

SURFICIAL GEOLOGY
OF
NERSTRAND BIG WOODS STATE PARK



Minnesota Department of Natural Resources
Division of Lands and Minerals
William C. Brice, Director

Project 336-3

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Glenn D. Melchert
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Surficial Geology of Nerstrand Big Woods State Park

Introduction

Nerstrand Big Woods State Park is located in eastern Rice County in southeastern Minnesota (see map in pocket). The focus of this project was on the surficial geology of the park. Surficial geology is defined as the geologic material encountered below the soil. The geology revealed in the park covers a span of time of almost 500 million years. Four bedrock units comprised of sandstone, shale, and limestone were deposited in a shallow subtropical sea that covered the area long ago. After a long period of erosion, glaciers periodically covered the area during the last one or two million years. Erosion of the glacial deposits has resulted in a dissected landscape visible today in the park and surrounding area.

Purpose. The goal of this study was to: 1) create a surficial geologic map of the park and surrounding area in a GIS format, and 2) to evaluate geologic or hydrologic reasons for the pervasive erosion and consistently wet trails in the park. The answers to the second purpose provide some siting and design criteria for trail placement within the park.

Methods. The surficial geology map and the results presented in this report were based on interpretations of 1:24000 USGS topographic quadrangles (Nerstrand and Canon City quads), digital orthophoto quadrangles (1991), color infrared air photos at 1:40,000 scale (NAPP dated 4/17/91), black and white air photos at 1:20,000 scale (dated 9/29/64), well log data (county well index), Soil Survey of Rice County (1999), published reports, and field work conducted from July to November 1999. The base map used in the field was a paper copy of a digital 1:24000 scale USGS topographic quadrangle superimposed upon a digital orthophoto quadrangle printed at a scale of 1:7200. Data collection in the field consisted of soil auger holes, test pits, and field observations in gully exposures, stream banks, and outcrops.

Geologic History

Bedrock Units. All of the bedrock formations exposed in the park were deposited during the Ordovician Period, representing a time from 500 to 440 million years ago. The St. Peter Sandstone is the oldest geologic formation exposed in the park. Other formations exposed, from oldest to youngest, are the Glenwood Formation, Platteville Formation, and the Decorah Shale, respectively (Figure 1). These sediments were deposited as a sea gradually encroached upon and covered this area. The sea came from the south.

The St. Peter Sandstone consists of nearly 100% pure quartz sand grains. This sand was deposited in a near-shore or beach marine environment. The individual sand grains are well rounded and weakly cemented together such that in some parts of the formation the sandstone crumbles to the touch. Outcrops appear smooth at a distance. They occur intermittently along the valley floor at the north end of the park.

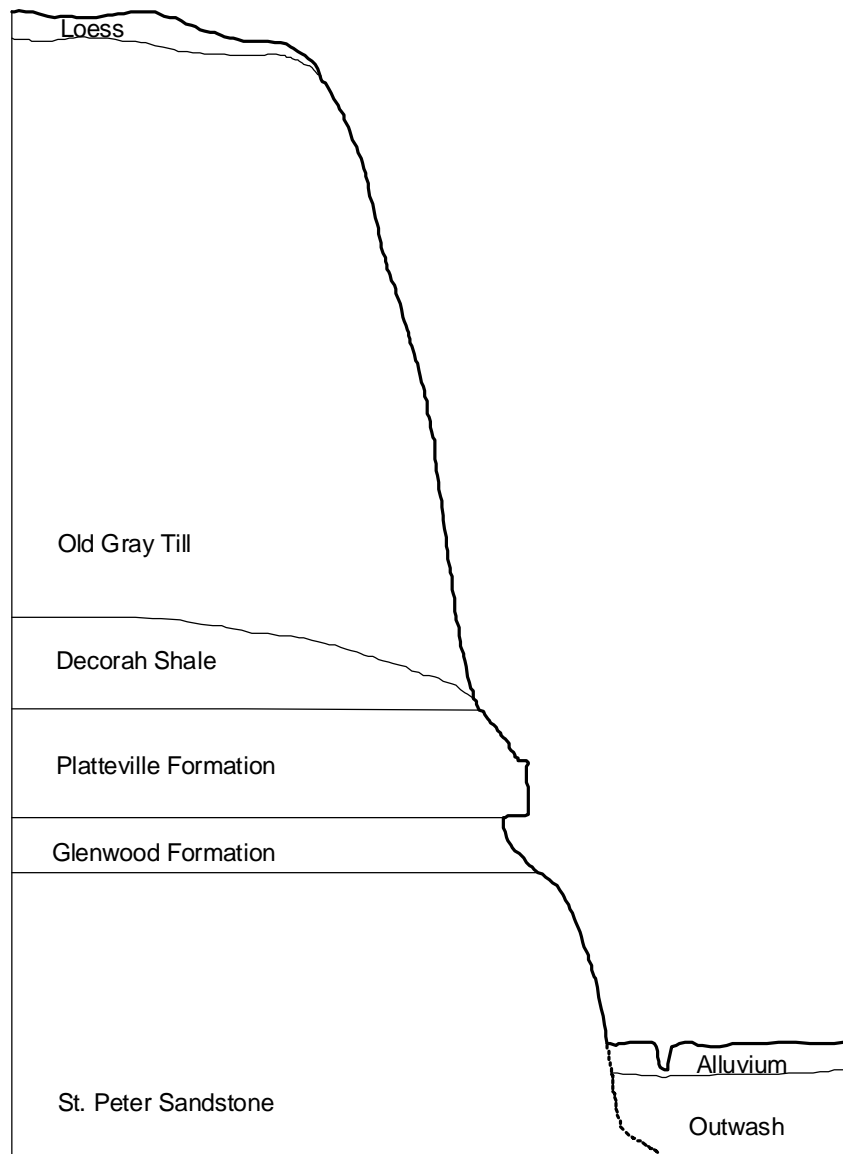


Figure 1. Schematic columnar section showing the stratigraphic relationships of the primary geologic units found in the park. The Decorah Shale, Platteville Formation, Glenwood Formation, and St. Peter Sandstone were deposited during the Ordovician Period. The glacial till and loess were deposited during the Quaternary Period.

As the sea advanced, the shoreline moved further north and silt and clay were deposited. This unit is called the Glenwood Formation. It erodes easily and usually is buried under soil and rock debris on slopes. Rare exposures occur in gullies and along stream banks where flowing water has removed the overlying soil.

The sea continued to rise and the shoreline moved far to the north resulting in relatively clear water. Warm, clear sea water was conducive to the chemical precipitation of calcite, which, along with the shells of numerous species of invertebrates, formed limestone which became the Platteville Formation. Periodic pulses of muddy water carried silt and clay into the area which settled out to form the shale beds within the Platteville Formation. The upper half of the formation is prone to erosion because of the numerous shale beds, and in many areas this portion is covered or eroded. The lower half of the formation contains almost no shale and therefore is resistant to erosion and forms ledges. Waterfalls flow over the lower half of the formation's resistant ledges.

An influx of silt and clay, perhaps coupled with a shallower sea, set the stage for deposition of the Decorah Shale. The Decorah Shale is soft and, without a cap rock such as limestone to cover and protect it, is eroded or buried under till in the area mapped. Only one outcrop was found in the entire mapping area.

At least four more formations, with a total thickness of hundreds of feet, were deposited over the Decorah Shale (Mossler, 1995). Withdrawal of the sea, however, and about 350 million years of erosion, with only one relatively short-term readvance of the sea, have removed most of these rocks from this part of the county and points north (Ojakangas and Matsch, 1982).

Glacial Units. The Pleistocene Epoch, a period in geologic time that marks the great ice age, began around two million years ago and continued until the last glacier in this part of the state melted about 10,000 years ago. This was a time when glaciers episodically came out of Canada and flowed across the state. Each glacier deposited a layer of till often along with deposits associated with melting glaciers, such as gravel, sand or lake sediments. Later glaciers typically flowed along the same routes and removed or buried the older glacial deposits.

Old glaciers, designated pre-Wisconsinan, covered all of Minnesota, except possibly for a segment of highland adjacent to the modern-day Mississippi River in southeastern Minnesota, sometime between 125,000 and 700,000 years ago. The pre-Wisconsinan glaciers that covered the park probably came from the northwest or north (Patterson and Hobbs, 1995). After they melted, the landscape in the park may have been similar to that found west of Interstate 35 – that of a gently rolling, poorly drained landscape with lakes and wetlands.

In most of Minnesota, but excluding the park and points east, glaciers from the most recent glaciation, known as the Late Wisconsinan Stage, covered the land. This glaciation occurred from around 30,000 to 10,000 years ago. The ice stopped probably just a few miles west of the park (Figure 2). Floodwaters from the melting glaciers carved, or at least enlarged, the large

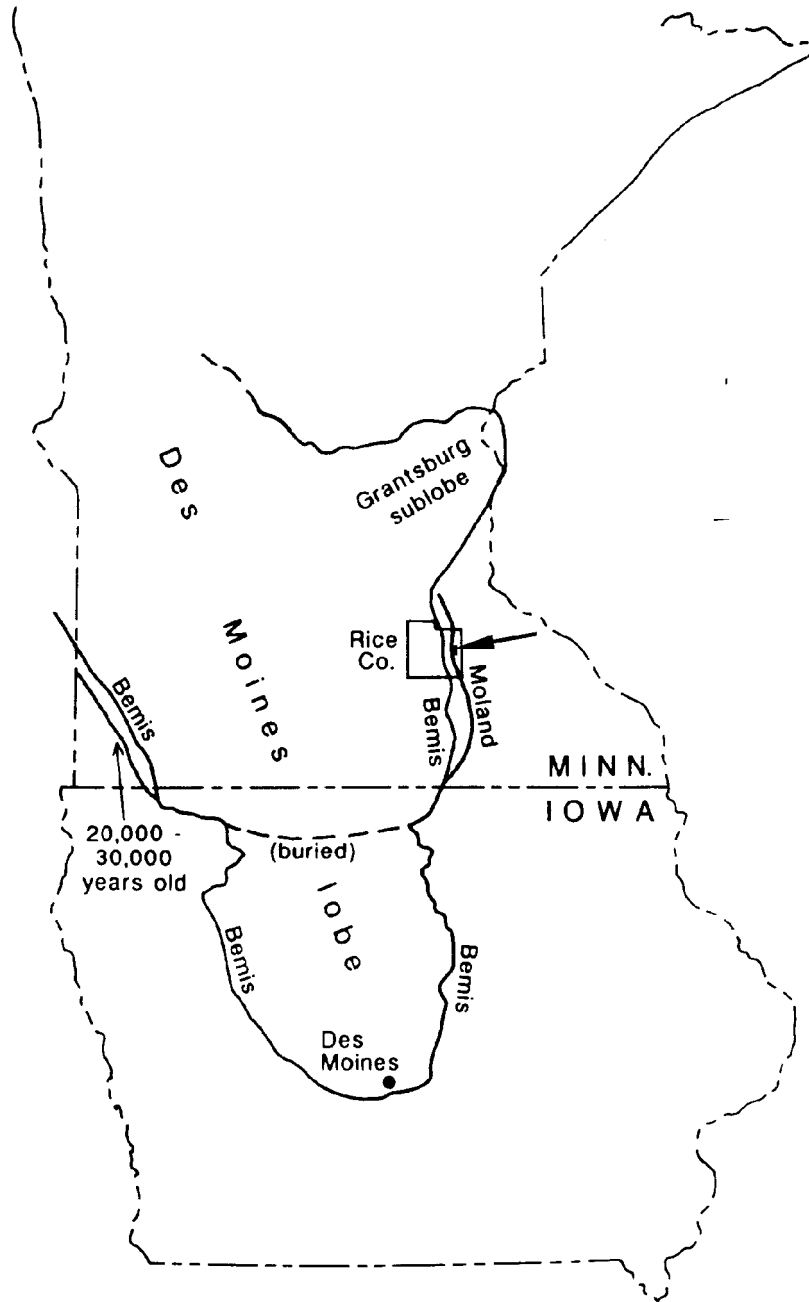


Figure 2. The Moland and Bemis moraines mark the southern extent of the last two advances of Late Wisconsin glacial advances in southern Minnesota and Iowa. The Moland advance stopped between 20,000 and 30,000 years ago and melted back to the north. About 15,000 years ago the Des Moines lobe advanced into Iowa and by about 10,000 years ago had melted back to Rice County. The arrow indicates the location of Nerstrand Big Woods State Park. Modified from Patterson and Hobbs (1995).

valley passing through the park as well as the valley in the northwest part of the map (Figure 3). The harsh climate associated with these glaciers was conducive to the generation of wind-blown dust that was deposited over the area as loess.

The harsh climate also allowed for extensive erosion of pre-existing soils by wind (Patterson and Hobbs, 1995). Evidence for this is that loess occurs directly on till with no intervening topsoil

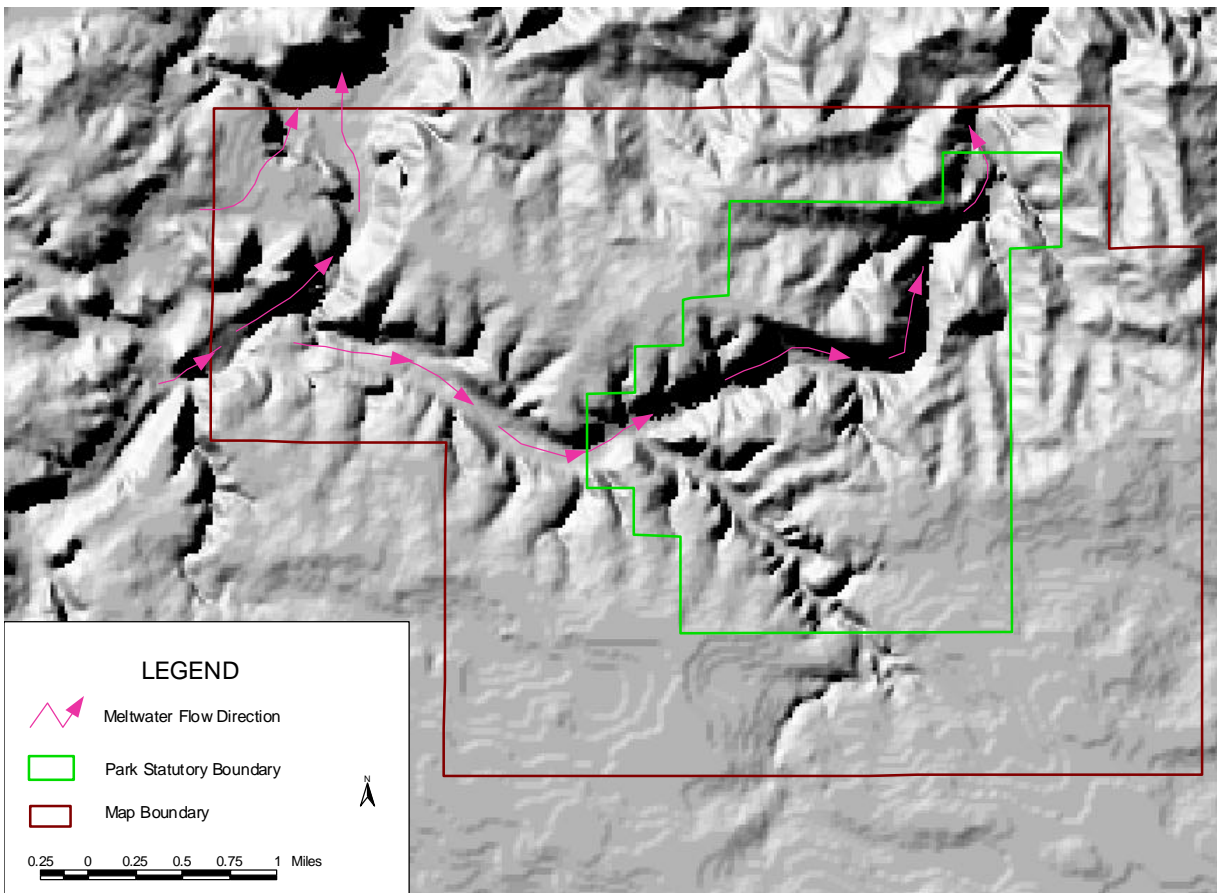


Figure 3. This digital elevation map shows glacial meltwater drainage patterns. Arrows are interpretations of flow routes and direction of glacial streams. Shadows are depicted on the map as though the sun was shining from the northwest.

layer in most areas of the park. In some places, especially swales, all that remains of the earlier soil is a lag, consisting of cobbles that remained after the smaller soil particles blew away.

Table 1 reviews the major features and sediments mapped in the park and surrounding area (see map in pocket) and how they formed.

Table 1. Associations between geologic age, features or landforms, sediments, and geologic processes in Nerstrand Big Woods State Park.

GEOLOGIC AGE	FEATURE OR LANDFORM	DEPOSIT	PROCESS OF FORMATION
Holocene Epoch of the Quaternary Period (10,000 years ago to present)	Flood plains, fans	Alluvium - consists of sorted silt, sand, gravel, and cobbles	Channelized water and stream flooding
Pleistocene Epoch (Ice Age) of the Quaternary Period			
<i>Late Wisconsinan Stage</i> (30,000 to 10,000 years ago)	Mantled landscape	Loess	Deposited by wind
	Meltwater valleys	Outwash sediments	Large volumes of flood waters from melting glaciers eroded and then deposited river sediments as flow waned
<i>Pre-Wisconsinan Stage</i> (125,000 to 700,000 years ago)	Till plain	Till - unsorted sediments ranging from clay to boulder size	Material carried at the base, within, and on top of glaciers form till when the glacier melts
Quaternary through Devonian Periods (700,000 to 400 million years ago)	Erosional surface (unconformity) on Ordovician rocks.	Nothing preserved in the park	Natural erosion of rocks and sediments over long periods of time.
Ordovician Period (500 to 440 million years ago)	Bedrock outcrops	shale, limestone, and sandstone	These rocks are comprised of sediments that were deposited in a shallow marine sea. Environments ranged from beach to deep offshore

Prominent Geologic Features

Waterfalls. One of the feature attractions at the park is Hidden Falls. The water flows over the lower half of the Platteville Formation, which is the most competent geologic unit exposed in the park. The falls are cliff-like because the underlying geologic unit, the Glenwood Formation, is relatively soft shale. The stream erodes the shale to the point of undercutting the overlying limestone so much that blocks of limestone break off, forming the cliff face. The limestone breaks along rather straight, vertical planes called joints. Joints are oriented cracks that formed in the rock long ago from deep, regional-scale geologic movements.

All waterfalls retreat or erode up stream. Hidden Falls does not appear to be retreating very rapidly. The primary mechanism of erosion acting upon the limestone forming the waterfalls is undercutting. As long as the rock debris near the base of the waterfalls remains, the retreat of the water falls should remain slow. If the debris were removed, the water would fall farther and scour a much deeper pool, permitting the soft shale under the limestone to be undercut much more than at present.

There are three other waterfalls within the statutory boundaries of the park. One is in the north part on public land, and the other two are on private property in the northeast. The volume of water flowing over these falls is much less than that at Hidden Falls. Two other waterfalls occur at the west end of the mapped area, one of which is in Caron County Park.

Stream divide. Near the western edge of the park statutory boundary, there is no stream along a short section of the large valley. This is a stream divide within the valley. Streams west of the divide flow westerly and those east of it flow easterly. It is unusual for stream divides to occur at the bottom of valleys. It could be that long ago, before the last glaciation, Prairie Creek, which enters the valley from the south part of the park, flowed west instead of east. In this situation the stream passing over Hidden Falls would have been quite small. When meltwaters from the Late Wisconsinan glacier or glaciers scoured this valley and deposited outwash sediments, the valley floor may have changed such that the modern-day Prairie Creek now flows east.

Meltwater valleys and misfit streams. A large valley cuts through the center of the park from west to northeast. The stream that flows in this valley is very small (misfit) in comparison to the size of the valley. This is especially apparent on the west side of the park in the area known as the "Hope pasture". This is a meltwater valley that formed when an overwhelming amount of water flowed from the glaciers as they melted. This water widened and scoured pre-existing valleys or lowlands leaving a layer of outwash consisting of sand, gravel, and boulders. This is mapped as outwash and alluvium on the surficial geology map. In the valley just upstream of Hidden Falls, the meltwater channel scoured down to bedrock (Platteville Formation). This cobble rich sand and gravel outwash deposit is visible in the stream bed for about 1000 feet upstream of Hidden Falls.

A clue that these valleys were carved by large flood events in the past is that the current streams flowing in these valleys are very small (misfit) in comparison to the size of the valley.

Sloped valley floor. The floor of the large valley near the western border of the park (in the vicinity of the Hope pasture) is not as flat as expected. It visibly rises toward the north side of the valley. Two soil borings in the valley floor indicate that the slope is due to a wedge of sand and silt overlying coarser sand and gravel. This wedge could occur due to chance if the waning glacial meltwater stream last flowed along the south side of the valley, or it could be in part a thick accumulation of loess, blown by northwesterly winds, that settled on the lee (north) side of the valley, or a combination of both.

Glacial erratics. Glacial erratics, which are large boulders that are out of place with respect to the local bedrock geology, are absent in the park. One unusually large erratic occurs near the northeastern part of Caron County Park, however, which is about 2 miles west of Nerstrand Big Woods State Park. This boulder is about 30 feet long. This large of an erratic this far south is unusual because boulders rarely are that big to begin with and they usually get broken up as they are transported by the glacier. This erratic is granite and may have come from the Lake Mille Lacs area, the Minnesota River valley, or from further north. The boulder was eventually uncovered from the till as river valleys developed in the area.

Loess. Loess was deposited over the park during the latest glaciation (late Wisconsinan). All of the topsoil in the area is at least partly comprised of loess. The largest sediments in loess are very fine sands. Due to frost action, occasional pebbles, cobbles, and boulders occur in thin (less than several feet) loess deposits. Frost gradually pushes rocks toward the surface from the till beneath the loess. If the topsoil does not contain anything larger than sand grains, then the loess extends below the frost line.

Old gray till. The park is unique in that very old till (pre-Wisconsinan) is exposed at or near the surface, which is rare in most of Minnesota. There may be more than one till, though no evidence was found for that. The till was deposited somewhere in the range of 125,000 to 700,000 years ago (Ojakangas and Matsch, 1982, Hallberg, 1986). A current hypothesis is that these tills are an age of pre-Illinoian, which is in the range of 400,000 to 700,000 years.

Geologic Discussion

Origin of the meltwater valleys. Patterson and Hobbs (1995) suggested that the large valley passing through the park as well as the one at the west end of the mapped area received flood waters from melting glaciers that existed during the Late Wisconsinan. They suggested the meltwaters came off of the Moland glacier that may have existed 20,000 to 30,000 years ago (Figure 2).

A thin gravelly till was found on one of the terraces in the northwest part of the mapped area.

This indicates a glacial advance occurred after the terraces and valleys were formed. If the till was deposited by the younger Des Moines lobe, then the meltwaters came from the Moland or an earlier glacial event. This relationship indicates the large valleys may be 20,000 to 30,000 years old or older.

Hydrology

Loess/till interactions. A blanket layer of loess deposited over the till significantly affects the surface hydrology in the park. The loess is relatively permeable and the till is not. Rainfall that soaks into the ground continues to percolate downward until encountering till. Since the till can't transmit water as rapidly as the loess, water accumulates above the till, forming a perched water table. Then the water moves laterally down gradient. In most places the top of the till parallels the ground surface, so if the slope is steep, the water moves rather quickly along the loess/till contact. If the slope is nearly flat, the water contained in the loess moves very slowly and may accumulate faster than it can drain away if evapotranspiration is low (spring and fall) or if frequent large rains occur. This situation may cause the soil to become saturated to the surface, creating wet areas.

The presence of water in the channels of small, shallow tributaries, even when it has not rained for several days, is evidence of lateral flow of shallow groundwater (perched water) along the loess/till contact. At times, water was observed flowing or dripping from the contact between the loess and till exposed in gullies and stream cuts.

As the perched water moves downslope, if the slope becomes less steep or the loess thins significantly, the water may rise to the surface in order to continue downslope, causing wet ground. Wet ground in the vicinity of the trails along hillsides could also be caused by compaction of the loess. Compacted loess transmits less water than uncompacted loess. This situation may exist along the southwest portion of the Hope Trail in the northwest part of the park.

Compaction occurs in nearly all of the trails (Figure 4). Puddles form after rains and may persist for days because of the reduced permeability of the soils in the trail.

Many of the trails have become channels for surface runoff because compaction has caused the trail to be lower in elevation than the adjacent land. Trails that angle along hillsides intercept all the overland flow above the trail and funnel it down the trail for as long as the trail continues downhill. This situation can result in large volumes of water at the lower portion of these trails, causing considerable erosion.

Seeps. Two seeps (springs) occur at the south end of the park where ground water appears to flow from buried sand and gravel lenses. These seeps appear to contribute a minor amount of water to the stream flow.

Trail Siting and Design

Erosion, primarily in the form of headward erosion of gullies, occurs naturally in the park landscape. Most of the erosion occurs in the loess which exists nearly everywhere. In some places human activities have accelerated erosion. Since loess compacts easily, the trails will compact to some extent which results in the channeling of overland flow on the trails.

Slope failure is a relatively common form of erosion on steep slopes in the park. Slope failure refers to a layer of vegetation and soil, commonly 1 to 2 feet in thickness, that slides down a slope (Figure 5). Slope failures in the park appear to occur naturally. Most are caused by a stream meander that erodes into the toe of a steep slope thereby removing the slope support. With the right soil moisture, the layer of soil then slides down the slope and often into the stream.



Figure 4. This photo shows the compaction that has occurred on some of the trails. The field book holding up the board and shovel is 4.75 inches high.

Conceptual recommendations. The top priority should be minimizing the channelization and ponding of water on the trails. Outsloping, where the traveled surface of the trail (tread) always slopes slightly downhill, is the best method for keeping water off of the trail (Hesselbarth and Vachowski, 1996). Unfortunately, because of compaction, it is nearly impossible to use that technique in the park without adding fill. The second best control of water, and still aesthetically pleasing, are grade dips (also known as rolling grade dips, terrain dips, coweeta dips, and swales). Grade dips can be built anywhere there is a visible slope to the land. They use the concept of grade reversal to divert water off of the trail.

Rolling grade dips are recommended (Figure 6). They consist of a short reversal of grade along the trail. If the trail is descending, a short climb followed by a return to the descent constitutes a rolling grade dip. Water flowing down the trail cannot climb the short rise and instead runs off the outsloped tread at the bottom of the dip. It is easiest to establish grade dips when the trail is being laid out and built. The varied topography in the north half of the park lends itself especially well to this method.



Figure 5. This slope failure occurred when this mass of vegetation and soil slid about 20 feet down this slope sometime in the last several years. The stream is just off the left side of the photo.

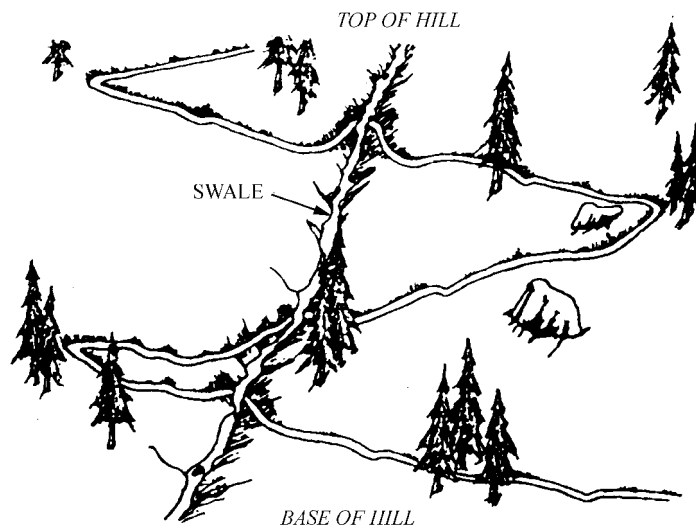


Figure 6. This figure shows how rolling grade dips (dips in the trail) are incorporated in the design of a trail on the side of a hill or valley. The trail is sited so changes in topography cause the water to be shed from the trail at set intervals. The spacing between grade dips is dependent on the steepness of the trail and how much water a given segment of trail captures during rains. Note that water is shed from the trail before reaching the swale or other erosion-sensitive areas such as gullies or bridges. Modified from Hesselbarth and Vachowski (1996).

Terrain dips use existing terrain as the control for grade reversal. The dips in the trail are placed at natural lows in the terrain. Terrain dips are not recommended along the lower portions of hillsides because of the potentially large area up slope that contributes to overland flow which can be intercepted by the trail and funneled into the dip. Large quantities of water increase the risk of forming gullies or enlarging existing ones.

In areas that are especially flat, such as in portions in the south half of the park, puddle drains may be necessary. Puddle drains are cuts in the downslope berm that are about 2 feet wide and at least as deep as the deepest part of the puddle. Where the terrain is gentle (around 5% grade) and the puddle is quite deep, it is necessary to extend the drain cut 10 to 15 feet away from the trail in order to get the water to drain. If the grade is much less than 5%, puddle drains probably are not practical (because of the long ditch required to drain the puddle) and alternatives are bringing in fill, building boardwalks, or abandoning that area.

Water bars, which are logs, boards, sculpted rocks, or other such features placed across the trails at an angle (usually 45 degrees), typically are used to divert water off of the trail once erosion starts taking a toll. Water bars often require regular maintenance, and may be aesthetically unpleasing. Many water bars would be unnecessary if grade dips and outsloping were incorporated into the original trail design and layout (Hesselbarth and Vachowski, 1996).

Specific recommendations:

- Site trails near the tops of hills and ridges to minimize the amount of water intercepted by the trails (for new or realigned trails).
- Use numerous rolling grade dips on every trail, even along the crests of ridges (for new or realigned trails).
- Grade dips should be designed to shed water from the trails prior to reaching areas sensitive to erosion. Areas sensitive to erosion include bridges, wet swales, swales near the base of long slopes, areas with active gully erosion, and areas with thick loess or sand deposits.
- Use natural terrain dips near the tops of hills, but not near the bottom of hills (for new or realigned trails).
- Puddle drains may minimize the wet conditions in certain portions of the trails.
- Stream meanders gradually migrate, eventually undermining banks and destabilizing the structures on those banks, so keep trails and structures away from bends in the channels.
- Depth to bedrock in the vicinity of the Oak Bridge is about 18 feet, so it is possible to drive pilings to bedrock and build the bridge on the pilings so it is elevated above the flood plain and less prone to damage from floods.

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