Mapping ecosystems at the landform scale in Washington State

By Jon Riedel and Jeanna Probala

Resource managers in the North Coast and Cascades Network (fig. 1) have used landform data to identify and understand endangered species habitat, geologic hazards, and cultural resources. Such data are used to create maps, which can help identify the extent of plant and animal communities, model locations of archaeological sites based on "old and stable" landform types, and predict soil distribution in rugged and inaccessible locations. Additionally, park managers may use landform data in the study of natural hazards and for the design of geotechnical projects (e.g., foundations, bridge sites and road cuts, surface and subsurface drainage systems, and remedial landslide stabilization measures). Because landforms directly relate to habitat types, collaboration with the USDA Forest Service has resulted in the identification of the extent of lynx and wolverine habitat by linking landtype, topography, and vegetation.

Resource managers ... have used landform data to identify and understand endangered species habitat, geologic hazards, and cultural resources.

Discrete geologic processes such as glaciation, mass movement, and flooding create particular landforms. The link between landforms and geologic processes is the key to their utility for a range of applications. For example, hazardous geologic processes create distinct landforms that are important to recognize for development and public safety.

Using landform data as the cornerstone for developing new approaches for mapping landscapes in Washington State allows resource managers to meet a goal of the Natural Resource Challenge: to complete inventories of soils and surficial geology. In 2003 we began a pilot mapping project at the landform scale (1:24,000) in the lower Elwha River watershed in Olympic National Park. The project's aim is to provide information on geology-soil-vegetation patterns for future restoration efforts following removal of hydroelectric dams. In addition to mapping terrace, alluvial fan, and floodplain boundaries, we also identified several important moraines deposited by continental glaciers at the end of the last ice age 17,000 year ago, as well as perched deltas and terraces formed in glacial Lake Elwha.

With our collaborators, we have produced landform and surficial geology maps for the Washington Cascades at three different scales: subsection, landtype association, and landform (table 1).

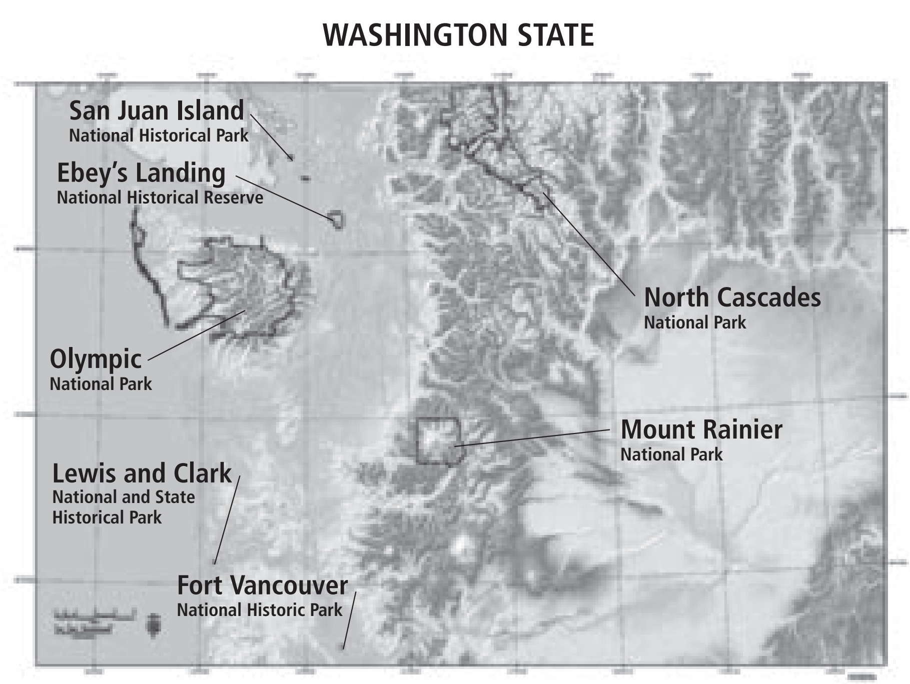


Figure 1. Since 1998 collaborators in landform-scale mapping have completed inventories of several watersheds within the North Coast and Cascades Network, which includes Ebey's Landing National Historical Reserve, Lewis and Clark National and State Historical Park (incorporating Fort Clatsop National Memorial), Fort Vancouver National Historic Site, North Cascades National Park, Mount Rainier National Park, Olympic National Park, and San Juan Island National Historical Park.

Units of the subsection scale (1:250,000) are determined by climate, bedrock geology, and topography at a regional scale. The landtype-association scale (1:62,500) is based on topography and features created by erosional processes (some landforms are relicts). The landform scale (1:24,000) focuses on depositional landforms created by a range of processes. This multiscaled scheme is a nested system for mapping ecological land units that is known as the "National Hierarchical Framework of Ecological Units" (USDA Forest Service 1993) (table 1). Ecological land units describe the physical and biological processes that occur across the landscape and are used for ecosystem classification and mapping purposes (Davis 2004).

Table 1. National Hierarchical Framework of Ecological Units

Ecological unit	Map scale range
Domain	1:130,000,000 or smaller
Division	1:130,000,000–1:7,500,000
Province	1:15,000,000–1:5,000,000
Section	1:7,500,000–1:3,500,000
Subsection*	1:1,500,000–1:1,250,000
Landtype association*	1:250,000–1:62,500
Landform*	1:24,000

Source: USDA Forest Service (1993).
Note: The National Park Service focuses on mapping at the landform scale.
*Scales at which the USDA Forest Service and National Park Service are mapping in Washington State.

Previous uses of landform mapping

In 1988 staff at North Cascades National Park used the landform-mapping scheme to assess distribution of archaeological sites. This program continued to develop in the early 1990s when a suite of 15 landforms was used to map floodplains and geologic hazards for the general management plan of Lake Chelan National Recreation Area, part of the North Cascades Park Complex. In 1995 the program expanded to meet the needs of North Cascades National Park as a "prototype park" in the national Long-Term Ecological Monitoring Program. To select ecological reference sites, we developed a 23-landform scheme and mapped the Chilliwack and Thunder watersheds, two of three "target watersheds" (table 2).

In 2001, staff at North Cascades National Park and the USDA Forest Service joined forces to map ecological units on all public lands in the North Cascades region. We mapped federal lands at the subsection scale for the Washington Cascades. Examples of the 23-unit scheme include high elevation plateaus and highlands, volcanic cones, and metamorphic cascade hills. We also have cooperatively mapped most of North Cascades National Park and all of Mount Rainier National Park at the landtype-association scale. Landtype-association units include scoured glaciated mountain slopes, glacial valley bottoms, and meltwater canyons. Since 1998 we have modified the 1995 landform-scale scheme to apply it at geologically different parks throughout the North Coast and Cascades Network (fig. 1).

Landform-mapping techniques

Primary tools used to map landforms are topographic maps, DEMs (digital elevation models), digital orthoquad images (digital aerial photos covering a 7.5-minute quadrangle), large-scale stereo air photos, and geologic maps. Initially we use the pattern of contour lines on USGS 7.5-minute topographic maps in conjunction with 1:12,000 color stereo air photos to outline landforms. Though some landforms (e.g., debris avalanches, bedrock benches, and debris cones) are easily recognizable using air photos and contour lines, other landforms (e.g., terraces and small mass movements) require field identification. Fieldwork generates additional information about terrace heights, floodplain boundaries, and material type. During field investigations, we also complete landslide inventories. After identifying the landforms and drawing the boundaries, we review each area for accuracy and mapping consistency. All boundaries of landforms are then drawn onto UTM- (Universal-Transverse-Mercator-) registered Mylar and a large-format scanner transfers lines into digital format. Using ESRI (Environmental Systems Research Institute) software, scans are edited and polygons (representing landforms) labeled, resulting in a digitized map (fig. 2, page 40).

For an assessment of geologic hazards in 2002 we acquired lidar (light detection and ranging) data for a pilot study of the Tahoma Creek watershed at Mount Rainier National Park, and in 2004 for the lower Stehekin Valley at North Cascades National Park (fig. 3, page 41). Lidar enhances and facilitates mapping because of its ability to penetrate vegetation cover, create three-dimensional bare-earth topographic images, and provide vertical accuracy to approximately 4 inches (10 cm). Because we had previously mapped landforms in these watersheds we used the lidar image to check the accuracy of mapping. We found that our original lines captured most landforms, but that lidar allowed us to adjust boundaries for better precision. Based on these results, we believe future soils, landform, and vegetation mapping projects would benefit from using lidar during the initial stages.

Results and discussion

To date, we have mapped all federal lands along the Cascade crest in Washington State at the subsection scale (table 1). At the landtype-association scale, all of Mount Rainier National Park and 75% of North Cascades National Park are complete. At the landform scale 73% of North Cascades, 15% of Mount Rainier, and 5% of Olympic National Parks are complete. We have mapped,

Table 2. Percentage of watershed by landform type, North Cascades National Park

Landform type (abbreviation)	Watershed (area)				
	Stehekin (209mi^2 [542 km^2])	Thunder (116 mi^2 [301 km^2])	Chilliwack (84 mi^2 [218 km^2])	Bacon (51 mi^2 [133 km^2])	Baker (95 mi^2 [246 km^2])
Alluvial fan (af)	0.5	0.2	0.1	0.0	0.1
Alluvial fan terrace (ft)	0.2	0.1	0.1	0.1	0.4
Arête (a)	0.5	1.3	1.1	0.5	1.0
Bedrock bench (bb)	1.0	1.0	0.0	0.6	0.3
Debris apron (da)	10.0	9.5	9.8	8.7	5.9
Debris cone (dc)	2.8	2.7	3.8	2.2	2.6
Cirque (c)	6.1	19.3	19.4	12.7	15.9
Floodplain (fp)	1.7	1.9	2.8	1.4	1.5
Horn (h)	0.4	0.6	0.6	0.1	0.2
Little Ice Age moraine (lm)	0.2	0.1	0.3	0.1	0.4
Mass movement–debris avalanche (mm-da)	0.3	2.1	1.5	0.4	0.8
Mass movement–debris torrent (mm-dt)	0.1	0.1	0.0	0.0	0.2
Mass movement–fall/topple (mm-f)	1.4	1.6	0.1	1.0	1.6
Mass movement–slump/creep (mm-s)	0.0	0.0	1.6	0.0	0.0
Other mountain (o)[1]	0.2	0.1	0.0	0.2	0.1
Pass (p)	0.1	0.2	0.2	0.0	0.0
Pleistocene moraine (pm)	0.5	0.2	0.5	0.3	0.1
Ridge (r)	0.7	0.6	2.2	1.1	1.0
River canyon (rc)	1.0	1.3	1.4	0.4	0.8
Terrace (t)	1.0	1.0	1.1	0.9	0.7
Undifferentiated (u)[2]	0.1	0.1	0.0	0.0	0.0
Valley bottom (vb)	0.9	0.5	0.2	0.3	0.7
Valley wall (vw)	70.5	55.4	53.1	68.8	65.4

Source: National Park Service (unpublished data 2005).

[1]Other mountain (o) is a low-elevation peak that was modified by the Cordilleran Ice Sheet.

[2]Undifferentiated (u) is a landform of unique expression that staff cannot explain and does not fit within other units in the scheme.

but not yet finalized, areas in San Juan Island National Historical Park and Ebey's Landing National Historical Reserve. At the 2001 George Wright Society biennial conference, we presented mapping at the three scales. We also showed our results of mapping specifically at the landform scale within North Cascades National Park at the 2003 Geological Society of America annual meeting (Riedel et al. 2003).

We have mapped all federal lands along the Cascade crest in Washington State at the subsection scale.

Using landform mapping at North Cascades National Park, we estimate that landslides cover an area of about 2.4% of each watershed mapped to date; combined with debris cones and debris aprons they cover about 11% of the park. The majority of the park is classified as cliff and valley wall, which underscores the active nature of geology in this region.

Information on landscape stability provides a means for site selection of long-term ecological monitoring reference sites and facility location. We created a landslide database to accompany landform maps with data collected on 18 characteristics of each landslide, including age (if known), activity, bedrock geology, volume, material type, and impact to streams. These characteristics describe the stability of a slope and the impacts to streams. They also aid in cost and risk management decisions of trail, campground, and bridge placement.

At North Cascades National Park, we identified 222 landslides in the Baker River valley and classified 33 as mass movement–debris avalanches (table 2). A debris avalanche is the largest of four landslide types mapped and these deposits are particularly significant because of their size, potential to block streams, and ability to transport massive amounts of large woody debris and sediment. Debris avalanches displace millions of cubic meters of debris. More than half of the avalanches mapped in the Baker River valley either delivered sediment to a stream or blocked it entirely. Three of the largest debris avalanches in the Thunder Creek watershed have periodically blocked Fisher Creek (fig. 2).

At the landform scale at North Cascades National Park, results indicate that floodplains and associated riparian and aquatic habitats are found in only 2% to 3% of the watersheds. Knowing the location and extent of the limited riparian and aquatic habitat has important implications for recovery of chinook salmon (*Oncorhynchus tshawytscha*) and bull trout (*Salvelinus confluentus*), two threatened and endangered aquatic species.

Stable, relatively old surfaces such as terraces and bedrock benches occur in only 2% to 6% of the mapped watersheds at North Cascades National Park. Previously linked landform-archaeological surveys in the park have shown a close relationship between archaeological site density and landform type (age). That is, the oldest surfaces in this rugged and remote area correspond to the most extensive human occupation during the past 10,000 years.

Needs and developments

A major gap in our natural resource inventories is information about soils. Soils data from the North Coast and Cascades Network are limited to an outdated soil survey for Ebey's Landing National Historical Reserve and a survey, in progress, at San Juan Island National Historical Park. Using "traditional" methodologies, relative inaccessibility and estimated high costs have precluded extensive soil surveys in North Cascades, Olympic, and Mount Rainier National Parks. Because parent material, time (age), and relief are three of five soil-forming factors, digital landform maps are the cornerstone of new approaches to mapping soils in remote, rugged landscapes. Understanding this link between soils and landforms allowed us to develop a pilot project with Washington State University that used our landform maps of Thunder Creek watershed as a primary data layer in development of a soils model.

A major gap in our natural resource inventories is information about soils.

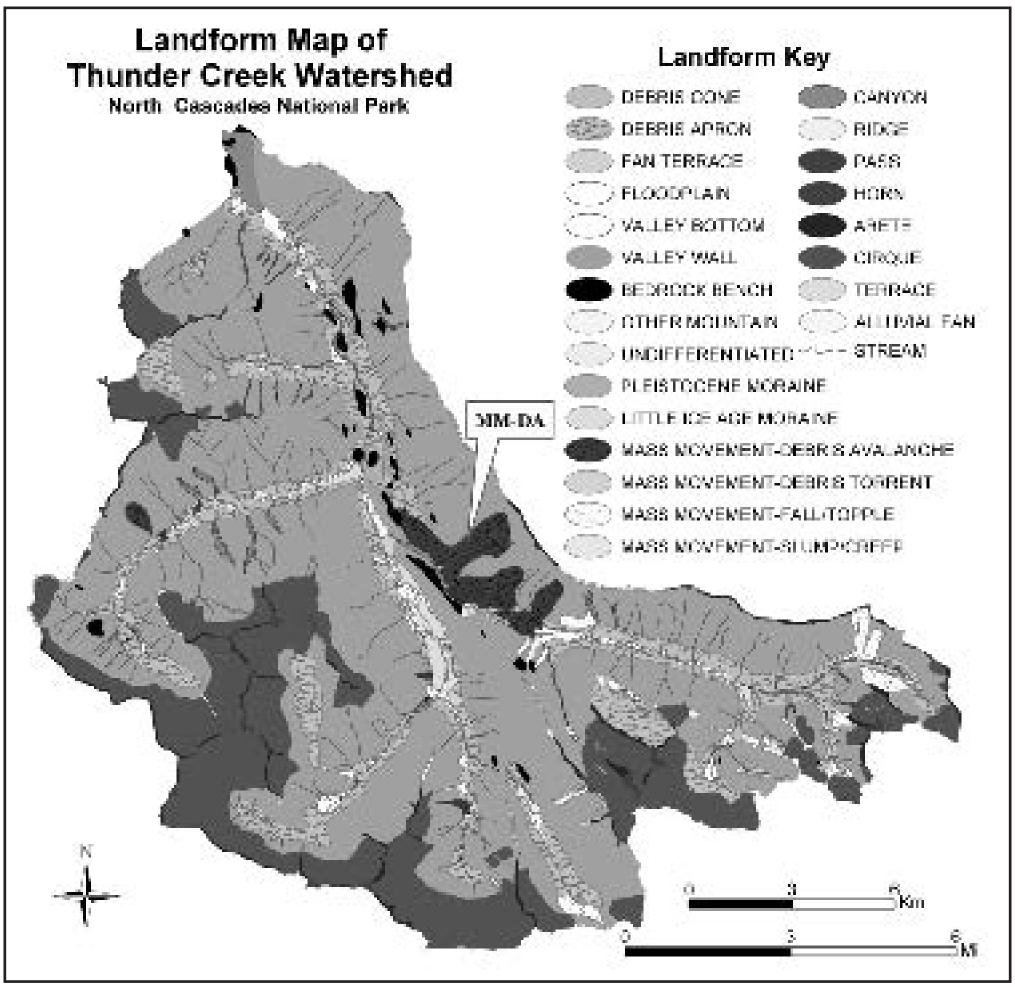
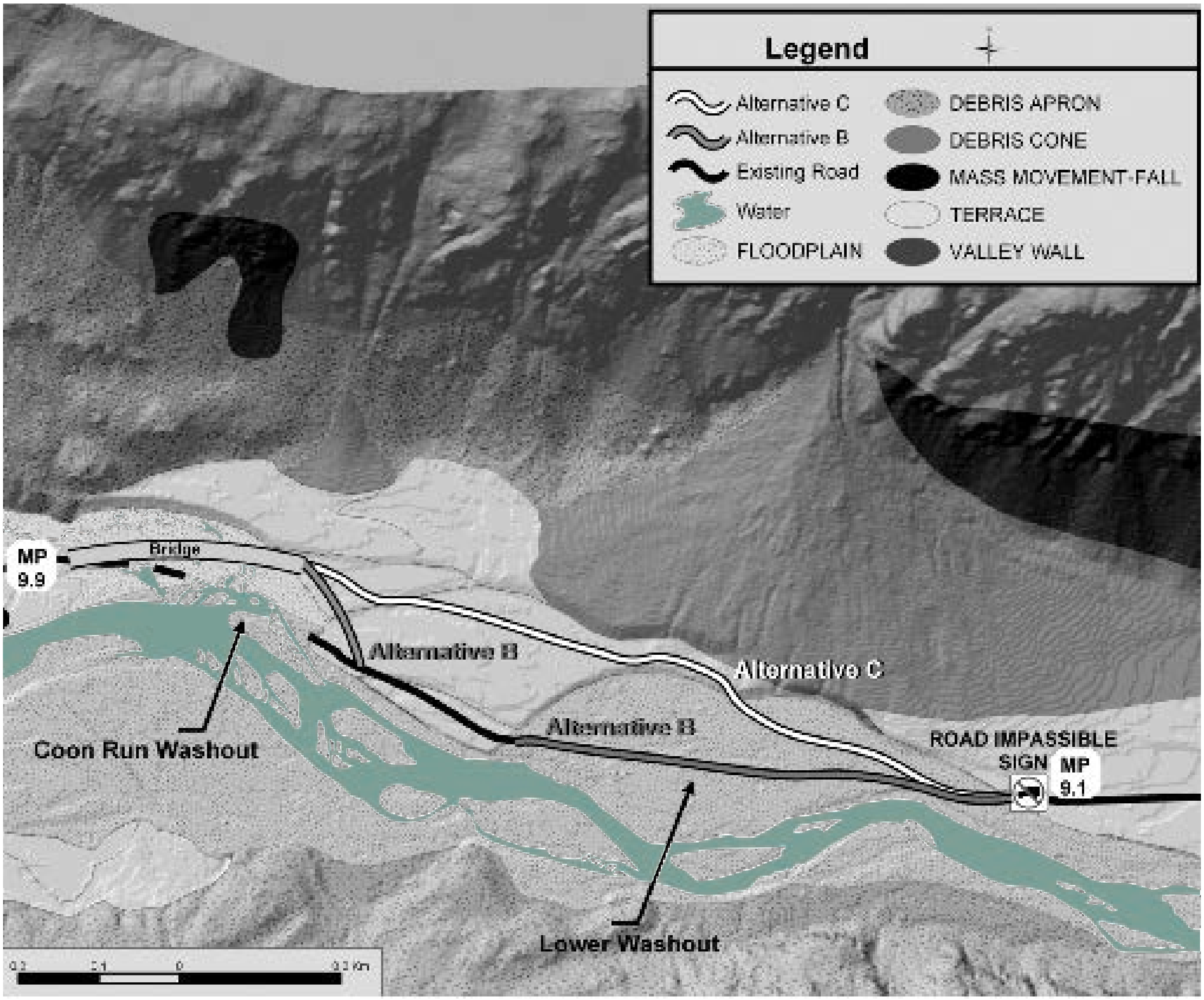


Figure 2. Landform maps at the scale of 1:24,000 provide the resolution necessary to address key resource management issues. Landslides, particularly the largest of four types called debris avalanches, are of management concern because of their size, potential to block streams, and ability to transport massive amounts of debris. The label "MM-DA" highlights one of the largest debris avalanches in the Thunder Creek watershed, covering an area of about 0.8 square mile (2 km²).

SOURCE: NATIONAL PARK SERVICE (UNPUBLISHED DATA 2003).



Soil Order Distribution Among Landforms

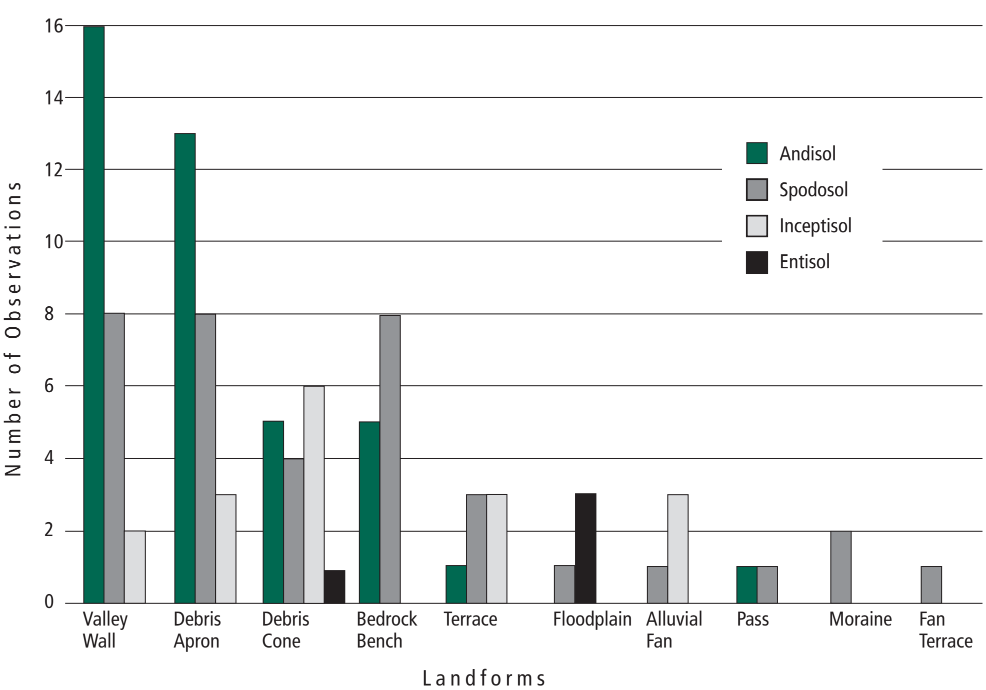


Figure 3 (map). In October 2003 a heavy rain-on-snow event flooded many rivers across western Washington. At North Cascades National Park, the floods washed out two sections of the Stehekin Valley road. Resource managers used landform maps and lidar to assist in developing road replacement alternatives. Alternative B suggests partially rebuilding the road on a floodplain; alternative C uses terraces adjacent to the floodplain; both use a bridge spanning the most hazardous spot.

SOURCE: NORTH CASCADES NATIONAL PARK (UNPUBLISHED DATA 2005).

Figure 4 (graph). Landform data show a strong correlation between landform type and soil order. For example, in the Thunder Creek watershed, andisols (soils formed in volcanic ash) are associated with landforms such as debris aprons where ash accumulates. Spodosols (acid soils with a subsurface accumulation of metal-humus complexes) are associated with older landforms such as moraines and terraces. Inceptisols (soils with weakly developed subsurface horizons) and entisols (soils with little or no morphological development) are found on recent floodplain and landslide deposits.

SOURCE: CRYSTAL BRIGGS, WASHINGTON STATE UNIVERSITY (UNPUBLISHED DATA 2003).

Linking soils information to landforms is a cooperative effort among North Cascades National Park, the Natural Resource Conservation Service state mapping program, USDA Forest Service, Washington State University, and the NPS Soils Program. A digital soils model using landform data from Thunder Creek watershed shows a strong correlation between landform type and soil order (fig. 4). Encouraged by these results, we are currently using landform maps to develop soil models for the remainder of North Cascades National Park. We will continue to develop this approach with our partners to obtain soil resource inventories for all units of the National Park System in Washington State.

Digital landform maps are the cornerstone of new approaches to mapping soils in remote, rugged landscapes.

Future work

In addition to soils mapping, our immediate efforts will focus on two areas. First, we will complete landtype-association scale mapping of North Cascades and Olympic National Parks. Second, we will complete landform-scale mapping for all of North Cascades and Mount Rainier National Parks, and the Elwha River valley at Olympic National Park. We will continue to use lidar, where available, to assist with mapping of new areas and to check previously mapped watersheds. Also, in order to standardize data collection within the network and to help assist future researchers, we are developing a landform-mapping protocol and a report for each large watershed.

References

Davis, C., 2004. Landtype associations of north-central Washington. USDA Forest Service, Wenatchee, Washington.

Riedel, J., M. Davis, and J. Probala. 2003. Surficial geology mapping of North Cascades National Park. Geological Society of America Abstracts with Programs 35(6):75.

USDA Forest Service. 1993. National hierarchical framework of ecological units. U.S. Department of Agriculture, Washington, D.C.

About the authors

Jon Riedel is the park geologist and Jeanna Probala is a physical science technician at North Cascades National Park in Washington. They can be contacted at 360-873-4590, x21, and x53, respectively, or at jon_riedel@nps.gov and jeanna_probala@nps.gov.