LANDSLIDES AND MASS-WASTING

What is Mass-Wasting?

Mass-wasting is the movement of Earth materials downslope as a result of the pull of gravity.

Landslide is any perceptible downslope movement of the bedrock, regolith, or a mixture of the two.

There are **many different types** of **movement**, **materials**, and **triggering events** may be involved in downslope mass movements of Earth material.

Types of Mass-Wasting Processes

1. All mass-wasting processes take place on slopes.
2. There are many kinds of slope movement, but there is no simple way to classify such movements.

Factors that influence the type and velocity of movement include:

- **Composition and texture of the material**
- **Amount of water or air in the mixture**
- **Steepness of the slope**

Mass-wasting could be divided into two basic categories:

Involving the sudden failure of a slope

downslope transfer of relatively coherent masses of rock or rock debris by slumping, falling, or sliding

involving the downslope flow of mixtures of sediment, water, and air

Here processes are distinguished on the basis of their velocity and the amount of water in the flowing mixture.

Slope Failures

When **failure** occurs, *material is transferred downslope until a stable slope condition is reestablished*.

Some of the most common types of slope failure include:

- **Slumps**
- **Slides**
- **Falls**

Slumps

A **slump** is a type of slope failure involving rotational movement of rock or regolith, that is, downward and outward movement along a curved, concave-up surface.

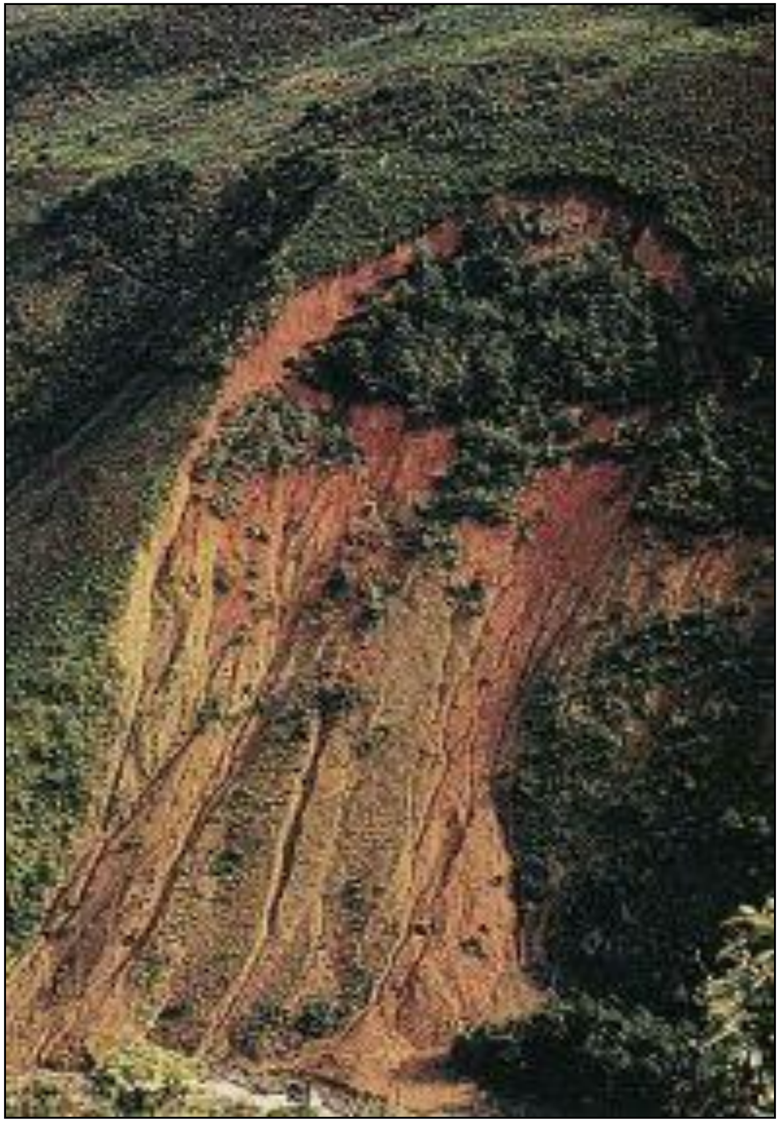
Slumps can range from small displacements covering only **one or two square meters** to large complexes that cover **hundreds or even thousands of square meters**.

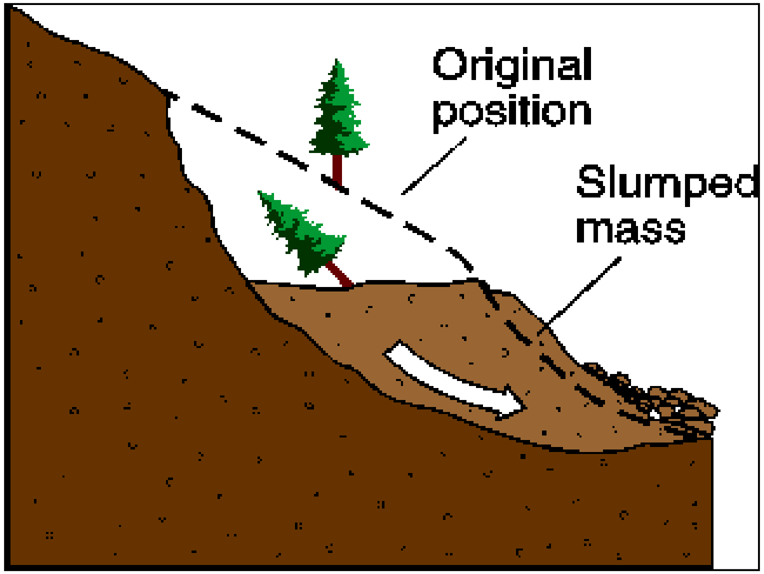
Slumps frequently result from **artificial modifications of the landscape**.

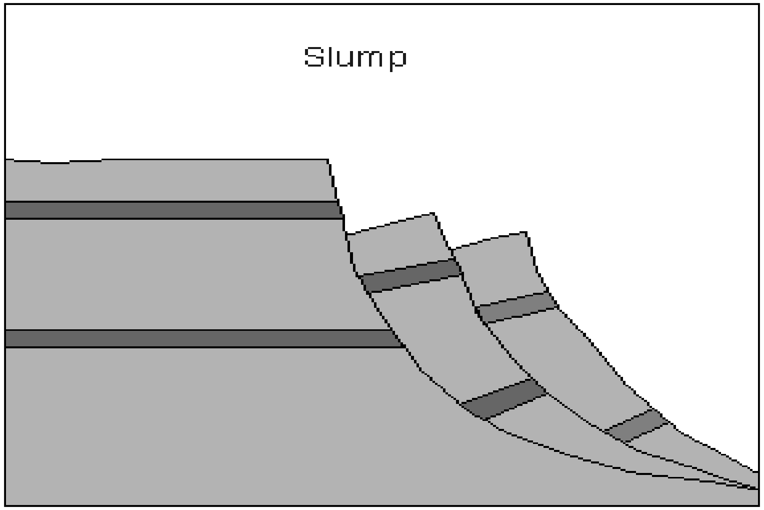
They are common along **roads** and **highways** where bordering slopes have been oversteepened by construction activity.

They can be seen also along **river banks** or **seacoasts** where currents or waves have undercut the base of a slope.

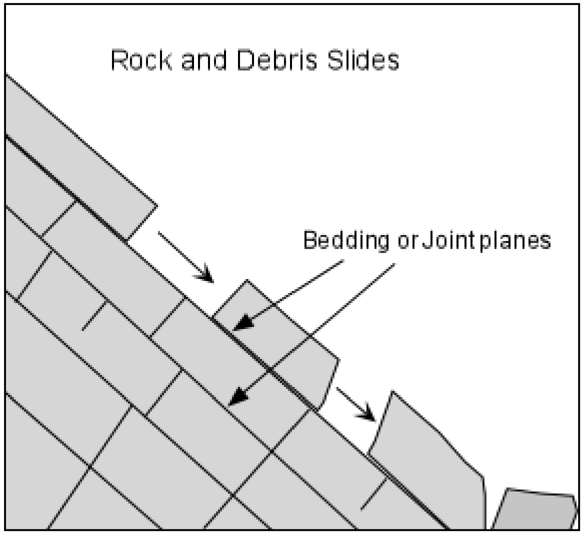
Slumps

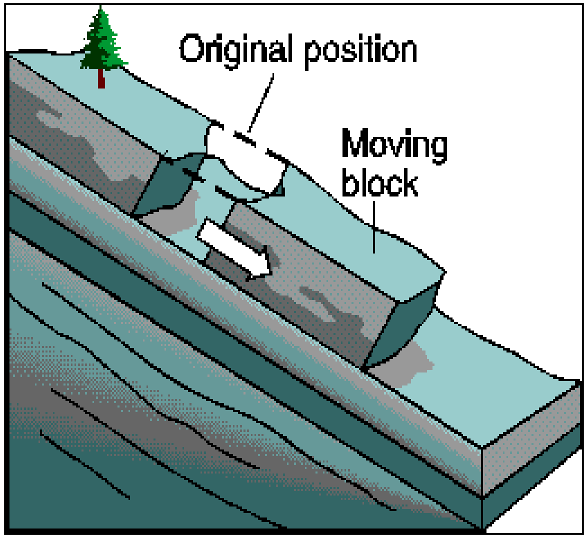






Slides





Slides involve the rapid displacement of masses of rock or sediment in one direction (translational), with no rotation.

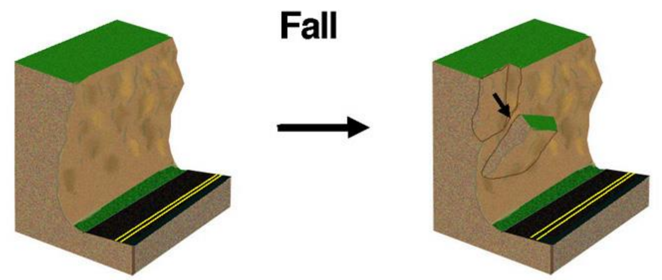
A **rockslide** is the sudden downslope movement of detached masses of bedrock.

A **debris slide** is the sudden downslope movement of debris.

Falls

Rockfall is the free fall of detached bodies of bedrock from a cliff or steep slope.

It is common in **precipitous mountainous terrain**, where **rockfall** debris forms conspicuous deposits at the base of steep slopes.



A **fall** is a sudden, vertical movement of Earth material.

A **rockfall** may involve the dislodgment and fall of a **single fragment** or the sudden collapse of a **huge mass of rock** that plunges hundreds of meters, gathering speed until it breaks into smaller pieces on impact.

The pieces continue to bounce, roll, and slide downslope before friction and decreasing slope angle bring them to a halt.

Sometime not only rock but **overlaying sediment and plants** are dislodged.

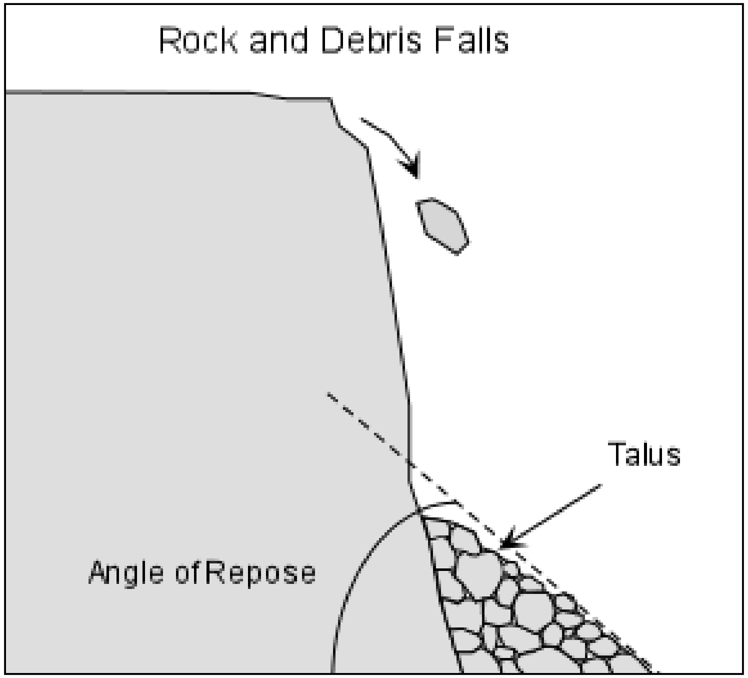
The resulting **debris fall** is similar to a rockfall, but it consists of a **mixture of rock and weathered regolith as well as vegetation**.

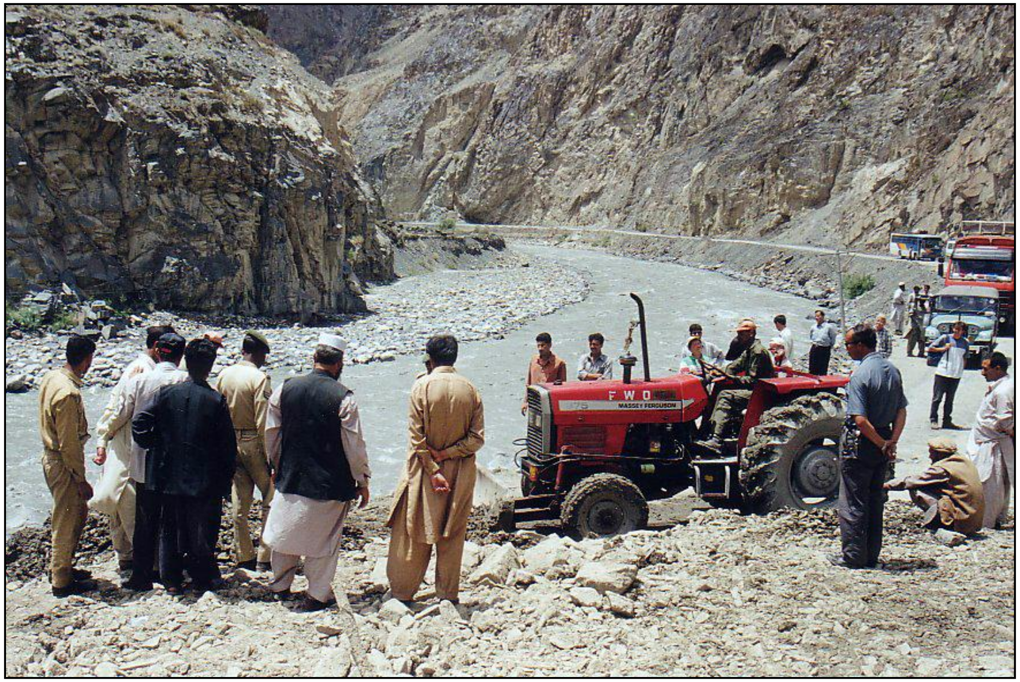
As a rock falls, its **speed increases**.

If we know the distance of the fall (h), we can calculate the **velocity** (υ) on impact as:

$$\upsilon = \sqrt{2gh}$$

where g is the acceleration due to gravity.





Flows

Flow is a mass-wasting process that involves the **chaotic movement of mixtures of sediment and water (or sediment, water, and air)**.

The way a sediment flows depends on:

- The relative proportions of solids, water, and air in the mixture.
- The physical and chemical properties of the sediment.

The **water** helps promote flow, but the **pull of gravity** is the primary reason for movement.

Flows are subdivided into two classes **based on water content**:

Slurry Flows

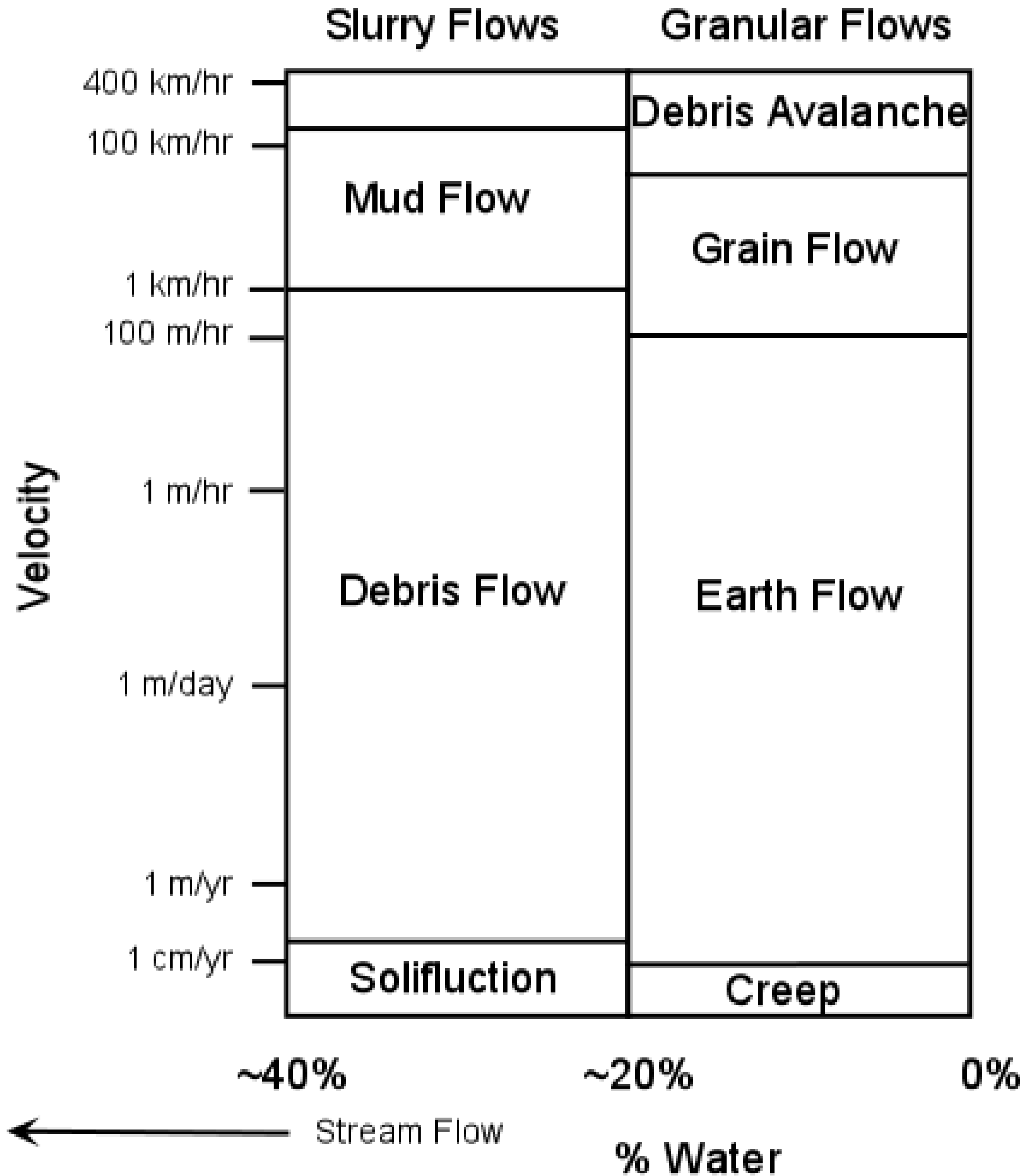
Water saturated mixtures

Granular Flows

Not water saturated mixtures

Each of these two classes is further subdivided on the basis of the velocity of the flow, which can range from very slow (**millimeters or centimeters per year**) to very fast (**kilometers per hour**).

- The transition from a **muddy streams** to a **slurry flows** occurs when the concentration of sediment becomes so high that the stream no longer acts as a transporting agent;
- Instead, gravity becomes the primary force causing the saturated sediment to flow.
- As the percentage of water decreases further, a transition from **slurry flow** to **granular flow** takes place.
- **Different types of slurry and granular flows are recognized on the basis of their mean velocity.**



Factors That Influence Slope Stability

Under **natural conditions**, a slope evolves toward an angle that allows the quantity of regolith reaching any point from upslope to be balanced by the quantity that is moving downslope from that point.

Such a slope is said to be in a **balanced**, or **steady-state**, condition.

Many factors affect **slope stability**. A change in any one or a combination of these factors can alter the steady-state condition of the slope.

The main factors that influence slope stability are:

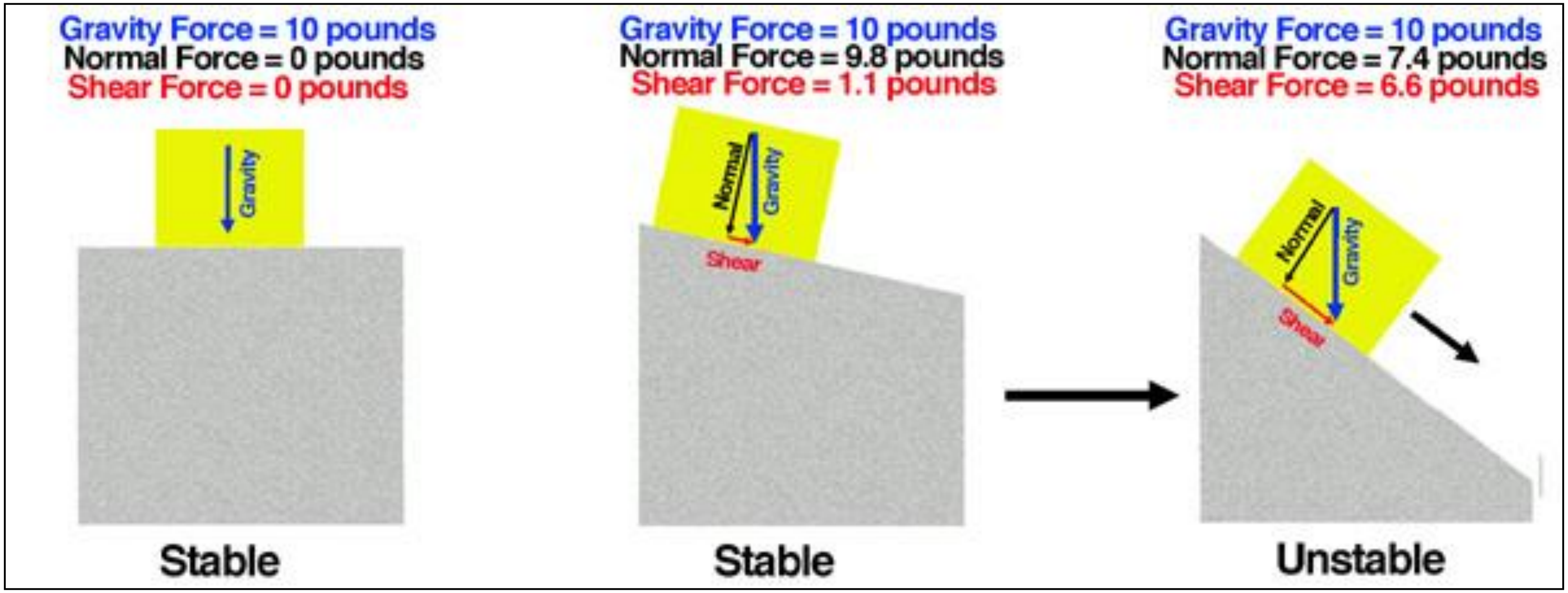
1. **The force of gravity, and therefore the gradient of the slope;**
2. **Water, and therefore the hydrologic characteristics of the slope;**
3. **The presence of troublesome Earth materials; and**
4. **The occurrence of triggering event**.

Gravity and Slope Gradient

Two **opposing forces** determine whether a body of rock or debris located on a slope **will move or remain stationary**.

These forces are

Shear Stress and **Shear Strength**



Shear stress causes movement of the body **parallel to the slope**.

The primary factor influencing shear stress is the **pull of gravity**, which is related to the **slope's gradient**.

On a horizontal surface, gravity holds objects in place by pulling on them in a direction perpendicular to the surface.

On any slope, gravity consists of two component forces.

The **perpendicular component (g_p)** acts at right angles to the slope and tends to hold objects in place.

The **tangential component (g_t)** acts along and down the slope and causes objects to move downhill.

As a slope becomes steeper, the tangential component increases relative to the perpendicular component and the shear stress becomes larger.

Shear strength is the **internal resistance of the body to movement**.

It is governed by **factors inherent in the body of rock or regolith**, such as

1) **friction**
2) **cohesion between particles** and
3) the **binding action of plant roots**.

As long as **shear strength exceeds shear stress**, the rock or debris **will not move**.

However, as these two forces approach a balance, the likelihood of movement increases.

This relationship is expressed in a ratio known as the **safety factor (F_s)**:

$$F_s = \text{shear strength} / \text{shear stress}$$

When the **safety factor is less than 1**, **slope failure is imminent**.

Hence, mass movement tend to increase as slope angle increases.

Water

Water is almost always present within rocks and regolith near the Earth's surface.

Unconsolidated sediments behave in different ways depending on whether they are dry or wet.

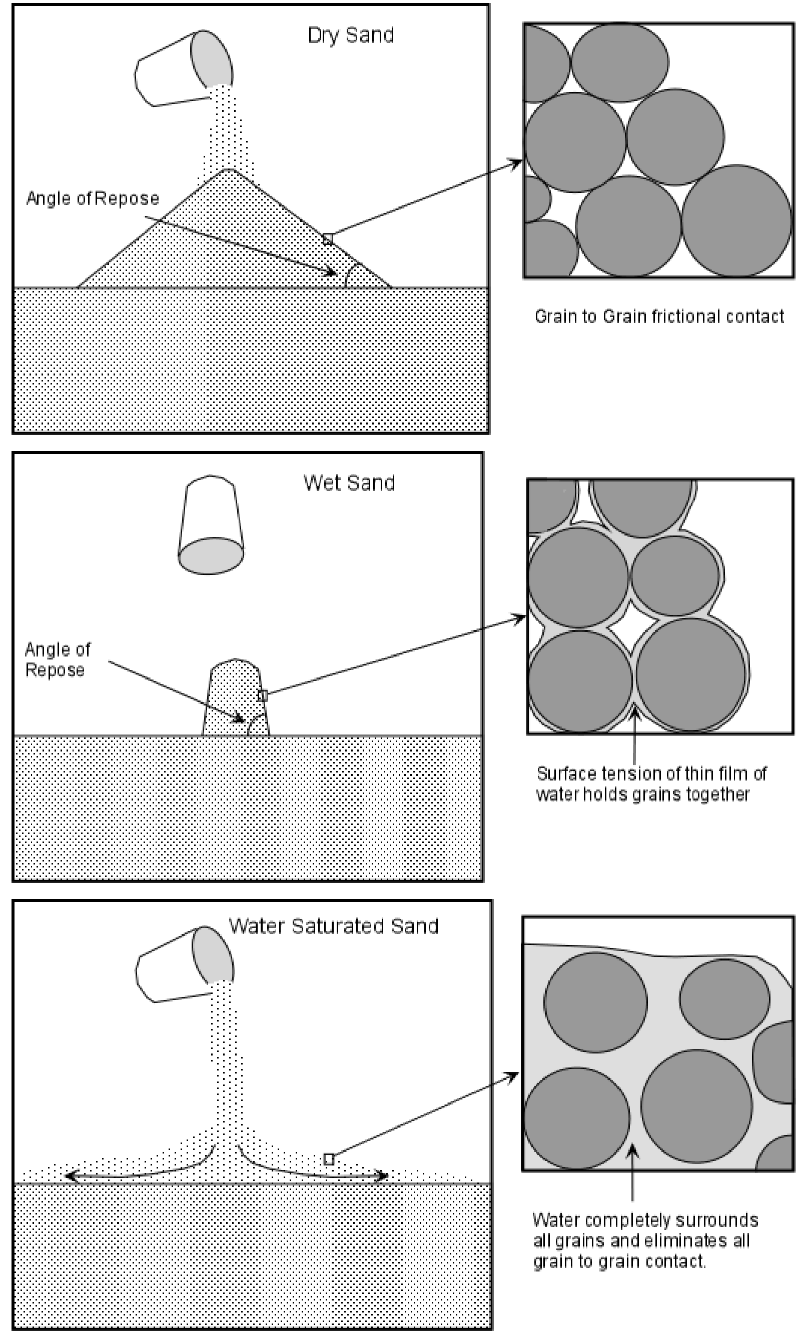
- **Dry sand** is unstable and difficult or impossible to mold.
- When poured from a bucket dry sand will form a cone-shaped mound.
- The **steepness of the cone's sides**, called the **angle of repose**, is determined by the characteristics of the material, primarily the **size** and **angularity** of the **particles**. Sand will always pile up with slopes of about **32º** to **34º**.

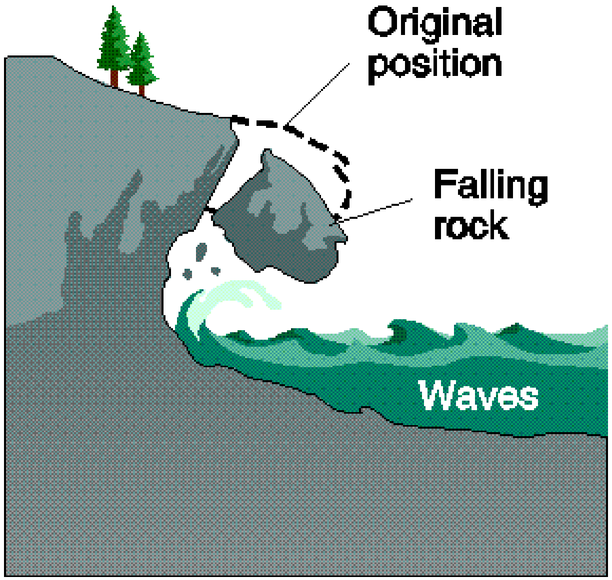
When a **little water is added**, the sand gains strength; its angle of repose is greater, so it can be shaped into vertical walls.

The **addition of too much water** saturates the sand; the spaces fill with water, and the sand grains lose contact with one another. The mixture turns into a slurry that easily flows away.

Hence, **water** can be instrumental in **reducing shear strength** and thereby promoting the movement of rock and sediment downslope under the pull of gravity. This done through:

1. **reducing the natural cohesiveness between grains** or by
2. **reducing friction at the base of a mass of rock** through increased water pressure.





Water can act in other ways that contribute to slope instability, such as

undercutting the base of the slope or

altering the chemical composition of the sediment.

Troublesome Earth Materials

Some Earth materials are particularly **susceptible to the types of changes and disturbances that can lead to slope failure**.

Such material, sometimes referred to as **problem soils**, are often involved in mass-wasting.

Liquefaction

The ***transformation of a soil from a solid to a liquid state, usually (but not always) as a result of increased water content***, is called **liquefaction**.

The ***point at which this transition occurs***, called the **liquid limit**, varies from one soil to another.

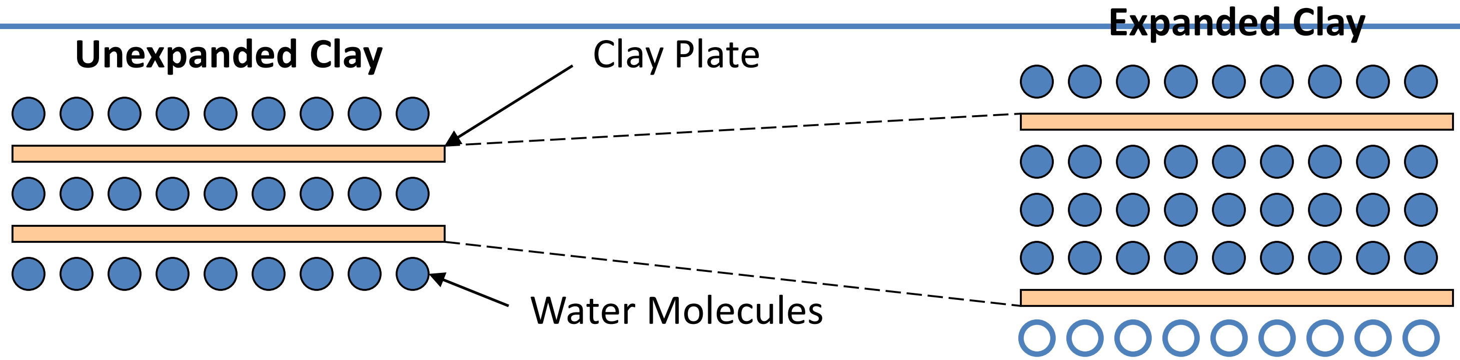
Some materials, particularly some **clay-bearing soils**, have very high liquid limits and may remain plastic over a broad range of water contents.

These soils can be particularly troublesome because by the time the liquid limit is exceeded, the moisture content of the soil is so high that the material behaves in an extremely fluid manner.

Expansive and Hydrocompacting Soils

Expansive soils (**shrink-swell soils**) **expand** greatly when they are **saturated with water** and **shrink** when they **dry out**.

Much of the increase in volume is caused by the chemical attraction of water molecules between the submicroscopic layers of **clay minerals** called **smectites**.



Expansion resulting from increased water content can drastically **reduce the shear strength** of an Earth material, often contributing to downslope movement.

When expansive clays **dry out**, they undergo a **decrease in volume**.

The ***process of shrinkage and/or collapse resulting from water loss*** is referred to as **compaction** (**hydrocompaction**).

Sensitive Soils

In some **clay-rich soils**, the particles are arranged in an **open**, **porous structure** like a **house of cards**.

Such an arrangement can occur in **very fine marine clays**, in which **salt** acts to stabilize the "**house of cards**" by "**gluing**" the particles together end to end.

Eventually, **fresh groundwater** may move through the area, **changing the chemical composition of the clay and washing away the salt**.

The clay particles **collapse** and take on a new, more **compact arrangement**.

The **transition from open to compact arrangement** causes a **sudden and dramatic loss of shear strength** – **liquefaction** – which can propagate with astonishing speed throughout the entire mass of clay.

Liquefaction or compaction that results from a disturbance of the internal structure of a soil is referred to as **remolding**.

Materials that lose shear strength as a result of remolding are called **sensitive soils**. Those that are most susceptible to remolding and liquefaction are called **quick clays**.

Triggering Events

Slope failures are often triggered by some extraordinary activity.

It is also common for a combination of conditions to lead to slope failure.

Among the most common types of triggering events are

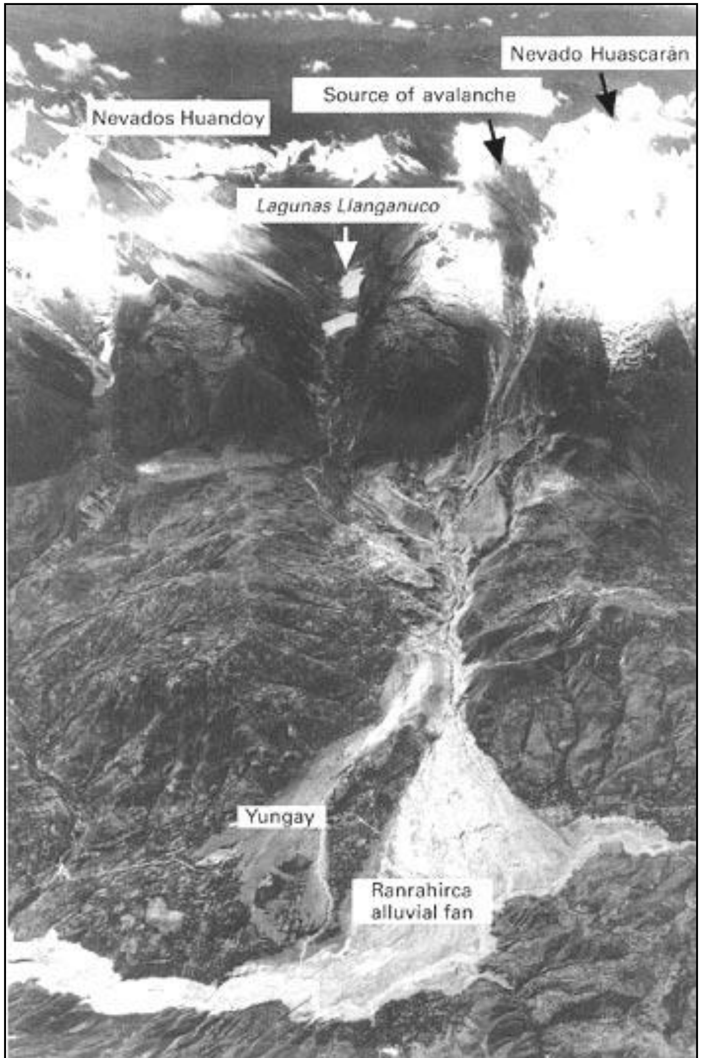
earthquakes,

volcanic eruptions,

slope modifications, and

changes in the hydrologic characteristics of an area (including the effects of prolonged or exceptionally intense rainfall).

Earthquakes and Other Shocks



An **abrupt shock**, such as **explosion**, an **earthquake**, or even a **truck passing by**, can **increase shear stress** and contribute to slope failure.

Earthquakes frequently generate landslides.

In **1970**, a large earthquake in **Peru** triggered **debris avalanche** that roared more than **3.5 km** down the steep, rocky slopes of **Mount Huascaran**, reaching speeds of **400 km/hr**. The village of **Yungay** and **Ranrahirca** were destroyed and as many as **20,000 people killed**.

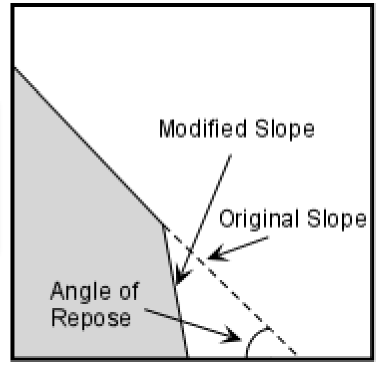
Volcanic Eruptions

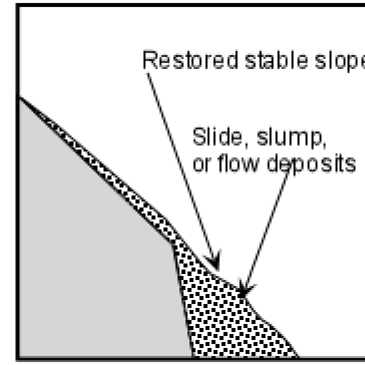
Volcanic eruptions are another mechanism for triggering mass-wasting events.

Large **stratovolcanoes** consist of inherently **unstable accumulations** of **inerlayered lava flows, rubble, and pyroclastic material that form steep slopes**.

Large volumes of water, released when summit glaciers and snowfields melt during an eruption of hot lavas or pyroclastic debris, **can combine with unconsolodated deposits to form rapidly moving lahars**. These highly fluid mudflows can travel great distances and at such high velocities.

Slope modifications and Undercutting





Landslides often result when **natural slopes are modified**, either by **natural processes** or by **human activities**.

Translational slides can occur where **roads have been cut** into regolith and unstable rock, creating an artificial slope that exceeds the **angle of repose** or exposes natural planes of weakness.

Such landslides are common along mountainous and coastal cliffs where roads have been carved into deformed sedimentary or metamorphic rocks.

Overloading – placing a building or a mass of excavated material at the top of a slope – can contribute to slope failure because of the **added weight** as well as the **steepening effect of the load**.

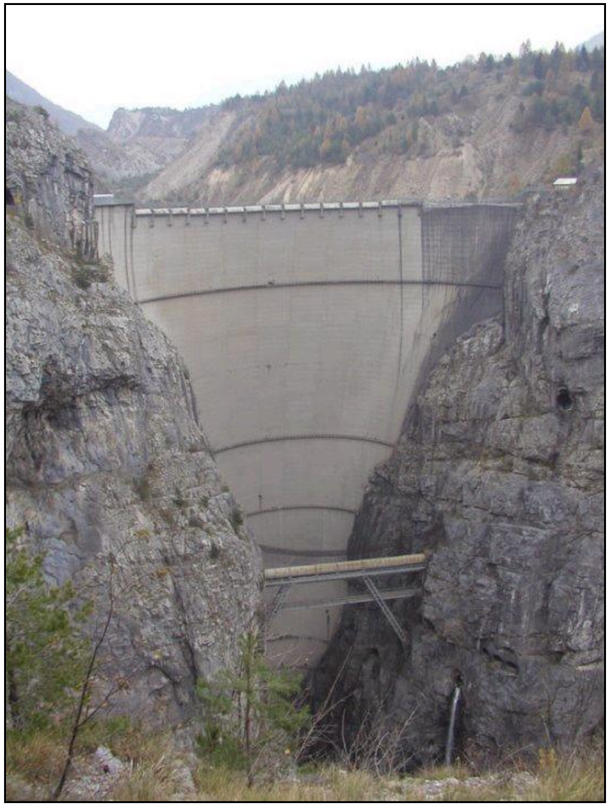
Changes in the Hydrologic Characteristics

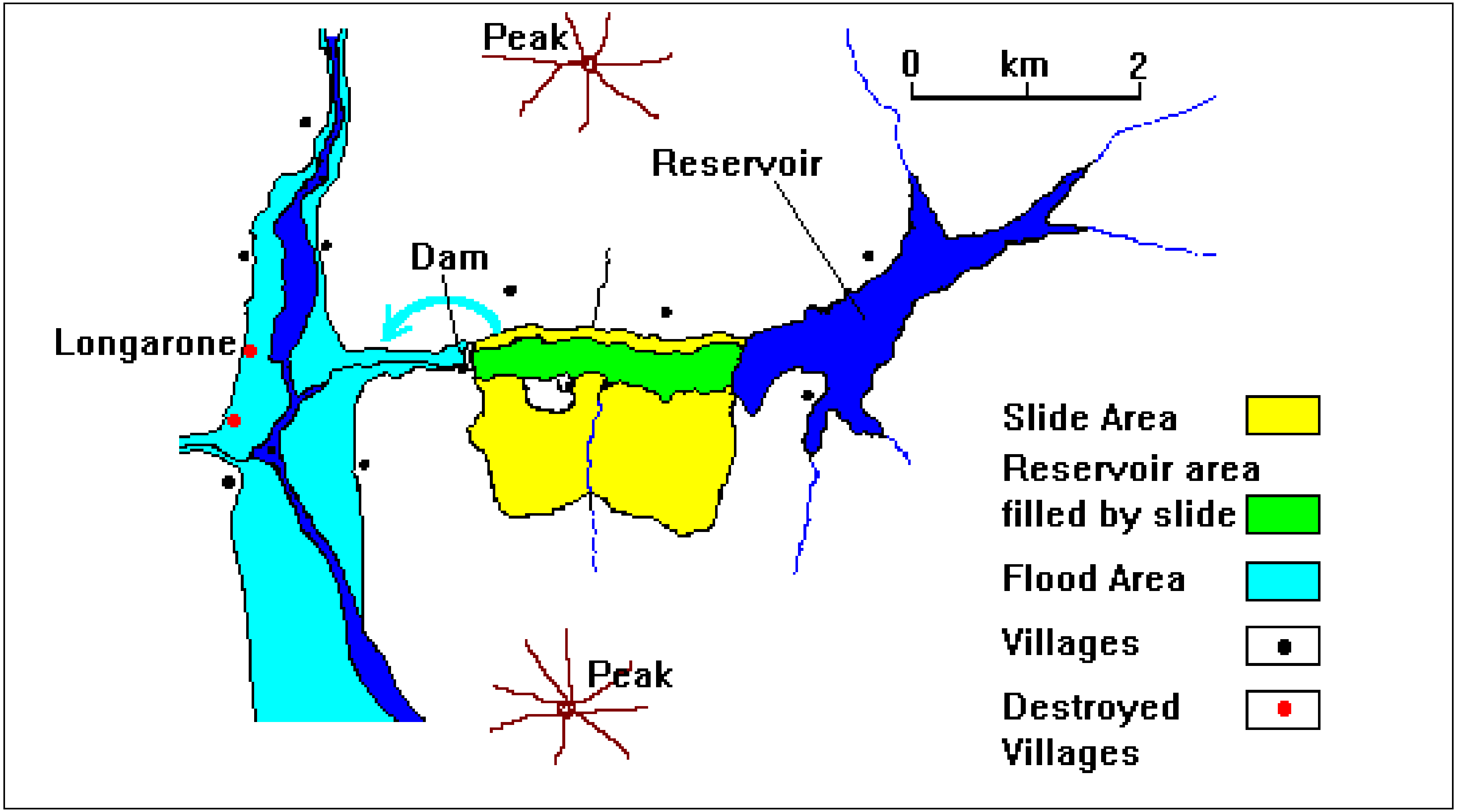
Changes in the characteristics of subsurface water or drainage in an area often contribute to landslides.

For example, **heavy** or **persistent rains** may saturate the ground make it unstable.

The **filling of a large reservoir** can also cause the increased water pressure in the pores of the underlying rock **combines with other destabilizing factors** to produce mass-wasting.

Such factors caused the **world's worst dam disaster**, which occurred in **Italy** in **1963**. A huge mass – almost **250,000,000 m^3** – of rock and debris slid into the reservoir behind the **Vaiont Dam**. The material filled the reservoir and created a **wave 100 m high**, which overflowed the dam and swept both up and down the valley, killing almost **3000 people**.




Peak
0
km
2
Reservoir
Dam
Longarone
Slide Area
Reservoir area
filled by slide
Flood Area
Villages
Destroyed
Villages
Peak

Assessing and Mitigating Mass-Wasting Hazards

Landslides and other forms of mass-wasting are ubiquitous, and they cause extensive damage and loss of life each year.

Prediction and Hazard Assessment

Assessment of the hazards posed by potential **mass-wasting events** are based on

1. **Reconstruction of similar past events in order to evaluate their magnitude and frequency;**
2. **Mapping and testing of soil and rock properties; and**
3. **Analysis of slopes to determine their susceptibility to destabilizing processes.**

Such information can be used in **determining how often an event of a certain magnitude is likely to recur in a given locality**.

Maps showing areas that could be affected by mass-wasting events are important tools for land-use planners. (**Hazard Maps**)

Prevention and Mitigation

Eliminating or restricting human activities in areas where slides are likely to occur may be the best way to **mitigate mass-wasting hazards**.

Scientific understanding of the geology of an area and its potential hazards is combined with **building codes and zoning laws** in setting limits on the types of activities permitted in the area.

Early warning systems can help reduce loss of life and, in some cases, property damage caused by landslides.

Some **engineering techniques** can be used to mitigate or even prevent landslides.

These include **retaining devices**; **drainage pipes**; **grading**; and **diversion walls**.

One of the most common approaches is the use of **concrete block walls**, **poured or sprayed concrete**, **rock bolts**, or **gabions** (**rock contained in wire mesh cages**) to strengthen slopes.

Slopes that are subject to creep can be stabilized by **draining or pumping water from saturated sediment**; this is accomplished by the **insertion of permanent drainage pipes, often in combination with a wall**.

Oversteepened hill slopes can be prevented from slumping if they are **regraded to angles equal to or less than the natural angle of repose**.

Downslope structures can be protected by the **construction of diversion walls**.

In short, scientific understanding of the types of rock and characteristics of slopes in a given area can be combined with weather analysis to delineate hazards, and sometimes, to issue predictions and early warnings of major landslides.

With careful planning, building regulations, and zoning laws, and the use of appropriate stabilization techniques, the impacts of mass-wasting processes on humans can often be reduced. Commonly used techniques include retaining devices (concrete, rock bolts, gabions), drainage pipes, grading, and diversion walls.