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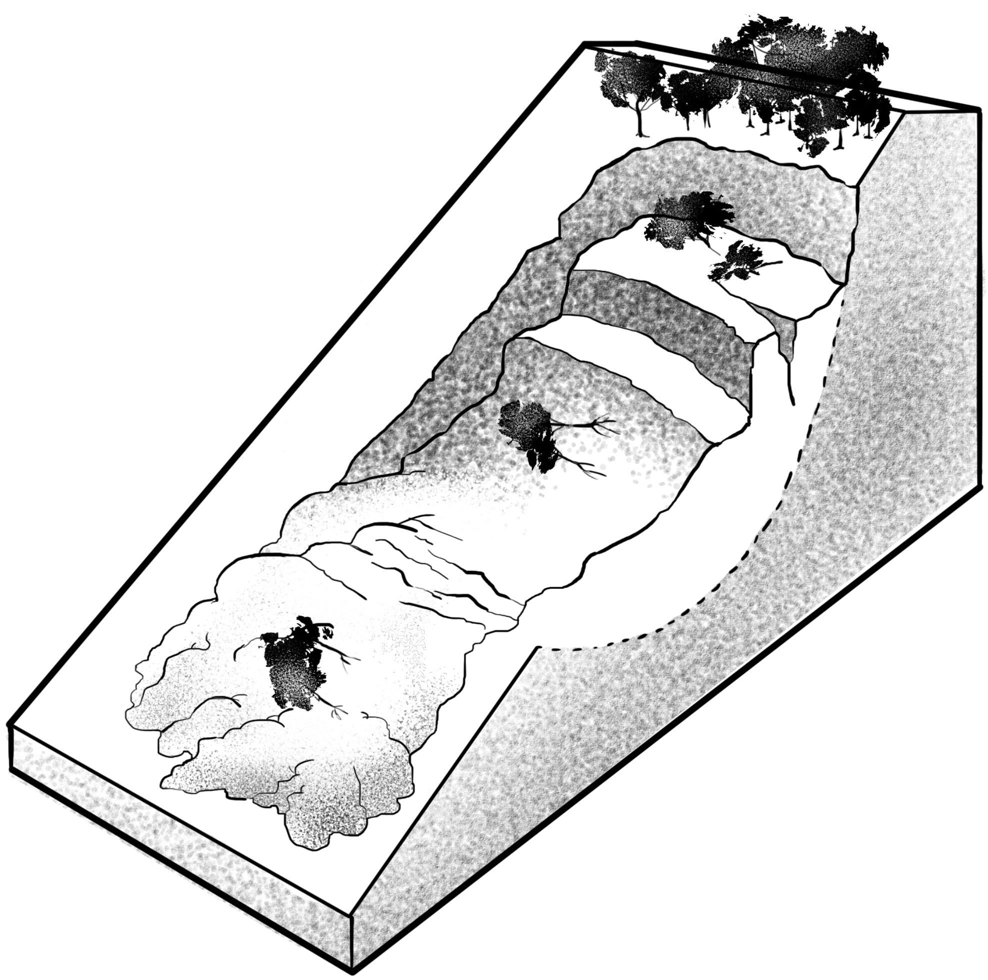
Landslide Field Evaluation For Landscape Architects

Companion Document



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School of Architecture
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Introduction

In Spring 2022, the authors initiated a landscape architecture directed studies course, supervised by Associate Professor Daniel Roehr, in response to the devastating landslides in both British Columbia and Brazil in 2021. Over the course of the summer, we developed a blog, available at https://blogs.ubc.ca/landslides/, to provide an easily accessible resource for landscape architects to better understand landslides and mitigate their risk through design. As part of this, we created a GIS-based approach for determining slope stability based on multiple criteria (available at https://blogs.ubc.ca/landslides/tools/). In creating this, we quickly realized certain limitations of this approach within a design approach — notably with regards of scale and site specificity . We therefore otped to develop an immersive, multisensory on-site evaluation tool to refine the scale of assessment and collect necessary site specific information.

During our research we came across A Guide for Management of Landslide-Prone Terrain in the Pacific Northwest, a document published by the B.C Ministry of Forest in 1994. While much of the information is still relevant, despite it being written nearly 30 years ago, we found two aspects that needed to be improved. Firstly, the document is fairly lengthy and technical making it difficult to navigate particularly for readers who are unfamiliar with its contents. Secondly, the document was created prior to the emergence of the internet and the multitude of resources it provides. With this site analysis toolkit (the landslide field evaluation and the present companon document), we aim to provide an updated version of the B.C Ministry of Forest document (Chatwin et al., 1994) that is accessible for designers with no formal training in geology or soil sciences.

The goal of the landslide field evaluation tool is to equip landscape architects with a useful protocol for site analysis in regards to mass movements, serving as a pedagogical resource to become familiar with the processes that affect slope stability. This will aid landscape architects in becoming more engaged in preliminary site discussions with other professions, such as engineers, planners, and developers. The companion document also contains relevant information for decisions made during the design process, particularly when determining topography. Both the landslide field evaluation and the GIS-based slope stability analysis are exemplified through terrain found in British Columbia near Vancouver, where the University of British Columbia is located; Most of the techniques and factors can however be applied and assessed elsewhere in a variaty of contexts around the world.

It is our hope that this toolkit reinforces the importance of a multisensorial approach to site analysis investigation that combines mapping technologies and the active, conscious use of the senses to immerse the designer with the site — all the physical components of it.

Landform

The shape of the landscape, both at a regional scale and site scale, can indicate unstable terrain. Depending on the size of the area under evaluation, landform observations can be conducted through air photos, topographic maps, and field reconnaissance. While onsite observations may be limited in scale comparatively, they are useful for understanding landforms at specific areas as topographic maps can be inaccurate at a small scale.

Topography Formed by Glaciers

At a regional scale, using satellite imagery, using software such as Google Earth, and topographic maps can determine how the landscape has been formed. This preliminary research can help indicate which type of landslide hazard may be present on site, prior to refining the analysis scale. This observation can also be done on-site by looking for the landscape features provided below (information from Chatwin et al.,1994):

Landscapes Prone to Rockfalls, Rockslides, Debris Avalanches, and Flows

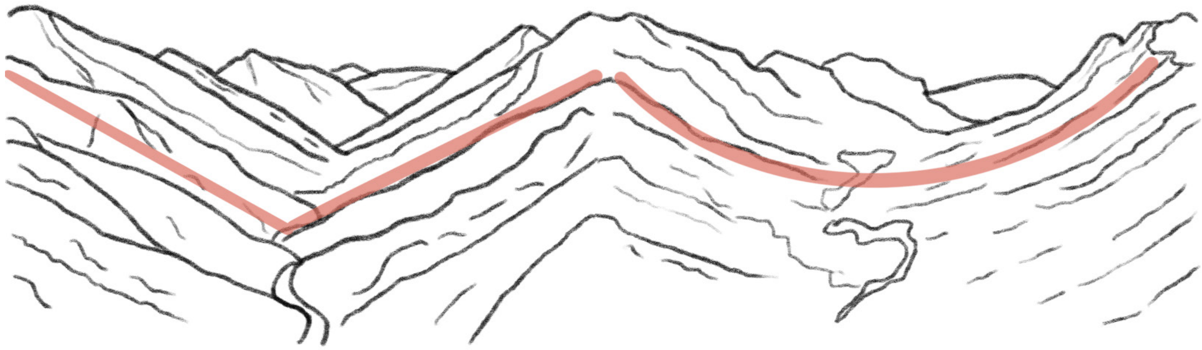

Figure 1. Illustration depicting a V-shaped versus U-shaped valley.

Non-glacial landscapes

- V-shaped valleys
- Steep planar side slopes due to joints, fracturing, faults and resistant hard bedrock
- Shallow overburden of locally derived coarse-textured materials
- Benches and escarpments of bedrock

Landscapes modified by glaciers

- U-shaped valleys
- Steep, glacially scoured side slopes
- Shallow overburden (mantles) of colluvium and till
- Extensive outcrops of bedrock

Landscapes Prone to Slumps and Earthflows

Figure 2. Rounded topography shaped by weathering (i.e. wind, rain); adapted from Chatwin et. al., 1994.

Non-glacial landscapes

- Soft, rounded topography due to weathering of fine textured bedrock (e.g., mudstone)
- Bench-like topography

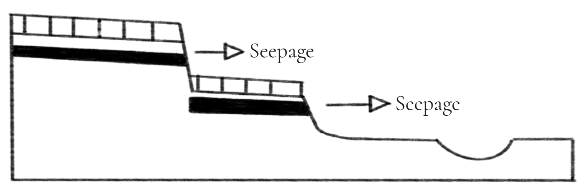

Figure 3. Terraced landscape indicating water seepage, potentially causing a slump or flow; adapted from Chatwin et. al., 1994.

Landscapes modified by glaciers

- Dissected valley-fill sediments
- Terraces, escarpments of glaciolacustrine silt/clay or ice contact materials with beds of finer sediments
- Raised marine terraces, escarpments along the ocean margin
- Till from fine-textured bedrock (e.g., shale)

Slope Shape

The slope shape can indicate the type of shallow landform moments that have occurred on site. Concave terrains tend to form due to slides that are initiated at moderate or relatively steep slopes. Convex and straight terrains suggest the movement is a less hazardous creep that slowly and continuously occurs on steep slopes. Since water collects in concave terrain, the risk of landslides is therefore higher than in straight or convex terrains (Fanyu, et. al., 2012).

In the image below, slopes (a) and (b) were formed by shallow slides, moving debris to the toe of the slope creating concave terrains. Slopes (c) and (d), on the other hand, were formed by creeps which slowly moved debris from the steep slope above, creating convex and smooth terrains (Zhang et al., 2012).

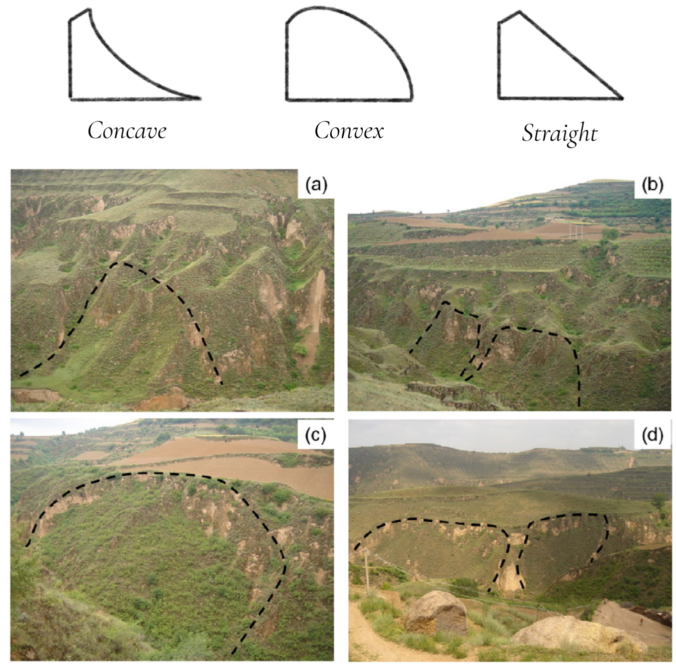

Figure 4. Photographs showing concave slopes (a & b) and convex slopes (c & d); Zhang et al., 2012.

Slope Configuration

Similar to shape, slope configuration can also indicate which kind of landform movements have occurred on site. Irregular terrains suggest that falls have shaped the surface as material releases from the headwall or sidewall causing rugged terrain. Conversely, smooth terrains suggest the landform has been shaped by a slow creep or very shallow slides (Zhang et al., 2012). However, while irregular slopes are less stable, they tend to also have a reduced travel distance, making the off-site hazard lower compared to smooth slopes (Chatwin et al., 1994).

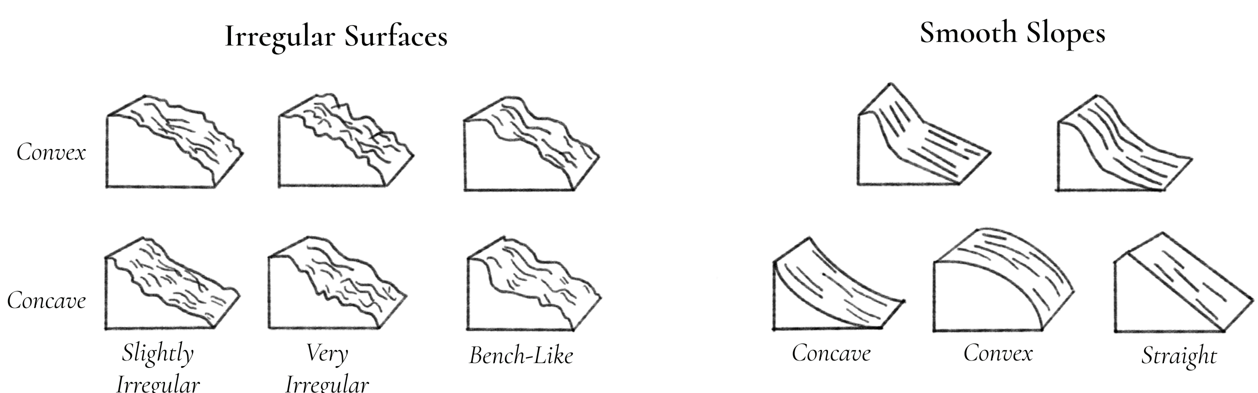

Figure 5. Irregular versus smooth slope configurations; adapted from Chatwin et. al., 1994

Slope Gradient

Slope gradient is a key factor in assessing the stability of a slope, as it determines the gravitational force exerted on soil or rock downslope. Slopes steeper than 36 degrees (73%) tend to be highly unstable while slopes under 26% (49%) tend to be stable, provided other conditions, such as soil saturation or cohesion, are not influencing the stability of the slope (Chatwin et al., 1994).

A cross-section profile is the most effective way to show slope angle and shape, which can be determined from a variety of surveying techniques and software. If this information is not readily available, it is possible to estimate slope by approximating the height of the slope (difference in elevation) and the length of the slope. To find the decimal slope percentage, divide the height by length (~S = ~DE / ~L).
See UBC Topography Literacy blog for more information.

Overburden

Soil Profile

Almost any meaningful site-specific soil description is based on the analysis of soil profiles. A soil profile is a **vertical cross-section through the layers (or soil horizons) from the surface to the parent material** that allows us to understand the evolution of the soil over decades and hundreds of years. The description of the soil profile is done by means of morphological characters such as color, texture, structure, and effervescence.

For the designer, the advantages of studying a soil profile in situ are multiple. First, it is among the simplest and most intuitive ways of grasping elementary concepts in soil science, soil taxonomy and pedology. Even without formal training in these fields (although it remains recommended), simply observing a soil profile and draw its layers (horizons) allows the neophyte to quickly appreciate the palimpsestic nature of soil and to identify some of its characteristics (texture, colour, odour, presence of oxidation, depth of the water table, etc.). Even beyond soil stability and mass movements' prevention, observing and analyzing the soil is of prime interest for any environmental designer or landscape architect, as it is the medium which supports plant growth; and cues of general soil health and fertility (good drainage and water holding capacity, microbial activity, nutrient retention capacity, etc.) can be approximated by looking at a soil profile.

Units of Measure in Pedology (adapted from WRB, 2022, and Krzic et al., 2021)

Soils are an intrinsically complex medium. Because soil properties continuously vary through space – the soil at any given location will be different, often in very subtle ways, from the soil even a footstep away – there are no naturally occurring soil "individuals", like there would be different individual birds or trees from a same species. This makes soil classification and taxonomy particularly challenging. The concept of an arbitrary definition of a basic soil individual – the ***pedon*** – was developed to circumvent that problem. A pedon is a 3-dimensional sample of a body of soil that is at the minimum 1 m^2 at the surface and extends to the bottom of the soil; it is the smallest, three-dimensional unit at the surface of the earth that is considered as a soil. Pedon descriptions are used among other things to classify soil and to define map units for a soil survey.

Soils are also composed of one or more distinct layers that are more or less parallel to the soil surface and which are called soil horizons. They constitute the "footprint" of the various soil-forming processes. Soil horizons can be more or less distinct and can sometimes be completely mixed, especially in the case with a history of human interference (such as agricultural soils). The most easily recognized horizons differ from each other in terms of their colour, structure, texture (the particles which compose it) or many other properties. In almost all soil classification systems around the world (including the World Reference Base for Soil Resources, or WRB), diagnostic horizons are used as a basis to define different soil "types" (formally called soil orders).

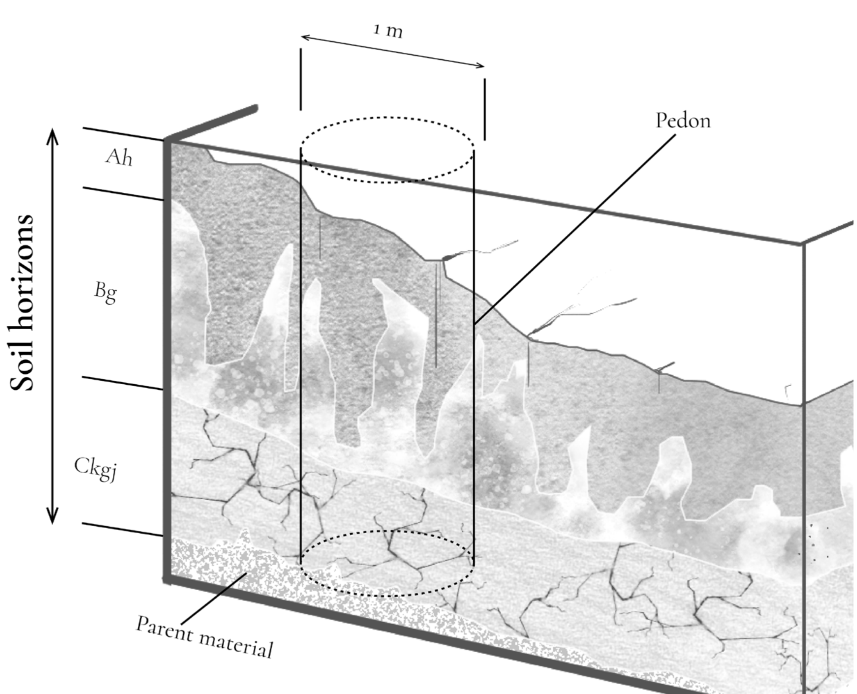

Figure 6.
The pedon and soil horizons. Adapted from the Canadian System of Soil Classification (1998)

Moreover, in every soil classification system, horizons are designed using a similar nomenclature: namely, they are assigned distinctive alphabetic symbols as a form of shorthand for their characteristics. Usually, a horizon is designed using a capital letter (master symbol) and one or more lowercase letter (suffixes) with specific rules for the combinations of symbols in one layer and for layer sequences.

There are broadly two distinct horizons groups: mineral and organic horizons. Organic horizons are those which contain 17% or more organic carbon by weight; mineral horizons have less than 17% organic carbon by weight.

Table 1 shows the master symbols used by the WRB and (with minor differences) by the Canadian System of Soil Classification (2022).

Table 1. Master symbols used by the WRB (adapted from WRB, 2022)

Symbol	Horizon group	Criteria
H	Organic	Organic or organotechnic layer, not forming part of a litter layer; water saturation > 30 consecutive days in most years or drained; generally regarded as peat layer or organic limnic layer.
O	Organic	Organic horizon or organotechnic layer, not forming part of a litter layer; water saturation ≤ 30 consecutive days in most years and not drained; generally regarded as non-peat and non-limnic horizon.
A	Mineral	Mineral horizon at the mineral soil surface or buried; contains organic matter that has at least partly been modified in-situ; soil structure and/or structural elements created by cultivation in ≥ 50% (by volume, related to the fine earth), i.e. rock structure, if present, in < 50% (by volume); cultivated mineral layers are designated A, even if they belonged to another layer before cultivation.
E	Mineral	Horizon that has lost by downward movement within the soil (vertically or laterally) one or more of the following: Fe, Al, and/or Mn species; clay minerals; organic matter.
B	Mineral	Mineral horizon that has (at least originally) formed below an A or E horizon; rock structure, if present, in < 50% (by volume, related to the fine earth); one or more of the following processes of soil formation: • formation of soil aggregate structure • formation of clay minerals and/or oxides • accumulation by illuviation processes of one or more of the following: Fe, Al, and/or Mn species; clay minerals; organic matter; silica; carbonates; gypsum • removal of carbonates or gypsum
C	Mineral layer	Mineral layer; unconsolidated (can be cut with a spade when moist), or consolidated and more fractured than the R layer; no soil formation, or soil formation that does not meet the criteria of the A, E, and B horizon
R	Consolidated rock	Consolidated rock; air-dry or drier specimens, when placed in water, will not slake within 24 hours; fractures, if present, occupy < 10% (by volume, related to the whole soil); not resulting from the cementation of a soil horizon.
I	Ice	≥ 75% ice (by volume, related to the whole soil), permanent, below an H, O, A, E, B or C layer
W	Water	Permanent water above the soil surface or between layers, may be seasonally frozen.

Soil Texture (adapted from WRB, 2022,and Krzic et al., 2021)

Soil texture is a fundamental property of soils and can be defined as the granulometric composition of soils according to the relative proportions of the various sizes of mineral particles that are less than 2mm. These mineral particles are:

> ***Sand*** – the largest group of soil particles, whose diameter is between 0.063 mm (63 μm) to 2 mm. The sand fraction is subdivided into five sub-fractions (very coarse, coarse, medium, fine, and very fine) (see table 2). Sand particles are generally spherical in nature, with jagged edges, hard and abrasive, and feel gritty and loose. Sand contributes to excessive drainage and low plant available water.
>
> ***Silt*** – consists of particles with intermediate size between sand and clay. The size range for silt is 0.002 mm to 0.063 mm (2 μm to 63 μm). When rubbed between the fingers, silt particles exhibit a smooth feeling.
>
> ***Clay*** – the smallest size fraction of soil mineral particles. The diameter of clay particles is less than 0.002 mm (2 μm). Clays are generally sticky and typically exhibit plastic behaviour, and clay particles can absorb water, causing soil to swell and shrink/crack when dry.

Together, all three size fractions, in various configurations, constitute the matrix of the soil, and according to the proportion of these particles, soils are assigned to different textural classes (see table 3). Soil particles that are more than 2 mm can simply be classified as rounded or angular; generally speaking, the shear strength of a slope (its resistance to gravitational forces and, by extension, mass movements) is lower for rounded particles than for angular particles.

Table 2. Particle-size classes according to ISO 11277:2009 (taken from WBR, 2022)

Particle-size class	Diameter of particles
Fine earth	all particles ≤ 2 mm
Sand	> 63 μm - ≤ 2 mm
Very coarse	> 1250 μm - ≤ 2 mm
Coarse	> 630 μm - ≤ 1250 μm
Medium	> 200 μm - ≤ 630 μm
Fine	> 125 μm - ≤ 200 μm
Very fine	> 63 μm - < 125 μm
Silt	> 2 μm - ≤ 63 μm
Clay	≤ 2 μm

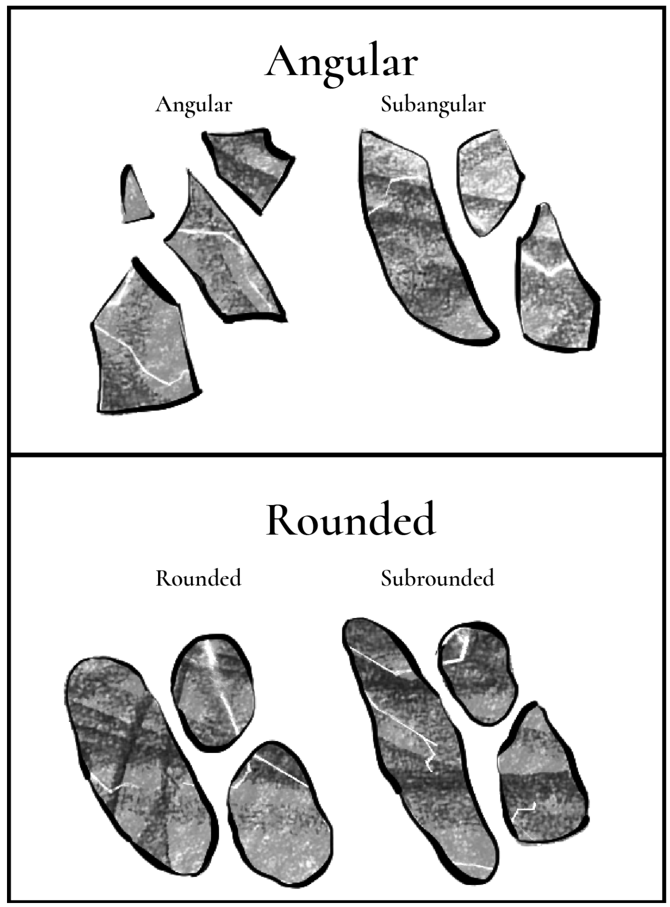

Figure 7. Different particle shapes.

Because the different textures of soil horizons can be a crucial determinant on the type of mass movement risk, it is fundamental that the environmental designer or landscape architect be familiar with the different soil textural classes. Moreover, soil texture dictates suitability for plant growth, land use capacity, and soil management.

In order to quickly estimate the texture of any given soil horizon on the field, the ribbon test technique is useful. It allows the observer to approximate the textural class of a soil sample by roughly estimating the proportion of sand and clay it contains.

1 2 Place approx. 1 tablespoon of soil (25g) in palm. Add a few drops of water and kneed soil to break down all aggregates. Soil is at proper consistency when it feels plastic and moldable, like moist putty.

Does the soil remain in a ball when squeezed?
- No → *Sand*
- Yes ↓

3 Place the ball of soil between the thumb and the index, gently sqeezing it upwards to forma ribbon of uniform thickness and width. Allow the ribbon to emerge and extend over the index, breaking from its own weight.

Does the soil form a ribbon?
- No → *Loamy sand*
- Ribbon < 25 mm? → *Loamy soil*
- Ribbon between 25 - 50 mm? → *Loamy/ clayey soil*
- Ribbon > 50 mm? → *Clayey soil*

4 Excessively wet a small pinch of soil in the palm and rub it with the index finger.

	Loamy soil	Loamy/clayey soil	Clayey soil
Does the soil feel very gritty? — Yes	*Sandy loam*	*Sandy clay loam*	*Sandy clay*
No → Neither gritty nor smooth? — Yes	*Loam*	*Clay loam*	*Clay*
No → Very smooth? — Yes	*Silt loam*	*Silty clay loam*	*Silty clay*

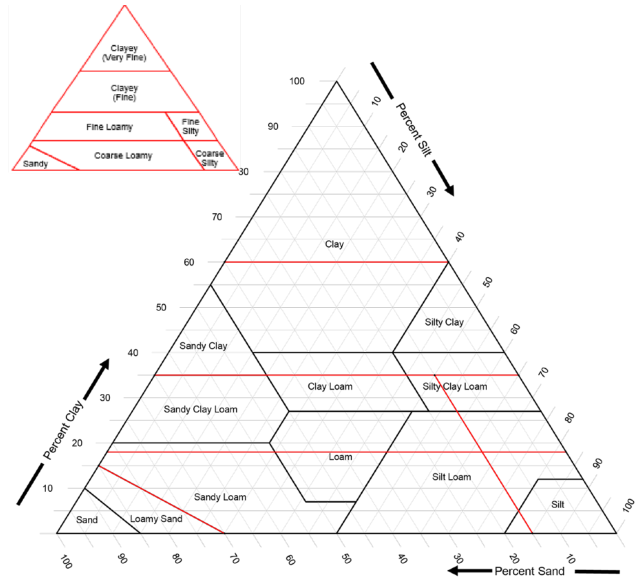

Figure 8. **USDA soil texture triangle:** a diagram of soil types according to their clay, silt and sand composition.

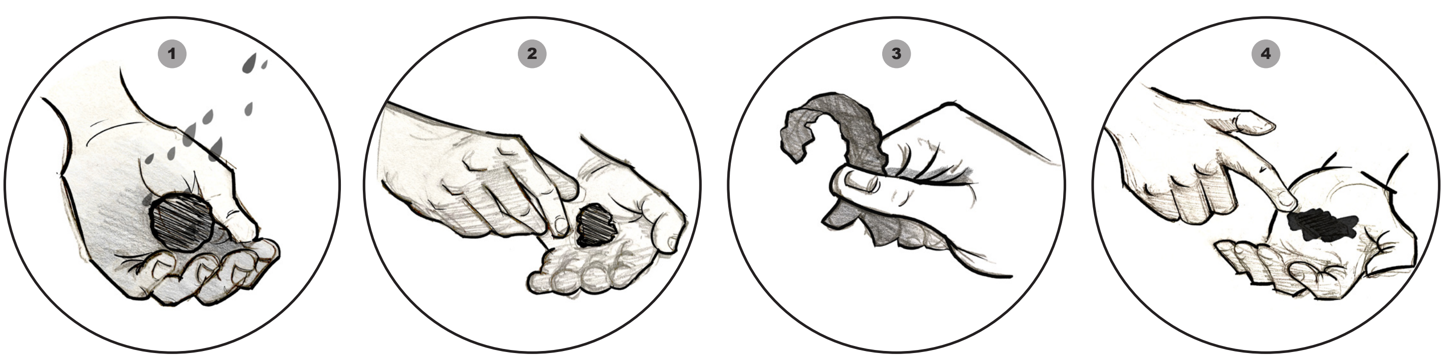

Table 3. Soil textural classes (taken from WRB, 2022)

Texture class	% Sand	% Silt	% Clay	Additional criteria
Sand	> 85	< 15	< 10	(%silt + 1.5×%clay) < 15
Loamy Sand	>70 to ≤ 90	< 30	< 15	(%silt + 1.5×%clay) ≥ 15 and (%silt + 2×%clay) < 30
Silt	≤ 20	≥ 80	< 12	
Silt Loam	≤ 50	≥ 50 to < 80	< 27	
Silt Loam	≤ 8	≥ 80 to ≤ 88	≥ 12 to ≤ 20	
Sandy Loam	> 52 to ≤ 85	≤ 48	< 20	(%silt + 2×%clay) ≥ 30
Sandy Loam	> 43 to ≤ 52	≥ 41 to < 50	< 7	
Loam	> 23 to ≤ 52	≥ 28 to < 50	≥ 7 to < 27	
Sandy Clay Loam	> 45 to ≤ 80	< 28	≥ 20 to < 35	
Silty Clay Loam	≤ 20	> 40 to ≤ 73	≥ 27 to < 40	
Clay Loam	> 20 to ≤ 45	> 15 to < 53	≥ 27 to < 40	
Sandy Clay	> 45 to ≤ 65	< 20	≥ 35 to < 55	
Silty Clay	≤ 20	≥ 40 to ≤ 60	≥ 40 to ≤ 60	
Clay	≤ 45	< 40	≥ 40	

Although this method is approximate and requires some practice to produce consistent results, it is useful because of its speed of execution and relative simplicity; it allows an observer unfamiliar with soil science to get acquainted with different soil textural classes, and their variations, by feel. If necessary, a laboratory particle size analysis will confirm the results of this method.

Soil texture is not to be confused with soil structure, which deals with the arrangement of sand, silt, clay, and organic particles into aggregates or peds. Although soil structure has a major influence on water and air movement within the soil, as well as other ecological characteristics (root growth, microbial activity, etc.), its analysis goes beyond the scope of this protocol and is left to the observer to study individually.

Geological Process

Evidence of Past Landslides

Examining the site and surrounding area for evidence of past landslides is very helpful as it suggests whether the existing conditions are prone to failure or not. Some of this information can be found through aerial photographs from Google Earth and similar programs, however a field examination of less obvious signs should be conducted also. These features include:

Landslide scars - an area that has little to no vegetation compared to adjacent vegetation, suggesting a recent slide, or vegetation that is younger than the adjacent area in less recent slides. In regions with sparse vegetation, a debris path and run out may be seen as a score in the hillside.

Fans or buried deposits - colluvial fans, material transported by downhill movement of rock and soil, are easily observable as they are the accumulation of material from the past landslide. If the landslide occurred awhile ago, less easily observable material, such as woody debris, may be buried under other material from the mass movement or more recent plant growth.

Tree throw/hole - a depression or cavity created when the stump of a tree is knocked over taking soil along with the roots, in this case from soil instability. This, however, can also be caused by strong wind.

Road or path cuts - potentially the head of a landslide that has eroded a portion of a road or path away. Further erosion could lead to a possible washout.

Tension fractures - tension cracks, or fractures, indicate that the ground has and may still be continuing to move downslope, creating gaps between soil or rocks. These gaps provide a space for water to collect, adding weight to the already unstable ground.

Gully Erosion - areas that are dissected by gullies, deep channels scored by water in the landscape, may indicate past debris flows and may contain evidence of other landslide types along the side and headwalls.

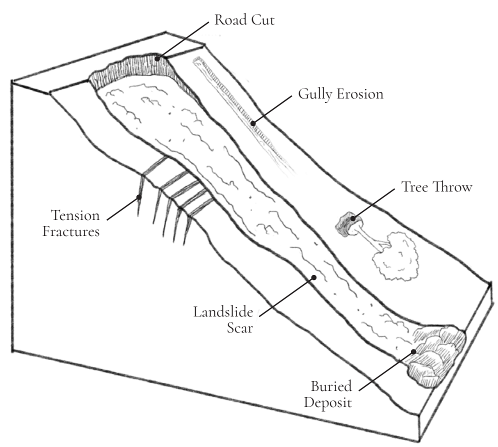

Figure 9. Diagram of past landslide evidence within the landscape.

Past Landslide Topography Characteristics

Slope Gradient	(see slope gradient under the Landform section, p. 05)
Land Use	has a large influence on landslides and may indicate what might occur if a similar condition is created or found on the site. Clear cuts in particular create a higher risk of landslides due the significant disturbance to soil stability it causes.
Slope Shape	(see slope shape under the Landform section, p. 05)
Slope Configuration	(see slope configuration under the Landform section, p. 05)
Slope Drainage	(see slope drainage under the Hydrological Characteristics section, p. 12-13)

Hydrological Characteristics

Because overall site drainage and hydrological characteristics are primary factors of slope failures, indicators of wet or poor drainage sites on slopes are important features to note in a field inspection. In addition to the items identified in the questionnaire, any additional evidence of zones of periodic flooding and potential sites of active pore-water pressures during high rainfall events must be noted.

Presence of Impermeable Layer

An impermeable layer refers to a soil layer (though not necessarily a horizon) that restricts the downward passage of water. It can result from:

Compaction (where the material is closely packed, such as clay layers or bedrock).

Cementation (more common in substances such as iron, calcium, or silica).

Textural changes (for instance, when coarse, loose material like gravel overlies a clay or silt bed that has a lower permeability).

The identification of an impermeable layer, and its depth below the surface, provides an estimation of the depth and type of failure that may occur at a site. Such layers can also indicate principal paths of subsurface water movement, (or possible zones of perched water tables), probable surfaces of failure on the slope, and root penetration limitations (which can be important for identifying areas made unstable by windthrow).

Surface 'Wet' Indicators

Surface features of poor drainage conditions include:

Specific vegetation observed on site- see p. 13.

Seepage and concentrated subsurface drainage, which are indicated by spring, sag ponds or moist areas on open slopes, as well as along road cuts. The locations of these areas of concentrated subsurface flow should be noted on maps and profiles as potential sites of active, unstable ground.

Shallow linear depressions oriented up- and downslope, which can represent old landslide scars or surface erosion gullies, and which identify concentrated surface and subsurface flow. Such features are potential sites for debris avalanches and debris flows.

Curved depressions and swales, which identify local areas of slump and earthflow failure and are sites of deep subsurface water concentration.

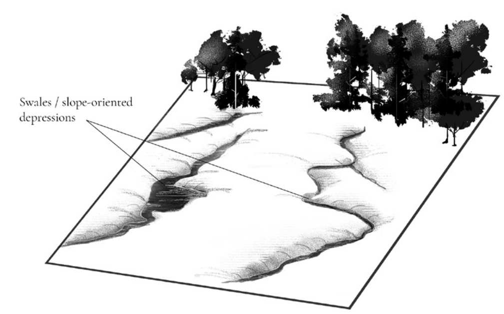

Figure 10. Shallow linear depressions can undercut a clope and create a risk of certain mass movements.

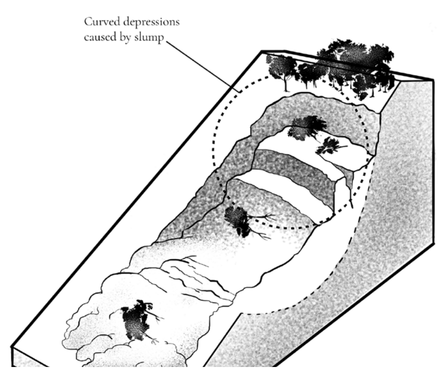

Figure 11. Curved depressions identify local areas of slump and earthflow failures.

Subsurface 'Wet' Indicators

Subsurface features of poor drainage conditions include:

Mottles, which are spots or blotches of different color (primarily reds and yellows) interspersed with the dominant soil color. Mottles (faint or distinct) present in the upper meter of soil generally indicate soil moisture in excess of field capacity for certain periods of the year.

Gleyed soils have wet/moist, gray B-horizons (indicating a strong reducing environment) overlain by a black, organic surface layer. Such soils remain wet for extended periods.

Figure 12. Oxidation and reduction (mottles) in soil. Photography by R. Lacroix, Soil Science Society of America (203).

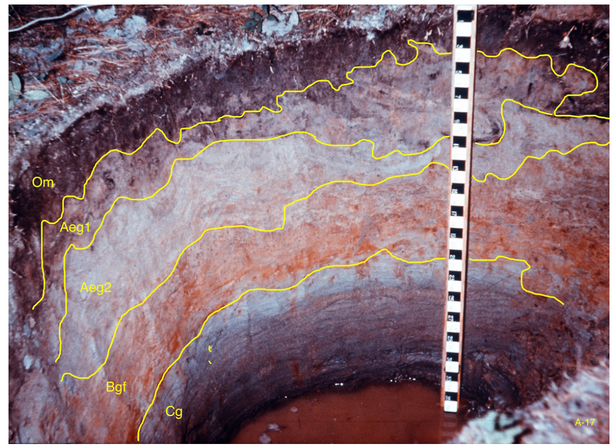

Figure 13. The mottled Bgf horizon overlies a blue-gray Cg horizon in this Gleysol. Canadian Society of Soil, 2020.

Overall drainage assessment

Soil drainage for a site can be estimated by the degree of oxidation or reduction evident in the soil profile. This is generally expressed as the relative amount of mottling or gleying indicated in the various soil horizons. Table 4 lists commonly used drainage classes and defining characteristics.

Table 4. Soil textural classes (taken from WRB, 2022)

Drainage class	Soil characteristics
Rapidly drained	Soils are free from any evidence of gleying or mottling throughout the profile. Common on steep slopes
Well drained	Soils are usually free of mottling in the upper 1 m, but may be mottled below this depth.
Moderatly well drained	Soils are faintly mottled in the lower part of the upper 1 m of soil (lower B-horizon).
Imperfectly drained	Soils are distinctly mottled throughout the B-horizon.
Poor to very poorly drained	Soils are usually strongly gleyed.

Vegetation

Beyond topography and elements beneath the surface, vegetation can be used as an indicator of soil stability on slopes. This can be done by looking for: water tolerant vegetation on or above a slope, unusual tree habit on a slope, or trees uprooted by wind. Since landscape architects have specialized knowledge of plants and their requirements, this section is one of the most effective assessments and may render additional results to other stability reports.

Water Tolerant Vegetation

While the presence of vegetation usually adds stability to slopes, the presence of water-loving vegetation, hydrophytes, on slopes can indicate instability due to heavily saturated soil. In such conditions, water tolerant plants on slopes indicate that the hillside is poorly drained and has high groundwater levels. This is significant since water is a main factor in triggering landslides due to its added weight on an unstable slope.

A short list of common water-loving vegetation in the Pacific Northwest is provided below. If using this tool outside of this region, additional research will be needed to identify common water tolerant plants in the area of the site.

***Alnus alnobetula subsp. sinuata* (Sitka Alder)**
Betulaceae (Birch Family)
General: Deciduous shrub or tree, 1-5 m tall; pointed axillary buds without stalks; bark scaly, sometimes lichen-covered, yellowish-brown or grey.
Leaves: Alternate, deciduous, smooth, finely toothed 1-2 times, oval with pointed tips, 4-10 cm long, brownish in the fall.
Flowers: Inflorescence of male and female catkins which open at the same time as the leaves on current year's growth; male catkins unstalked.
Fruits: Small nutlets, with broad wings; female cones 1.5-2 cm long, egg-shaped.

Source: Klinkenberg, 2020a

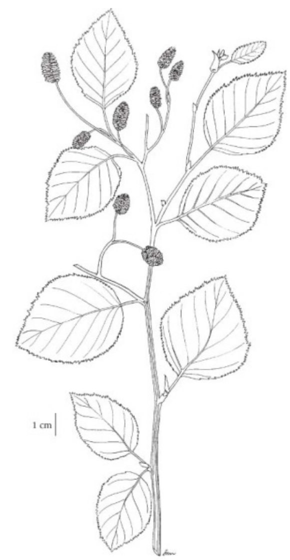

Figure 14. Sitka Alder stem, leaves, and fruits; Douglas et. al., 1998.

***Equisetum arvense* (Common Horsetail)**
Equisetaceae (Horsetail Family)
General: Perennial from a felty-hairy, tuber-bearing rhizome.
Stems: 10-80 cm tall, 3-5 mm thick, with their central cavity less than 1/2 the stem diameter, regularly branched, the sheaths with 10-16 pointed teeth; branches in regular whorls, triangular in cross-section; the 1st internode of branches longer than the corresponding stem sheaths; fertile stems appearing in spring before sterile stems, about 10-15 cm tall, pale brown, unbranched, dying after the spores are shed, the sheaths 4-6, pale brown with 6-12 darker teeth.
Cones: 1-4 cm long, with solid centres, rounded on the tops.

Source: Klinkenberg, 2020b

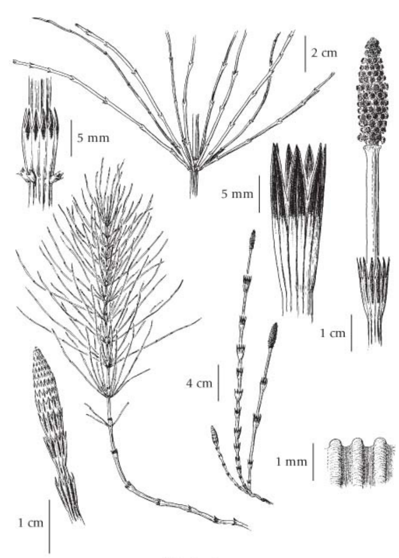

Figure 15. Horsetail stems and cones; Douglas et. al., 1999a.

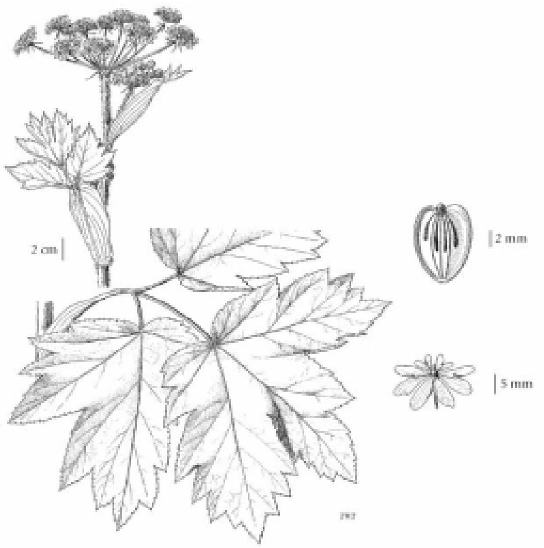

Figure 16. Cow Parsnip leaves, flowers, and fruit; Douglas et. al., 1999a.

***Heracleum maximum* (Cow Parsnip)**
Apiaceae (Carrot / Celery Family)
General: Perennial. Stem 1-3 m tall, hairs woolly.
Leaves: Widely sheathing petioles 10-40 cm long, upper sheaths enlarged, bladeless, blade 20-50 cm wide, round to kidney-shaped, leaflets 3, 10-40 cm wide, ovate to round, lobed or toothed, usually hairy.
Flowers: Inflorescence usually 10-20 cm in diameter, woolly or long-hairy, peduncle 5-20 cm long, involucre bracts 5-10, deciduous, narrow, 5-20 mm long, involucel bractlets similar to involucre bracts, rays 15-30, 5-10 cm long. Petals obovate, white.
Fruits: Fruit 8-12 mm long, obovate to heart-shaped, narrowed toward base, flat, winged, glabrous or hairy.

Source: Klinkenberg, 2020c

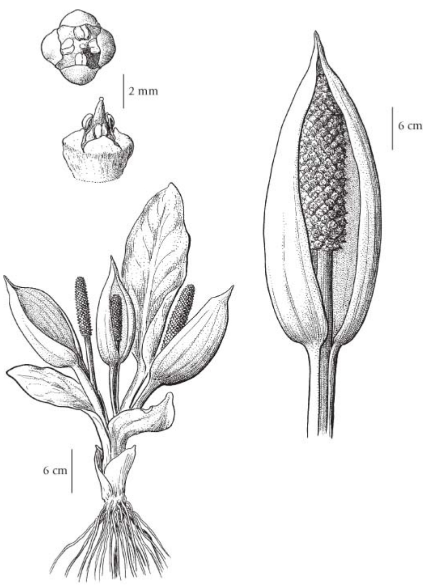

Figure 17. Skunk Cabbage leaves, flowers, and fruit; Douglas et. al., 1999a.

***Lysichiton americanus* (Skunk Cabbage)**
Araceae (Arum Family)
General: Perennial semi-aquatic or terrestrial herb from a short, thick rhizome and fibrous roots; stems several, 30-70 cm tall.
Leaves: All basal, blades egg-shaped to broadly lanceolate, entire, 30-150 cm long, 10-70 cm wide, short-stalked.
Flowers: Inflorescence of numerous, densely packed, perfect flowers in a cylindric spike 7-12 cm long, the spike on a 30- to 50-cm long stalk and subtended by a yellowish bract similar to the leaves in shape but much smaller; perianth 4-lobed; ovaries 2-celled.
Fruits: Berry-like, broadly egg-shaped, greenish to reddish, 6 mm long; seeds 1 or 2.

Source: Klinkenberg, 2020d

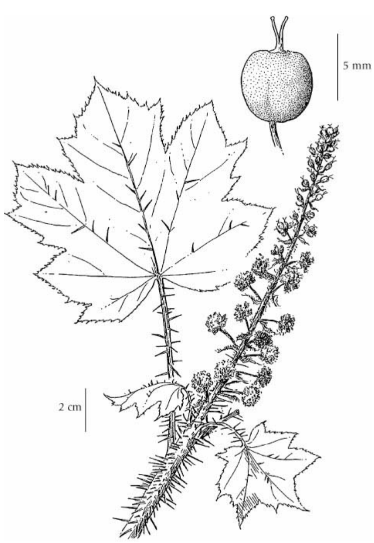

Figure 18. Devil's Club leaves flowers and fruit; Douglas et. al., 1999b.

***Oplopanax horridus* (Devil's Club)**
Araliaceae (Ginseng Family)
General: Tall, deciduous shrub; stems 1-3 m tall, punky, thick, strongly armed with yellow spines 5-10 mm long.
Leaves: Palmately lobed, the leaf blades shallowly 7- to 9-lobed, 10-35 cm wide, heart-shaped at the base.
Flowers: Inflorescence of small, headlike umbels in elongate panicles or racemes, up to 25 cm long; flowers greenish-white, short-stalked.
Fruits: Bright red berries, 2-3 seeded, 5-8 mm wide.

Source: Klinkenberg, 2020e

Movement Indicators

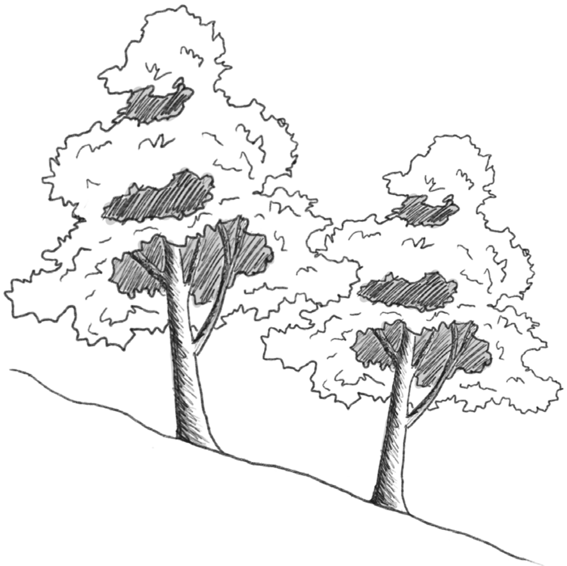

Figure 19. Trees leaning in different directions due to ground movement.

Leaning trees - trees tilted in different directions indicate active ground movement, repositioning the trees as the slope moves downslope.

Figure 20. Tree split from unequal ground movement.

Split trees - unequal movement on two sides of a tree can cause trees to split in the middle, indicating active ground movement.

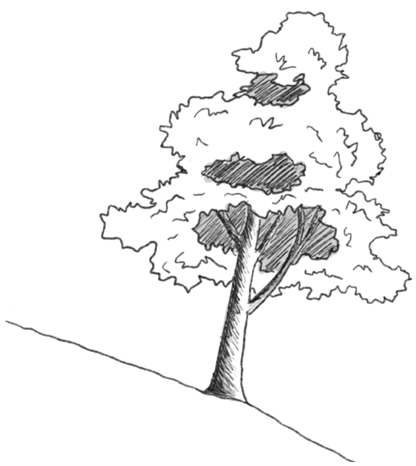

Figure 21. Tree pointed downslope from ground movement.

Trees tipped downslope - recent ground shifting can cause trees on steep slopes to point downslope and may indicate potential slope failure.

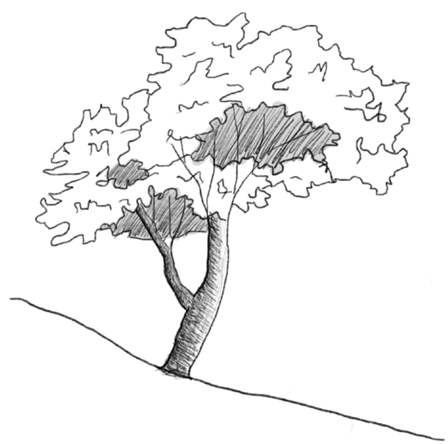

Figure 22. Tree with bent trunk due to soil creep over time.

Curved trees - presence of tree trunks bent downslope, recurving the trunk as soil moves downslope, may indicate soil creep. This, however, is an indicator in areas that do not receive heavy snowfall as snow creep can produce the same effect.

Evidence of Windthrown Trees

Trees that have been uprooted by wind on a slope may indicate poor drainage and/or shallow soils, a sign of potential slope failure. Windthrown areas can be identified using satellite imagery software, such as Google Earth, however images may not be up to date and, therefore, site observations are needed.

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