of drain is often used when the source of water is uphill from the area to be protected. Historically, it has been used in Colorado to protect individual houses or small neighborhoods from seepage from unlined irrigation canals. A typical interceptor drain consists of a gravel or sand-filled trench, either with or without a drainpipe. It may be lined with a permeable fabric membrane to help prevent clogging, or it may include an impervious membrane on the down-hill side of the trench.



Layout (A) and details (B) of an interceptor drain used to intercept seepage from an irrigation canal. Modified from Jochim (1987).

Area drain. An area drain runs beneath streets and gathers subsurface water from the perimeter drains of individual houses and other sources, and diverts the water to an acceptable gravity outfall. The trenches for the drain are typically dug below the level of other utility lines. The upper part of the trench is most often filled with compacted native backfill.



Map view of a typical area drain layout.

Area drain systems are common in newer subdivisions along Colorado's Front Range as an alternative to individual sump systems. They have the advantage of intercepting numerous sources of subsurface water from a relatively large area. They require careful sloping and an outfall location that will allow gravity drainage and should have backflow barriers. The system must be maintained and inspected regularly, because covering or clogging of the outlet may lead to widespread water build-up and possibly even flooding and swelling soil damage.

Septic systems. Septic systems with leach fields are often installed for houses in rural settings. Leach fields are a source of liquids that infiltrate into the ground, and therefore should be located well away and downslope from the house if swelling soil is present. Proper siting of leach fields is necessary so that the resulting perched water does not flow toward or affect soil around any nearby houses.

C

APPENDIX C

HOW TO CHECK A PROPERTY FOR SWELLING SOIL

It is important to find out if swelling soil is present, and how severely the soil has heaved or may heave in the future, if you are thinking of buying a resale or new home or an undeveloped property.

This section gives some general guidelines for assessing whether or not the soil is a potential problem. The following items are offered as a checklist for highlighting potentially serious conditions.

RESALE HOMES

There is often evidence of swelling in the case of older, resale homes in the form of actual damage or as detailed in repair reports. Beginning around 1990, many building practices were updated and mandated by municipalities, counties and warranty companies; older houses may not meet these updated practices.

Much of the damage caused by swelling soil can be detected by thoroughly inspecting the house and yard. *To begin the inspection, stand across the street from the house, so that you have a full view of the front. Note the following items closely:*

1) Driveway. An inspection of the driveway is often revealing. Does the driveway have a smooth surface or does it have a wavy appearance? Check the point where the driveway and the garage door meet. If the garage slab is high in the center and there are gaps where it meets the doorway, heaving caused by swelling soil has probably occurred. On the other hand, if the garage slab is flat and the driveway is bowed and tilts toward the garage, settlement of the backfill may have occurred.

Swelling soil has caused this garage slab to heave and bow at its center. Note the gaps or "batwings" on both sides, where the garage door is not in contact with the slab.

Check the driveway concrete for cracking. Some cracking of concrete is considered normal in Colorado and may be attributed to any number of causes (swelling soil, concrete shrinkage, settling, frost heave, tree roots, poor quality of concrete or installation). Excessive or severe cracking allows water to infiltrate into the soil beneath the slab, where it can cause or intensify soil heaving.

Look to see if all or part of the concrete in the driveway has been recently replaced. This may be a sign that swelling soil caused damage to previous slabs. If the slabs and sidewalks next to the house are newer than other sections, it may indicate that a trench was dug around the house for structural or drainage system repairs.

The presence of asphaltic pavement, which is more flexible and may not be damaged as easily as concrete, may indicate that a former slab was replaced. Check all asphalt areas for excessive or severe cracking and heave deformation.

2) Sidewalks, curbs, and gutters. All exterior flatwork should be checked to see if any cracking or heaving has occurred. Small "hairline" cracks are common and are often the result of concrete shrinkage. Wider cracks may be the result of heaving of swelling soil or, alternatively, settling of backfill due to improper compaction. Large open cracks in the concrete are undesirable, as they provide access for water and accelerate the rate of damage. The presence of new sections of sidewalks and gutters may indicate that swelling soil damage has occurred, although there can be other reasons for replacement.

Swelling soil is responsible for the destruction of this sidewalk. Note the ponded water in the street, which could infiltrate through cracks and into the soil.

The asphalt patches seen in this street are indicators of multiple repairs and swelling soil.

3) Streets. The presence of multiple asphalt patches may indicate that swelling soil has damaged the streets or the underlying utility lines over a period of time. Look for evidence of rough, uneven, or heaved road surfaces. The presence of "roller-coaster roads" (especially in areas of steeply dipping bedrock) may indicate that localized heaving of bedrock layers is occurring.

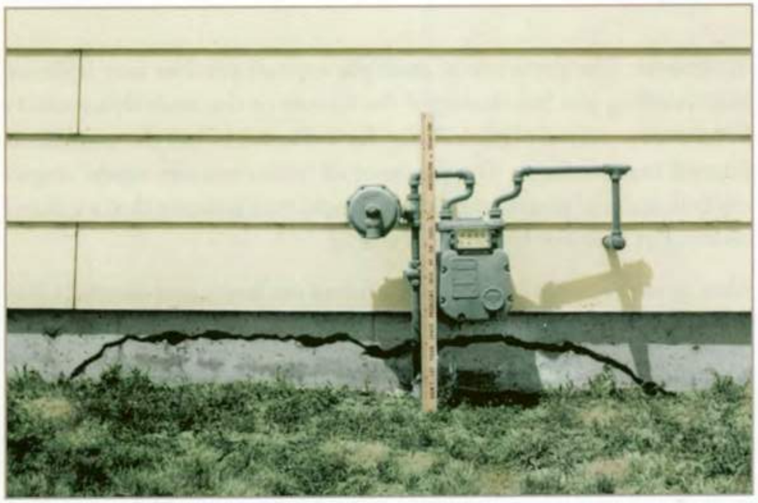
Now, go closer to the house. Walk around the house and carefully look at the following items, all at the same time if possible:

4) Exposed soil. Take a look at the soil for desiccation cracks or "popcorn" textures (see Chapter 1 for photos). These features may not be visible if the native soil is covered by topsoil or turf. Large cracks in the ground or soil that has pulled away from a foundation wall, forming a gap, may indicate swelling clay soil that has undergone shrinkage.

Notice the slope of the soil surrounding the house. The soil should slope away from the house and there should be no evidence of water ponding against the foundation. If swelling soil is present, areas of flat or poorly drained soil will make the problem worse. Such areas will need to be built up and sloped to carry runoff water away from the house.

5) Patios, porches, and sidewalks. Check patios, porches and sidewalks beside the house for cracking and heaving. Make sure they do not slope toward the house. There should be a gentle, one to two percent slope away from the house in order to keep water away from the foundation.

6) Foundation walls. Inspect the foundation wall for cracks around the entire house. Almost without exception, every house will have some cracks in the foundation as a result of shrinkage due to curing of the concrete and tension cracks due to minor movement. This type of crack is typically 1/16-inch wide or less. Larger cracks may indicate more serious foundation movement.



Large foundation crack caused by lateral pressures from highly swelling soil. This situation could be dangerous if the heaving ruptures the natural gas line. From Jochim (1987).

7) Brick and block walls. Check for significant cracks in the outside walls of houses built with brick veneer, structural bricks, or concrete or masonry blocks. Cracks may follow mortar lines or may split bricks in extreme cases. Cracking caused by soil shrinkage will most often occur at the corners of a house. Brick veneer may separate and lean away from the wood frame of the house in cases of extreme swelling soil damage.

Split bricks and damaged window framing (on left). From Jochim (1987).

8) Chimney. Check the chimney for separation from the outside wall and for cracks in the masonry. A heaved and damaged chimney can be dangerous in terms of human safety.

The chimney of this house had separated and tilted away due to swelling soil heaving and had to be removed before it collapsed. From Jochim (1987).

9) Perimeter Drain. Ask the owner if the house has an underground perimeter drain, and where it discharges. If it discharges to a gravity outfall, check the outlet to see if the pipe is clear of debris and in good working condition. (See item 17, below, if the perimeter drain is connected to an indoor sump pit).

Now check inside the house:

10) Interior walls. Check interior walls for cracks in plaster, drywall, or wallpaper. Cracks are most common around door and window frames. If the cracks are straight, they may be the result of poor sheetrock taping or shrinkage of green (uncured) wood. Diagonal cracks may be the result of heave or settling of the foundation. Make sure that the walls have not pulled away where they meet the floor and ceiling.

Diagonal cracks in drywall in an interior wall, caused by soil heaving or settling.

Door frame wedged against the door jamb by heaving of swelling soil. The door binds and does not open or shut easily.

11) Doors and windows. Check all doors and windows to see if they open and close properly. Binding or inoperable doors and windows, wedge-shaped gaps at the top or bottom, and distorted glass panes may be due to foundation heave or settlement. However, the use of green wood or poor construction quality may cause similar conditions.

12) Floors and ceilings. Look for cracks in the corners of ceilings where stress is greatest. Check for unusual high or low spots in floors and ceilings as you walk around. Swelling soil or green wood may be responsible for these cracks and surface distortions.

This concrete slab is broken and shows an offset due to differential heaving.

This structural wood basement floor has buckled after undergoing intense heave and lateral pressure from swelling soil.

13) Basement and basement floor. Check the basement walls and floor slab for significant cracks and offset across the cracks (one side higher than the other). The walls should not bow or lean excessively into the room near the middle of their span; if they do, they may be under excess pressure from swelling soil or improperly placed backfill.

Concrete floor slabs constructed directly on swelling soil should be separated from all outer walls and have expansion joints that allow the slab to move up and down in response to the heaving motion of the soil. All slabs should be jointed or scored on the order of 15 feet apart (or as recommended by the soil report). Basements on floating slab floors should remain unfinished or have specially designed partitions to accommodate some vertical movement of the slab.

Structural, or suspended, floors are much less likely to show damage from swelling soil. Uneven, wavy, or bent flooring may indicate that parts of the outside wall are being heaved. This type of flooring should have a shallow "crawl space" underneath. Take a flashlight and inspect the crawl space (be sure to wear old shoes and clothes if you actually enter ... this part can get muddy!). Check to see that there is some kind of passive or motorized ventilation system to keep moisture from building up in the crawl space.

Check to see whether the soil surface under the house looks flat, or if it has heaved upward. Make sure that the soil has not heaved to a point where it has closed the void space and is in contact with the concrete grade beam at the bottom of the foundation wall. The void space will be 4 to 6 inches high for a new house. If the soil is in contact with, or close to, the grade beam, there is a chance that the soil could push up against the grade beam and damage the house.

14) Basement walls. If the basement has a floating concrete slab floor, check the gaps at the base or top of the interior walls. This may require removing a section of molding. If the gap between the wall and floor has closed to an inch or less, it is possible that heave of the floor slab has occurred or is occurring.

The flexible boot at the top of this furnace has collapsed, leaving it vulnerable to damage if further heaving of the underlying soil and slab floor occurs.

15) Utility pipes. Water, sewer, and gas pipes should be inspected to see if they are bowing or pulling apart. Where plumbing lines enter through the floor, they should be designed to absorb movement or slip through the floor without breaking. Gas lines should have a flexible connection (where allowed by code) to reduce the chances of breaking as a result of movement.

16) Furnace (on slab-on-grade floor). Check the ducts above the furnace to see that they are not crushed, bent, or crowded against the ceiling. Furnaces in many newer homes contain flexible duct connections (boots) to reduce the potential for damage as a result of slab heaving. The rigid parts of the duct should be separated by several inches across the boot.

17) Sump. If the basement contains a sump pit, inspect the sump. Note whether the sump is currently dry or wet. Standing water or constant inflow from the drain pipes indicates a poor drainage condition.

Looking down into a sump pit that has standing water and constant inflow from the two drain pipes.

Ask the owner how the sump operates and how often the pump has been activated to drain the sump. Check to see if the lower part of the sump pit is perforated or non-perforated. A non-perforated base is better if swelling soil is present.

18) Owner's records. Ask the owner about whether the house has undergone heave or settlement. The owner is legally required to disclose any information they have about previous damage or repairs. Ask for a copy of previous inspection, appraisal, damage, soil, or repair reports prepared by home inspectors, house appraisers, engineers, or contractors, or a written statement regarding the owner's property history. You may wish to hire a structural engineer to read and assess these technical reports or written statements.

You should watch out for cases where prior damage has been temporarily fixed or "hidden." This is another instance where the assistance of a structural engineer may be useful. Your local (county or city) building department may contain records for remedial repair permits.

Find out if the owner has monitored the displacement of significant inside or outside cracks. If the cracks are growing steadily larger, or if they expand during the wet season and contract with the dry season, then swelling soil may be present and active beneath the house.

19) Other records. Engineering soil and foundation reports (see next section) for the original subdivision and house site may be available through the local jurisdiction's planning and building departments. Does the foundation design for the house match the recommendation given in the soil report? If they are different, it is important to find out if the actual design is an improvement. You should be concerned if it is not.

You may wish to ask the local homeowners association (HOA) about swelling soil conditions, and examine the HOA meeting minutes for evidence or complaints about swelling soil damage at the house or in the neighborhood. Newspapers frequently carry stories about swelling soil damage in subdivisions, and may be a historical resource.

NEW HOMES AND UNDEVELOPED PROPERTIES

It is not possible to tell if a new home, a recently built resale home or an undeveloped property will be affected by swelling soil because movement and damage have not yet occurred. The buyer must rely on engineering soil reports, engineering inspections, city or county design and construction regulations, structural warranty company construction standards, and the ability of the developer and builder to recognize swelling soil and to design and construct a home accordingly.

The only way to identify whether there is swelling soil under a house or property in these cases is to obtain a **soil report** (sometimes called a **soil and foundation report**). Soil reports can sometimes be obtained from the builder or, in some cases, from the county or city building department. Once you have a copy of the soil report for the house, it is important to answer three basic questions:

1) Is there swelling soil or bedrock beneath the house?

2) If so, what is the degree or severity of potential swelling?

3) Is the house designed and built with proper consideration for the actual soil conditions?

To answer these questions, it may be advisable for you to hire a specialist to read and interpret the soil report. In most cases, a structural engineer (for assessments of the structural integrity of already constructed houses) and/or a geotechnical engineer (for assessments of soil reports for sites before they are/were constructed) will have the necessary expertise to assist you with your final decision.

An engineer's review of a soil report and structural review of the house typically costs around $200–800. Be a good consumer and look for an engineer who will perform a comprehensive inspection, with no "corner-cutting." For a listing of professional engineering consultants, look in the local yellow pages under "Engineers—Foundation," "Engineers—Geotechnical-Soils," or "Engineers—Structural."

OTHER CONSIDERATIONS

In preparing this booklet, we met with several engineers who make their livings at repairing houses that have been damaged from soil movements. Here is some of the advice they offer potential homebuyers:

Ask the builder questions such as: How much heave could I expect? Or, with overexcavation, how much settlement could I expect? What kind of drain system does this house have? Do you have a maintenance manual? What is your response or procedure for doing repairs?

Look for key phrases in the engineering soil report, such as, "If the owner is willing to assume the risk..." If the builder has chosen a lesser design, ask them in writing what kind of risk they have accepted in doing so.

If you purchase a house that is being built, familiarize yourself with the design and observe the site often. Check to see that the piers are being drilled to the prescribed depths and that the reinforcement rebar is centered. Make sure that the engineering inspections are conducted and signed.

A typical repair should include soil testing (with test holes drilled to 40 feet depth), an inventory of distress, an elevation survey, a description of components of the house and foundation type, and a description of components and condition of the surrounding grading, water runoff and drainage, subsurface soil and water, etc.

Before selecting and hiring an engineering consultant or contractor, screen several potential individuals or companies. Don't evaluate strictly on basis of cost alone. Ask them questions about relevant experience, education, publications, and professional society affiliations.

APPENDIX D

FURTHER READING AND INFORMATION SOURCES

D

REFERENCES CITED AND SUGGESTIONS FOR FURTHER READING

Note: in addition to the titles listed here, the Denver Water, Xeriscape Colorado, and Colorado State University Cooperative Extension Service web sites (see next section) contain a large number of Xeriscape-related books and pamphlets.

Colorado Climate Center, 1984, *Colorado average annual precipitation 1951–1980:* Colorado State University, Department of Atmospheric Science, map scale 1:500,000.

Colorado Division of Real Estate, 2006, Division of Real Estate manual: www.dora.state.co.us/real-estate/manual/manual.htm.

Denver Water, undated, *The right grass in the right place:* pamphlet.

Denver Water, 1996, *Xeriscape plant guide:* Golden, Fulcrum Publishing, 184 p.

Ellefson, C.L., and Winger, D., 2004, *Xeriscape Colorado—the complete guide:* Westcliffe Publishers, Englewood, Colorado, 226 p.

Farnsworth, R.K., Thompson, E.S., and Peck, E.L., 1982, *Evaporation atlas for the contiguous 48 United States:* National Weather Service, NOAA Technical Report NWS 33.

Greenfield, S.J., and Shen, C.K, 1992, *Foundations in problem soils.* Prentice Hall, Englewood Cliffs, New Jersey, 240 p.

Hart, S.S., 1974, *Potentially swelling soil and rock in the Front Range Urban Corridor, Colorado:* Colorado Geological Survey Environmental Geology 7, 23 p., 4 map plates, scale 1:100,000.

Hoffman, G.C., and Friedman, M.C., 1993, *How to inspect a house, expanded edition:* Addison Wesley Publishing Co., 179 p.

Holtz, W.G., and Hart, S.S., 1978, *Home construction on shrinking and swelling soils:* Colorado Geological Survey Special Publication 11, 18 p. *[Note:out of print and replaced by this book.]*

Jochim, C.L., 1987, *Home landscaping and maintenance on swelling soil:* Colorado Geological Survey Special Publication 14, Revised, Fifth Printing, 31 p. *[Note: out of print and replaced by this book.]*

Knopf, J., 1999, *Waterwise landscaping with trees, shrubs, and vines—a Xeriscape guide for the Rocky Mountain region, California, and the desert Southwest:* Chamisa Books, Boulder, Colorado, 408 p.

Nelson, J.D., and Miller, D.J., 1992, *Expansive soils—problems and practice in foundation and pavement engineering:* John Wiley and Sons, Inc., New York, 259 p.

Nuhfer, E.B., Proctor, R.J., and Moser, P.H., 1993, *The citizens' guide to geological hazards:* American Institute of Professional Geologists, Arvada, Colorado, 134 p.

Shelton, D.C., 1979, *Nature's building codes—geology and construction in Colorado:* Colorado Geological Survey Special Publication 12, 72 p.

Weinstein, G., 1999, *Xeriscape handbook:* Fulcrum Publishing, Golden, Colorado, 144 p.

Xeriscape Colorado, Inc., 2003, *At home with Xeriscape:* pamphlet.

INFORMATION SOURCES

The following agencies may be sources of helpful information on swelling soil and related topics:

Swelling Soil

Colorado Geological Survey, Colorado Department of Natural Resources, 1313 Sherman Street, Room 715, Denver, CO 80203. (303) 866-2611, or geosurvey.state.co.us.

U.S. Geological Survey, U.S. Department of the Interior, Information Services, Box 25286, Denver Federal Center, Denver, CO 80225-0046. (303) 202-4200 or toll free (888) 275-8747.

U.S. Natural Resources Conservation Service, U.S. Department of Agriculture, 655 Parfet Street, Lakewood, CO 80401 (Front Range area). (303) 236-2886. For local listings, look in the U.S. Government section of the phone book blue pages, under "Agriculture Dept of," or offices.sc.egov.usda.gov/locator/app.

Xeriscaping and Soil Improvement

Colorado State University Cooperative Extension Service. See local phone book listing in the County Government section in the phone book blue pages under "Colorado State University" or "Extension Office," or www.ext.colostate.edu/cedirectory/allcounties2.cfm. Xeriscape fact sheets can be accessed at www.ext.colostate.edu/pubs/garden/pubgard.html.

Denver Water, 1600 West 12th Avenue, Denver, CO 80254. (303) 628-6000, or www.denverwater.org.

Municipal Xeriscape web sites can be accessed at www.xeriscape.org/resources.html, and demo gardens can be viewed at www.xeriscape.org/demogardens.html.

U.S. Natural Resources Conservation Service. See previous section, or www.nrcs.usda.gov/partners/for_homeowners.html.

Xeriscape Colorado, Inc., www.xeriscape.org.

Building Requirements, Maps, and Records

Look under the government blue pages in the phone book for the appropriate city or county planning department or building department.

Real Estate

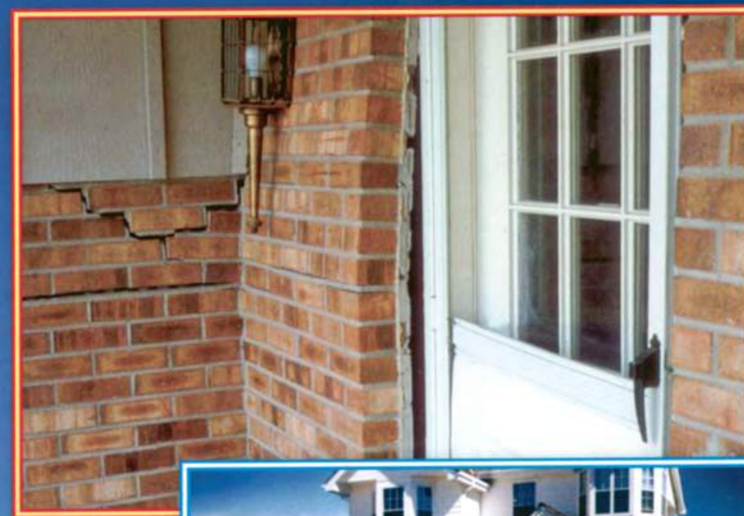
Colorado Division of Real Estate (including Real Estate Commission and Board of Appraisers), Colorado Department of Regulatory Agencies, 1900 Grant Street, Suite 925, Denver, CO 80202. (303) 894-2166, or www.dora.state.co.us/real-estate.

Swelling soil is a common problem in Colorado. It is capable of causing severe damage to homes.

The purpose of this book is to assist Colorado homebuyers and homeowners in reducing the potential for damage caused by swelling soil.

Although risks from swelling soil cannot be completely eliminated, they can be significantly reduced through proper site investigation, design, construction and maintenance practices.

An awareness of these topics may be critical for the Colorado homeowner whose house is built on swelling soil.



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