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Watershed Soils, Erosion, and Conservation

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Soil conditions, and the connections among soils throughout a watershed, play important roles in controlling how water moves into, over, and through the watershed. Water movement, in turn, affects both surface water and groundwater quality.

By understanding the relationships among soil properties, soil positions in the landscape, and watershed hydrology, you can make better decisions about watershed plans and activities. Because soils affect so many practical things–riparian plantings, stream bank protection, agricultural productivity, forest management, homesite development, fence building, road construction, erosion, and sedimentation–a general knowledge of soils is essential for implementation of a successful watershed enhancement program.

In this chapter you'll learn:

- What soils are and why they are important in watershed ecosystems
- Key soil properties that can influence watershed functions and management
- Key interpretations of soil behavior for watershed management
- Essential functions of soils in relation to watershed hydrology
- Erosion processes and erosion control techniques in forested, agricultural, and urban areas
- Watershed enhancement with respect to road drainage, stream crossings, new road construction, and unstable terrain

WHAT IS SOIL?

Of the many ways we can think about soils, perhaps the most important is that ***soils are essential natural resources.*** Soils, along with air, water, and sunlight, are necessary for both plant and animal life. All of these resources function together as a unit–an ecosystem or a watershed.

Unlike their resource partners, however, soils are under foot and out of sight. It's easy to forget the critical roles they play in watershed ecosystems. Soil is much more than "dirt"! Perhaps Russell Lord's (1962) definition best captures the essential nature of soil resources: "Soil, ever flowing in streams to the sea, is like a *placenta* that allows living things to feed upon the earth."

On a more practical level, soils can be defined as complex mixtures of weathered mineral grains (sand, silt, and clay), decomposed organic material (humus), living soil organisms (roots, bacteria, fungi, and insects), and varying amounts of air and water. This definition identifies essential soil components, but it doesn't explain how they interact to create a dynamic system that performs several vital watershed functions (Figure 1).

Figure 1.—Soil is made up of mineral components, decomposed organic material, living soil organisms, air, and water. (Source: Natural Resources Conservation Service)

See Section II, Chapters 1, 2, and 5, and Section III, Chapters 1, 3, and 4 for information related to this chapter.

Section II

1 Planning

2 Hydrology

5 Assessment

Section III

1 Riparian Functions

3 Livestock

4 Steam Ecology

SOIL FORMATION AND VARIABILITY

Soils form through the actions of *climate* (rainfall and temperature) and *organisms* (vegetation, animals, and insects) operating through *time* on a *parent material* (e.g., basalt, gravelly deposits, or volcanic ash) located in a specific *landscape position* (e.g., hilltop, valley sideslope, stream terrace, or floodplain). We call the italicized terms the five factors of soil formation; each unique combination of these factors results in a unique kind of soil.

Because there are many, many subdivisions of each factor, it's easy to see how there can be hundreds of thousands of kinds of soils worldwide. Even within a single watershed, there can be many kinds of soils, each with different implications for watershed use and management.

Here's an important take-home lesson: **Just because a management practice works well in one part of a watershed does not necessarily mean it will work equally well in another part of the same watershed.** Soil and other resources must be evaluated within each part of the watershed where management practices are planned.

Variability is a normal, natural feature of soils. You must accept variability and learn to live with it. **Resist the temptation** to throw up your hands and say the soil is so variable you might as well ignore the differences and assume it is the same throughout the watershed!

The best way to deal with variability is to define management units that minimize it. Trained observers identify parts of the landscape where the five factors of soil formation are reasonably uniform (Figure 2). Gently sloping ridgetops, steep hillslopes, undulating slump benches, and concave footslopes are examples. Within these landforms, soils, though not exactly the same everywhere, are reasonably homogeneous. Thus, they can be managed with the expectation that their behavior and response to treatment will be fairly uniform.

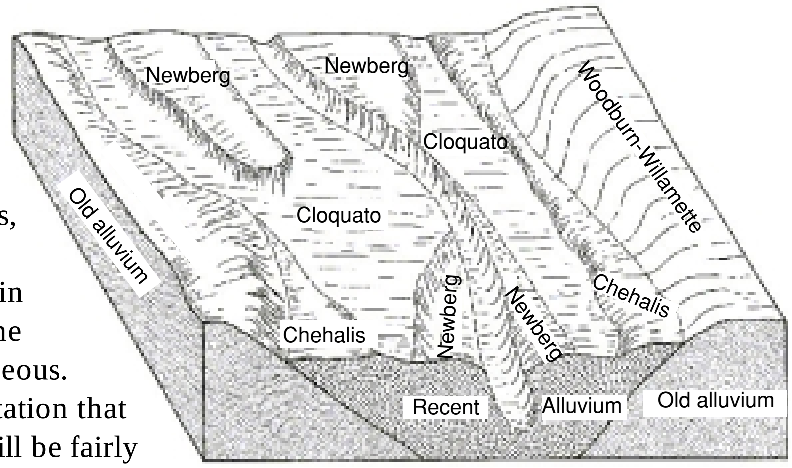

Figure 2.–Spatial relationships among soils, parent materials, and landscape position for a riparian portion of a watershed in western Oregon.

THE SOIL SURVEY

Dividing the landscape into units based on soil-landform elements enables us to make a *soil survey* (for example, of a watershed or county). Each part of the landscape with reasonably homogeneous soils is called a *body of soil* (analogous to a single plant or animal). Its representation on a soil map is called a *delineation*. A *map unit* is the collection of all delineations of the same kind of soil in a watershed or survey area. Each map unit is defined in terms of its dominant kind or kinds of soil. These relationships are illustrated in Figure 3.

Even within a map unit, there is some natural variability. Variations from the dominant soil are called *inclusions*. These are small areas of very different soils that might behave quite differently than the dominant soil. Due to their small size, they cannot be shown separately on a map. Inclusions are discussed in map unit descriptions, thus indicating what kinds of variability might be expected. Inclusions might be particularly important for site-specific uses such as homesites or on-site waste disposal facilities.

Soil surveys have three parts:

- *Maps* show the location of each piece of the soil–landscape mosaic.
- *Text* describes the different kinds of soils and highlights some of their key properties and behaviors.
- *Tables* provide a wealth of interpretations for a wide variety of urban, agricultural, and forestry uses.

To be most useful, all three parts must be used together. Specific examples of each are used throughout this chapter.

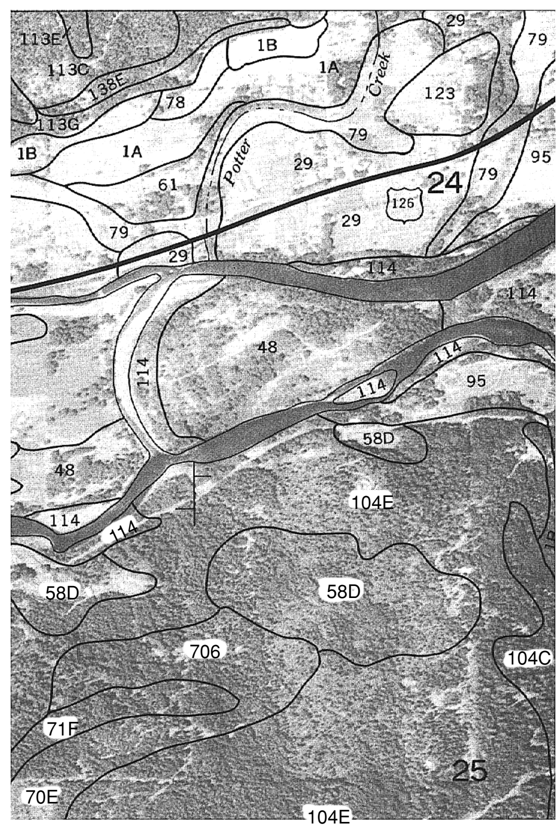

Figure 3.–Sample soil survey of representative watershed landscapes. Map units 58D and 104E are steeply sloping forest soils. Map units 48 and 114 are frequently flooded riparian soils along the McKenzie River. Map units 1A, 1B, 29, 61, 78, and 79 are productive agricultural soils on low river terraces.

KEY SOIL PROPERTIES AFFECTING WATERSHED MANAGEMENT

Soil resources are characterized by many chemical, physical, and biological properties. These properties can be observed in the field or measured in a lab. Here we'll discuss a few that are most directly related to watershed management.

Texture and structure

Soil *texture* refers to the amounts of sand, silt, and clay in a soil sample. A *loam* is a mixture of sand, silt, and clay. A typical loam might contain 40 percent sand, 40 percent silt, and 20 percent clay. An equal mixture of sand, silt, and clay is a *clay loam* because of the strong influence clay has on soil properties. Soils containing more than 50 percent sand are *sandy loams*, or, when the soil consists almost entirely of sand, *loamy sands* or *sands*. Soils with very little sand, a lot of silt, and small amounts of clay are *silt loams*. A similar soil with a little more clay is a *silty clay loam*. Soils with more than 40 percent clay are either *silty clays* or *clays*.

Soil texture is important because it is closely related to many aspects of soil behavior that are important for watershed management. Water moves into and through sandy soils faster than through loamy and clayey soils. Loamy soils, however, can store and release more water for plants than either sandy or clayey soils.

Sandy soils provide better foundations for roads and houses than loamy or clayey soils. Wet, clayey soils can be quite sticky and moldable and are very difficult to excavate or garden in. On the other hand, they might release water to streams over long periods of time, including during the dry season. Some clays expand a lot when wet and contract when dry, creating very unstable conditions for any kind of structure.

Soil *structure* refers to the aggregation of individual grains of sand, silt, and clay into larger units called *peds*. Peds form with the help of binding agents such as plant roots, sugary substances secreted by plants and animals in the soil, and the stickiness of clay particles. Peds are separated from each other by cracks or spaces, which create areas of weakness in the soil, allowing plant roots to penetrate and gardeners to dig in the soil.

The structural framework created by peds and the zones of weakness between them is important because it complements the effects of soil texture, especially in controlling the movement and storage of air and water in soils. Water moves rapidly through the relatively large spaces between peds. These spaces also provide oxygen to plant roots. Conversely, the much smaller spaces between grains within peds retain water much longer and make it available to plants as needed. Soils with a well-developed, stable structure provide a favorable combination of aeration and water storage.

Organic matter

Soil *organic matter*, or humus, is composed of decomposing plant and animal tissues, the microorganisms that feed on and decompose these tissues, and the secretions produced by the microorganisms. Organic matter, especially in surface soils, is extremely important because it provides food for soil bacteria, fungi, and other decomposers. These organisms, in turn, are responsible for the release and recycling of essential plant nutrients, particularly nitrogen, phosphorus, and sulfur. Sticky organic substances also play a large role in the formation and stabilization of soil structure, which, as we have seen, promotes water retention, aeration, and workability of the soil.

Healthy soils have plenty of organic matter. Impoverished soils often have lost some or all of the organic-rich topsoil and cannot support diverse microbial populations. Thus, a fundamental principle of watershed management is to **do everything possible to maintain or increase the organic matter content of the surface soil.**

When excavating, especially in urban watersheds, try to set the rich topsoil aside and return it to the surface when finished. Adding several inches of compost in areas to be used for lawns or landscaping is helpful. You can increase the organic matter content of lawn and garden soils by incorporating compost, manure, bark chips, leaves, or grass clippings. In gardens, growing winter cover crops will increase soil organic matter.

In agricultural fields, return as much crop residue as possible to the soil. Additions of manure and municipal biosolids also help. In forested watersheds, minimize disturbance of the natural forest floor, and try not to scrape away any of the organic-rich topsoil.

Porosity, density, and compaction

Porosity is simply the total amount of pore space, or void space, in the soil. As important as total pore space, however, is the mix of pore sizes. Large pores are needed for water and air movement, while small pores store water for plant use. Similarly, large pores might deliver water relatively quickly to streams, while small pores drain slowly and can be important for dry-season flows.

Soil *density* is the dry weight of soil per unit volume of soil, including all of the pore space. Soil *compaction* is the compression of soil particles into a smaller volume, which increases density.

Do everything possible to maintain or increase the organic matter content of the surface soil.

Density and porosity are clearly related, as an increase in one causes a decrease in the other. A typical cultivated agricultural soil might have a total porosity of 50 percent and a density of 1.3 grams per cubic centimeter (gm/cc). Near the surface, many undisturbed forest soils have porosities as high as 70 percent and densities of about 0.7 gm/cc. Dense or highly compacted soils, on the other hand, might have porosities as low as 30 or 35 percent and densities of 1.8 gm/cc. Intentional compaction of soils for earth dams and runway subgrades can yield densities of almost 2.0 gm/cc.

Undisturbed soil often is soft, highly porous, and allows water to penetrate easily. Traffic by animals, people, or farm or logging vehicles easily compacts it. Compaction degrades soil structure, reduces the volume of pores (especially the large, water-conducting pores), increases density, and impedes root growth. If these changes occur over large areas, surface runoff and erosion might increase and stream flow patterns might be less favorable (e.g., larger peak flows and smaller low flows). Areas of potential concern include slopes with many heavily compacted logging skid trails, heavily grazed pastures, livestock feedlots, urban construction sites, and intensively cropped fields. Contrary to popular belief, wet soils are not necessarily more prone to compaction than drier soils, but rutting and other problems are more likely with traffic on wet soils.

You can evaluate soil porosity and compaction both visually and with specialized equipment. During periods of heavy rain or snowmelt, you can recognize low soil porosity by the presence of ponded water or surface runoff. Some clayey soils have naturally slow drainage, so take care to distinguish this natural condition from slow drainage caused by human activities.

Poorly growing vegetation is another indicator of compaction and low porosity. Compacted soil is difficult for plant roots to penetrate, and the tiny pores often cannot provide roots with enough oxygen. Under these conditions, most plants don’t grow well.

One way to measure porosity and compaction is with a *ring infiltrometer*. After partially inserting an open ring into the surface soil, an observer adds a measured amount of water and notes how long it takes the water to enter the soil. This technique is especially useful for demonstrating the difference between undisturbed soil and heavily compacted soil.

Other evaluation methods use *soil cores* and *penetrometers*. Soil cores allow you to remove a sample of known volume, from which you can calculate the bulk density. Penetrometers measure the resistance of the soil to probing, which typically increases when soil is compacted. A spade or narrow metal rod can serve as a simple penetrometer. Specialized devices provide quantitative measurements. For example, some probes give values in pounds per square inch.

When assessing changes in soil porosity and compaction, it can be challenging to identify relatively undisturbed soils as a baseline for comparison. This is especially true in agricultural and urban areas, but even forested areas might have old, compacted trails that are difficult to see.

It's also a challenge to take enough samples to assess soil conditions accurately, especially if you want to determine whether soil changes are affecting watershed hydrology. To make such an assessment, you first need an accurate estimate of natural soil variability, i.e., the location of soil variations throughout the watershed. With this base knowledge, you can monitor changes in the soil over time.

Many watershed management objectives require a good understanding of the interactions between water and soil.

Depth to bedrock

The soil survey report presents depth-to-bedrock information for the dominant soil in each map unit. Depth to bedrock is directly related to the volume of soil available for plant roots, the amount of water that can be stored for plants and dry-season stream flow, the potential for water to move laterally through the soil above bedrock, and the potential for excavation and use of the bedrock as construction materials (e.g., gravel for roads). The shallow soils found in mountainous terrain often contribute to "flashy" streams that rise quickly after rain or snowmelt.

KEY SOIL INTERPRETATIONS FOR WATERSHED MANAGEMENT

Many watershed management objectives require a good understanding of the interactions between water and soil, i.e., the way water runs into, through, and over the soil. Although it's possible to carefully measure the rates of these processes, it usually isn't practical to do so. It is possible, however, to make good estimates based on knowledge of the soil's texture, structure, organic matter, density, and horizons (soil layers).

These estimates are called *soil survey interpretations*, and they can be found in published soil surveys. Specifically, the soil survey tables on Physical and Chemical Properties and on Soil and Water Features contain a lot of information that is directly relevant to the understanding and management of watershed soils. Table 1 (page 8) shows the kinds of information found in those tables, and the following sections of this chapter describe the interpretations.

Table 1.–Sample soil survey information on hydrological features of watershed soils.

Soil	Permeability Surface (in/hr)	Permeability Subsoil (in/hr)	Depth to bedrock (in)	Water table (ft)	Hydrologic group	K factor
Dominantly agricultural soils						
Clawson	2–6	2–6	>60	2.0	C	0.28
Holland	0.6–2.0	0.2–0.6	40–60	>6	B	0.37
Dominantly forested soils						
Jayar	0.6–2.0	0.6–2.0	20–40	>6	C	0.17
Pearsoll	0.2–0.6	0.06–0.2	10–20	>6	D	0.20

Infiltration and permeability

Infiltration refers to the rate of water entry into the soil. *Permeability* refers to the rate of water drainage through the network of soil pores. Infiltration and permeability are not the same, as infiltration refers only to the process by which rainwater, snowmelt, or irrigation water at the ground surface enters the soil. Once in the soil, water moves in response to the processes that control permeability.

Infiltration is a very complex process that is affected by many factors (Table 2). One is time. You might observe that water readily enters dry soil, but as the soil gets wetter, the rate of entry slows down. In other cases, water might run off a very dry soil until the soil becomes moistened.

Many other factors affect infiltration, including the kind and amount of vegetative cover, the amount of soil organic matter, and the strength and stability of soil structure. Compaction, which reduces porosity, can slow infiltration substantially. Hot forest or range fires can create vapors of organic compounds that condense in the soil, making it water-resistant and decreasing infiltration.

Because infiltration is such a complex and dynamic process, it's difficult to define a characteristic infiltration rate for a given soil, and you won't find infiltration data in a soil survey report. Sometimes we use the permeability of the surface soil as an indicator of potential infiltration, but this is not a true infiltration rate.

More often, we evaluate infiltration in relative terms, based on key properties of the surface soil. Then we compare relative infiltration potentials among several soils in a watershed. For example, the litter layer and surface soil in an undisturbed Coast Range forest soil is so porous that virtually all rainfall infiltrates, even on steep slopes after prolonged storm events. Once in the soil, the water might build up pressure and cause a landslide, or it might move through the soil to lower positions in the landscape.

Permeability rates range from very slow (<0.06 in/hr) in tight, clayey soils to very rapid (>2.0 in/hr) in coarse, gravelly soils. Medium-textured soils (loams and silt loams) usually have moderately slow (0.2–0.6 in/hr) to moderate (0.6–2.0 in/hr) permeability. For a given texture, a high organic matter content and high porosity increase permeability. If soil with the same texture has very little organic matter or is more dense, permeability can be much slower.

Table 2.—Factors that influence infiltration rates.

Ground surface characteristics	Soil properties
Texture	Vegetation cover
Structure	Amount of duff and litter
Organic matter	Amount of impervious surface
Porosity	Surface roughness
Depth	Surface cracking
Layering	Surface crusting and sealing
Shrink-swell	
Physical conditions	**Water repellancy**
Antecedent water*	Natural plant chemicals
Frozen soil	Fire-induced hydrophobicity
Trapped air	Extreme dryness

**The amount of water in the soil at the onset of a rainfall or irrigation event.*

Permeability information is given in a soil survey for each of three or four major layers in the soil. If the texture changes little with depth, permeability is similar in all layers.

Many soils, however, have subsoils whose texture or density differs dramatically from that of the surface layer. Heavy, clay layers, layers of weathered bedrock, and naturally dense layers all have much slower permeability than the layers above them. These restrictions cause water to *perch* above them, and the water is diverted laterally to flow parallel to and above the restricting layer. We refer to this type of flow as *throughflow*.

Water moving laterally through the landscape might break out at the surface, forming seeps or springs elsewhere in the watershed, or it might discharge directly into a stream, wetland, or lake. In any case, throughflow is a major hydrological process in many landscapes.

Leaching

Leaching is the process by which water moving through the soil carries with it soluble materials picked up en route. In humid regions, leaching removes soluble salts, gypsum, and carbonates and eventually acidifies the soil. Leaching can carry nitrates and other soluble fertilizer materials below the root zone. Leaching also can transport soluble residues from some chemical pesticides.

Leaching can result in contamination of groundwater if unwanted materials move with water downward through the soil. Lateral leaching also occurs as water moves through the landscape roughly parallel to the land surface. Throughflow discharge into streams and lakes, as well as discharge of leaching water from drainage lines in the soil, can add contaminants to surface water bodies.

Runoff and hydrologic group

Runoff is simply overland flow that occurs when inputs from rainfall or irrigation exceed the infiltration capacity of the soil. The goal of watershed management is to conduct runoff water downslope in ways that minimize its potential to cause erosion on hillslopes and sedimentation in streams and lakes. Techniques for achieving this goal are discussed in the sections on erosion control and road construction and maintenance.

Hydrologic group is a soil survey interpretation that groups soils with similar runoff potential given similar storm and groundcover conditions. Soil properties that influence runoff potential include texture, structure, depth to a seasonally high water table, permeability after prolonged wetting, and depth to a very slowly permeable layer.

In soil surveys, there are four basic hydrologic groups–A, B, C, and D:

- Group A soils have low runoff potential. They have both high infiltration rates and high permeability rates and consist mainly of deep sands or gravels.
- Group B soils have moderately low runoff potential and moderate rates of infiltration and permeability. They consist mainly of silt loams, silty clay loams, loams, clay loams, and sandy loams that are more than 20 inches deep.
- Group C soils have moderately high runoff potential. Slow rates of infiltration and permeability are caused either by clayey textures or by a slowly permeable subsoil layer.
- Group D soils have high runoff potential because of very slow rates of infiltration and permeability. Because they drain so slowly, they remain wet for long periods and cannot absorb much additional water. High shrink-swell clays, soils with a permanent high water table, those with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material are in this group.

Erodibility

Erodibility reflects a soil's susceptibility to the erosive force of water running over bare soil. Texture, structure, and organic matter content are the primary properties that influence erodibility of exposed soils. Sandy soils with adequate amounts of organic matter and well-developed structure are the least erodible. Silty soils with low amounts of organic matter and very weak structure in the surface soil are most erodible.

Erodibility is characterized by the K factor in the Universal Soil Loss Equation (A = RKLSCP). K is simply a number that has been derived from numerous experiments in which simulated rainfall is applied to a wide variety of soils. Values of K range from 0.02 to 0.67, with higher numbers indicating higher erodibility. K values are provided in soil survey reports and are particularly useful for comparing the relative erodibility of two or more soils. (For example, see Table 1.)

Soil functions help us think about what soils do for us in the watershed.

Depth to water table

Water tables can be measured, but because of high seasonal and annual variability, only long-term records provide useful information. Because long-term data are scarce, water table information in soil surveys is based largely on an interpretation of color patterns in the soil.

Well-aerated soils have brown colors because iron oxides coat soil grains, much as rust coats a piece of iron. In saturated soils, some of the iron is removed in solution, leaving gray, uncoated soil grains. As the soil dries out and air reenters the larger pores, iron might again oxidize, creating a bright yellowish-brown spot.

These patterns of gray and yellowish-brown colors are interpreted by soil scientists as indicators of the long-term average position of the seasonally high water table. These estimated depths are the numbers reported in soil survey reports.

Presence of a high water table might affect buildings, septic systems, crops, pastures, plant species, riparian plantings, and use of mechanized equipment.

KEY FUNCTIONS OF WATERSHED SOILS

Soil functions help us think about what soils do for us in the watershed, or, more properly, their roles in making the watershed operate as an integrated unit. Thinking about soil functions, and their interaction with other watershed resources, helps us evaluate how specific management practices might affect not just soils but all other aspects of watershed behavior that are linked to soils.

Regulate watershed hydrology

This probably is the soil function most influenced by human activities. Simply put, **soils regulate the balance between infiltration and runoff**. Rainfall, snowmelt, or irrigation water that reaches the ground surface can do only one of two things: it either soaks in, or it runs off. If it soaks in, it continues to move within the soil–landscape system according to the principles of permeability. Lateral throughflow, downslope discharge, leaching to groundwater, and buildup of pore water pressures all become possibilities. If it runs off, its velocity and erosion potential are determined by the steepness of slope, the length of the slope, and the barriers to flow created by vegetation or topography.

The important lesson here is that **any land-use activity probably will change the balance between infiltration and runoff**. Many practices or activities shift the balance toward less infiltration and more runoff. For example:

- Soil compaction with heavy equipment (or countless pairs of feet on hiking trails) reduces porosity and infiltration, thus increasing density and runoff.
- Covering soil with asphalt and buildings causes a dramatic shift toward runoff.
- Removal of organic-rich topsoil reduces infiltration and exposes subsoil. This change not only increases runoff but also increases erosion potential, as the subsoil is likely to be more erodible (higher K value) than the original surface soil.
- Loss of soil organic matter through burning or cultivation destabilizes soil structure and decreases infiltration.

Sometimes, however, we intentionally shift the balance toward more infiltration, as when we add compost to garden soils or use deep tillage to break up compacted layers or natural hardpans.

Any watershed project must assess the relative advantages and disadvantages of infiltration versus runoff. There always are trade-offs. If erosion control is the objective, you might strive to increase infiltration. However, increased infiltration might increase the risk of groundwater contamination or landslides. If groundwater protection is the objective, you might wish to minimize infiltration and leaching. The tradeoff is higher potential for runoff, erosion, and lateral leaching to surface water bodies. The key is to find a balance and to use soil regulation of watershed hydrology to achieve your desired goals.

Regulate nutrient cycling

Soils are vast reservoirs of plant nutrients. The organic part of the soil in particular is a major source of nitrogen, phosphorus, and sulfur. Biological decomposition of organic matter makes these nutrients available to plants. Other major nutrients, such as calcium, magnesium, and potassium, also reside in large pools in the soil and are constantly cycling between vegetation and soil.

Regulate water quality

Soils improve water quality by filtering out contaminants (nonpoint source pollution) before they are carried to groundwater or streams. Soils are naturally leaky, however, so some pesticides and fertilizer nitrates might be leached all the way to groundwater. Surface water might be contaminated by sediment carried in runoff water or by phosphorus or pesticide residues attached to eroded soil particles.

Provide habitat for living organisms

Soil is home not only to plant roots and burrowing animals but also to billions of bacteria, fungi, algae, protozoa, mites, insects, nematodes, collembola, and earthworms. Soils provide all of these organisms with air, water, nutrients, and space to live. They in turn facilitate structure formation, infiltration, permeability, nutrient cycling, and water purification—the processes that allow the entire watershed ecosystem to function as a whole.

PROCESSES OF SOIL EROSION

We've seen how important soils are in regulating watershed hydrology and that many common watershed practices can tilt the balance toward runoff and erosion. Because erosion and sedimentation affect both soil and water quality, we'll now examine in more detail key erosion processes and some methods for dealing with them.

Erosion is an important watershed process. It is responsible for shaping landscapes of great scenic beauty; for the creation of rich alluvial soils; and for depositing large wood, spawning gravel, and fine sediment that help salmon determine when and where to spawn. Erosion is a natural, ongoing process, but erosion types and rates vary widely with climate, soils, terrain, and vegetation (Figure 4, page 14). Erosion often increases during periods of unusually high rainfall or rapid snowmelt.

Our concern with soil erosion is not so much with the natural process as with accelerated erosion due to human activities—

Erosion is essentially a three-stage process: detachment, transport, and deposition.

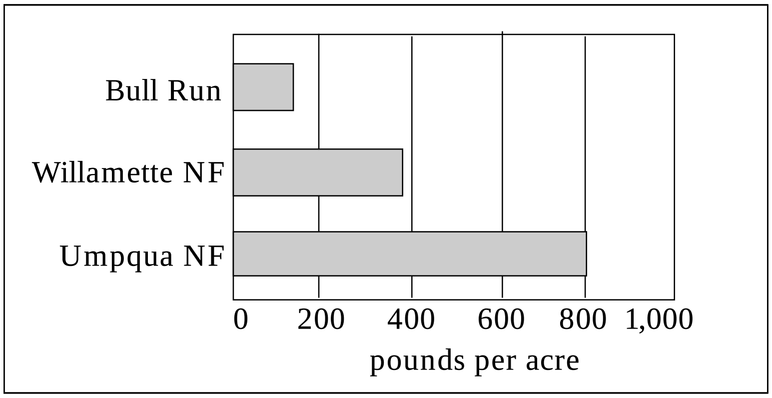

Figure 4.–Average annual erosion, undisturbed forests.

cultivation, logging, grazing, urban construction, and road building. These activities add a more or less constant pulse of erosion above what we would call "natural," or background, erosion.

In the continental U.S., an estimated 1 billion tons of sediment is delivered to streams and lakes each year.

In Oregon, there are three major agents of erosion: wind, water, and gravity. Glacial ice also erodes soils and landscapes, but it operates as a natural geologic process and has little impact on Oregon watersheds.

Erosion is essentially a three-stage process: detachment, transport, and deposition. Detachment requires energy to physically separate a particle of soil from the ped or soil mass of which it is a part. Detachment forces are resisted by forces that create soil strength and hold the soil together. That's why the first line of defense against accelerated erosion is to use vegetation, soil organic matter, and soil structure to minimize the potential for detachment.

Once a particle is detached, it is suspended in runoff water and carried downslope. Or, in the case of wind erosion, it is suspended in air and carried downwind.

In either case, deposition occurs when the velocity of flow decreases to the point that suspended particles settle out. For water erosion, deposition often occurs at the base of a slope, where the gradient decreases. Note that a significant portion of the eroded material is deposited before it reaches a stream or river. This deposition still can cause damage, however, for example by burying a neighbor's crops. Furthermore, these sediments might enter the stream later if a major flood causes the stream to erode its banks and cut into the area of prior deposition.

Wind erosion occurs mainly in eastern Oregon, where strong, steady winds blow over dry, sparsely vegetated soils that are low in organic matter and have weak structure. The force of the wind detaches fine sand, silt, and clay particles and transports them, sometimes for great distances. In addition to loss of topsoil, wind erosion can cause other problems. The abrasive action of soil particles can cause serious crop damage, and reduced visibility can lead to traffic accidents.

Water erosion

Water erosion begins when rainfall exceeds infiltration, a thin layer of saturated soil forms at the surface, and overland flow begins.

Runoff itself sometimes has limited energy to detach soil particles, but the impact of raindrops on this thin film of saturated soil splashes soil particles in the air, detaching them from soil peds. Some of these particles simply slake off and settle in adjacent pores, leading to surface sealing, reduced infiltration, and increased runoff. Some are carried along by runoff water and act as abrasive tools to detach additional soil particles.

As runoff water begins to concentrate in microchannels, the cutting action creates a series of channels, or rills, a few centimeters deep. Rill erosion often is evident on recently cultivated, sloping soils following heavy rainfall. Continued flow and cutting might enlarge rills to the point that they cannot by crossed with field equipment. Such channels are called gullies. As gullies get larger and deeper, vast amounts of soil can be removed, and local water tables might be lowered.

Water erosion is particularly severe on cultivated soils in eastern Oregon where the soil freezes. Rain falling on thawing soil quickly forms a layer of saturated soil lying directly on frozen soil. This layer of saturated soil has very little strength, and runoff easily forms a network of deep rills that transport large amounts of soil off the field. This soil is deposited at the base of slopes and in road ditches at field edges.

In agricultural watersheds of western Oregon, soils in the midslope position often are more prone to erosion than those near hilltops. These midslope soils have slowly permeable layers at relatively shallow depths. Water that infiltrated higher on the slope flows laterally through these layers, causing midslope seeps to develop when water pressure builds up in the soil downslope. These seeps saturate the soil, weaken it, and provide a starting point for rill erosion.

Mass wasting

Gravity manifests itself in two ways: dry ravel and pore water pressure. With *dry ravel*, both individual grains and small soil aggregates simply tumble down a slope in response to gravity until they reach a more stable position. This process occurs mainly on steep mountain slopes and might be accelerated where vegetation has been removed by logging, road construction, or fire. Granitic soils on steep slopes are particularly prone to dry ravel.

Pore water pressure refers to the pressure exerted on the soil mass by the weight of water filling the soil pores. Pore water pressure is a major factor triggering landslides and other forms of mass movements, which are common in steep, unstable terrain in the Coast Range and Cascade Mountains. In these soils, infiltration

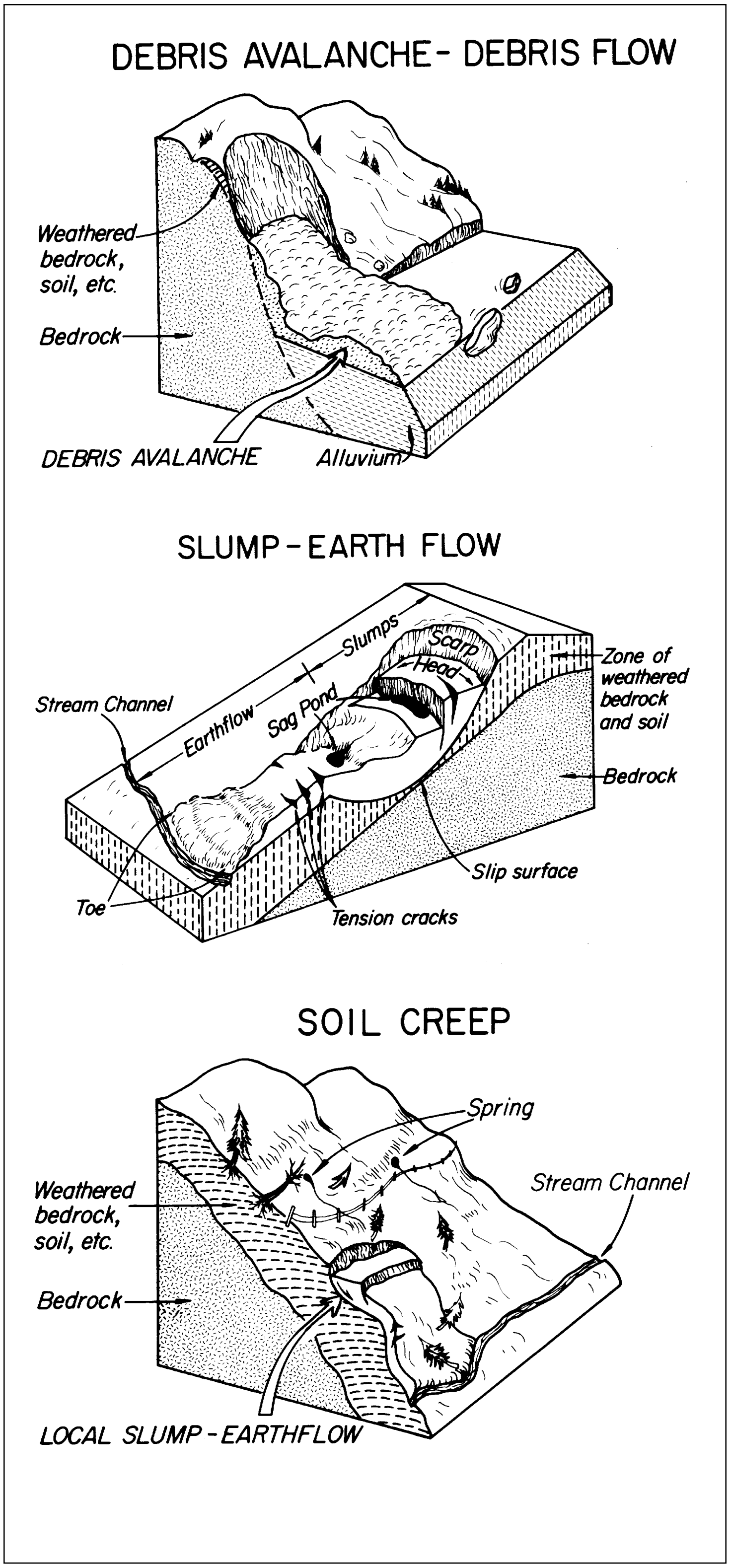

Figure 5.—Types of mass movement.

rates tend to be very high, so most rainfall enters the soil, contributing to a buildup of pore water pressure. Usually, the soil has enough strength to counteract this pressure. During episodes of prolonged, heavy rainfall, however, sustained, very high pore water pressures can exceed soil strength. In this case, the whole mass fails and slides downslope.

Mass movements can be rapid and dramatic or very slow and subtle (Figure 5). *Debris avalanches* or *slides* are shallow, rapid mass failures that are common in steep, upland areas with thin soils over bedrock. If debris avalanches or slides reach a stream channel, they might become fluid and change to a *debris flow*, or *debris torrent*. These flows can scour extensive lengths of stream channels, but they also deposit large quantities of sediment and other debris where they stop.

Slumps and *earth flows* are large, slow mass movements in areas of deep, fine-textured soils. Rotational slumps usually are storm-driven phenomena in which soil moves only a few feet. Slumps can plug road ditches, leading to further erosion and sedimentation from inadequately drained roads.

Earth flows are slow and gradual and might move only inches per year, but they might be an important, chronic source of sediment where they occur near stream and river channels.

UNSTABLE TERRAIN

Unstable terrain is land that is particularly susceptible to mass failures. Places where landslides occur can be important sources of stream sediment and woody debris, both natural and management related. Identifying these areas can help you understand current watershed conditions and prescribe management activities.

Keep in mind that different types of slope instability can present different concerns for watershed management. Slow-moving earthflows that are a chronic, natural source of stream sediment might be difficult or impossible to control. On the other hand, landslide potential might be reduced locally by avoiding road construction along a slope that shows evidence of past debris avalanches.

It's not possible to identify exactly where failures will occur, but broad areas of current and potential instability can be recognized. Some clues include:

- Very steep slopes (e.g., >65 percent)
- Slope depressions or other areas where water might concentrate
- Slopes with active seeps or springs (Indicators include localized water-loving plants and black or "mottled" soils.)
- Very uneven or hummocky slopes
- Very shallow soils over bedrock
- Deep, wet soils with high clay content
- Bulging stream banks with actively sloughing soil
- "Jackstrawed" trees (leaning in many directions)
- "Pistol-butt" trees (curved trunks at the base)
- Slopes with tension cracks or "cat steps" (soil slippage that forms small benches on the slope)
- Bedrock faults or rock beds parallel to the landscape surface

Most topographic maps and aerial surveys provide only a rough picture of actual ground conditions that contribute to instability. For example, a recent study by the Oregon Department of Forestry showed that standard topographic maps poorly identified the locations of steep slopes. Likewise, aerial photos failed to show many existing landslides, especially in forested areas.

STRATEGIES FOR EROSION CONTROL

Erosion is most likely to have a significant environmental impact on bare, exposed, or compacted areas. Important locations where such conditions might be found include road rights-of-way, construction or development sites, recreational areas, agricultural fields, grazed areas, or logged areas.

Preventing or controlling erosion and sedimentation from these critical areas is largely a matter of exercising common sense. The following sections discuss key concepts for doing so.

Consider extreme events

Extreme events are periods of very heavy precipitation or high stream flow that might trigger mass failures or major water erosion. The nature of extreme events and their implications for watershed management are discussed in more detail in Chapter II-2, “Watershed Hydrology.”

Promote infiltration and permeability

One method of restoring infiltration and permeability is deep tillage of heavily compacted areas. Another is to improve growing conditions for protective vegetation. Where topsoil has been lost or removed (e.g., in heavily eroded areas or on abandoned roads), you might need to add fertilizer, organic amendments, or nitrogen-fixing plants (legumes) to restore productivity.

Soil organic matter and soil structure improve soil porosity, decrease density, and promote infiltration. Organic matter tends to “fluff up” the soil, increasing the total pore space, and it stabilizes soil structure and increases the diversity of pore sizes. Good management of watershed soils often means preserving or adding organic matter and avoiding compaction so as to improve porosity.

Use physical barriers and sediment traps

You also can enhance infiltration by slowing down surface water so that it has time to soak into the soil. One method is to leave surface duff (plant litter), logging slash (tree debris), or crop residues on the soil surface. Adding mulch accomplishes the same thing. Another technique is to leave the soil surface as rough as possible. Farming across slopes, using minimum tillage, and constructing diversion terraces are other methods for slowing down water and trapping soil.

Use vegetation and buffer strips

Vegetation enhances infiltration. Plants and their litter shield the soil from raindrops, which can break down soil structure and clog large pores, resulting in surface runoff. Plants, roots, and plant litter also help slow runoff, hold soil in place, and promote soil porosity.

Watershed enhancement thus can include measures to improve vegetation cover and litter accumulation. Such improvements are especially important where plants are absent or sparse and increased runoff and erosion are evident. You might find these conditions around roadsides, ditches, construction areas, fields, or pastures.

The *Oregon Interagency Seeding Guide* and the OSU publication *Seeding to Control Erosion along Forest Roads* are two helpful references for enhancing vegetation. You might need to improve soil conditions through tillage, fertilization, or organic amendments to ensure that new plants thrive and cover the area well.

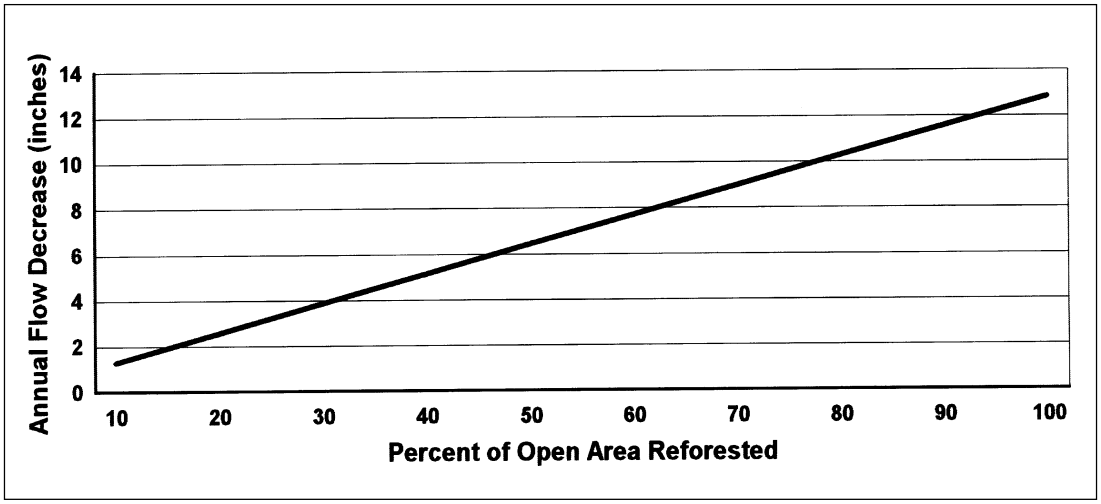

Figure 6.–Relationship of stream flow to increasing forest cover.

Keep in mind that tree planting or natural reforestation can significantly change a forest and have unintended effects on water resources. For example, where dense, vigorous alder stands grew after logging of riparian forests, reduced summer flows (probably from heavy water uptake) or water-quality effects (e.g., increased color and dissolved organic matter) sometimes have been noted.

Reforestation of agricultural fields or other open lands also might reduce local stream flows because forests use more water than do crops and other plants. Figure 6 shows how stream flows in other regions generally decreased as forest cover increased. While streamside plantings often are desirable to provide shade, which helps maintain cooler water temperatures, carefully consider the trade-off with potential stream flow reductions.

Control erosion in urban areas

Most erosion in urban areas is associated with runoff originating from construction sites or impervious surfaces such as roofs, streets, and parking lots. Controlling erosion from bare, exposed soil at construction sites is largely a matter of common sense: minimize the amount of soil exposed, keep water off disturbed or compacted soil, plan for catch basins and sediment traps in case runoff does occur, mulch, and revegetate as soon as possible. Many communities now require silt fences, sediment basins, and covering piles of excavated soil.

Runoff from impervious surfaces causes erosion when large volumes of water are concentrated into very small channels that discharge onto the ground surface or into natural stream channels.

Homeowners can help control erosion by making sure gutter downspouts don't discharge directly onto bare soil.

At the community level, runoff from houses, driveways, and streets usually enters the storm sewer system. The point of concern is where the sewer enters a natural drainage channel. Because storm events can generate very high discharge volumes, soil in the channel and along the banks is particularly susceptible to erosion. The first line of defense is to make sure stream banks are as fully vegetated as possible, both to anchor soil in place and to dissipate the energy of the stormwater flows. Riprap might be necessary to provide additional stabilization.

Runoff from most parking lots also enters the storm sewer system. Increasingly, however, some commercial establishments and public agencies are turning runoff from roofs and parking lots into an asset rather than a liability. They collect the water on-site and use it to create wetlands and other water features that are both aesthetically pleasing and beneficial to wildlife.

Control erosion in agricultural areas

Erosion control strategies on agricultural soils focus on promoting infiltration, slowing runoff, and reducing stream bank erosion. Continuous vegetative cover promotes infiltration, so it's always a good idea to use *permanent cover crops* on highly erodible soils wherever possible. Winter cover crops help protect soil during the rainy season if crops are not being grown.

Replacing traditional moldboard plowing with *minimum tillage* practices also reduces erosion potential. With these techniques, residues from previous crops are left in place. This practice reduces the exposure of bare soil and minimizes compaction from machine traffic.

Runoff gains speed as it flows over long slopes, and runoff velocities are higher on steep slopes. A major goal of erosion control is to slow down the water as it moves over the landscape.

Contour tillage (tilling across the slope instead of up and down) avoids creating pathways for water to flow downslope and produces a series of miniature check-dams to keep water velocities low and encourage infiltration. Similarly, leaving the surface as rough as possible and leaving crop residues on the soil both place physical barriers in the path of flowing water.

Constructed *bench terraces* shorten the length of slope over which water runs. Runoff collected behind these terraces is diverted across the slope to a *grassed waterway* in which water can move downslope without contacting bare soil.

Techniques for reducing stream bank erosion include stabilizing banks, establishing riparian buffers, and managing livestock access.

Bank stabilization can be accomplished with vegetation or, in some cases, with energy-absorbing structures such as tree branches or rock riprap. A *riparian buffer* is a zone of natural vegetation several feet wide on each side of the stream. Buffers are created by not cultivating, grazing, or logging all the way to the edge of the stream.

Where grazing animals have unrestricted access to stream channels, soils immediately adjacent to the stream often become denuded, compacted, and less resistant to erosion. By locating water troughs and salt licks in uplands, you can attract livestock away from wet soils, streams, and small drainages. A permit is needed to divert water from streams for such uses, but permit fees are kept low to encourage such improvements. See Chapter III-3, "Livestock and Forage Management," for more information about ways to minimize livestock damage to riparian areas.

Control erosion in forested areas

We've already touched on many of the principles of erosion control on forested soils. Because undisturbed forest soils have naturally high infiltration rates, the most important goal is to disturb as little of the natural forest floor as possible. Control equipment traffic to minimize compaction, and try not to scrape away any more of the natural topsoil than necessary.

A system of *designated skid trails* can control logging vehicle traffic and ground disturbance. This approach includes felling to lead (felling trees toward skid trails) and log winching to the trails. Similarly, develop and maintain designated trails for hikers, bikers, horses, and off-road vehicles to minimize compaction.

Where soils have been compacted, infiltration and productivity can be improved by breaking up the compacted soil with tillage equipment. The publication *An Evaluation of Four Implements Used to Till Compacted Forest Soils in the Pacific Northwest* provides helpful information about soil tillage options. Tillage results from different types of equipment are shown in Figure 7.

Forest managers often use slash treatment or scarification to increase reforestation success after logging. Slash treatment usually involves piling or burning, while scarification consists of mechanically disturbing the topsoil. Both techniques can enhance seedling

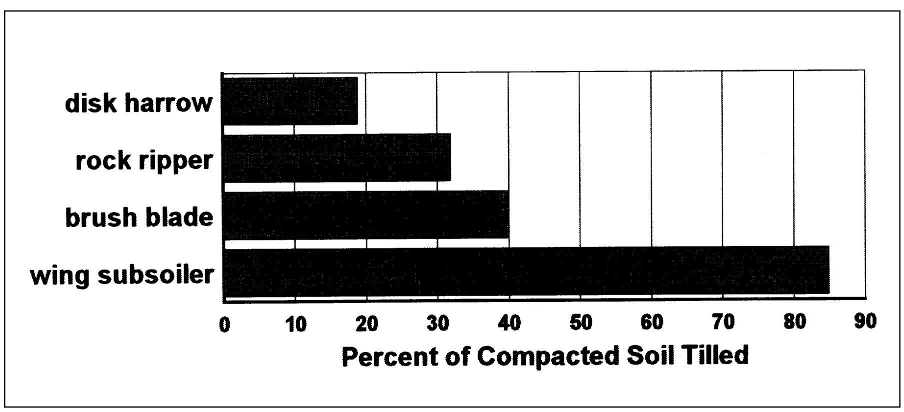

Figure 7.—Tillage results from four different types of equipment.

survival. Both, however, also expose more soil surface, which might increase the risk of runoff, especially on sloping terrain.

You can help reduce surface runoff by leaving some duff and by piling slash in windrows along slope contours. Try to manage slash to balance the needs of site preparation and watershed functions. If you do burn slash, schedule burns when weather conditions, slash, and other fuels are cool and moist enough to limit burn intensity.

Learn to recognize the signs of unstable terrain, and try to avoid actions in these areas that would increase the potential for future failures of devastating proportions. Do nothing that might increase the amount of *hydraulic loading* (the amount of water accumulating in the soil) in such areas, and avoid practices that cut into slopes and decrease their strength and resistance to mass movements.

It's often very difficult or costly to improve slope stability in very unstable terrain. Simply put, it's hard to hold back naturally weak soil on a very steep slope when it's soaked by an unusually large storm. However, some practices can at least help maintain existing soil strength, and a few can increase it somewhat.

One such practice is to direct road drainage away from unstable slopes. Another is to avoid broadcast burning or herbicide applications that remove duff and vegetation over large areas. Rock buttresses can be used along unstable road cutbanks, and tree planting on steep, grassy slopes might add some root strength. Experts familiar with slope stability problems and solutions can assess such opportunities.

Tree removal to reduce landsliding is a method that has not been validated by research. Tree weight is insignificant compared to the weight of wet soil, and tree roots provide some soil strength. Most studies in very unstable terrain have shown some increase in landslides in the first decade after clearcutting, but some locations and young forests have shown fewer landslides after such cutting.

The Oregon Department of Forestry recently was given greater control of forest operations in highly unstable terrain, and other efforts to deal with landslide hazards are underway. However, it's essential to recognize that, in very unstable terrain, a significant landslide risk will exist regardless of human activities.

CONTROLLING EROSION FROM ROADS

Unpaved roads often are a significant source of erosion and sedimentation in rural areas. This is true throughout a watershed, but especially in forested landscapes. The most important erosion control practice is to build and maintain roads properly.

Road use and maintenance

In most cases, landowners and managers rely heavily on existing roads. How these roads are used and maintained should be a major part of your watershed evaluation and enhancement efforts.

For example, sediment losses from unpaved roads can increase if traffic is heavy or if travel occurs during wet weather. Thus, in areas where sedimentation is a major concern, it might be wise to reduce or suspend traffic on unpaved roads during wet weather. Likewise, scheduling timber harvest and log hauling during the summer might reduce sedimentation from forest roads.

Both routine and emergency road maintenance can be critical to preventing or reducing erosion and sedimentation problems. Ensuring that the road drainage system functions well is a major focus of both types of maintenance. Figure 8 shows some important differences between a well-maintained and a poorly maintained forest road. It's best to do routine road maintenance before the rainy season and before roads are used heavily (for example, for log hauling or crop harvest). Key maintenance activities include:

- Road *grading* to smooth ruts and direct water off the road surface
- *Ditch and culvert cleaning* to efficiently move road drainage to stable areas
- Adding fresh *surface gravel* when earlier applications become worn by traffic

Emergency maintenance involves monitoring road conditions during large storms so that clogged ditches and culverts can be cleaned out promptly to prevent serious problems such as gullies, washouts, or landslides.

To help you determine what kind of road maintenance is

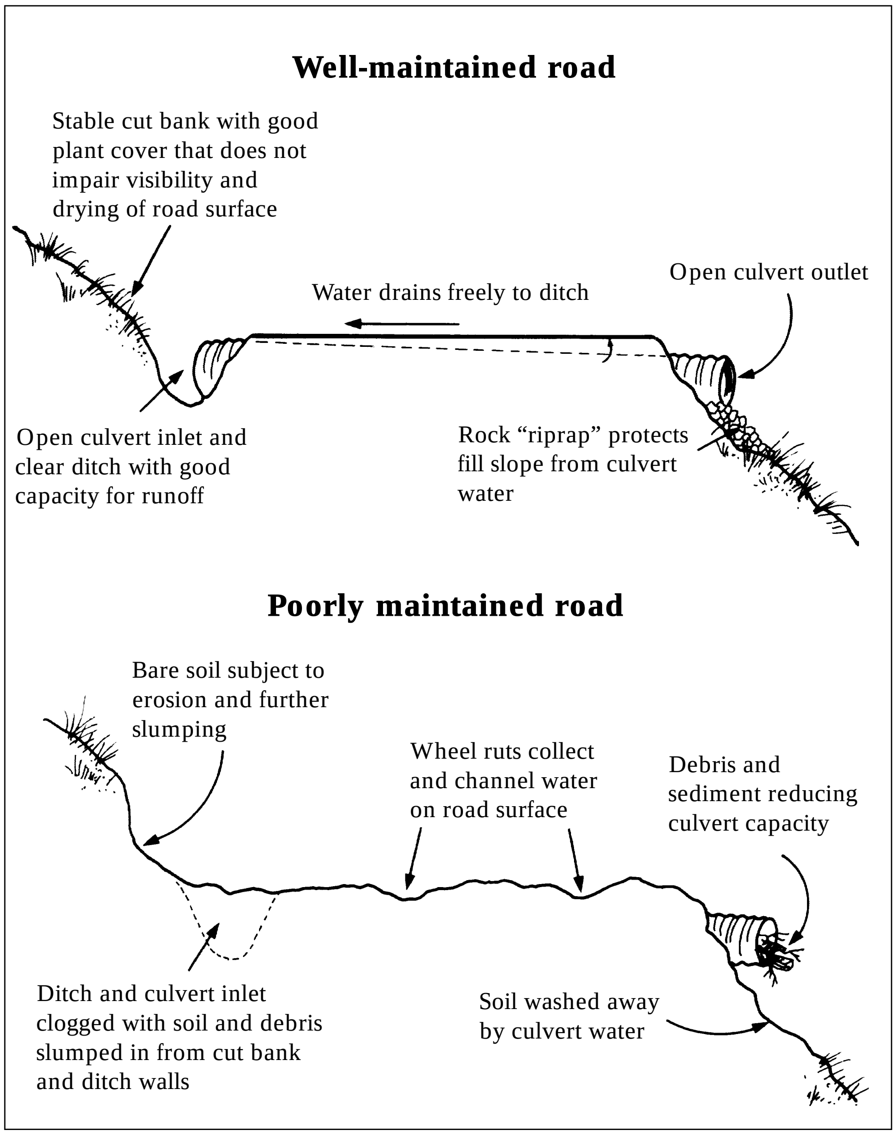

Figure 8.—Examples of some important differences between well-maintained and poorly maintained woodland roads.

needed in your watershed, see the “Checklist for Storm-proofing Rural Roads: Road Maintenance” (Appendix A).

Drainage design

Road improvements to prevent or reduce watershed problems usually focus on drainage systems. To move water off quickly to a ditch or roadside, road surfaces usually are designed with a crown (drains evenly to both sides), inslope (drains toward the inside road edge), or outslope (drains to the outside road edge). Generally, these slopes should be 2–3 percent greater than the travel grade; otherwise, water will move down the road surface rather than off to the side.

Simple maintenance grading is sufficient to provide surface drainage on many roads. In some cases, however, a road might need additional soil or rock to create an adequate slope.

The OSU Extension publication *Designing Woodland Roads* illustrates good road drainage design features. Another helpful tool for evaluating existing roads is the “Checklist for Storm-proofing Rural Roads: Road Drainage Design” (Appendix B). Be aware that road design can be quite complex, and you might need help from an engineer or other specialist.

Where roads are cut into a slope, ditches and cross-drains usually are needed to direct water to stable locations. If road ditches are eroding or forming gullies, they might need to be stabilized with armor rock or vegetation, or they might need additional cross-drains. Even with many cross-drains, however, heavy storm flows might cause erosion at either the inlet or outlet of the drain.

Three types of cross-drains commonly are used on simple rural roads–ditch-relief culverts, rolling dips, and water bars. Tables 3 and 4 summarize key features of these designs.

Ditch-relief culverts are the most common type of cross-drain. Where costs or maintenance requirements make them impractical, however, consider options such as rolling dips and water bars.

STREAM CROSSINGS

Stream crossings are a point of direct contact between streams and roads. Thus, erosion and other problems at these locations can quickly have a substantial impact on water quality and fish habitat. Many older crossings have a limited capacity to handle storm flows. Some of them continue to add sediment to streams when high flows erode fill material around culverts or bridge abutments. Another important concern with stream crossings is that some culverts are a barrier to migrating fish.

Table 3.–Cross drainage on rural roads.

Ditch-relief culverts–The 5 Ds	
Divert	Culvert inlet should provide direct and unhindered diversion of ditch water (i.e., water should not bypass inlet). Angle culvert at least 30 degrees downslope from the road for efficient flow into and through the pipe.
Debris	Keep inlets cleaned of debris and sediment (e.g., watch for cutbank slumps and ravel, ditch erosion, and sedimentation). Slope the culvert at least 3 percent and at least 2 percent greater than the ditch slope to help keep it self-cleaning of sediment and debris. Where debris and sediment are a chronic problem, consider control measures such as catch basins, drop inlets, and recessed cutslopes.
Discharge	Culvert installation should have sufficient capacity to handle flows from very large storms; minimum 12-inch pipe size recommended. Consider local conditions (e.g., storm intensities, slope position, cutbank seepage) that might add to flows.
Distance	Carefully space culverts to prevent ditch erosion and to avoid large discharge flows onto steep or unstable slopes. Closer spacing is needed with steeper road grades, erodible soils, locally intense storms, etc.
Dissipate	Use riprap, downspouts, etc. at culvert outlets to dissipate erosive energy of discharge water, especially on steep or unstable slopes.

Source: "Considerations in placement of cross drain culverts," by R.L. Beschta. Short course notes. Design and Maintenance of Forest Road Drainage (Oregon State University College of Forestry, Corvallis, 1991).

Table 4.–Other cross-drainage options.

Where costs or maintenance requirements make ditch-relief culverts difficult to use, consider such options as rolling dips and water bars.	
Rolling dips	Dips generally are suitable for road grades less than about 10 percent. Begin the dip cut a minimum of 50 feet upslope of the dip bottom, and extend it at least another 15 feet beyond the dip bottom. Cut the dip 1–2 feet into a firm roadbed, and angle it 45–60 degrees downslope from the road centerline. Increase the outslope cut of the dip uniformly from the upper inside start of the dip to the outlet. Use riprap or other outfall protection on steep or unstable slopes.
Water bars	Construct water bars at least 1 foot high, with a 30–60 degree angle from the road centerline and a clear, stable outlet. Carefully space and locate bars, e.g., consider using ditch-relief culvert spacing guidelines. Where significant traffic is expected, consider flexible water bars.

Crossing types

The most common stream crossings are culverts and bridges. Culverts generally are less costly than bridges for crossing small streams. However, they must be designed and installed carefully to provide for storm flows and fish passage. Design suggestions are discussed later in this section. Many older culvert crossings don't meet these standards and might be good candidates for enhancement projects.

Some relatively inexpensive bridge designs are available. Examples include log and rail car bridges as well as some newer prefabricated, sectional designs.

Where traffic is very light, carefully designed fords or temporary crossings may be used. A *vented ford* crossing is a unique way to minimize the disturbance and expense of large road fills (e.g., in floodplains) while maintaining clean water and adequate fish passage during low flows. These crossings combine a small culvert (i.e., capacity for moderate storm flows) with heavily armored fill at or near the crossing to handle overflows during heavy storms.

Flow capacity

It's critical that stream crossings have adequate flow capacity to prevent erosion or washouts during large storms. Oregon's Forest Practices Rules require that crossings be designed to handle a 50-year storm flow. By using the following procedure to check flow capacities of existing crossings, you can identify sites that might benefit from an upgraded design.

First, you need to determine the 50-year storm flow. The easiest way to do this is to use the peak flow map developed by the Oregon Department of Forestry (ODF). Part of this map is shown in Figure 9.

The map shows some areas where the 50-year peak flow is between 100 and 150 cubic feet per second (cfs) per square mile (640 acres) of drainage area. For a stream crossing in such a location, first estimate the watershed area that drains to the crossing, and then adjust the map value accordingly.

For example, if the drainage area above a local culvert crossing is 160 acres, the 50-year flow is calculated as follows:

160 acres ÷ 640 acres = 0.25 sq mile
100 cfs x 0.25 = 25 cfs
150 cfs x 0.25 = 37.5 cfs
50-year flow = 25–37.5 cfs

The next step is to measure the size of the culvert to see whether it can handle this flow. Table 5 shows the flow capacities of some common sizes of round culverts.

Table 5.—Flow capacities of round culverts.

Culvert diameter (inches)	Flow capacity (cfs)
24	5–11
30	12–20
36	21–31
42	32–46
48	47–64
54	65–87
60	88–113

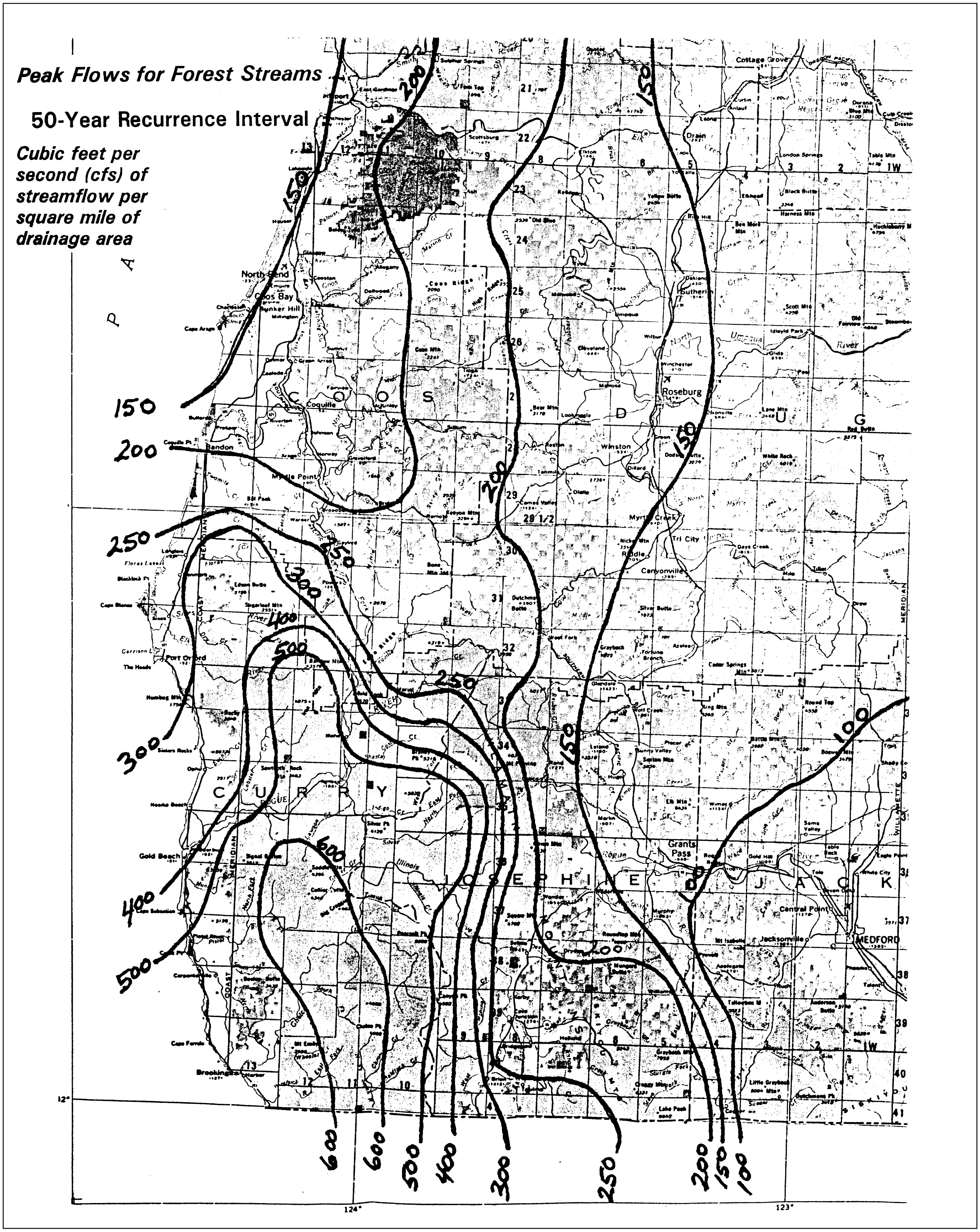

Figure 9.–Peak flow map for forest streams. (Source: Oregon Department of Forestry)

If the culvert crossing in our example has a pipe 36 inches or smaller, it's in danger of experiencing a washout during a heavy storm. Replacing the culvert with a larger pipe could reduce this risk.

Keep in mind that in many parts of Oregon the storms of February and November 1996 were among the largest recorded in the past century. In some locations, the resulting stream flows probably were 25- to 50-year return events, or even greater.

The condition of stream crossings after these storms provides evidence of locations where improvements might be warranted. Look for signs of eroding fill material around pipes, bridge approaches, and abutments. Also look for evidence that shows whether water flowed over the road as it ponded behind the fill.

Other guidance is available for estimating storm flows and the capacities of pipes and bridges to handle these flows. One source is the OSU publication *Estimating Streamflows on Small Forested Watersheds for Culvert and Bridge Design in Oregon*. Another is the "Checklist for Storm-proofing Rural Roads: Stream Crossings" (Appendix C).

Because stream crossing issues are complex, you might need help from engineers and other technical specialists for successful evaluation and enhancement projects. Replacing or installing culverts larger than those shown in Table 5 is one situation where special expertise probably is needed.

Fish passage

Fish passage at stream crossings is a major concern because barriers to passage can effectively eliminate many miles of valuable spawning or rearing habitat. Oregon's Forest Practices Rules require that new stream crossings provide for upstream and downstream passage of both adult and juvenile fish.

Older forest stream crossings and those on nonforest lands often were installed with little or no consideration for fish passage. Thus, upgrading crossings that restrict access to valuable habitat might represent an important watershed enhancement opportunity. More detailed information on this topic is available in Chapter III-5, "Stream Assessment and Restoration."

NEW ROAD CONSTRUCTION

Both watershed concerns and construction expense make it desirable to build as few new roads as possible. If new roads are needed primarily for logging activity, keep in mind that some logging systems require more roads than others.

Generally, ground-based logging requires the most roads. Systems that can carry logs over longer distances (e.g., multispan cable skylines or helicopters) require the fewest roads. These methods tend to be more expensive, however, and are best suited to steep or less accessible terrain.

Proper road location can prevent or reduce watershed impacts. Key principles include building roads far from streams and other drainages, minimizing the number of crossings, and avoiding potentially unstable areas.

In steep terrain, ridgetop roads can limit soil excavation and exposure. They also reduce the amount of water that the road's drainage system must handle because there is less area upslope to add runoff.

New road construction provides an ideal opportunity to incorporate design features that reduce or prevent watershed impacts. As mentioned earlier, most of these features focus on road drainage and stream crossings.

Subgrade preparation, or preparing the road for surfacing, is another important part of road design. In steep terrain, for example, *full-bench* and *end-haul* construction can reduce landslides and other erosion problems. In this approach, the entire road width is cut into the slope, and the excavated material is hauled to a stable location. This method contrasts with *cut and fill* construction, in which some of the excavated material is used to build up a portion of the road surface. In wet or weak soils, synthetic fabrics or other subgrade enhancements can improve road strength and reduce rutting and drainage problems.

Gravel surfacing is another way to reduce erosion and sedimentation from forest roads. The OSU publication *Rocking Woodland Roads* provides further information.

Soils freshly exposed by construction can be especially prone to erosion, so build roads early enough in the year to allow soils to stabilize before the rainy season. The OSU publications *Planning Woodland Roads* and *Road Construction on Woodland Properties* include a suggested construction schedule and other ways to reduce problems. Another helpful resource is *Seeding to Control Erosion Along Forest Roads,* which includes guidance on both species and application method.

Summary/Self review

- Soil is a key component of watershed and ecological function. If you improve your understanding of soils, you can improve your ability to make wise watershed management decisions.
- Soils are essential natural resources that make life on earth possible. They are a complex array of minerals, organic matter, organisms, and pore space. They provide support and sustenance for plants and also store and influence water resources.
- Soils form under the influence of five factors: climate, time, parent material, organisms, and topography.
- Soils can be quite variable, and understanding landscape positions can help you recognize and deal with soil variability more effectively.
- Soil surveys contain practical information about the soils in your watershed, including map unit descriptions and various tables.
- Key soil properties are texture, structure, organic matter content, density, porosity, and depth to bedrock. All of these properties affect water and air balance in soils.
- Adding or building organic matter can improve the physical, chemical, and biological properties of the soil. Organic matter is the main energy source for soil organisms.
- Soil compaction can decrease porosity and increase density, which decreases infiltration, increases runoff, and restricts root growth.
- Key processes that reflect soil behavior and are directly related to soil properties include permeability, infiltration, leaching, runoff, and erosion.
- Depth to water table is an important soil feature of site hydrology and can have many practical implications for land-use and watershed management.
- Soils regulate hydrology, nutrient cycling, and water quality. They also provide habitat for living organisms.
- You can minimize erosion by taking some key steps to prevent it. Providing cover or vegetation on bare ground and keeping soil on-site are two basic measures.
- Unpaved roads can be a major source of erosion and sedimentation. You can reduce road impacts by designing and maintaining roads properly. You can improve road drainage through road grading, ditch and culvert cleaning, and adding new surface gravel.

Exercises

You can do these exercises on your own, but it will be helpful to work as a group so you can compare notes and discuss your findings.

Soil drainage enhancement plan

Identify a local farm, woodland, or construction site that shows evidence of a significant soil drainage problem such as excess runoff or surface erosion. Give priority to areas where the runoff or eroded soil enters a stream channel. Develop a plan to improve soil infiltration and permeability, using the following key steps and information:

1. Visit areas where surface runoff and/or erosion seem to be increased by compaction from farm or forest operations. Evaluate and rank the severity of observed problems, noting particularly whether recent storm runoff and/or sediment has been delivered directly to a stream channel.
2. Examine data on storm intensities and soil infiltration rates in local climate summaries and soil surveys. Using ring infiltrometers or other field methods, test and compare infiltration rates at a significant problem area with a relatively undisturbed adjacent area. If differences exist, evaluate the probable primary source of these differences (e.g., soil compaction, soil exposure, or lack of runoff barriers).
3. Consider infiltration enhancement options for the problem area (e.g., soil tillage, modified farm or forest practices, mulching, seeding, or planting) and develop preliminary project plans. Estimate labor, materials, construction, and maintenance requirements and costs for the different options. If possible, have a soil scientist review the options and plans.
4. Review the advantages and disadvantages of each enhancement option. If funding is available, contact potential contractors for bids. Be sure to check about necessary notification or other requirements by agencies such as ODF.
5. Develop a preliminary plan for monitoring the implementation and results of the treatments, including soil behavior under both normal and extreme conditions (e.g., major storms) over time.

(continued)

Stream crossing enhancement plan

Identify a small, local stream crossing that shows evidence of a significant problem such as restricted fish passage or overtopping or erosion during recent major storms. Develop a plan to replace or improve the crossing, using the following key steps and information:

1. Estimate the 10-, 25-, and 50-year peak flows for the crossing, using topographic maps and the ODF peak flow map. Collect and consider site-specific information (e.g., shallow soils or terrain features) in determining an appropriate design flow. See *Estimating Streamflows on Small Forested Watersheds for Culvert and Bridge Design in Oregon* for more information.
2. Examine and evaluate the current crossing for:
   - Sufficiency to pass expected flows
   - Specific problems such as erosion, debris clogging, etc.
   - Upstream and downstream adult and juvenile fish passage
3. Using the above information, consider crossing enhancement or replacement options and develop a preliminary design. For example, you might be able to reduce erosion by adding riprap or other protection to road fills or bridge abutments. Excavating a resting pool below a culvert crossing might enhance fish passage. An undersized pipe could be replaced by a larger pipe or bridge. Estimate labor, materials, construction, and maintenance requirements and costs for the different options. If possible, have a hydrologist, engineer, or road specialist review the options and plans.
4. Review the advantages and disadvantages of each enhancement option. If funding is available, contact potential contractors for project bids. Be sure to check about necessary permits or scheduling requirements by agencies such as ODF, ODFW, etc.
5. Develop a plan for monitoring the installation and performance of the stream crossing, including maintenance under both normal and extreme conditions (e.g., major storms).

Resources

Training

Oregon State University (College of Forestry, Extension Service, etc.) and the *Oregon Department of Forestry* occasionally offer public seminars, field trips, and short courses on topics related to upland watershed management and enhancement. Training programs also might be offered by nonprofit and private organizations, including consultants. If you're interested in self instruction, consider the publications and audiovisual programs listed below.

Information

General practices

The Care of the Earth, by Russell Lord (New American Library, 1962).

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Ordering instructions

OSU Extension Service publications are available from county offices of the OSU Extension Service or from: Extension & Station Communications, Oregon State University, 422 Kerr Administration, Corvallis, OR 97331-2119; fax: 541-737-0817; Web: eesc.oregonstate.edu. Call for current prices.

OSU Extension Service videos are available for purchase from: Extension & Station Communications, Oregon State University, 422 Kerr Administration, Corvallis, OR 97331-2119; fax: 541-737-0817; Web: eesc.oregonstate.edu (These programs also might be available for viewing or loan from county offices of the OSU Extension Service.)

OSU Forest Research Lab publications are available from: OSU Forestry Publications Office, Forest Research Lab 227, Corvallis, OR 97331-7402; phone: 541-737-4271, fax: 541-737-3385; Web: www.cof.orst.edu/cof/pub/home/

OSU Forestry Media Center slide-tape, film, and video programs are available for purchase or rental from: OSU Forestry Media Center, 248 Peavy Hall, Corvallis, OR 97331-5702; phone: 541-737-4702; fax: 541-737-3759; e-mail: forestrm@ccmail.orst.edu; Web: fmc.cof.orst.edu/

Oregon Department of Forestry publications are available from local ODF offices, or from: Oregon Department of Forestry, 2600 State St., Salem, OR 97310; phone: 503-945-7422, fax: 503-945-7212;
Web: www.odf.state.or.us/

Moving forward–the next steps

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your watershed group ahead in improving your understanding of watershed soils, erosion, and conservation.

1.

2.

3.

Appendix A
Checklist for Storm-proofing Rural Roads
Road Maintenance

Road surface

- ❒ Rutting or uneven surface concentrates or sends water to wrong area
- ❒ Rock surfacing has deteriorated or migrated into subgrade
- ❒ Other risky situation or comments:

____

____

Drainage ditches and roadsides

- ❒ Eroding ditch material (gullies, etc.)
- ❒ Cutbank slumping or ravel blocking ditch flow
- ❒ Roadside berms concentrate or send water to wrong area
- ❒ Cracks in road fill, indicating soil instability
- ❒ Other risky situation or comments:

____

____

Cross-drains

- ❒ Erosion at inlet or outlet
- ❒ Sediment or organic debris clogging pipe
- ❒ Denting from traffic or ditch maintenance
- ❒ Other risky situation or comments:

____

____

Other considerations

- ❒ Heavy traffic (e.g., farm vehicles or log trucks) expected
- ❒ Plans for emergency maintenance during storms
- ❒ Other:

____

____

Appendix B
Checklist for Storm-proofing Rural Roads
Road Drainage Design

Road location

- ❒ Intense storms locally common
- ❒ Erodible or unstable soils locally common
- ❒ Streamside location could be subject to washout
- ❒ Other risky feature: ______________________________

Road grades

- ❒ Steep grades add to erosive power of runoff
- ❒ Low grades allow water to accumulate on surface
- ❒ Other risky feature: ___________________________________

Road bed and surface

- ❒ Soft road bed (e.g., weak or wet subgrade material)
- ❒ Erodible surface material (e.g., bare, fine-textured soil)
- ❒ Slope angles of road crown or sideslope inadequate for efficient flow
- ❒ Other risky feature: ___________________________________

Drainage ditches

- ❒ Erodible ditch material (e.g., bare, fine-textured soil)
- ❒ Cutbank seepage adds to ditch flows
- ❒ Low ditch grade accumulates water
- ❒ Other risky feature: ___________________________________

Cross-drain size and spacing

- ❒ Small pipe could overflow or become easily clogged
- ❒ Wide spacing could cause ditch erosion or overflow at inlet
- ❒ Other risky feature: ___________________________________

Cross-drain angle, grade, and installation

- ❒ Pipe might not efficiently move water and be self-cleaning of debris
- ❒ Fill too shallow or not well compacted (e.g., erosion or pipe bending)
- ❒ Other risky feature: ___________________________________

Cross-drain inlets and outlets

- ❒ Inlet might not divert all ditch water into pipe
- ❒ Flow from outlet could cause erosion or instability
- ❒ Other risky feature: __________________________________

Appendix C
Checklist for Storm-proofing Rural Roads
Stream Crossings

Culvert size or bridge clearance

- ❒ Insufficient capacity to pass 50-year storm flow
- ❒ Potential for clogging by woody debris, etc.
- ❒ Water diversion with excess flow or clogging creates other risks away from crossing
- ❒ Other risky situation or comments:

____

____

Pipe or bridge condition

- ❒ Evidence of deterioration (e.g., rust or rot), settling, etc.
- ❒ Other risky situation or comments:

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____

Inflow and outflow area condition

- ❒ Evidence or potential for erosion at high flows
- ❒ Other risky situation or comments:

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____

Road fill height and condition

- ❒ Low fill height could be overtopped at high flows
- ❒ Evidence of poorly compacted fill (e.g., seepage, settling)
- ❒ Other risky situation or comments:

____

____

Road surface and ditches

- ❒ Road drainage contributes to flow at crossing
- ❒ Potential for direct sedimentation from road surface or ditch
- ❒ Other risky situation or comments:

____

____

5

Assessment and Monitoring Considerations

Paul W. Adams

"We should do some monitoring" is a common response when concerns are expressed about local watershed conditions or resources. But you need to consider many issues before acting on this idea. There's a long list of potentially useful watershed characteristics that can be assessed, and an even longer list of ways to assess them. Without some careful planning, you may waste a lot of time, energy, and money.

You can use monitoring to identify both watershed enhancement opportunities and to evaluate results of enhancement activities. Monitoring can be very challenging, however, because regardless of location within a watershed (stream, riparian area, wetland, or upland), there are many conditions that can be measured. Furthermore, these conditions vary a lot depending on time, location, and management approaches.

Simply put, you may need to take many careful measurements in order to understand a situation. Usually, there are few shortcuts to a well-designed watershed evaluation or monitoring plan.

Many formal watershed assessments and resource monitoring programs have been or soon will be conducted under a variety of public and private initiatives. Detailed guidelines and technical assistance on these activities are available from many organizations,

In this chapter you'll learn:

- The need for clear objectives and terminology for evaluation and monitoring
- Why careful sampling and analysis are essential for accurate assessments
- Different approaches for comparing watershed practices and conditions

including the Governor's Watershed Enhancement Board (GWEB), Oregon Department of Fish and Wildlife (ODFW), Oregon Department of Forestry (ODF), and USDA Forest Service (USFS).

This chapter simply provides a general overview of some important considerations when undertaking nearly any type of watershed evaluation or monitoring effort. It will serve as a foundation for your work with specific projects as discussed in other chapters in this section.

See and Section III, Chapters 1, 2, 5, and 8 for information related to this chapter.

Section III

1 Riparian Functions

2 Riparian Enhancements

5 Stream Assesment

8 Water-quality Monitoring

PLANNING ASSESSMENT AND MONITORING PROJECTS

Perhaps the most important first step is to ask, "What's the objective of our evaluation or monitoring effort?" Often, the objective is to answer one or more basic questions about the condition of a watershed resource or the effects of a management activity or enhancement project.

The challenge is to ask a question that is broad enough to have a useful answer, yet specific enough to keep the time and expense of data collection and analysis reasonable. "Is the stream quality good?" is a question that is phrased much too simply to help direct an assessment project. The following questions, while still broad, get closer to striking the right balance between usefulness and feasibility:

- What is the current dissolved oxygen level of this stream?
- Do the temperature levels of this stream meet regulatory or other desired standards?
- Are levels of chemical contaminants in this stream declining or increasing over time?
- Does this new or different farm or forest practice reduce or prevent erosion or sedimentation?
- Has this stream restoration or enhancement practice produced better fish habitat?

Another useful step is to consider some of the major types of evaluation and monitoring projects. If you understand project types and use standard terminology to talk about them, you'll improve planning and eliminate confusion about the nature and objectives of your evaluation and monitoring projects.

The following list of monitoring categories was modified from a U.S. Environmental Protection Agency publication, *Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska*. (See the "Resources" section.)

- *Baseline* assessments establish a reference point for measured conditions. You then can compare this baseline measurement to measurements taken at different times or locations.
- *Trend* monitoring repeats measurements over time and compares them to a baseline measurement to see whether a pattern emerges (e.g., increasing, decreasing, or a cycle).
- *Implementation* monitoring determines whether an activity such as a watershed enhancement project is being carried out as planned.
- *Effectiveness* monitoring often follows implementation monitoring to see whether an activity produces the desired results or benefits.
- *Compliance* monitoring is similar to implementation monitoring, but usually assesses whether an activity meets legal or other administrative requirements.
- *Impact* monitoring is similar to effectiveness monitoring, but typically is used to determine whether a resource use or management activity has negative impacts.
- *Validation* monitoring usually refers to measurements that are designed to see whether a mathematical model or other prediction tool provides accurate results or should be improved or used differently.

Looking at this list, you can see that, in some cases, you may need to do more than one type of evaluation and monitoring to meet a general objective or information need.

SAMPLING AND STATISTICAL CONSIDERATIONS

It's impossible to evaluate and monitor everything everywhere in a watershed, so you'll need to decide what, how, when, where, and how often to take measurements. The following discussion of some of the issues involved with assessing suspended sediment levels in a stream will give you an idea of the complexity of these decisions. Similar concerns arise when you evaluate nearly any other watershed characteristic (e.g., fish habitat, stream shading, or soil infiltration), especially when you want to determine how management activities may affect these factors.

For most evaluation or monitoring efforts, such as an assessment of suspended sediment levels, you'll need to meet the following general objectives:

- The samples or measurement points should accurately represent the larger area to be assessed (e.g., a stream). In other words, you need *good sampling design and technique.*

- There should be no changes or confusion in the samples or measurement data that may affect the results. Thus, you need *proper sample and data handling.*
- The sample and data analyses should accurately assess the characteristic of interest, so you need *good analytical procedures and statistical methods.*

With these things in mind, how can you sample a stream for sediment? One common way is to take "grab" samples, i.e., stand in the stream and collect a sample in a bottle or jar.

But how well does such a sample represent all of the sediment carried by the stream? Suspended sediment isn't carried uniformly across the width and depth of a stream. For example, coarse materials such as sand and gravel usually are carried closer to the stream bottom. Thus, samples taken only near the surface may not accurately represent total sediment levels. Specialized equipment is available for sampling coarser sediments, but such equipment adds to the cost of assessment.

Another issue is the number of samples needed. All watershed characteristics vary over space and time, some tremendously. How can you be sure you've taken enough samples to understand and account for this variability?

One approach is to take a preliminary set of samples and use a statistical analysis to see whether more samples are needed. Such a *pilot study* not only can help determine the number of samples needed, but also can identify other concerns such as equipment needs, personnel needs, or limitations of the sample design (for example, specific locations or extremely high variability that require more intensive sampling).

The following equation often is used to assess sample size in this approach:

$$n = \frac{t^2 s^2}{p^2}$$

The symbols in this equation mean the following:

- *n* is the number of samples needed to precisely estimate the mean value of a measurement with a desired level of confidence.
- *t* is the "student's t value" for the desired level of confidence (e.g., a 95-percent probability of obtaining a precise estimate). This value is available in most statistics textbooks.
- s^2 is the variance of preliminary sample set or variance expected from other sampling experience.
- *p* is the desired precision of the estimate (how close you want your estimate to be to the true value, for example, +/-5 percent).

To use this procedure, it helps to have some familiarity with statistical analysis and a calculator with statistical functions. Even if you don't, however, it's important to appreciate that this type of analysis can show how difficult and costly it may be to provide clear and reliable answers to questions about watershed conditions and management effects.

For example, Table 1 shows the results of an analysis to find out how many stream water samples are needed to accurately identify a 10 percent increase in sediment levels. The reason so many samples are needed is that sediment in individual samples varies so much with time and stream flows.

Table 1.–Samples needed to detect 10% increase in sediment concentration (small forest stream–Oregon Coast Range).

Stream flows (cfs)	Samples required
0.0–1.5	7,968
1.5–2.2	1,947
2.2–5.0	3,253
5.0–25	3,493
>25	51

(Adapted from "Sampling water quality to determine the impact of land use on small streams," by R.M. Rice, R. Thomas, and G. Brown (unpublished paper, presented at ASCE Watershed Management Symposium, Utah State University, 1975.)

The effect of stream flow on suspended sediment, as well as on many other stream characteristics, often is substantial and complex. As a result, it may be difficult to sample a stream at the right time or often enough to accurately characterize its condition.

Figure 1 shows how suspended sediment levels in a stream in the Oregon Coast Range change as stream flow rises and falls in response to a winter storm. Note that for the same stream flows, suspended sediment level can vary a lot, depending on whether the stream is rising or falling.

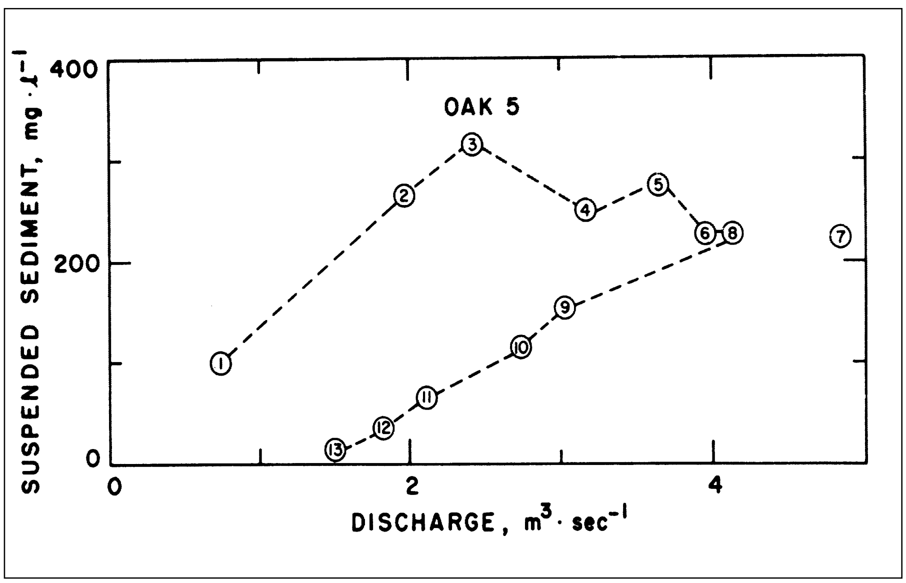

Figure 1.–Suspended sediment levels and stream flows for a small Oregon Coast Range stream.

This type of complex water-quality response to flow changes is why researchers sometimes use automated samplers to take many samples during storms. Not surprisingly, it can cost a lot to purchase and maintain this equipment.

Potential *errors* or *biases* in sampling or measurement methods are another vital concern in evaluation and monitoring. Such problems result in measurements that differ from the true values. These erroneous measurements in turn can yield unclear, exaggerated, or wrong observations or conclusions.

Using grab samples to assess water quality is an example of a method that may introduce errors. For example, the types or amounts of material collected by grab samples may not accurately represent the sediment that a stream actually carries.

A common source of sampling bias in natural resource measurements is the tendency for people to work in locations that are more accessible and easier to move around in. Carefully designed sampling schemes can reduce such bias, but they don't always overcome the physical challenges of working in difficult areas such as dense, rugged riparian zones or large, complex streams.

For example, a random number table can be used to identify numbered plots for *random* sampling; a grid with consistent, fixed distances between sample points can be used for *systematic* sampling; grouping sample plots in areas with similar conditions (e.g., soil type, slope, cover, or habitat type) is an approach for *stratified* sampling. Keep in mind that if you can't achieve the fundamental assumptions on which statistical procedures are based (e.g., use of truly random or systematic samples), your results or their interpretation may be invalidated or seriously questioned.

Equipment errors also are common in watershed measurements. The most reliable and accurate equipment can be very costly to purchase and maintain; thus, older or less expensive equipment often is used. Such equipment can provide useful data and information, but you may need to verify or calibrate these measurements against those taken with better equipment to ensure that your measurements are accurate and usable. *Calibration* often involves further calculations to carefully define the relationship between similar measurements collected with different equipment.

If you send samples to a laboratory for analysis, you may run into two additional kinds of errors–sample handling and storage errors, and lab measurement errors. To identify such problems, you can take additional test and control samples and handle and analyze them in the same or different ways.

Test samples are collected normally, but specifically are used to check handling and analytical procedures. *Control* samples contain known amounts of the material or other characteristic being evaluated (e.g., a water sample that is "spiked" with a carefully measured amount of nitrate) and also are used to verify procedures.

If you use commercial laboratories, ask about quality-control procedures or professional certification. These labs also can provide information about expected measurement errors for their analytical procedures and equipment.

COMPARISON STUDIES

A common objective of evaluation or monitoring projects is to make a comparison. For example, you may want to identify effects of different management practices or see whether resource characteristics change over time.

You can use several approaches to make such comparisons. Each method has advantages and disadvantages.

For example, you might want to evaluate changes or differences in water quality or fish habitat related to a management practice such as adding a riparian buffer next to a subdivision or agricultural field. To do so, you might make *upstream vs. downstream* comparisons. That is, you could compare measurements taken from stream locations immediately upstream and downstream of a stream reach where the particular practice is used (Figure 2).

Another approach is the *paired watershed* comparison. This method compares conditions such as water quality or habitat features in two nearby watersheds (Figure 3).

For either the upstream vs. downstream or paired watershed approach to provide accurate and useful comparisons, you need to be sure that site differences (other than the management practice of interest) between the compared areas have little or no effect on the conditions being studied. If they do have an effect, you need to be able to account for this effect and clearly separate it from the management effect.

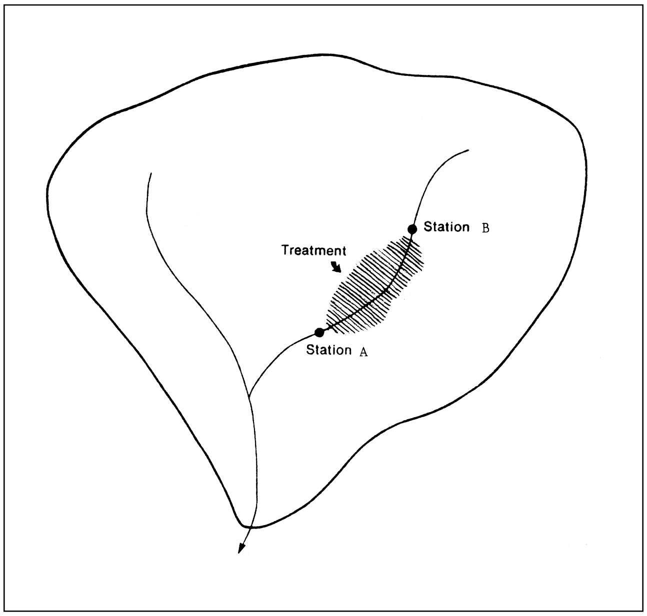

Figure 2.–An upstream-downstream comparison looks at measurements taken from stream locations immediately upstream and downstream of a stream reach where a particular practice is used.

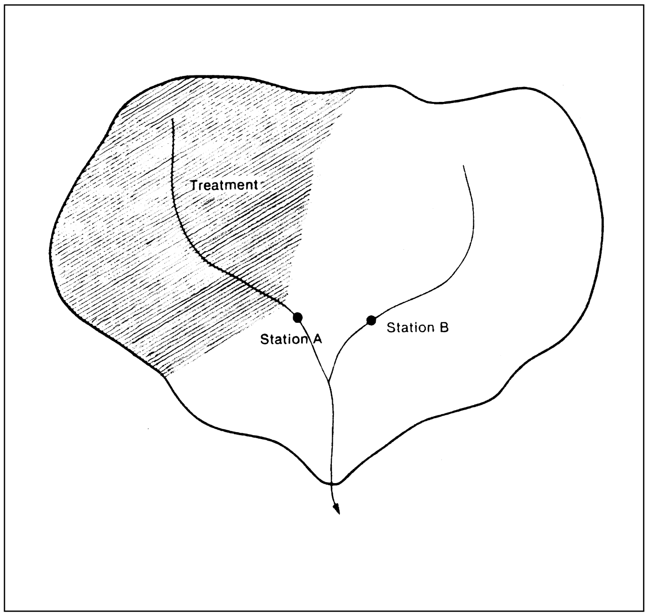

Figure 3.–A paired watershed comparison looks at conditions in two nearby watersheds.

It can be very difficult to distinguish between effects of management and other factors because no two streams or stream reaches are exactly alike. There always are differences in flow, gradient, substrate, or morphology, for example. One way to deal with differences between sites is to use *replicate* comparisons, which means to compare various locations to see whether any effects due to management occur in a consistent pattern.

A third approach is the *before and after* comparison. This approach requires that site characteristics such as local climate patterns that may affect the condition being measured be very similar before and after the treatment or change of interest is implemented. Also, to use this method, you need to be sure to establish an accurate *baseline* condition to use in the comparison. As suggested by the discussion of suspended sediment measurements, it can be very challenging to identify what is "normal," given how much measurements can vary based on changing background conditions such as stream flow.

Regardless of which comparison approach you use, consistent methods and good record keeping are essential. Different sampling procedures, tools, or field crews can produce different results that may render a comparison unclear, inaccurate, or invalid. Similar weaknesses can result from poor record keeping. Both of these requirements are especially important when you make the substantial investments needed for useful long-term comparisons.

Finally, keep in mind that although well-designed comparison studies can help identify management effects or resource trends, without further study it can be difficult to determine the specific cause of an observed difference or trend. And, without some caution, it can be easy to reach a wrong conclusion.

For example, if stream sediment or temperature varies between the upper and lower points of a stream reach where a land management enhancement practice occurs, it's tempting to credit the management practice with causing the difference. Until such key factors as local channel features or cool seepage are carefully accounted for, however, the influence of the activity remains uncertain. Thus, an important question to try to answer is: "Is this a case of cause and effect, or guilt by association?"

SUMMARY/SELF REVIEW

Watershed evaluation and monitoring can be very challenging because of the time and effort often needed to provide accurate and useful information for resource management. Careful project planning begins with defining the primary evaluation and monitoring objectives and approaches. Identifying procedures for effective sample and data collection, handling, and analysis is especially important. Giving close attention to these key considerations in watershed evaluation and monitoring can help ensure that your observations and conclusions are accurate and correct. Whenever possible, avoid taking shortcuts that can lead to poor information

EXERCISES

Do these exercises as a group with the help of appropriate experts.

Visit a watershed study site with a researcher.

The objective of this exercise is to see, discuss, and learn more about what it takes to answer questions about watershed conditions and influences with a reasonable level of accuracy and confidence. Ask the researcher to focus specifically on demonstrating and providing insights about study design, sampling, and analytical requirements, including such factors as:

- Degree and sources of variability in samples/measurements
- Numbers and location of samples/measurements
- Timing and frequency of sampling/measurements
- Handling and lab/office analysis of samples/measurements
- Type and expense of field and lab/office equipment
- Time and expense of field and lab/office personnel
- Role of experience and expertise of personnel

Visit a USGS stream/river monitoring site and discuss agency databases.

The objective of this exercise is to see and learn how some of our streams and rivers are regularly monitored. As in the exercise above, sampling equipment and design should be discussed, including issues of variability, sampling/measurement accuracy, and equipment and personnel needs and costs.

In addition, the broad array of available USGS and other agency monitoring databases should be discussed. Ideally, do this portion of the exercise indoors so that some of the databases can be shown. If World Wide Web access is available, you'll be able to view some of these databases online (e.g., http://wwworegon.wr.usgs.gov/).

Resources

Training

Oregon State University and government organizations occasionally offer short courses on topics related to watershed evaluation and monitoring. Training programs also may be offered by various nonprofit and private organizations, including consultants. If you're interested in self instruction, consider the publications below.

Information

"How to study a stream." In *Stream Hydrology–An Introduction for Ecologists*, by N.D. Gordon et al. (John Wiley & Sons, Inc., New York, 1992). ISBN 0-471-95505-1. Available by order through bookstores.

Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska, EPA 910/9-91-001, by L.H. MacDonald et al. (U.S. Environmental Protection Agency, 1991). Available from the U.S. EPA, Region 10, NPS Section, WD-139, 1200 Sixth Ave., Seattle, WA 98101. Also available on the Web at http://www.epa.gov/clariton

Oregon Watershed Assessment Manual (NonPoint Source Solutions for the Governor's Watershed Enhancement Board, Salem, 1998).

"Reliability of water analysis kits," by C.E. Boyd, *Transactions of the American Fisheries Society* 109:239–243 (1980). Available through university and other technical libraries.

Volunteer Water Monitoring: A Guide for State Managers, EPA 440/4-90-010 (U.S. Environmental Protection Agency, 1990). Available from U.S. EPA, Office of Water, Washington, DC. Also available on the Web at http://www.epa.gov/clariton

Water Quality Monitoring Programs, Technical Paper WSDG-TP-00002, by S.L. Ponce (Watershed Systems Development Group, USDA Forest Service, Fort Collins, CO, 1980). Available through university and other technical libraries.

Wildland Water Quality Sampling and Analysis, by J.D. Stednick (Academic Press, Inc., San Diego, 1991). ISBN 0-12-664100-5. Available by order through bookstores.

MOVING FORWARD–THE NEXT STEPS

On your own, use the lines below to fill in steps, actions, thoughts, contacts, etc. you'll take to move yourself and your watershed group ahead in understanding watershed assessment and monitoring.

1.____

2.____

3.____