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Soil and Water Road-Condition Index - Desk Reference

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INTRODUCTION

The San Dimas Technology and Development Center (SDTDC) of the Forest Service, U.S. Department of Agriculture, developed the soil and water road-condition index (SWRCI) to provide a road-condition assessment tool for watershed- and project-scale analysis. SWRCI is intended to be a rapid-assessment tool for soil scientists and hydrologists to use to identify effects of roads to soil quality and function, as well as impacts to water quality and downstream values.

The SWRCI desk reference is a companion document to the SWRCI field guide and rating form. The desk reference:

- Provides a description of each road attribute (road-surface shape, road-stream connectivity).
- Identifies the questions the attribute addresses for a project- or watershed-scale road analysis.
- Identifies related indicators and the usefulness of the attribute in identifying road impacts to soil and water resources with referenced research findings.

Once the SWRCI forms have been completed for a road, project area, or forest, the desk reference provides the watershed specialist (soil scientist, hydrologist, geologist) with information to more fully disclose and document the cause-and-effect relationship of a road-condition rating and the potential impacts to soil and water resources.

The desk reference is formatted to emulate the fields within the SWRCI rating form. The first section addresses a description of each indicator used to characterize the road segment as in step 1 of the SWRCI form. The second section follows step 2 of the SWRCI form and presents information on the indicators used to determine the road-condition evaluation. Finally, in the third section there is a discussion on how traffic levels and soil texture may be used in the SWRCI process.

Section 1: Characterizing the Road

1. Road-Surface Shape

Description

Road-surface shapes include insloped, outsloped, crowned, entrenched, turnpiked, and user-created. Design elements of a road include the traveled-way width, shoulders, road gradient, curve widening, and pavement structures (Forest Service Handbook (FSH) 7709.56 Chapter 4-Design). An entrenched road has a constructed berm or throughcut on both sides of the road prism preventing runoff from leaving the road prism except at designated locations. Turnpiked-road templates are constructed above the natural topography of the adjacent landscape. Turnpiked roads are used where soil strength is low and where surface ponding may occur for significant portions of the year. The user-created road evolves from use of an area. The road does not have any design elements and may be limited to wheel tracks only.

The road-template design may vary with changes in topography, hillslope position, hillslope gradient, road gradient, and surface and subsurface drainage features. The road design criteria includes environmental and resource considerations, safety, traffic requirements, and traffic-service levels.

Changes in the design of the road template are logical road-segment break points.

Questions potentially addressed

- How and where does the road template modify the surface and subsurface hydrology of the area?
- How and where does the road template cause surface erosion?
- How and where does the road system affect mass wasting?
- How and where is the road hydrologically connected to the stream system?
- How do the connections affect water quality?
- How and where does the road-template design cause diversion potential?
- How and where does the road reduce soil quality?

Related indicators

- Road-surface drainage.
- Stream-crossing condition.
- Diversion potential at crossings.
- Road-stream connectivity.
- Road-surface material.
- Road gradient.
- Hillslope gradient.
- Cutslope and fillslope condition.

Utility (Usefulness of the indicator or attribute)

The appropriate road-surface shape (road-design template) is determined by topography, climate, and access. The surface shape identifies how the road prism affects runoff and potential impacts to soil and water resources.

Measure

Each road-surface shape has an associated set of road-drainage features that can be anticipated. For example an insloped road will generally have cross-drained culverts and a ditch. An insloped road may be used on steep hillslopes to ensure driver safety. Conversely, outsloped roads are generally located where hazards from driving off the road are not a concern, for example on flat-to-moderate gradient roads (less than 8-percent gradient), and may use drainage dips to break up the contributing road-drainage area.

In some cases a road-surface shape may be undefined due to lack of maintenance, or may change throughout the length of the road. Use the road-surface shape as a tool to segment the road and thereby categorize associated road-drainage features.

2. Hillslope Position

Description

The hillslope position of a road segment can determine sediment potential and drainage design. Hillslope-position classes include: ridge (upper one-third), midslope (middle one-third), and bottom (lower one-third), or within a streamside-management zone (SMZ) or riparian area designation, and a climbing segment from the bottom to the ridge.

Questions potentially addressed

- How does the road-segment location affect erosion and sediment production?
- How and where does the road-segment location intercept subsurface drainage?
- How and where is the road segment hydrologically connected to the steam system?

Related Indicators

- Road-surface drainage.
- Diversion potential.
- Road-stream connectivity.
- Road gradient.
- Hillslope gradient.
- Cutslope and fillslope condition.

Utility

The hillslope-position indicator is associated with erosion and the sediment production potential of a road segment. Studies in Oregon identified road segments in the midslope location have the potential to deliver the most sediment over other slope locations. Croke (2001) identified road-to-stream linkages that occurred at relief culverts draining cut-and-fill roads in midvalley positions. However, bottom locations—or segments within streamside management areas—have the highest proportion of road segments hydrologically connected to streams (Skaugset 1998). Studies on the Bluff Creek watershed in California found road failure rates 30 times higher in the lower (bottom) position of the hillslope compared to the upper position (Furniss 1999).

Measure
Circle the hillslope position of the road segment being evaluated. Hillslope position is another indicator used to segment a road.

3. Road Gradient

Description
Road gradient is the slope of the road along its longitudinal axis. Road gradient is a key design element affecting the type of vehicles that use the road, vehicle speed, and safety. The road gradient also affects soil and water resources in terms of erosion potential, runoff, and sediment delivery. “Erosion potential increases as a function of the square of the slope and of the third power of the water velocity” (FSH 7709.56, Ch. 4.32). Studies identify sediment generation as a function of the traffic intensity, road gradient, and road contributing length.

Road gradient also determines the type of road-drainage structure, road-template design, and road-surface requirements. Forest Service guidance on road grades is identified in the Forest Service Manual (FSM) 7700 and FSH 7709.56 chapters 2 and 4. Steep road-gradient segments are common throughout National Forest System roads and require review to ensure that adverse impacts to soil and water resources do not occur.

Questions potentially addressed
- What percentage of a road is within a given road-gradient class?
- What type of road-template design is used on steep road grades and is it effective?
- What type of road-drainage structure is used on steep road grades and is it effective?
- What erosion- or sediment-production rates are associated with different road gradients?

Related indicators
Additional indicators that help to identify the effect of road gradient on soil and water resources include:
- Soil texture.
- Hillslope gradient.
- Diversion potential.
- Road-stream connectivity.
- Road-surface shape.
- Road-surface drainage.

Utility
The gradient of a road segment will change depending on how frequently the road is segmented. More frequent segmentation can

identify significant erosional processes associated with road gradient especially when combined with slope length. In a study by Luce and Black (1999), the interaction between length and gradient found little effect to sediment production when the gradient was low regardless of how long the segment was. However, when combining long segment lengths with higher gradients there was significant sediment production. Kahklen (2001) identified gradient and road-surface material particle size to be the two most important variables that influence the development of rills on the road surface.

Measure
Identify the road gradient with a clinometer for the segment being traversed. Road gradients range from 0 to 8 percent, 9 to 15 percent, and greater than 15 percent.

4. Hillslope Gradient

Description
Hillslope gradient is the uphill and downhill slope where the road is located. The hillslope gradient is important from several aspects. First, any hillslope runoff onto the road needs to be accounted for in a road-drainage structure. The steeper the hillslope gradient, the larger the cutslope tends to be, which may increase erosion and/or the interception of subsurface flows. Secondly, it is difficult to disperse runoff on steep hillslopes without causing fillslope erosion. Gentler hillslopes provide more opportunities to disperse runoff, whereas steep slopes often develop concentrated flowpaths. Routing road runoff to natural stream channels through inside ditches is common on steep hillslopes.

Questions potentially addressed

- What kind of road-design template is used on steep-hillslope gradients?
- What if any problems are associated with this?

Related indicators
The influence of hillslope gradient on soil and water resource impacts is most helpful when evaluated using these indicators:

- Road gradient.
- Road-template design.
- Road-surface shape.
- Condition of culverts and/or drainage facility.
- Hydrologic connectivity.
- Diversion potential.

Utility
Hillslope gradient is a significant topographic feature that often dictates the road-construction methodology. Steep slopes—over 35 percent gradient—may have full-bench construction where the road is cut into the hillside with no fill. Other roads—on somewhat gentler slopes—may be a combination of cut and fill, where approximately half the road prism is constructed from compacted fill material excavated from adjacent areas. The steeper the hillslope gradient, the greater the cutslope area and the increased potential for intercepting subsurface flows. The soil profile exposed in a cutslope is difficult to revegetate due to low organic-matter content and nutrient composition. Road segments with steep hillslopes can be costly and difficult to maintain.

Key design considerations for a road on a steep hillslope include runoff from the hillslope above, potential interception of subsurface flows, and identifying suitable locations to disperse runoff without creating gullies below the road prism. Many roads on steep hillslopes use overside metal drains or culvert extensions to route runoff below the road to protect the fillslope. Gullies can form at the outlet of the structures without adequate energy dissipaters.

Wemple et al. (1996) found that gully incision is significantly more likely below culverts on steep hillslopes (greater than 40 percent gradient). Croke and Mockler (2001) found a correlation between midslope roads and length of contributing areas. The midslope roads drained a greater area, and the gradient of the discharge hillslope was much steeper than ridgetop roads.

Measure
Use a clinometer to field verify both uphill and downhill slope gradient. To guarantee an accurate reading, ensure that the measurement is taken away from the road's cut and fill.

5. Road-Surface Material

Description
The SWRCI focuses on native-surface roads, but can be used to inventory an entire watershed rapidly. Roads with a higher maintenance level may be aggregate surfaced or paved.

Questions potentially addressed

- How and where does the road-surface material affect erosion and sediment potential?
- How and where does the road-surface material adversely affect soil quality through road widening or braiding?
- How and where does the road-surface material intercept subsurface flows?

Related indicators

- Traffic.
- Road-surface drainage.
- Road gradient.
- Soil texture.
- Surface condition.

Utility

Studies indicate that forest roads are a source of sediment production (Croke 2001; Forman 2003; Furniss 1999; Luce 1999; Reid 1984). Road-surface material can help reduce erosion and sediment delivery by preventing rutting on roads used during wet conditions.

The type and condition of surface material used, combined with surface traffic, affect the erosion and sediment potential of a segment. McDonald and Coe (2005) found that as little as 10 centimeters of coarse aggregate on the road reduced the sediment production rate by an order of magnitude over a native surfaced road. Foltz (1996) studied sediment production rates comparing different aggregate quality and found that aggregate quality affected sediment production. The study determined that the quality of the aggregate was more important with higher traffic and higher rainfall.

Measure

Circle the road-surface material, such as native, aggregate (gravel), or paved for the road segment evaluated.

Section 2: Road-Condition Indicators

1. Road-Surface Drainage

Description of indicator

Surface drainage provides for the interception, collection, and removal of water from the surface of roads and slope areas. Surface drainage features may need to accommodate debris movement, mud flows, and runoff. For a proper drainage system, combine the appropriate design elements to protect adjacent resources. Road-surface drainage is intimately associated with the road-surface shape, topography, and climate. Key design considerations include the length of the contributing road area and the contributing hillslope above the road.

Surface-drainage structures commonly include ditch-relief culverts, drainage ditches, drainage dips, lead-off ditches, and overside drains. Culverts in natural stream crossings are not considered a component of the road-surface drainage structures but are addressed in the stream-crossing condition indicator.

Questions potentially addressed

- How and where does the road drainage modify the surface and subsurface hydrology of the area?
- How and where does the drainage structure cause surface erosion?
- How and where is the road hydrologically connected to the stream system?
- How and where does the road drainage cause diversion potential?
- What is the typical length and size of the contributing area?

Related indicator

- Road-surface shape.
- Stream-crossing condition.
- Diversion potential.
- Soil texture.
- Road gradient.
- Hillslope gradient.
- Fillslope condition.
- Cutslope condition.

Utility

Road-surface drainage directly affects soil and water quality properties from the time of construction throughout the life of the road. Roads reduce infiltration and modify hillslope drainage. Therefore, surface-drainage structure design and subsequent structure maintenance is critical to the degree of impact a particular road segment has on soil and water resources. Proper design and maintenance of road-drainage structures can minimize the effects of the road and limit onsite and offsite impacts to soil and water resources.

The road surface is a main source of erosion and sediment generation (Croke and Hairsine 2001; Croke and Mockler 2001; Grace 2004; Luce 2002; Luce and Black 2001; Reid 1984). Well-designed roads with functioning surface-drainage structures can minimize erosion and sediment delivery.

Studies by Borga (2005) evaluated the influence of roads in steep forested areas prone to landslides. Roads concentrate flow, creating shallow landslides. Sources of runoff include overland flow from the compacted road surface and subsurface flow intercepted by road cutslopes. In some instances increased road runoff occurred from partially plugged or blocked culverts causing shallow landslides below the road.

Croke and Hairsine (2001) identify the importance of road-drainage spacing as a key design variable for effective roads management. Drainage spacing is linked to road gradient and regional rainfall characteristics. The position of the drainage discharge or outfall point in the landscape can create erosion at the outlet.

Evidence of scour in the drainage ditch or at the outlet of a culvert indicates an exceedance of threshold stream power (Croke 2001). At this point the ditch and area below the culvert outlet become a source of sediment, which affects the road-condition rating.

The road-drainage structure combined with slope position also can affect the road segments' impact on soil and water condition. Croke and Mockler (2001) found statistically significant differences between ridgetop roads with winged ditches versus midslope roads with ditch-relief culverts. The contributing road length was up to three times longer on midsloped roads. Midsloped roads discharged onto hillslopes that were twice as steep. The study found that linkages between midsloped roads with ditch-relief culverts can have deleterious impacts to water quality.

Road segments that are entrenched concentrate surface runoff and may intercept subsurface flows. In some topography it is difficult to avoid short (25- to 50-foot) entrenched road segments. Avoid long entrenched segments to reduce road-derived sediment.

Measure

Drainage structures cause adverse effects to soil and water resources by increasing drainage density, accelerating erosion, creating diversion potential, increasing hydrologic connectivity, plugging with debris, and increasing drainage-ditch scour and erosion.

Field evaluation of drainage structures using physical features, including rill or gully erosion, sediment deposition, and blocked structures, identifies how well the structures function.

Road-Surface Drainage Types

Ditch-Relief Culverts. Ditch-relief culverts periodically relieve the ditch flow by piping water to the opposite side of the road, where flow can disperse away from the roadway without creating erosion. Spacing depends on road gradient, road surface and ditch soil types, runoff characteristics, and the effect of water concentrations on slopes and streams below the road (FSH 7709.56 Road Preconstruction Handbook).

A survey conducted for the Oregon Department of Forestry determined that "sediment blockage and crushing of culvert inlets are the most common factors reducing the capacity of stream and road-crossing culverts"(Skaugset 1998). Approximately 28 percent of the ditch-relief culverts had inlet capacities reduced by at least half.

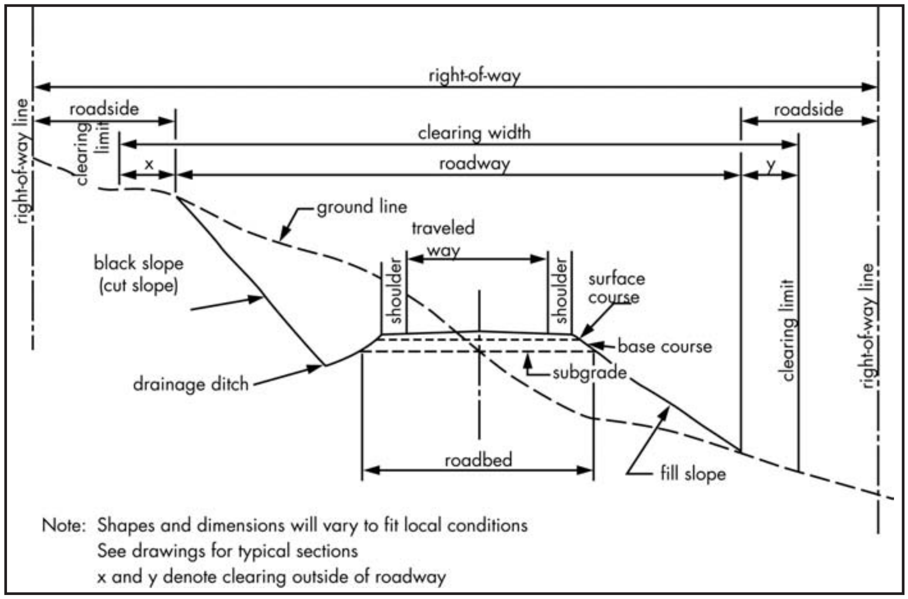

Figure 1—Components of a road.

Drainage Ditch. The drainage ditch transports water leaving the road surface or cutslope to the nearest ditch-relief culvert, lead-out ditch, or natural channel. The ditch is constructed between the traveled way and the adjacent terrain. Drainage ditches are found on insloped, outsloped, and crowned roads. Drainage-ditch effectiveness varies with length, slope, and armor.

Lead-Off Ditch–Winged Ditch. A lead-off ditch (or winged ditch) is designed to carry water away from the road. This ditch is used in flat or gentle topography and often is associated with a crowned road design. The lead-off ditch is located at the point where a roadside ditch daylights onto natural ground.

The road-section length and width contributing to a lead-off ditch determines the distance sediment travels downslope (Grace 2005).

Drainage Dips. Drainage dips intercept and remove surface water from the traveled way and shoulders. When properly constructed, they provide uninterrupted flow of traffic and are relatively maintenance-free drainage structures. Drainage dips are not recommended on road gradients greater than 10 percent.

Overside Drains. Overside drains are used to protect the fillslope from increased erosion. Overside drains are commonly used in conjunction with drainage dips or entrenched road prisms. All structures must be located, installed, and maintained properly to be effective.

2. Stream-Crossing Structure Condition

Description of indicator

Proper road drainage is critical in preventing adverse impacts to water and soil resources. Stream-crossing structures are designed with consideration of topographic, climatic, hydrologic, and other environmental conditions (sensitive soils, springs, unstable geology). Evaluation of the indicator identifies the physical condition of the structure as well as its ability to pass debris and water over time.

Questions potentially addressed

- Does the structure provide passage of runoff and associated sediment and debris?
- How and where does the stream crossing cause erosion?
- Does the crossing have diversion potential?
- Is there the potential for cascading effects with other drainage structures within the segment?
- Is the road hydrologically connected to the stream-crossing structure?

Related indicators

The stream-crossing structure condition is related to the road-surface drainage indicator. Combining the two indicators provides a synopsis of how surface drainage is removed from the surface of roads and slopes, and the physical condition of the structure.

Evaluation of stream-crossing structure condition is linked to the diversion-potential indicator.

Utility

A survey conducted for the Oregon Department of Forestry determined that “sediment blockage and crushing of culvert inlets are the most common factors reducing the capacity of stream and road-crossing culverts”(Skaugset 1998).

Measure

Field review of the stream crossing identifies its physical condition and evidence of its ability to handle runoff and provide the debris passage required for a road-segment rating.

3. Road-Subsurface Drainage

Description

Subsurface drainage is designed to intercept, collect, and redirect ground water that may otherwise flow into the road subgrade. Subsurface-drainage features also lower water tables and drain isolated water pockets.

Subsurface-drainage design may use a ditch and ditch-relief culverts to intercept and redirect ground water into a stream. Permeable fills are constructed to allow ground water to percolate through the subgrade of the road. For isolated water pockets, use French drains or design an engineered drainage system to keep water away from the road surface. This will provide stability and increase load-bearing capacity.

Questions Potentially Addressed

- How and where does the road segment intercept subsurface flow?
- How and where does the road modify or change subsurface flow?
- How and where does the road change adjacent vegetation?

Related Indicators

- Road-surface drainage.
- Cutslope condition.
- Fillslope condition.
- Hydrologic connectivity.
- Road-segment location.

Utility

Roads that intercept subsurface flows create adverse affects on soil and water resources in several ways. The degree to which a road intercepts subsurface flow—and subsequently redirects it—varies from location to location.

Wemple (2003) tested a theoretical model to evaluate how roads interact with hillslope flows dominated by subsurface flow and the hydrologic response during storms. The model can target road segments that need restoration or removal because of subsurface-flow interception. Findings showed variability as each segment of a forest road acts as a subcatchment for the hillslope above the road. Therefore the road catchment includes the hillslope above the road, the road surface, and the roadside ditch draining to the culvert. Road segments responded differently with hillslope length, soil depth, and cutbank depth as key variables for determining road-runoff production. Findings demonstrated that as road segments intercept subsurface flows and redirect them to ditches and streams, the timing of water delivery in the catchment is altered. The key is in identifying which road segments intercept subsurface flows and whether they significantly augment the hydrograph and increase the potential flooding.

La Marche and Lettenmaier (2001) developed a model to determine how forest roads contribute to streamflow based on:

(1) Interception of subsurface flows by road cutslopes.

(2) Road-generated runoff to the stream network via the road-drainage system.

Their study, conducted on the Deschutes River in Washington, tried to discern the impacts of increased runoff from forest roads versus increased runoff from vegetation removal at different scales. Findings from the predictive model and field testing identified a synergistic response of increased runoff where vegetation removal occurred above forest roads. The road cutslope height did not affect ditch runoff.

Tague and Band (2001) built on Wemple's (1996) studies of connectivity and developed another model. The study was to identify the hydrologic affects to areas below roads where subsurface flows were intercepted and redirected away by ditches, and areas below cross-drain culverts that were not hydrologically connected to the stream. Results showed that redirecting subsurface flows can produce a significant reduction in downslope soil moisture and may lead to adverse affects on vegetation over time. Vegetation health in water-limited environments may be an indicator of change in subsurface water storage and possibly a change in water quality.

These studies were conducted in the Pacific Northwest and illustrate the road's effect in the interception and redirection of subsurface flows. On forests with roads that intercept and redirect subsurface flows, staff should be cognizant of the potential adverse offsite effects of increased runoff and flooding that may occur. This indicator, as tested by Wemple, helps identify road segments that require further analysis, reconstruction, or potential road removal.

Measure

Evaluations of the effect of functioning subsurface drainage include factors, such as erosion of ditches from the change of subsurface to surface flows in a ditch, change in vegetation community, and/or adverse impacts from concentration of flows and flooding.

4. Diversion Potential at Crossings

Description of indicator

Diversion potential predicts how a stream responds if the capacity of the stream-crossing structure is exceeded, or if the structure becomes plugged. If the stream overtops the crossing and remains in its natural channel, there is no diversion potential. If the stream overtops the crossing and flows down the road, there is diversion potential.

Diversion potential exists on roads that have a continuous climbing grade across the stream crossing or where the road slopes downward away from a stream crossing in at least one direction (Furniss 1997).

Diversion potential affects the SWRCI when the road-design elements do not adequately account for diversion. In many cases, designed diversion-prevention dips below culverts ensure that a stream that overtops its culvert will stay in its natural channel.

Questions potentially addressed

- Do the road segment design elements (physical characteristics of the road) account for diversion potential?
- What is the diverting feature (road or ditch)?
- What is the potential diversion distance (how far will the water flow before entering its original channel or another existing channel)?

Related indicators

The following indicators help assess the potential adverse effects of stream diversion. A diversion potential on an outsloped road with a road gradient of less than 5 percent may have localized erosion. The diversion potential can be eliminated easily with a diversion-prevention dip. On an insloped road with a road gradient of 12 percent, the extent of diversion potential may be greater and the solution is more difficult and costly.

- Road-template surface shape.
- Road gradient.
- Road-surface drainage.
- Road-surface material.

Utility

Diversion potential at road-stream crossings is relatively easy to identify and inexpensive to repair (Furniss 1997). The potential effect of a stream diversion to soil and water resources can be significant and very costly—if not impossible—to repair in many locations. The soil lost during the incision process of the new stream channel is rarely accounted for in the damage-survey report. Repairs generally modify the road-prism geometry to prevent diversion potential, but in some cases, the fix comes after a significant soil loss and deterioration of water quality.

Inventory data collected in California, Oregon, and Washington, determined that 56 percent of the 1,922 road-stream crossings on Federal lands would divert with exceedance events. The potential diversion distance varied with 36 percent exceeding 31 meters in distance (Furniss 1997). Road-stream crossing assessments have been the focus on many forests to alleviate the threat of diversion potential. (Scaife, personal communication).

Measure
Diversion potential in a road segment is determined by identifying the interaction of drainage structures (road-stream crossings and ditch-relief culverts) with the road-design template or road-surface shape. Reviewers evaluate the low point of the road over the crossing structure compared to surroundings to determine where water will flow should the crossing pond water and overtop. The number of crossings with diversion potential on the road segment is then divided by the total number of crossings to identify a percentage of crossings.

5. Road-Stream Connectivity

Description of indicator
Connectivity is the extent to which the drainage features of a road system are linked directly to the channel network. Research shows that roads intercept surface and subsurface flow and reroute runoff to the channel network through ditches (Forman 2003). Connectivity generally is expressed as the percentage of the total road length connected to the channel network rather than the percentage of a given road segment.

A road's hydrologic connectivity includes flows between cross-drain culverts on an insloped or crowned road, and any continuous flowpath from the culvert outlet to the stream via a gully. Steeper hillslope gradients (greater than 40 percent) have a higher predictability of gullying at cross-drain outlets (Wemple 1996).

Questions potentially addressed
- How and where is the road hydrologically connected to the stream?
- What are the characteristics of the segment that is hydrologically connected to the stream?
- What percentage of the road network in a watershed is hydrologically connected?

Related indicators

The effect of hydrologic connectivity can be better assessed in combination with these related indicators:

- Road-template design/surface shape.
- Road-surface drainage.
- Condition of culvert/drainage facility.
- Diversion potential.
- Road gradient.
- Hillslope gradient.
- Cutslope condition.
- Fillslope condition.

Utility

The hydrologic connectivity of roads is a simple indicator to identify and provides valuable information on the amount of total road-stream connectivity in a watershed. Where road-stream hydrologic connectivity exists, accelerated runoff, sediment, and road-associated chemicals have a direct route to surface waters (Furniss 2000).

Wemple (1996) studied surface runoff from roads by analyzing the amount (volume) and timing effect from increased drainage efficiency. Approximately 57 percent of the road length surveyed functioned as flowpaths and was hydrologically connected to the stream network. The type of flowpath varied and included road segments directly draining to streams, and road segments draining to culverts with gullies incised below.

Wemple tested a model to predict gullies below ditch-relief culverts. Gullies were predicted accurately using the length of road segment contributing to the culvert and the hillslope gradient where the road is located.

In contrast, La Marche (2001) found that the hillslope curvature and distance to the natural stream channel are the most important variables in determining connectivity of ditch-relief culverts to the channel network. Hillslope curvature relates to the “concentration of subsurface flow and, therefore, to the occurrence of surface flow and channel initiation” (La Marche 2001).

Croke et al. (2001) studied gully initiation and road-to-stream linkages in Australia and found that 18 percent of the surveyed road was hydrologically connected to the stream via gully development from culverts. Most hydrologically connected road segments were in the midslope position (on the hillslope) and had three times larger contributing areas than the roads on the ridgetop position. Additionally, gully development could be predicted 79 percent of the time from a statistical functional analysis using contributing road length or area and hillslope gradient. Croke et al. also found that the size of sediment produced from the roads fell into the less than 2.0 millimeter in diameter class. Other studies link deleterious effects to aquatic organisms from fine sediment.

The utility of the hydrologic connectivity indicator is that—once identified—the ability to "disconnect" road segments can be achieved through reconstruction, maintenance, and relocation. Croke (1999) suggested that runoff delivery in nonchannelized pathways could be controlled by manipulating the runoff volume and better distributing runoff across a hillslope. Croke found that sediment concentrations in runoff entering a gully will persist within the gully pathway without any deposition. Therefore, practices that reduce hydrologic connectivity through gullies and focus on dispersive road-surface drainage designs, such as outsloping, may substantially cut sediment delivery to streams.

Measure

Road-stream connectivity is determined two ways: (1) Identify ditch lengths and road segments that drain directly into a stream. Ditches on insloped roads commonly drain to the inlet of a stream-crossing structure. (2) Identify ditch lengths that drain to ditch-relief culverts that show scour at the outlet, which result in gullies that eventually lead to a stream channel. Measure those ditch lengths with gully erosion greater than 10-meters below the culvert. Identify the length of contributing area for each category of culvert and divide by the total length of the road segment to rate.

6. Road-Surface Condition

Description of indicator

Road-surface condition identifies active erosion or rutting on the road surface. Rill and gully formation within the traveled way may adversely affect soil and water quality. Potential erosion of surface fines from heavily used roads, which result in soft powdery materials susceptible to erosion, also may adversely affect soil and water quality.

There are different types of erosion: sheet, rill, and gully. Sheet erosion is a uniform detachment of soil particles from the soil surface. Rill erosion is the detachment and transport of soil by a concentrated flow of water. Rills are a minimum depth of 1 inch, a minimum length of 12 feet, and a depth change of at least 25 percent over the 12-foot length. A gully is defined as an erosion channel where water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 to 2 feet to as much as 75 to 100 feet. (Brady 1984)

Questions potentially addressed

- How does the road-surface condition affect erosion rates?
- How does the road surface channelize surface flow?

Related indicators

- Road gradient.
- Soil texture.
- Road-surface drainage.
- Road-surface material.
- Traffic level.

Utility

Rills, gullies, and ruts are detected easily while surveying a road segment. Loose road material also can be a key factor in the surface condition. Roads receiving high levels of traffic or experiencing droughty conditions become dusty and have excessive material that is mobilized easily in a storm event. Road-gradient and road-surface material particle size are two key variables influencing sediment production from roads (Kahklen 2001).

Clues to how a road responds to runoff are not always apparent. Field review of a road segment during the summer may not reflect rutting from wet-season use. Maintenance activities, such as road grading, may remove or repair evidence of rill-and-gully patterns. Ziegler (2004) found that flow-path changes caused by ruts were later remedied with maintenance. Similar results are seen with loose road material. The first storm provides an initial flush of sediment with a gradual decline in material transported. Sediment transport is limited by the detachment of new material, which is a function of surface erodibility. Adjust field visits accordingly to target segments that may be vulnerable to rills, gullies, ruts, and loose road material.

Measure

Surveyors determine the surface condition by identifying the presence, absence, and extent of rills, ruts, and gullies along the road segment.

7. and 8. Cutslope and Fillslope Condition

Description of indicator

The footprint of a road on the landscape is measured from the top of the cutslope to the toe of the fillslope. The amount of material removed or disturbed during road construction affects revegetation and overall hillslope stability. Subsurface flows on cutslopes may cause instability and long-term maintenance needs. Fillslopes provide buffers and can disperse runoff and trap sediment effectively if well-vegetated and stable.

Questions potentially addressed

- How and where does the road intercept subsurface flow?
- How and where does the road affect cutslope or fillslope stability?
- How and where does the cutslope modify erosion rates?

Related indicators

The cutslope- and fillslope-indicator is examined in the context of the following indicators:

- Road gradient.
- Hillslope gradient.
- Road-surface drainage.
- Road-stream connectivity.
- Soil texture.

Utility

The cutslope and fillslope condition affects sediment production. Cutslope and fillslope stability is observed by determining the amount of surface vegetation and cover on the slope. Luce and Black (1999) found that road segments cleared of vegetation produced seven times more sediment than road segments where vegetation was retained. Researchers (Appelboom 2002; Burroughs 1990; Burroughs and King 1985; Croke 2006; and Wemple 2003) identified the importance of the cutslope in sediment-production capability and the effectiveness of different mulches and vegetation in reducing sediment.

Burroughs (1990) found that filter windrows are cost effective in reducing sediment yield by 88 percent compared to untreated fillslopes. Burroughs found sediment-reduction decreased as slope-gradient and silt-content increased.

Measure

Identify the effective soil cover and stability rating for both the cutslope and fillslope. Use tools, such as aerial photography to identify roads with large cuts and fills, and geographic information systems to overlay hillslope gradient, roads, and sensitive soil types to detect potentially unstable areas.

Section 3: Other Road Condition Evaluation Considerations

Traffic Level

Traffic is the amount of use a road receives. Traffic is defined by type, frequency, and seasonality. Unfortunately, Forest Service traffic counts are seldom collected over an entire watershed. However, information on commercial haul is accounted for in timber receipts and estimated from road-use permits.

Questions potentially addressed

- How and where does traffic affect the erosion and sediment potential of the road?
- How does the seasonality of use affect the road condition?

Related indicators

- Road-surface material.
- Road-surface condition.
- Road gradient.
- Soil texture.

Utility

Studies link the traffic level on roads to erosion and sediment production from roads with high-traffic use (defined as over four logging trucks per day) (Cederholm et al. 1980). Studies by Croke (1999) in the Cuttagee Creek watershed found traffic volume influenced the amount of sediment available for mobilization. Estimates of traffic were ranked similarly to those of Cederholm et al. (1980) and Reid (1981). Croke's work complements earlier studies by Reid and Dunne (1984) and found the following:

1. Sediment concentrations in road runoff were between five- and eight-times higher on well-used roads than abandoned ones.
2. Roads with higher intensity traffic have greater volumes of loose material available at the surface.
3. Roads used infrequently or abandoned have little sediment and are minor sources of sediment (Croke 1999).

Measure

Traffic on a road segment is divided into three categories: high, low, and closed. The three categories serve as an initial screening tool despite the relative subjectivity that may occur between designating a high or low surface-traffic level. Prior to conducting SWRCI, each forest staff should document the criteria for assessing surface traffic. In many areas, traffic levels adjust seasonally based on access and recreational opportunities. In other situations, commercial log-haul or chip-van access can occur for just one to two seasons with low traffic thereafter.

A closed road has a barrier to prevent vehicle access. A level 1 road has barriers that prevent vehicle traffic. The SWRCI assessment must be done by walking the road.

A road may be rated as high from administrative and commercial traffic associated with a forest health project; oil and gas exploration; or recreational traffic to a popular destination, such as a campground, fishing area, or day-use facility. Generally, collector and arterial roads have more volume, and low-traffic volume roads are associated with local and spur roads.

Soil Texture

Description

Soil erosion from a road's surface, cutslope, or fillslope can adversely impact water quality. Erosion reduces soil quality, and vegetation establishment on degraded soils is more difficult. Keep soil erosion to a minimum to reduce a road's potential adverse impact on soil and water resources.

Different erosional processes occur on roads due to reduced infiltration. The response of roads to runoff varies with soil-particle size, slope length, and road gradient. Roads constructed with large cuts and fills may use road-surface material from another soil horizon or imported from offsite. Identifying the soil texture can help in locating and designing a road to prevent accelerated erosion and to ensure adequate bearing capacity of the road.

Questions potentially addressed

- How and what erosional processes occur on the road?
- What soil-particle size is dominant throughout the road segment?
- What segments of road have the higher erosion rates?
- What type of road-template design and road-surface drainage is present on roads with high erosion rates?
- What is the length of the contributing area?
- How does the road drainage affect erosion on or off the road?

Related indicators

Indicators directly related to the erosional process on a road include the following:

- Road gradient.
- Road-surface material.
- Cutslope condition.
- Fillslope condition.

Utility

Soil texture provides information on potential adverse effects to downstream values from erosion and subsequent sediment delivery. Fine-textured soils may adversely affect spawning gravels, or reduce water clarity. Soil texture is a component of the WEPP model. The WEPP road model (Elliott 2004) data are entered into the Web-based model to estimate sediment production and delivery. Forest staff and private landowners collect information on soil texture as a part of the WEPP model to estimate the sediment loads from unpaved roads entering streams (Watershed Conservation Resource Center, unpublished paper).

Luce and Black (1999) found that soil texture has a strong effect on sediment yield. The finer textured soil produced more sediment than coarser, sandy soils. Even with gravel (aggregate) placed on roads, silty-clay loam soils produced nine times more sediment than roads constructed on a gravelly loam. Burroughs (1992) using laboratory tests and rainfall simulation found low erodibility in clay- and sand-dominated soils, with higher erodibility as the silt-fraction increased.

Measure

Identify the dominant soil texture: clay loam, sandy loam, silt loam, or loam. Soil texture can be preidentified from the soil-resource inventory for the forest and used to pre- or post-stratify road segments. The soil textures can be included in the Web-based WEPP model to identify sediment production from different road segments.

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