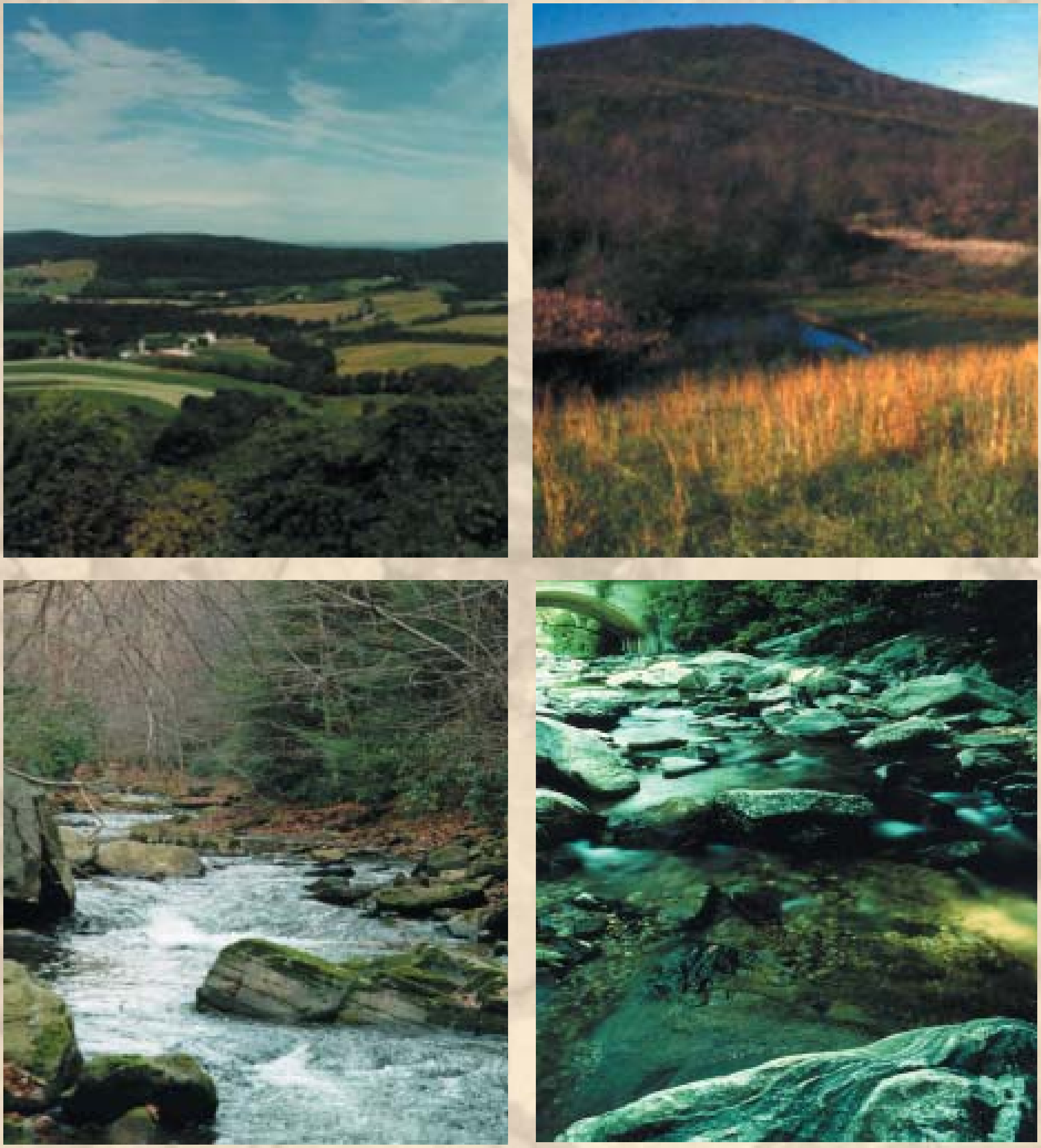
MARYLAND STREAMS

TAKE A CLOSER LOOK



Maryland Department of Natural Resources
Landscape and Watershed Analysis Division

Maryland Streams

Take A Closer Look

Robert L. Ehrlich, Jr., Governor
Michael S. Steele, Lt. Governor

C. Ronald Franks, Secretary

May 2005
(Reprinted from original document, March 2000)

This document was compiled by Sean Smith of the Landscape and Watershed Analysis Division (LWAD) with contributions from Frank Dawson, Mike Herrmann, Larry Lubbers, Niles Primrose, Kevin Smith, and Ken Yetman of LWAD; Joann Wheeler of the Resource Assessment Service; Jim Reger and Ken Schwarz of the MD Geological Survey; and Ed Doheny and Judy Wheeler of the U.S. Geological Survey. Original document layout and design were developed by Alex Gagnon. Final layout, design, and graphics were completed by Lisa A. Gutierrez.

This document is dedicated to Alex Gagnon.

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Funded, in part, by the Environmental Protection Agency.
Contents do not necessarily reflect the position of the EPA.

Support for printing of this document was provided by the EPA Chesapeake Bay Program.

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INTRODUCTION

Maryland has over 14,000 miles of streams flowing to the major tributaries of the Chesapeake Bay, the Atlantic Ocean, and even the Mississippi River. These waterways have importance far beyond their basic function as water conduits. Streams are integral components of our environment that offer many benefits to Maryland's residents. They provide natural beauty, habitat for fish and wildlife, a variety of recreational opportunities, and part of our water supply. Their protection through scientific understanding and proper care is fundamental to the maintenance of our health, safety, and quality of life.


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Swallow Falls in Garrett County

Whether flowing through the mountainous terrain of Western Maryland or the flat lowlands of the Eastern Shore, all streams have two banks and a bed, convey water, and transport sediment. At a finer level of detail, streams have unique characteristics and behavior patterns that reflect their landscape and watershed settings. The most basic differences that we see in streams across the state are the result of the long term geologic processes that created the underlying rocks and shaped the land surface. Over shorter time scales, streams are influenced by the frequency and magnitude of the water and sediment flowing across the land surface and into defined channels. Spatial and temporal variations in the factors influencing streams gives them a complex and indeterminate character that creates a diversity of aquatic habitat conditions across the state.

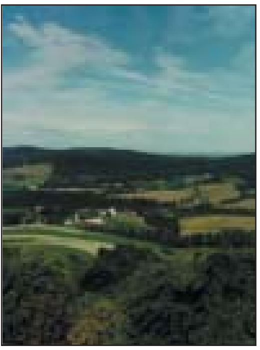
The characteristics that make streams intriguing landscape elements can also complicate our ability to interpret and manage them. Effective stream conservation requires an understanding of physical processes. An awareness of the value of this understanding has taken on a new intensity in recent years and inspired greater attention towards the integration of the disclipline of fluvial geomorphology (the study of streams and the processes that influence their physical behavior) into natural resources management and civil engineering. This document has been developed using concepts in fluvial geomorphology in order to provide a summary of information that helps foster an interdisciplinary stream management perspective. The intention is to introduce popular scientific concepts and the literature that supports them, while illustrating the utility of a spatially-based framework for the assessment of the processes affecting streams in the different landscape settings across the state.

This document is organized into four levels that are useful for the development of an understanding of the physical processes affecting the appearance and behavior of streams. The levels provide the format for the document and are presented with examples taken from across the state to illustrate the unique characteristics of streams and the factors that affect them over different time scales and settings.

IMAGINE YOU ARE STANDING IN A STREAM...

- **How would you describe its appearance?**
- **What makes it look the way it does?**
- **Does its appearence change over time?**
- **How do the stream's physical characteristics affect the fish and insects that live in it?**

The following spatial hierarchy is recommended to help with these types of questions.



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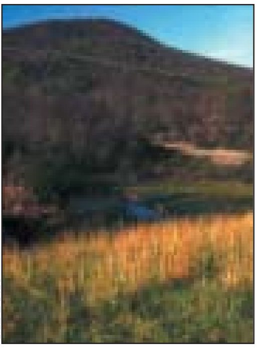
CONSIDER THE REGIONAL LANDSCAPE CONDITIONS

- Consider your surroundings. Is the land mountainous, hilly, or flat?
- How did the dominant landscape conditions develop and how do they influence the appearance of stream channels?
- What types of geologic materials are present and how do they influence the stream channel appearance and patterns of adjustment?



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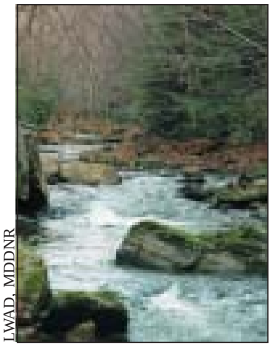
THEN, CONSIDER LOCAL CONDITIONS IN THE WATERSHED

- Where is the stream located in the watershed? Is it at the top or bottom?
- Is the land draining to the stream channel developed, agricultural, or forested?
- What are the local geologic conditions and soil types?



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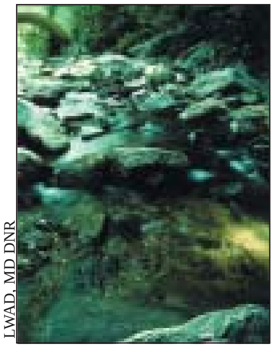
THEN, CONSIDER THE SPECIFIC CHANNEL REACH

- Is the channel alignment straight or meandering?
- Is the stream channel wide and shallow, or narrow and deep?
- Does the land adjacent to the stream have trees, grasses, or urban infrastructure?



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THEN, FOCUS ON THE SPECIFIC STREAM FEATURES

- Is the stream bottom rocky or sandy?
- How fast and in what direction is the water moving within the channel?
- What habitat elements are available for aquatic organisms?

STREAMS ACROSS MARYLAND

(AS REFERENCED IN THE DOCUMENT)

Marsh Run in Washington County

Hunting Creek in Frederick County

Grave Run in Baltimore County

Fifteen Mile Creek in Allegany County

Jabez Branch in Anne Arundel County

Northwest Branch in Prince George's County

Battle Creek in Calvert County

Watts Creek in Caroline County

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LANDSCAPE LEVEL

Looking at streams from the Landscape Level provides the broadest information about the conditions that influence their appearance and behavior. Traveling from Maryland's western border to the Eastern Shore, dramatic differences in the landscape are easily observable. Starting from the western side of the state, the land gradually transitions from mountains, to rolling hills, to flat coastal plains on the Atlantic coast. These topographic features were created by varied geologic materials undergoing chemical reactions, weathering, uplifting, erosion, and deposition over thousands of years. Streams look very different across the state because they are reflections of very different land-forming processes.

There is a direct link between the way a stream looks and behaves and its surrounding geology. For example, regional geological characteristics govern the relief, size, and shape of the watersheds draining to streams in different locations throughout the state. The configurations of the watersheds determine the way that water is conveyed across the landscape and into stream channel networks. The geologic environment also influences the types of materials that are found along the banks and bottom of streams. These materials, in turn, affect channel appearance, the erosion rates, and the types of aquatic habitat communities found streams in different areas of the state.

At this broad level of consideration, our discussion of Maryland's streams will cover the different rock types that can be found in the state and describe how different geologic processes result in varied landscape conditions. We will also describe Maryland's five primary physiographic provinces and how the topographic and geologic conditions in each province broadly impact the characteristics of streams.

P. Breeding for MDDNR

The road cut for I-68 at Sideling Hill has created a museum that illustrates the geologic history of the area around Washington County.

The Basics Of Maryland’s Geology

To understand the physical characteristics of stream channels across Maryland, it is helpful to look at several fundamentals of geology. Geologists generally refer to rocks as *igneous*, which form from molten materials such as volcanic magma, *sedimentary,* which form through deposits of sediments, or *metamorphic*, which emerge through changes in pressure or temperature on existing igneous or sedimentary rocks. When igneous rocks are exposed on the surface they are gradually worn down into tiny fragments by weathering and erosion. The fragments are carried by wind and water to rivers, lakes, or the sea, where they settle in layers and slowly turn into sedimentary rocks as they are buried. These rocks can then be worn away to form new sediment layers or transformed by pressure and heat into metamorphic rocks. Exposed metamorphic rocks are, in their turn worn away to form new sedimentary rocks.

There is an inseparable relationship between geology and landscape. Two very important landscape forming characteristics are lithology and structure. Lithology refers to a rock’s composition and characteristics while structure refers to whether the rock is flat, tilted, folded, or faulted. The characteristics of regional landscapes are governed by the resistance of different rock types to erosion and by repose of the underlying bedrock whether the rock is flat-lying or tightly folded.

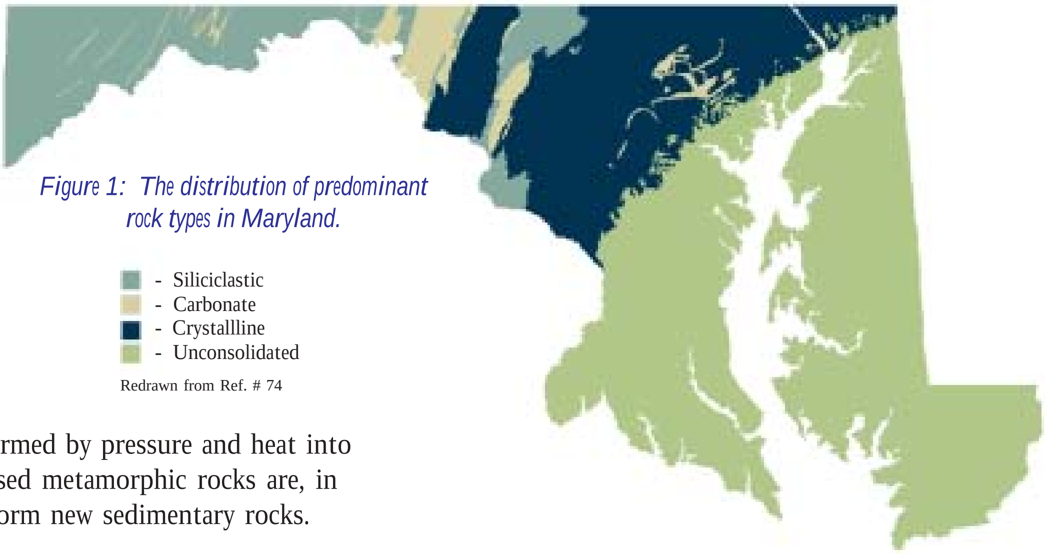


Figure 1: The distribution of predominant rock types in Maryland.

Redrawn from Ref. # 74

MARYLAND’S ROCK TYPES -

The lithology of Maryland’s rocks can be broken down into four major types based on the predominance of minerals they contain.

Siliciclastic: These are sandstone, siltstone, shale, and conglomerate noncarbonate rocks containing silicon that are moderately resistant to weathering. The vast majority of this material lies from South Mountain and west to the state’s border with West Virginia.

Carbonate: These are limestone and dolomite sedimentary rocks formed with carbonate materials that are highly susceptible to erosion. The two largest areas of carbonate rocks are the Hagerstown Valley and the Frederick Valley, both of which are underlain by limestone and dolomite. In Central Maryland, there are several broad valleys underlain by marble, a metamorphosed limestone. Examples include Timonium Valley, Green Spring Valley, and Worthington Valley, all near Baltimore. Carbonate rocks also occur throughout Western Maryland along the bases of hills and the sides of valleys.

Crystalline: These include schist, quartzite, and gneiss metamorphic rocks, as well as granite igneous rocks that are composed of crystals or crystal fragments and are not easily eroded. Central Maryland (eastern Frederick, Montgomery, Carroll, Baltimore, most of Howard, and Harford counties) and the Middletown Valley between Catoctin Mountain and South Mountain are underlain with crystalline rocks.

Unconsolidated: These are easily eroded sediments composed of sands, silts, and clays. This material dominates the low-lying coastal plains roughly east and south of I-95 on the eastern and western shores of the Chesapeake Bay.

MARYLAND'S PHYSIOGRAPHY

The *structure* of Maryland's rocks can be broadly described by five distinct landform regions. These regions are called physiographic provinces. Maryland's highest elevations are found in the Appalachian Plateau. The lowest are in the Coastal Plain. In between lies the variable landscape of the Ridge and Valley, the narrow mountainous strip called the Blue Ridge, and the broad Piedmont Plateau that transitions to the Coastal Plain surrounding the Chesapeake Bay.

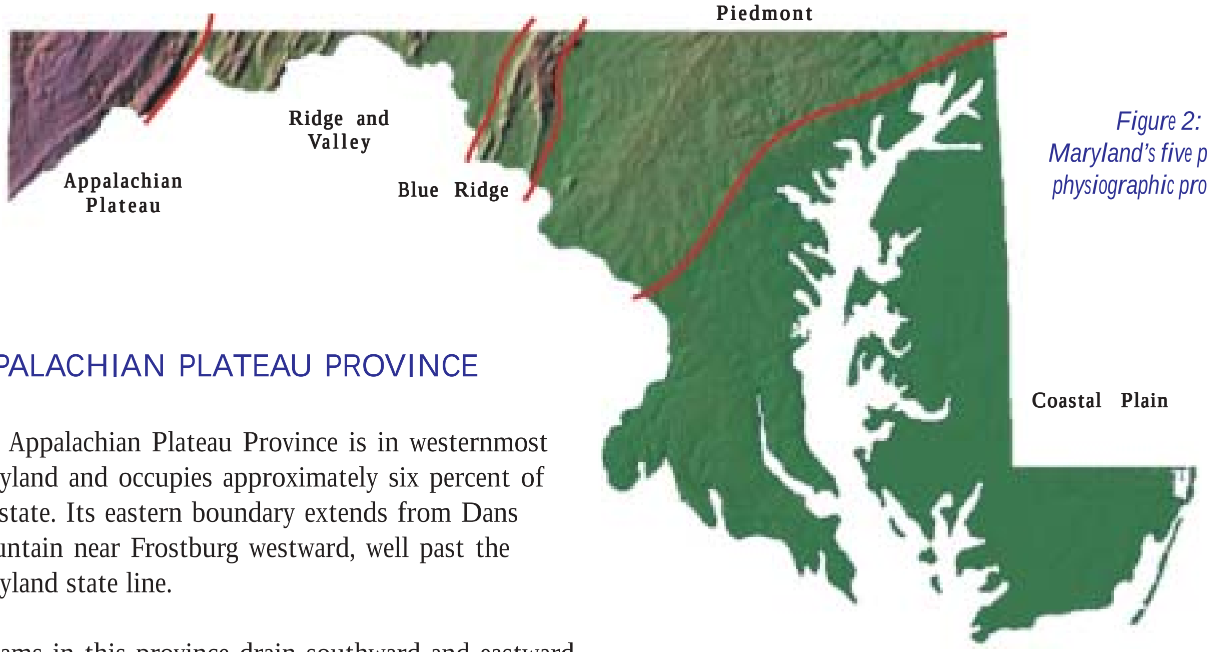


Figure 2: Maryland's five primary physiographic provinces.

APPALACHIAN PLATEAU PROVINCE

The Appalachian Plateau Province is in westernmost Maryland and occupies approximately six percent of the state. Its eastern boundary extends from Dans Mountain near Frostburg westward, well past the Maryland state line.

Streams in this province drain southward and eastward to the Potomac River, which flows to the Chesapeake Bay;or, northward to the Ohio River, eventually reaching the Gulf of Mexico via the Mississippi River. The bedrock of the Appalachian Plateau consists primarily of gently folded shale, silt, and sandstone. There are several hills capped by sandstone reaching elevations over 3,000 feet. The valleys between the ridges consist of easily eroded shale rocks with carbonate limestone materials at the outer edges. Because of the rugged terrain, stream channels in this reagion often have steep slopes dotted with waterfalls and rapids. Many large rocks and bedrock outcrops form the substrates that are found in these fast-moving waterways.

LWAD, MDDNR

Bedrock outcrops can be found along the Youghiogheny River in Garrett County.

LWAD, MDDNR

Small mountains dominate the landscape in the Appalachian Plateau Province in Garrett County.

RIDGE AND VALLEY PROVINCE

The Ridge and Valley Province extends westward from the edge of South Mountain to Dans Mountain and occupies approximately twelve percent of Maryland. This province has two distinct sections, including the Western Ridges and the Great Valley.

The Western Ridges consist of numerous sandstone ridges formed by mountain-building forces that compressed flat-lying sedimentary rocks. The compression caused the rocks to become folded and faulted, somewhat resembling a pleated skirt and placing materials of different resistance to erosion in more or less parallel bands. The valleys between the ridges are underlain by shale and limestone. Streams with steep gradients flow from the ridges into more moderately sloped channels in the valleys, resulting in the larger streams generally following the exposures of less resistant rocks. Most of the landscape in eastern Allegany and western Washington County developed this way. The north - northeastern alignment of the ridges and valleys in this area are well illustrated on topographic maps.

MDDNR

Sideling Hill (center) and Long Ridge (lower right) run perpendicular to the Potomac River (bottom)in Allegany County.

The Great Valley in Eastern Washington County (also called the Hagerstown Valley), the Cumberland Valley in Pennsylvania, and the Shenandoah Valley in Virginia, are all distinguished by broad and gently rolling lowland areas positioned between mountainous landscapes to the east and west. These areas developed on a great thickness of folded and faulted limestones and dolomites, allowing the streams to have lower gradients than those in the western ridges and extenstively meander through the landscape. Materials found in streams in the Great Valley are composed primarily of fine silts with some boulders of limestone and dolomite. Numerous quartzite boulders can also be observed in streams near the base of South Mountain, along the eastern border of the province.

BLUE RIDGE PROVINCE

The Blue Ridge Province, which includes Catoctin Mountain at the eastern boundary and South Mountain at the western boundary, comprises roughly five percent of the state. Like the Appalachian Plateau Province, the Blue Ridge is underlain by folded and faulted sedimentary rock. The rocks in this province are exposed in two large anticlinal ridges (rock layers that have been warped upward in the shape of an arch), including one in central and one in western Frederick County. These ridges occupy most of the Blue Ridge Province and are composed of quartzite and resistant sandstone.

A broad valley that is floored by gneiss (transformation of shale and mudstone formed under extremely high pressure and temperature) and volcanic rock lies in the trough between the two ridges. Stream channels are characterized by steep slopes on Catoctin and South Mountains, and moderate slopes in the interspersed valley areas. Sediments found within the valley streams are derived from gneiss and volcanic rocks, which create a variety of gravel, cobble, and boulder-size materials.

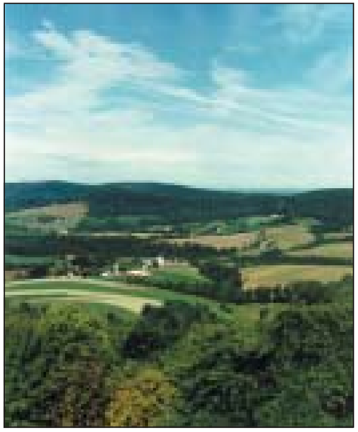
MDDNR

South Mountain borders the agricultural areas of the carbonate Great Valley (lower left).

PIEDMONT PLATEAU PROVINCE

The Piedmont Plateau Province covers roughly twenty-nine percent of Maryland. This province runs from Catoctin Mountain eastward to the edge of the Coastal Plain and is characterized by rolling terrain and low ridges. Streams generally flow within valleys that have cut into the landscape through many years of erosion. Most Piedmont streams have moderate slopes controlled by bedrock outcrops at the surface; however, steeply sloped areas and even small waterfalls exist. Because streams enlarge their valleys by eroding both vertically and laterally as the landscape gets older, the surface is increasingly dominated by slopes. In time, the entire landscape may be mostly hills and valleys. The relatively gentle topography of this area has promoted extensive urban development, much of which has been historically focused near larger streams and rivers.

MDDNR



Rolling hills and agricultural land characterizes the rural areas of the Piedmont Plateau Province.

Bedrock in the eastern part of the Piedmont consists of gneiss and schist (another transformation of shale and mudstone), gabbro (an igneous rock that formed deep beneath the ground), and other highly heated and “squeezed” sedimentary and igneous rocks. The rocks of the western part of the Piedmont are diverse and include phyllite, slate, marble, and moderately to slightly metamorphosed volcanic rocks. Most stream bottoms have a mix of gravels and sand. Streams with metamorphosed schist rocks have bottoms consisting of flat stones while stream bottoms underlain with limestone bedrock are dominated by silty sediment. Streams running over rocks or sediments with fairly uniform resistance to erosion, such as the complex crystalline rocks of central Maryland, tend to develop tree-like drainage netork patterns.

LWAD, MDDNR

The Northwest Branch in Prince George’s County flows through large bedrock outcrops as it traverses the Fall Zone.

COASTAL PLAIN PROVINCE

The Coastal Plain is the easternmost and largest physiographic province in Maryland, covering almost one-half of the state. Stream channels crossing from the Piedmont into the Coastal Plain change from being lined with hard rock materials to a less resistant, more easily eroded bottom. This transition area, or ‘Fall Zone’, begins at the western boundary of the Coastal Plain. After crossing through the Fall Zone, small stream channels are often characterized by lower gradients and greater potential for deep incision into the landscape. The thick sediment layers that overlie the bedrock basement materials in the Coastal Plain consist of unconsolidated sands and gravels. Some of these sediments are of oceanic origin, while others originated in the Piedmont Plateau and were imported into the floodplains of coastal rivers and swamps.

MDDNR

The flat landscape of the Tuckahoe Creek watershed in Queen Anne’s County.

The Coastal Plain is subdivided into the Western Shore Uplands, the Estuaries Region, the Chesapeake Estuary Region, and the Delmarva Peninsula Region. The topography of the Western Shore Uplands and the Estuaries Region is rolling. Some areas, such as Calvert County, the land surface appears as a very bumpy surface with pronounced topographic knobs. In this region, streams can have moderate to low slopes, steep valley walls, and bottom materials dominated by sands and gravels. Generally, the Chesapeake Estuary Region is flat, with gently sloped channels that are dominated by sands or gravels. The Delmarva Peninsula Region has very flat topography that is drained by very low gradient streams. The sediments that dominate channel bottoms in that area are typically smaller in size than the coarser gravels characteristic of streams closer to the western boundary near the Fall Zone.

PUTTING OUR UNDERSTANDING INTO PRACTICE

The first step in assessing alternatives for stream management is to consider the landscape setting, including geology, climatic conditions, topography, and long-term history. An assessment approach should begin by considering where the stream is located.

MARYLAND EXAMPLE

REGIONAL GEOLOGY

General geologic information can provide a good historical background of a project site. The presence of specific types of bedrock materials near the land surface can give a general indication of a channel's appearance and behavior.

Consider two streams on opposite sides of the state. From our basic understanding of the physiographic provinces in Maryland, we know that Watts Branch in the Coastal Plain does not have bedrock near the surface that controls the elevation of the channel bottom. There are also no large boulders or rocks in the channel. Conversely, Bear Creek in the Appalachian Plateau has slope and dimensional characteristics that are governed by bedrock formations at the land surface. You can expect to find large rocks and boulders in the channel. General knowledge of these natural physical differences is important for the assessment and comparison of the health of streams across the state.

TOPOGRAPHY

Each of Maryland's physiographic provinces has it own distinguishing topographic characteristics. A preliminary overview of the topography of an area can provide useful information regarding drainage patterns, the relief of land surfaces, and channel gradient. General topographic information can also give an indication of stream energy characteristics. Steeper land surfaces have the potential to generate faster moving flows.

MARYLAND EXAMPLE

There is little relief to the land surrounding Watts Branch. This low slope environment keeps streams on the Eastern Shore from eroding deeply into the landscape, despite the absence of resistant bedrock. Bear Creek is steeply sloped and generates high flow velocities; however, resistant bedrock controls incision of the channel into the landscape. Knowledge of slope and structural information is useful for the initial planning of stream management and rehabilitation projects.

LWAD, MDDNR

The sand bed channel of Watts Creek on the Delmarva Penninsula of the Coastal Plain.

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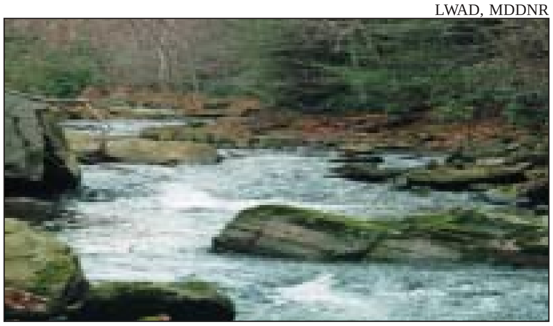


The bedrock lined channel of Bear Creek in Garrett County

PHYSIOGRAPIC REGION

County	High*	Low*	Relief*
Appalachian Plateau Province			
Garrett	3360	960	2400
Ridge and Valley Province			
Allegany	2895	420	2475
Blue Ridge Province			
Frederick	1895	200	1695
Piedmont Plateau Province			
Montgomery	845	10	835
Coastal Plain Province			
Anne Arundel	300	0	300
Somerset	46	0	46

* Units are in feet above sea level

Source: Maryland Geological Survey

WATERSHED LEVEL

The discussion in the Landscape Level provides an overview of the regional differences in Maryland geology and topographic conditions, as well as a description of how these differences affect the general appearance and behavior of stream channels. The Landscape Level considers the way that geologic materials and the land surface change over time, thereby influencing the physical environment over the long-term. The shorter-term influence of water flow moving over and under the land surface into stream channels is also important and can be considered at the Watershed Level.

A watershed, also called a catchment or drainage area, is the land area that drains surface waters to a common outlet at some point along a stream, pond, wetland, estuary, or the ocean. If the highest points of land surrounding a stream were joined by a fence, the resulting configuration would approximate the watershed boundary. The size and shape of a watershed is governed by the landscape setting, including the regional geology and topographic characteristics.

The Watershed Level narrows the focus to the relations between stream channels and their contributing drainage area. The investigation of a watershed's local geologic and landform characteristics provides important information regarding water conveyance to streams and how a channel might change in response to runoff conditions. In this section, we will focus on how the water movement, land use, and topography of watersheds all influence the form and appearance of stream channels.

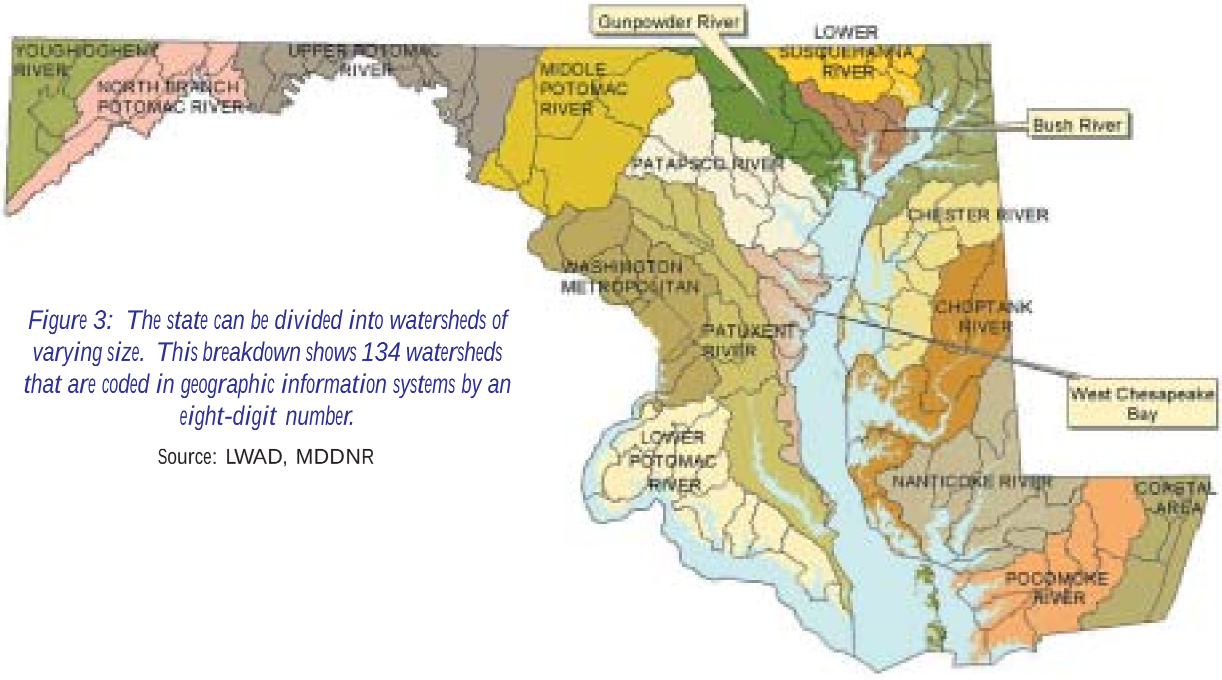


Figure 3: The state can be divided into watersheds of varying size. This breakdown shows 134 watersheds that are coded in geographic information systems by an eight-digit number.

Source: LWAD, MDDNR

MARYLAND'S WATERSHEDS

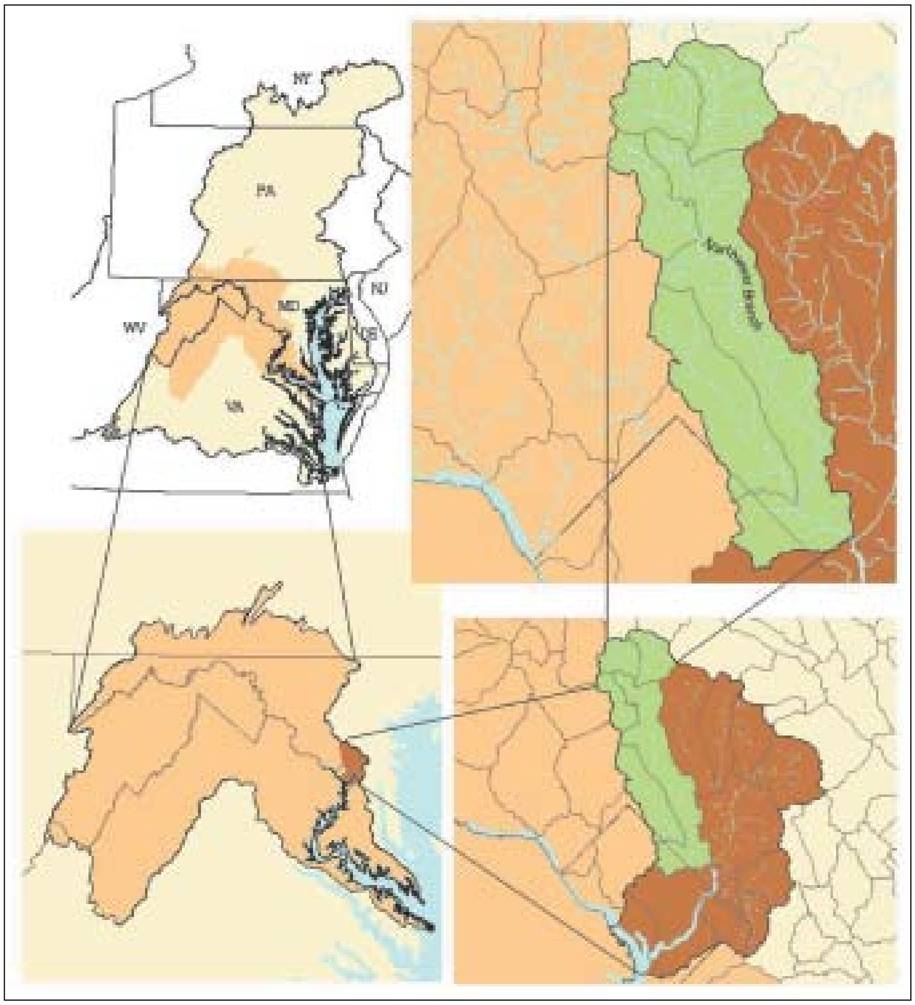
Maryland is nested in one of the largest watersheds on the East Coast, the basin draining to the Chesapeake Bay. The Chesapeake Bay watershed is approximately 64,000 square miles and extends from New York through Pennsylvania, Delaware, West Virginia, Maryland, Virginia, and the District of Columbia (*fig.* 4). The Bay watershed is composed of many smaller watersheds, such as the Potomac River basin which covers 14,670 square miles and extends from the Bay to West Virginia. Within the Potomac River watershed there are smaller watersheds, such as the 400 square mile Anacostia River watershed. This watershed is composed of still smaller watersheds, such as those draining to the Northwest Branch and Paint Branch. All the other watersheds in the state are nested in a similar manner.

THE DRAINAGE NETWORK

Streams can be described at the Watershed Level from an aerial-view in terms of the drainage network. These networks can take on different patterns depending on topography, geology, and land cover characteristics.

Within a drainage network, streams can be compared using a ranking system called 'stream ordering.' The smaller the order number, the smaller the channel. A first order stream has no tributaries. A second order stream has at least two first order streams draining to it, and so on (see *fig.* 5). Watersheds are often described in terms of the highest order stream within them. This methodology allows researchers and resource managers to differentiate channels using a protocol other than channel size. Drainage network comparisons can also be made using "drainage density", which is defined as the ratio of the cumulative length of stream channels to the total watershed area. Drainage density is important to the understanding of the processes affecting channel form at a watershed scale because it is influenced by the watershed slope, geology, and vegetative cover. High densities can be expected in more steeply sloped areas of Maryland, such as Allegany County, where less than an acre of watershed area may be necessary to initiate a first order channel. Conversely, the flat topography of the Eastern Shore promotes the development of a low drainage density with several acres being necessary to initiate a channel.

Processes related to sediment transport and stream channel adjustments vary with location within a drainage network. Local slope environments usually decrease with distance from the top to the bottom of the network, thereby influencing spatial trends in sediment transport and long term channel adjustments.



Source: LWAD, MDDNR

Figure 4: The Chesapeake Bay Watershed is composed of many smaller watersheds such as the Potomac River Basin (lower left), the Anacostia River Basin (lower right), and the Northwest Branch Basin (upper right).

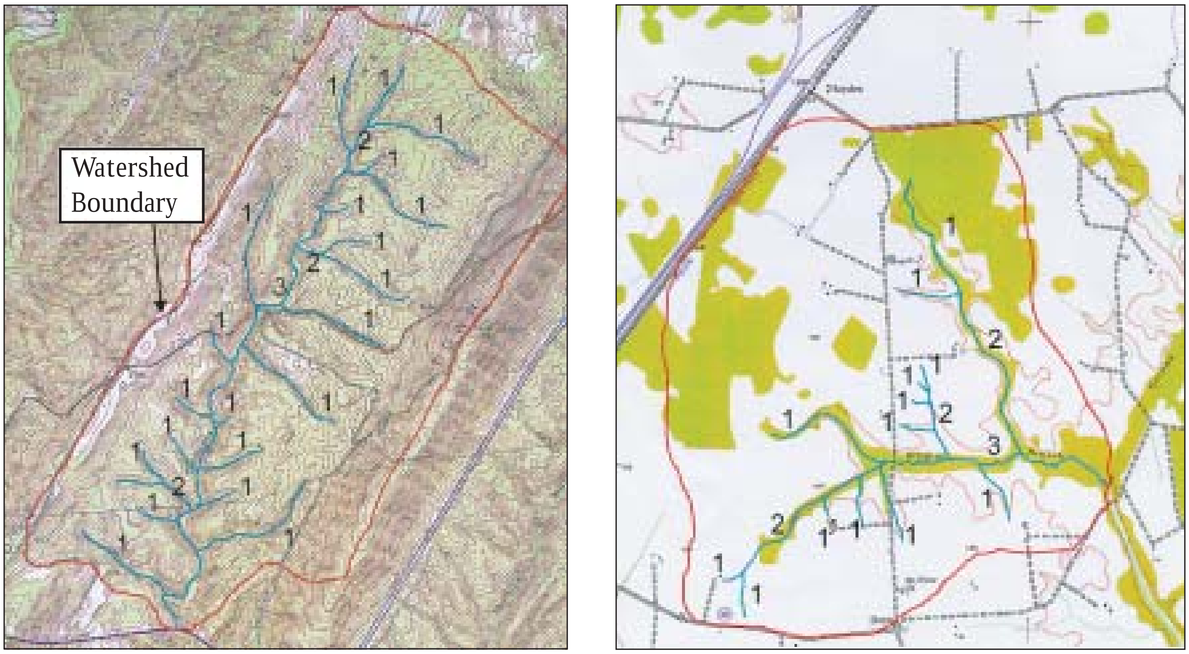
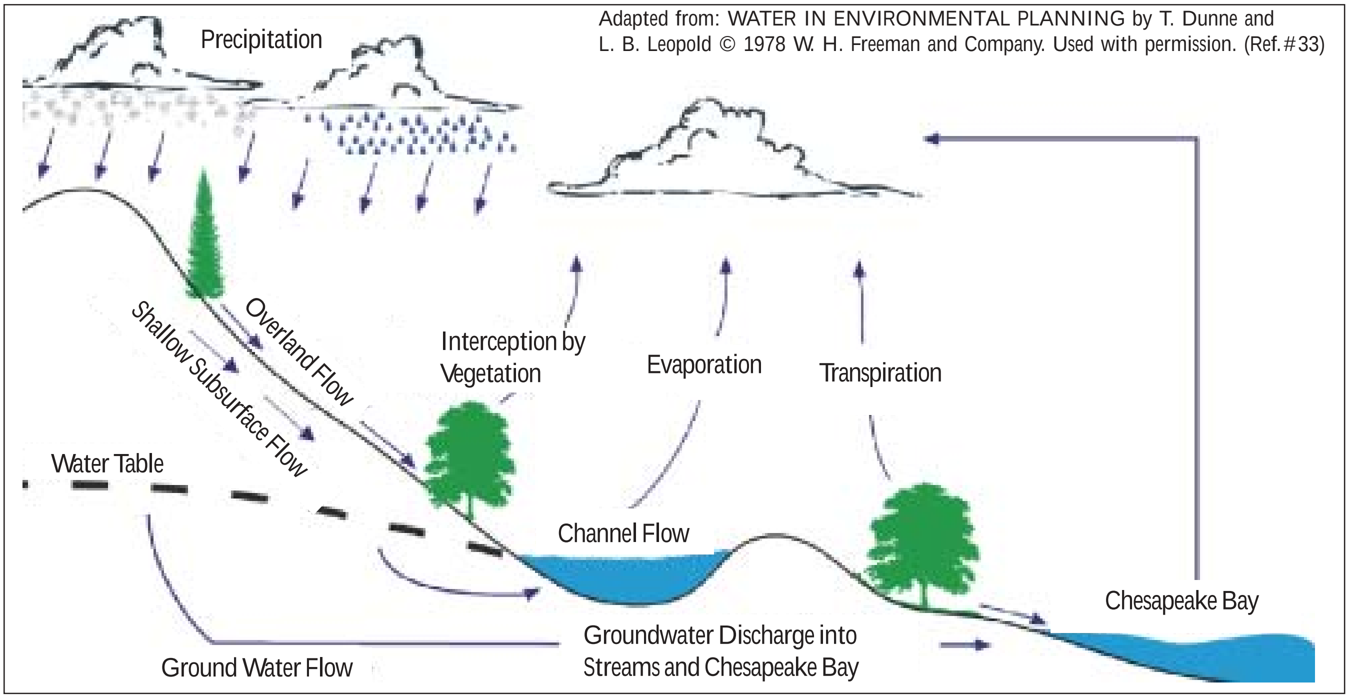


Figure 5: The Terrapin Branch watershed (left) has a high drainage density and long narrow shape because of its location between Green Ridge and Town Hill Ridge in western Maryland. Wildcat Branch (right) has a low drainage density and teardrop shape because of the flat topography of the eastern Coastal Plain. The channel orders are numbered for each network.

HOW DOES WATER FLOW THROUGH A WATERSHED?

When it rains or snows, several things can happen to the water falling on the land: 1) it can evaporate back into the atmosphere; 2) it can be taken up by plants and released back into the atmosphere in a process called transpiration; 3) it can seep into the ground and move below the surface as ground water; or, 4) it can flow across the land as surface water *(fig. 6)*. The two primary pathways for water movement through a watershed and into streams include ground water and surface water.



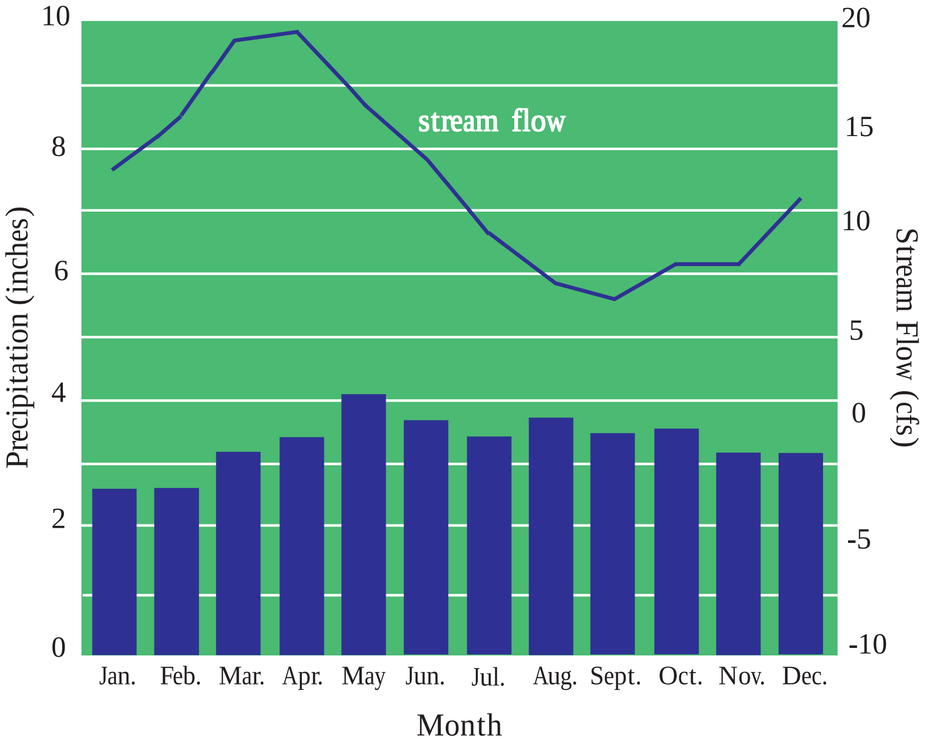
Adapted from: WATER IN ENVIRONMENTAL PLANNING by T. Dunne and L. B. Leopold © 1978 W. H. Freeman and Company. Used with permission. (Ref.#33)

Figure 6: The water cycle, including precipitation, ground water and surface water flow paths.

GROUND WATER

A portion of the precipitation that makes it to the ground infiltrates into the soil and is stored below the land surface. The rate of infiltration depends on the land use, geology, soil type and moisture condition, land slope, and the amount and duration of precipitation. In shallow aquifers, ground water moves below the surface until it emerges in response to a change in topography or "head" that results from a gradient in groundwater elevation or pressure over a distance. The time required for water to move from its entry to its exit varies from a few hours in the shallow aquifers to many years, decades, or even centuries in deeper aquifers. Discharges from shallow aquifers provide the water source that support stream flows during periods of low precipitation. During the winter, the water table can rise due to low rates of evaporation and transpiration by vegetation. These conditions, combined with decreased interception by vegetation and the ground-saturating precipitation events that occur in winter is why average stream base flows tend to increase during from January through early spring *(fig. 7)*.

Figure 7: Precipitation in Hagerstown and average streamflow recorded in Marsh Run at nearby Grimes, Maryland. (Data Source: USGS, Towson, MD).



SURFACE WATER

When the ground becomes too saturated to absorb the water that is conveyed to it, water will flow over the land surface. Surface water moves as sheet flow, shallow concentrated flow, open channel flow, or a combination of these pathways. Sheet flow occurs as a thin layer of water moving over the land surface. These flows can increase in depth and velocity as runoff converges into low areas, creating shallow concentrated flow. Eventually, water moving as shallow concentrated flow becomes substantial enough to be called channelized flow, resulting in the formation of true channels. Many first order streams form exactly this way.

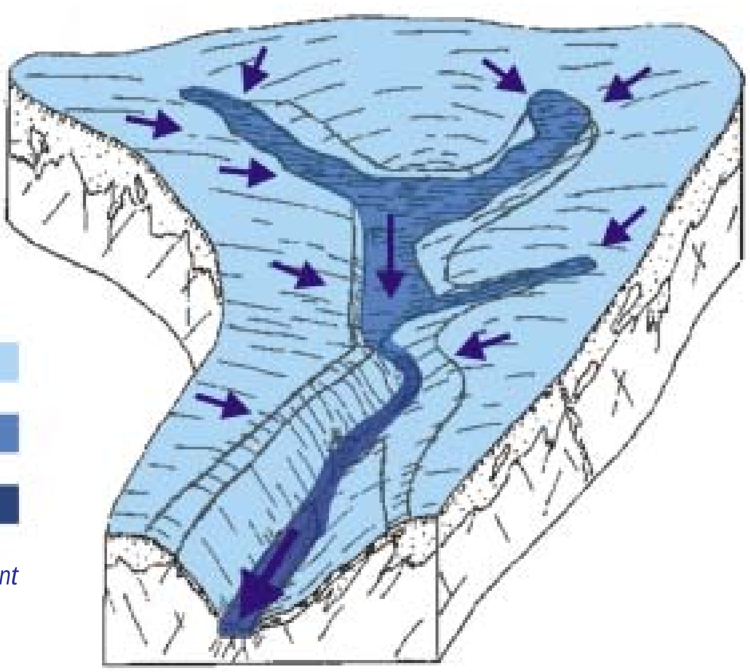


Figure 8: Three primary modes for surface water movement through a watershed.

Source: Adapted from drawing by Emery Cleaves,
Maryland Geological Survey

HOW MUCH WATER MAKES IT TO THE STREAM?

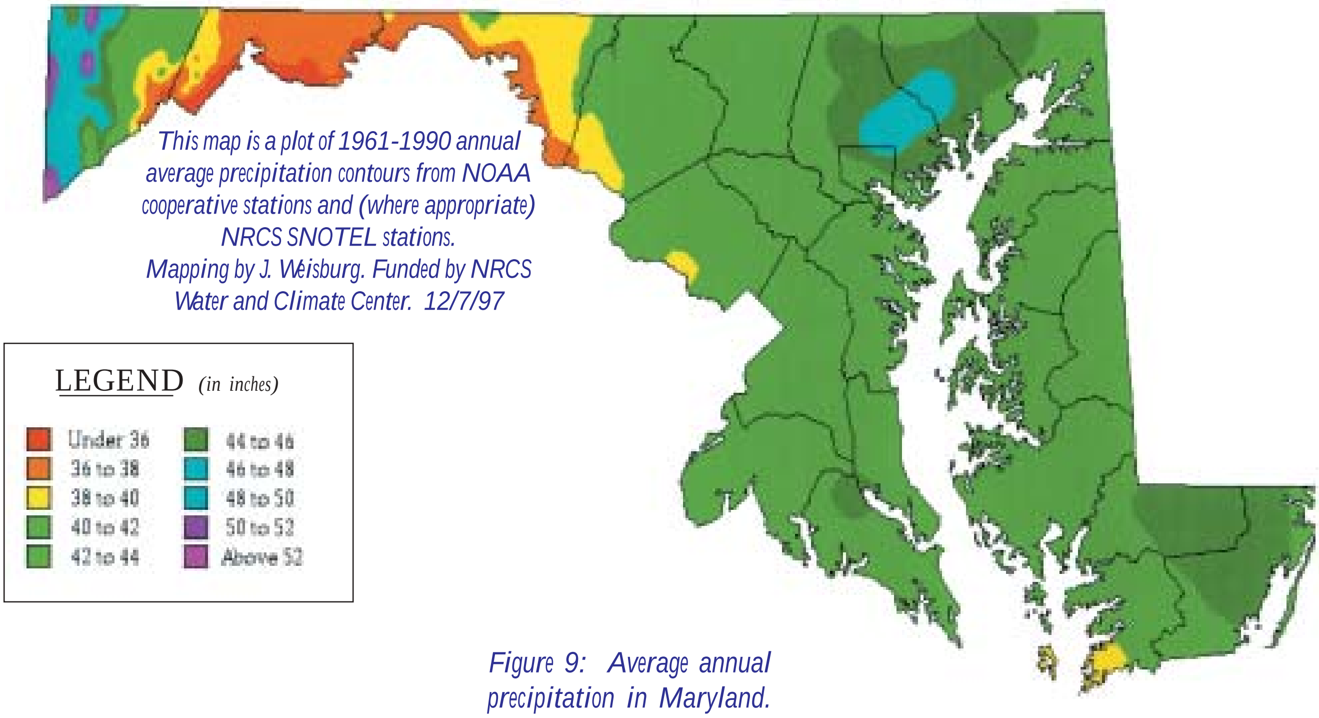
The amount of water entering a stream from precipitation depends on the intensity and the duration of the rainfall, the amount and type of vegetation, and the permeability of the soil. The amount and frequency of precipitation varies slightly across Maryland (*fig. 9*). Although peak total monthly precipitation often correlates with the late spring season, high rates of rainfall can occur during the late summer as a result of localized thunderstorms. Even though total rainfall may be highest in the summer, stream flows are typically lower (*fig. 7*). This is due to the high evaporation associated with warm air temperatures and high transpiration rates of growing vegetation.

Short, heavy thunderstorms can produce large quantities of runoff because the water falls too quickly to be absorbed by the soil. The lower the soil permeability and the higher the soil moisture content, the less infiltration and greater the amount of surface runoff. Frozen soils can generate large quantities of runoff because the ground is saturated and relatively impervious. Paved surfaces generally have the least capacity for infiltration and generate the greatest amount of runoff.

LWAD, MDDNR

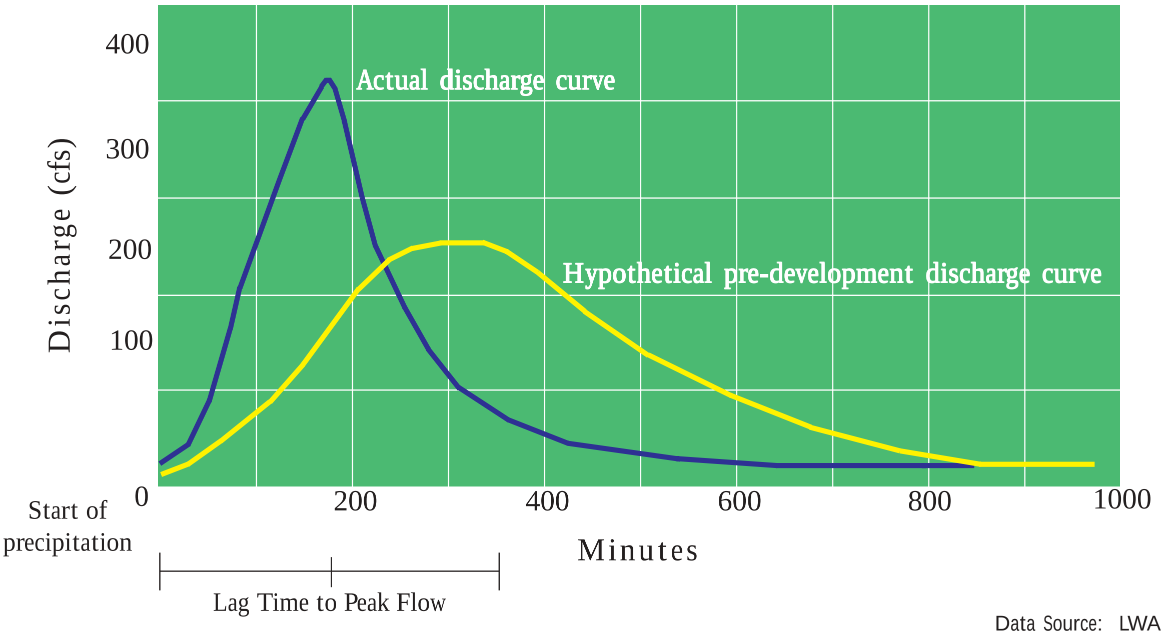
Precipitation falling on urban areas flows rapidly off of impervious surfaces and into nearby streams.

Steeply sloped land causes water to flow more quickly than gentle slopes. Smooth and compacted land surfaces, such as lawns and parking lots, generate faster runoff velocities because they have low surface roughness. In contrast, forested lands have a higher level of roughness that slows runoff velocities. As a result, runoff travels more quickly to streams in urbanized watersheds than in forested watersheds, producing higher peak flows and lower lag times for runoff concentration (*fig. 10*).



This map is a plot of 1961-1990 annual average precipitation contours from NOAA cooperative stations and (where appropriate) NRCS SNOTEL stations.
Mapping by J. Weisburg. Funded by NRCS Water and Climate Center. 12/7/97

Figure 9: Average annual precipitation in Maryland.



Data Source: LWAD, MDDNR

Figure 10: The measured discharge that occurred in White Marsh Run during a January 1997 rainfal event compared to the discharge that would have been expected prior to deforestation of the watershed. The changes that result from urbanization typically include increases in the peak discharge and decreases in the time from the beginning of precipitation to the peak discharge.

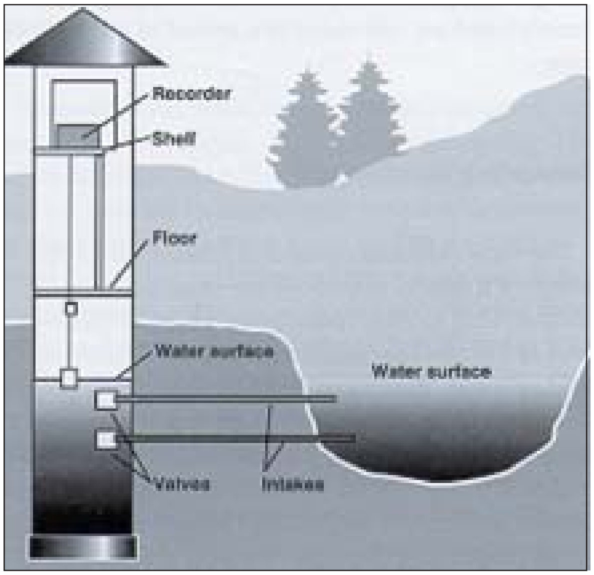
WATERSHED FACTORS THAT INFLUENCE RUNOFF CONTRIBUTIONS TO STREAM FLOW		
Affecting amount	Geology and Soils:	The amount of rainfall that is absorbed into the ground is determined by the permeability of the soil and underlying geology. Clay soils have lower permeability than sandy soils. Consequently, clay soils will promote greater amounts of surface runoff than sandy soils.
Affecting rate	Shape:	The shape of a watershed can influence the rate of discharge at the drainage network outlet because the distances from the watershed boundary to the outlet vary with shape, thereby governing the timing of flow concentration.
	Slope:	Steeply sloped watersheds will convey water to streams more rapidly than watersheds with gentle slopes.
Affecting rate and amount	Land Use:	Forested watersheds often have very little surface runoff in small to moderate precipitation events. Vegetation reduces runoff by intercepting rainfall, increasing roughness, and enhancing soil permeability. In urban areas, impervious land cover (such as parking lots) increases the amount of surface runoff, the velocity of overland flow, and time of runoff concentration during storm events.

COMPARING FLOWS

When a large rainstorm causes flooding, news reports often define the event in terms of an annual flood. For example, "Marsh Run near Hagerstown had a 20-year flood today." This 20-year reference, called a recurrence interval, identifies the frequency with which a discharge is expected to occur given the record of annual maximum discharges measured or calculated at a particular stream. The recurrence interval (R) of a discharge is calculated using a ranking of annual maximum discharges and is inversely related to the discharge exceedence probability (Pe) (i.e., R = 1 / Pe). The occurrence of a 20-year flood does not mean that the same event cannot occur the following year; rather, there is a 5% probability that the event will occur in a given year *(fig.11)*.

HOW ARE STREAM FLOWS MEASURED?

Flows within Maryland's stream channels are monitored using a network of stream gages. Most are maintained by the United States Geological Survey (USGS) and are located on relatively large waterways (i.e, third order or greater). The data collected usually include continuous monitoring of the water surface elevation, also referred to as the flow "stage". The stages correlate with discharges that are calculated using flow velocity and channel cross section measurements taken during several low to moderate flow events.



Schematic of a stilling well and shelter.
(Redrawn from Ref. #79)

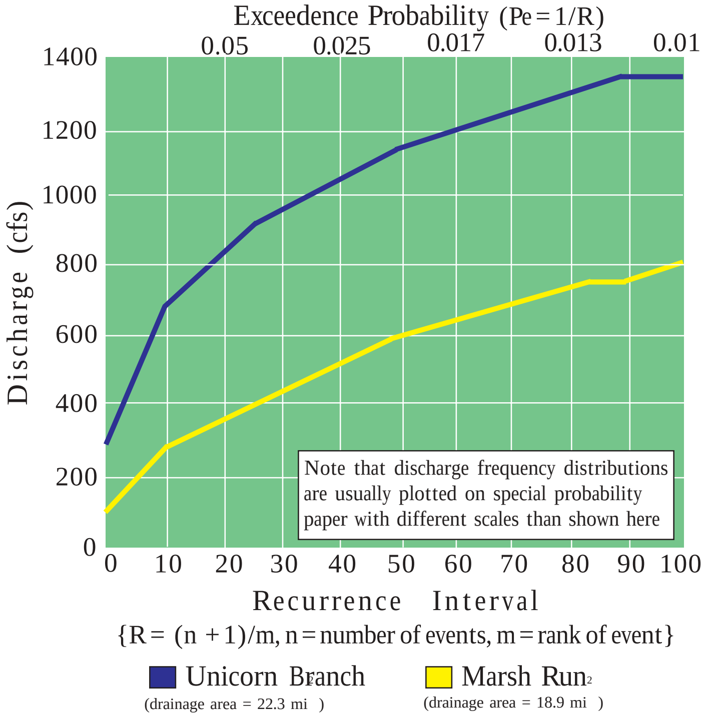


Figure 11: Flood frequency curves from Marsh Run in Washington County and Unicorn Branch on the Eastern Shore.

Data Source: USGS, Towson, MD.

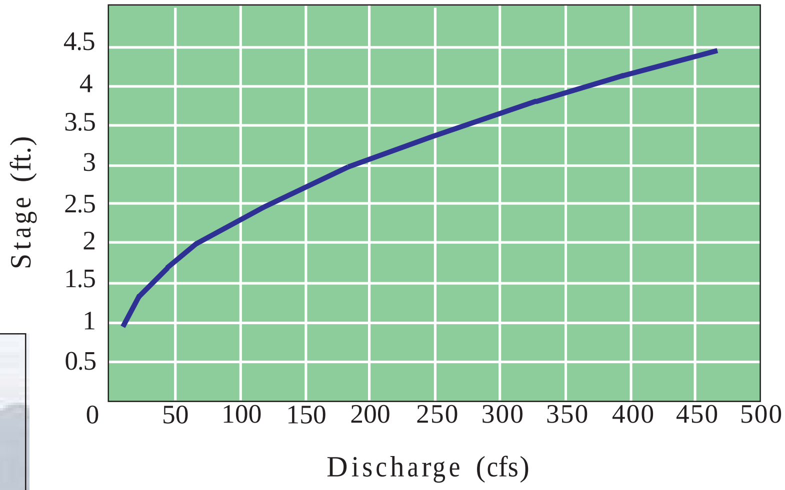


Figure 12: This graph shows the relationship between discharge and stage at the gaged cross section located in Marsh Run at Grimes, Maryland.

Data Source: USGS.

The information from active and historic gages is used for a variety of purposes, including the monitoring of public water supplies, flood forecasting, engineering, and the evaluation of the environmental impacts from human activities. Data from numerous gaging stations that continuously operate for a decade or more significantly improve the ability to estimate flooding and properly manage streams and their surrounding floodplain areas.

PUTTING OUR UNDERSTANDING INTO PRACTICE

The examination of watershed characteristics can provide important information about the factors that influence stream channel appearance and behavior. The local geologic conditions influence the shape of the watershed and configuration of the drainage network. The soils and land-use characteristics affect the magnitude and frequency of runoff, thereby governing stream flows.

LOCAL GEOLOGIC FORMATIONS:

The geology of the State has been extensively mapped. Use of these maps can help locate areas where bedrock might crop out, where areas that have natural tendencies to accumulate sediment exist, and where changes in bedrock composition occur.

MARYLAND EXAMPLE

The Deep Run watershed in Howard and Anne Arundel Counties traverses the border between the Piedmont and Coastal Plain. The transition that occurs through this physiographic boundary changes the shape of the stream valley and the behavior of the channel reaches within it. Depositional zones found in these types of boundary areas are locations where relatively rapid stream channel adjustments can occur. Knowledge of unique locations like this can be important for proper stream channel assessment and management (*fig.13*).

LAND USE EFFECTS ON FLOW

Land cover changes can have significant influence on channel appearance and behavior because of the relationship with rainfall runoff, which can affect both stream stability and baseflow conditions.

MARYLAND EXAMPLE

Streams channels are highly susceptible to erosion from urban storm flows, particularly in the easily eroded materials of the Coastal Plain. Stormwater quantity management attempts to focus on this problem by reducing the magnitude of the peak flow increases resulting from development. Simultaneous consideration of other factors affecting channel stability, such as sediment supply and stormflow duration, is equally important for successful stream management. Low flows can also be affected by development through decreases in groundwater recharge and increases in groundwater withdrawals for water supply (*fig. 14*), thereby reaffirming how important it is to consider the water flow pathways within a watershed when planning development.

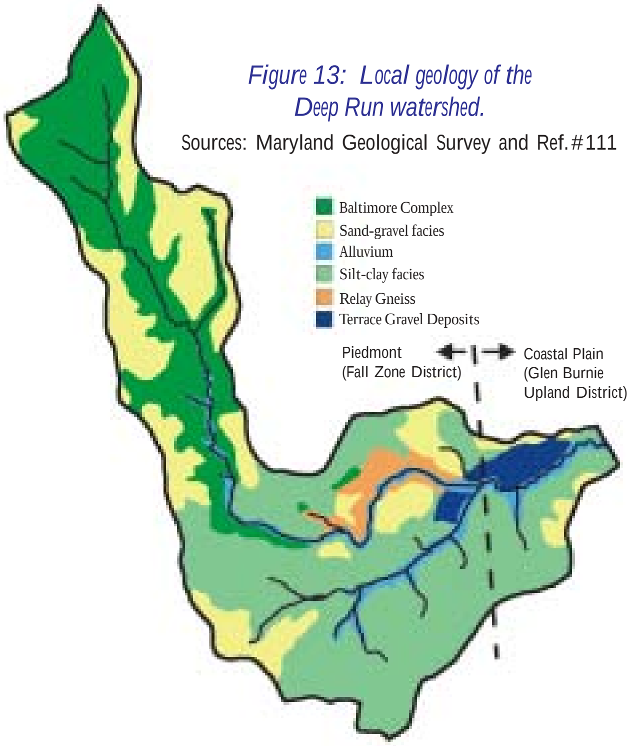


Figure 13: Local geology of the Deep Run watershed.

Sources: Maryland Geological Survey and Ref.#111

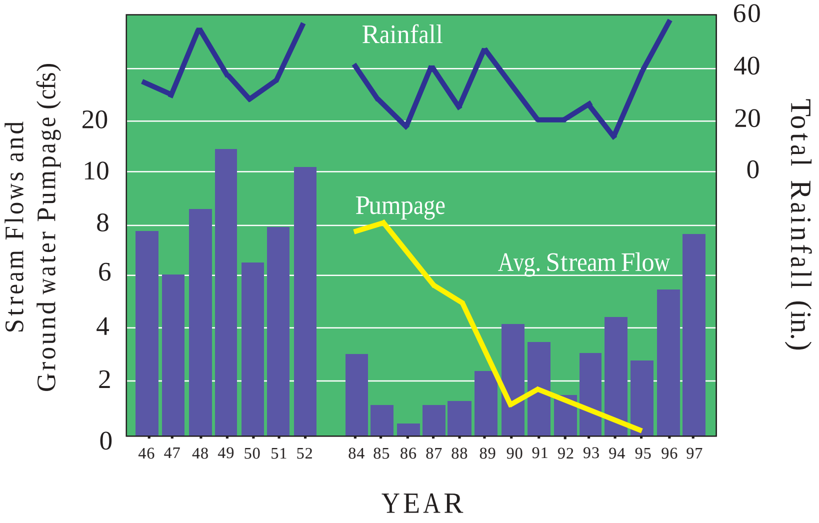


Figure 14: Graph showing the relations between ground water withdrawal and baseflows in Sawmill Creek in Anne Arundel County. The decline in baseflows was reversed in the 1980's with reductions in ground-water withdrawals from the underlying aquifer.

Sources: Ref. # 103 and 113

REACH LEVEL

In the previous two sections, we examined the landscape and watershed characteristics that influence how water and sediment is delivered to streams. In this section, the focus is narrowed to a specific part of the watershed drainage network, referred to as a stream "reach". A reach can generally be defined as an uninterrupted length of channel with similar physical characteristics and no artificial boundaries. In practice, a reach is usually no longer than several hundred yards, but has no standardized limits.

The focus of the Reach Level is on the behavior of stream channels in response to water and sediment movement. The physical components of stream reaches that are "self-formed" by processes of sediment erosion and deposition include the active channel and adjacent floodplain. However, it is important to note that incising headwater channels at the upper end of drainage networks often do not have floodplains.

Three basic flow regimes can influence the physical characteristics of a "self-formed" channel reach, including base flows that provide aquatic habitat, frequent storm flows that govern the channel form, and rare flood flows that instigate changes in the channel form. The frequency and magnitude of these flows, combined with the characteristics of sediment movement through a reach, determine the appearance and stability of streams. Cross section, planform, and longitudinal spatial perspectives are relevant to the evaluation of channel appearance and behavior. Where they are free to adjust, channels can migrate vertically and horizontally within their valleys. The rates of migration are governed by complex relations between sediment flux, the channel structure, and water flow.

Common research, engineering, and management interests at the Reach Level are related to the understanding of the linkages between landscape setting, watershed position, and channel stability under different hydrologic and hydraulic conditions. Related investigations involve the quantification of water flow velocities and sediment movement within a stream reach over different spatial and temporal scales.

S. Clotworthy, MDDNR

One of the great meander bends at Paw Paw on the Potomac River in Allegany County.

THREE STREAM CHANNEL PERSPECTIVES

A stream reach can be described using three different perspectives, including the planform, cross section, and longitudinal views. Different dimensional measurements can be associated with each of these perspectives.

PLANFORM PERSPECTIVE

The planform perspective is the view taken looking down from above the stream (*fig. 15*). This view focuses on the relation between the stream and the surrounding landscape and shows the downstream path of the active channel.

The primary dimensional parameter in this perspective is sinuosity (*fig. 16*). Sinuosity is the ratio of stream length to the valley length. The higher the sinuosity, the more sinuous the channel and the longer its downstream path through the valley. The overall planform pattern is governed by the downstream valley slope and the resistance of the landscape to erosion. "Straight" channels occupy the same alignment and distance as the stream valley. "Sinuous" channels have straight banks and alternate bar features that create a low flow path that is slightly longer than the valley length. Truly "meandering" channels have paths that are significantly longer than that of the stream valley.

Some streams contain large sediment deposits that divide the channel into multiple independent flow paths. *Braided* streams have divided flow caused by bars that are composed of unstable sand or gravel. These bars may change frequently during high flows because the sediments that compose them are unconsolidated and easily moved. *Anastomosed* streams also have divided flows, but much more stable bar formations due to the presence of organic matter (leaves and woody debris), cohesive sediments, or living plant roots. Battle Creek Cypress Swamp in Calvert County is a good example of an anastomosed channel (*see photo, page 3*).

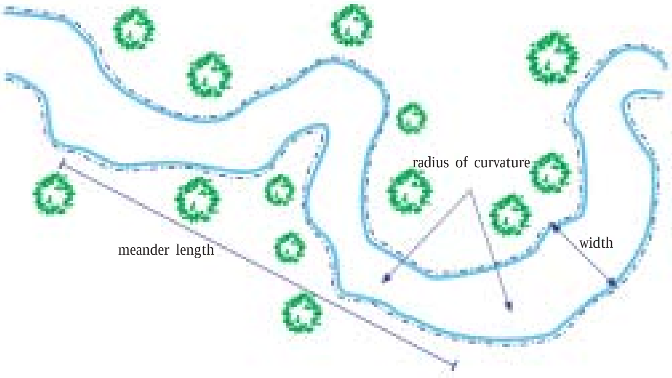


Figure 15: Planform perspective.

$$\text{SINUOSITY} = \frac{\text{Channel Length (ft.)}}{\text{Valley Length (ft.)}}$$

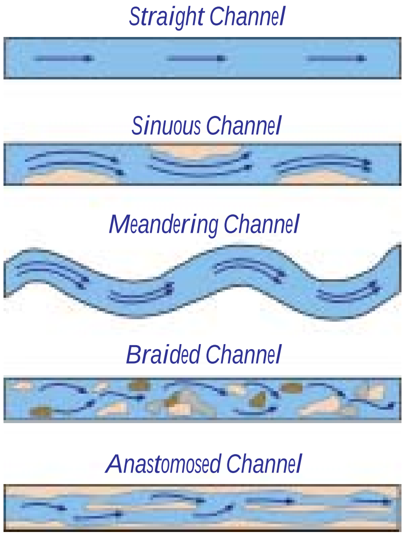
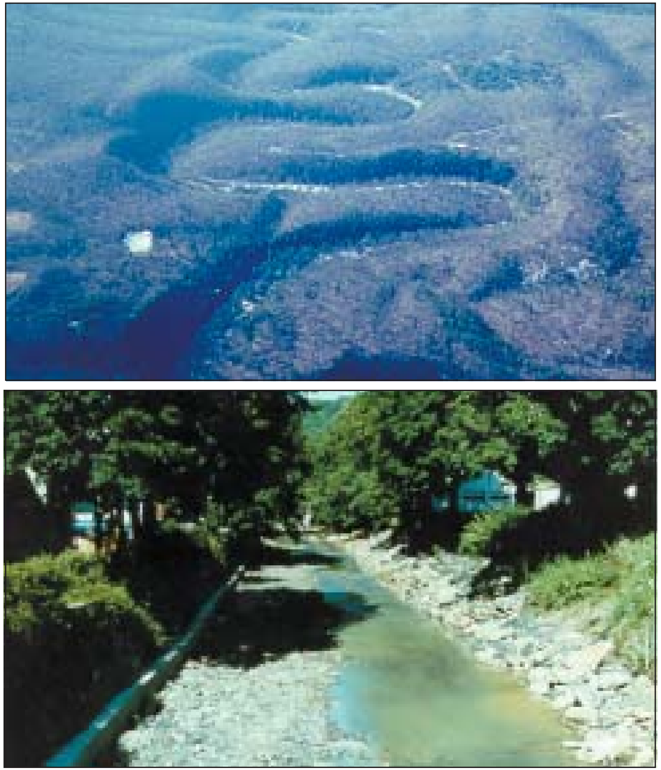


Figure16: Channel reach planform morphologies.

MDDNR



LWAD, MDDNR

A meandering reach in Sideling Hill Creek (top) and a straight reach in George's Creek (bottom).

CROSS SECTION PERSPECTIVE

The cross section perspective is the view that would result from a cut made perpendicular to the down-stream flow path. Dimensions taken in this perspective can provide measurements of the width and depth of the flow area. These dimensions comprise the channel's shape, influence its ability to move water and sediment, and determine aquatic habitat conditions.

Figure 17: Cross-section perspective.

Channel dimensions in the cross section perspective are typically taken from the bankfull elevation. This elevation corresponds with the tops of depositional features created by the processes that form the active channel and floodplain. Self-formed channels shaped by these processes usually have the capacity to convey only low to moderate flows. In eroding environments characterized by incising channels, the cross section dimensions measured up to the tops of the channel banks are often capable of conveying a larger range of flows (including large discharges that infrequently occur.)

LONGITUDINAL PERSPECTIVE

The longitudinal view or profile is the perspective taken if you could remove one side of a stream channel and look at it as if it were a flight of stairs. Moving from the top to the bottom of a watershed, streams generally decrease in slope and increase in cross section area. This trend is easily seen in Maryland where headwater tributaries begin in steep to moderately sloped areas, progressing downstream into more gently sloped valleys or estuarine embayments.

The longitudinal profile is important because of its association with the slope of the water surface in the downstream direction. This slope governs the force and power of the flow. While stream bottom profiles are generally bumpy with variable slopes, the water surface tends to have a more consistent slope. The relationship between irregular stream bottoms and the more consistent water surface slope produces differing depths and flow velocities. These changes in water depth and velocity create a variety of habitats for aquatic organisms.

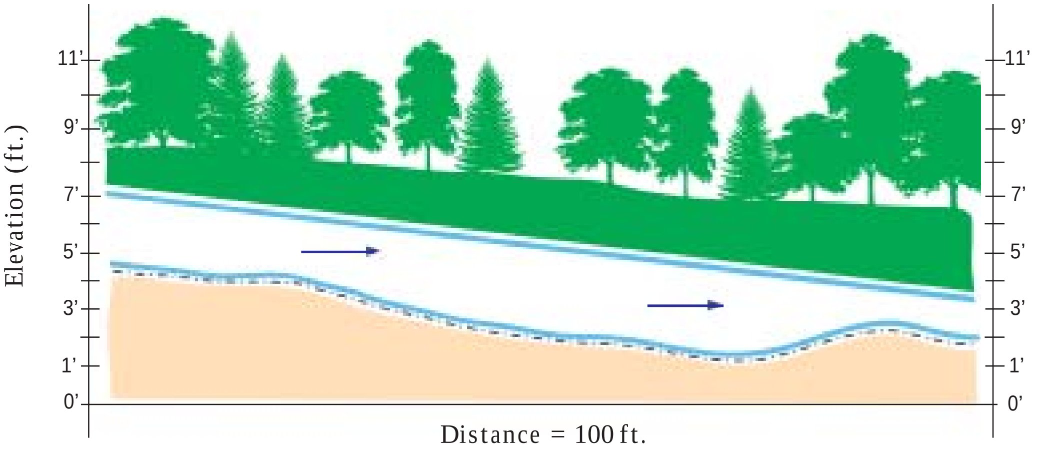


Figure 18: Slope measurements taken from the water surfacein the longitudinal perspective.

$$\text{SLOPE} = \frac{7-3\ (\text{ft.})}{100\ (\text{ft.})} = \mathbf{0.004\ or\ 0.4\%}$$

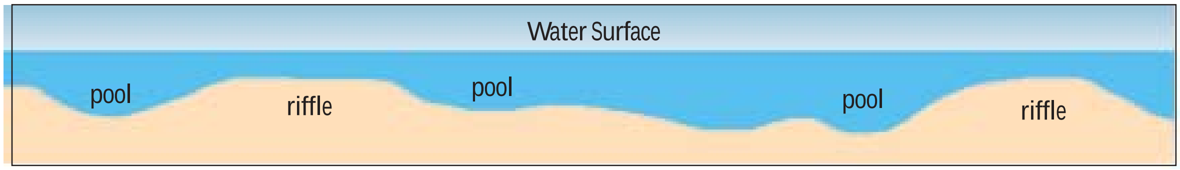


Figure 19: This longitudinal perspective can provide a view of the undulating stream channel bottom and a more consistently sloped water surface.

CHANNEL HYDRAULICS: HOW STREAMS CONVEY WATER

THREE BASIC FLOW REGIMES CAN AFFECT A CHANNEL REACH

Self-formed streams are composed of an active channel and adjacent floodplain. The lateral extent of water movement away from the active channel and related physical adjustments vary with the amount of flow being conveyed.

Base Flows: Base flows originate as slow releases of ground water or surface releases from ponds, wetlands, and spring seeps in the absence of precipitation. These flows, which vary throughout the year, are an important determinant of aquatic habitat because they provide a discharge in streams during periods without precipitation.

Bankfull Flows: These flows fill the channel up to the top of its banks in self-formed channels and are often responsible for shaping and maintaining the channel dimensions in alluvial valleys. In the absence of watershed alterations from urbanization or agriculture, bankfull flows have been found to occur at a frequency of once every one to two years in Maryland Piedmont streams; however, they can occur more frequently in disturbed watersheds in response to increases in rainfall runoff.

Flood Flows: Discharges that overtop stream banks and move onto the floodplain are called flood flows. These flows occur less frequently than bankfull flows but can have influence on the behavior and appearance of channels for years or decades thereafter.

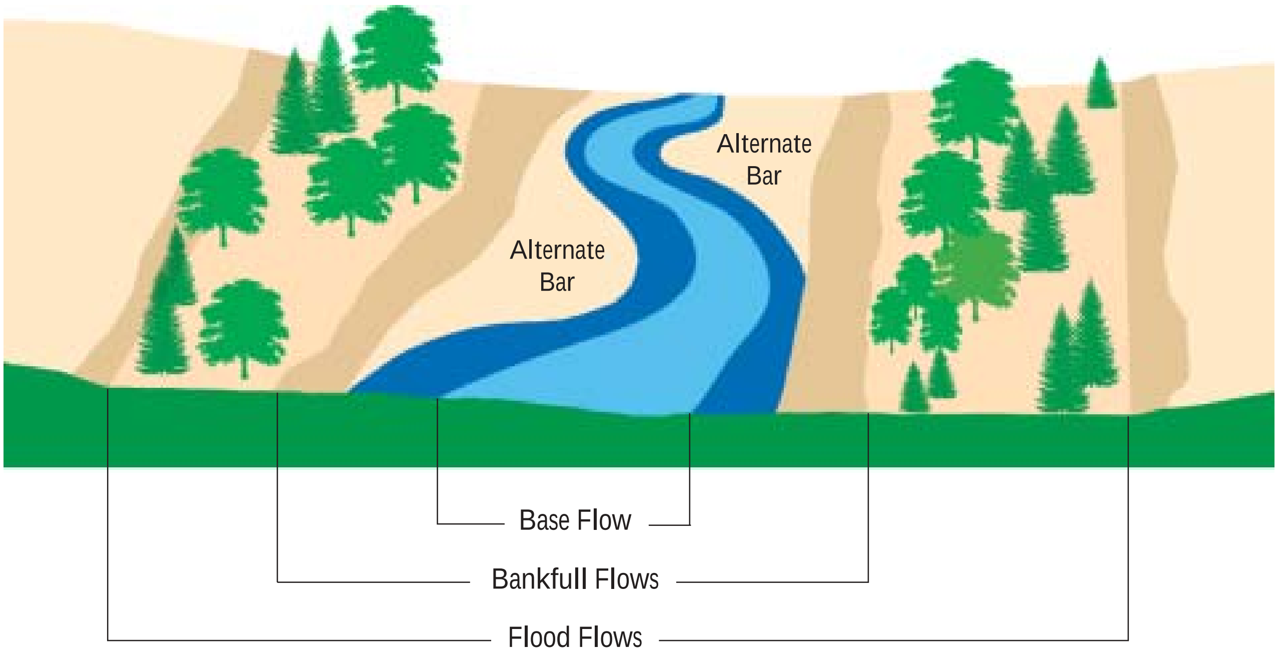
CONTINUITY

The water discharge in a stream is measured as a volumetric rate of downstream movement. The basic relation between flow cross-section area, average flow velocity, and discharge can be expressed through the continuity equation. This relation is a way of accounting for mass conservation, meaning that flow inputs equal flow outputs in a system (i.e., channel reach). In a simplified system with a constant discharge and incompressible fluid, reductions in the cross section area of the flow will cause the flow velocity to increase. Conversely, if the flow cross section area increases, the average flow velocity will decrease.

CONTINUITY EQUATION

$$Q\ (ft^3/s) = V\ (ft/s) * A\ (ft^2)$$

Where: Q = discharge, A = area , V = velocity



Adapted from drawing by PWA, Ltd.. Used with permission. (Ref.#123)

Figure 20: Typical areas of inundation by base flows, bankfull flows, and flood flows in alluvial valleys.

VELOCITY: HOW FAST IS THE WATER MOVING?

The velocity of the water moving through a reach can be described by the Manning equation. The equation relates the flow velocity to the water depth, water surface slope, and channel roughness.

Manning Equation:

$$V = 1.49/n\ (R)^{2/3}\ (S_f)^{1/2}$$

Where: V = Velocity (ft/s),
R = Hydraulic Radius (ft),
S_f = Energy Gradient (ft/ft),
n = Roughness Coefficient

THE ENERGY GRADIENT (SLOPE)

The energy associated with flow at a given location can be approximated using the sum of hydraulic terms characterizing flow pressure, elevation, and velocity. The "energy gradient" associated with a flow is the change in the energy that occurs with distance downstream. The water surface slope can be used as an approximation of the energy gradient if an assumption of steady flow (i.e., velocity is constant over time) is valid. The channel slope can be used as an approximation of the energy gradient if an assumption of uniform flow (i.e, velocity is constant over a distance downstream) is valid.

Steep mountain streams, such as those near Cunningham Falls, create steep water surface slopes and fast-moving flows. Coastal Plain streams, such as Watts Branch on the Eastern Shore, have gentle slopes and slow-moving flows. For the same discharge rate, flows moving over the top of Cunningham Falls experience a larger energy gradient than those in Watts Branch because the velocity and change in elevation over the falls are greater. Despite the high gradient and resulting hydraulic forces, the bedrock channel resists erosion, which limits incision. Coastal Plain streams have no bedrock controls, but also do not have steep topography that create steep gradients.

WHAT SLOWS DOWN THE WATER?

As water moves downstream, a variety of elements in the channel and floodplain regulate the flow velocity by exerting retarding forces *(fig. 21, following page)*. The resistance created by these elements, which can include bottom sediments, meander bends, localized changes in channel width, bar formations, and turbulence, can be collectively approximated by a single roughness parameter (Manning's roughness coefficient) that has an inverse relation with flow velocity.

LWAD, MDDNR

The fast moving flows of Cunningham Falls in Frederick County.

LWAD, MDDNR

The slow moving flows of Watts Creek in Caroline County.

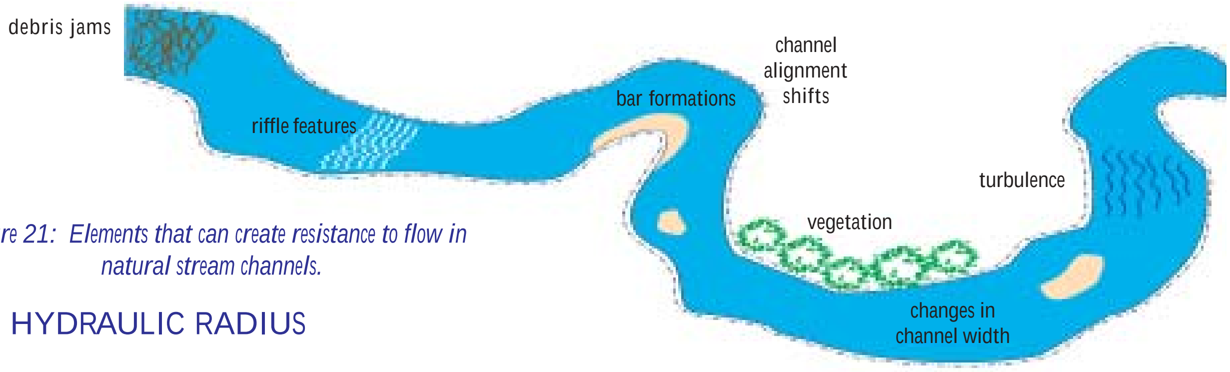


Figure 21: Elements that can create resistance to flow in natural stream channels.

THE HYDRAULIC RADIUS

The Manning equation is based on a balance between gravity-driven (thrust) forces and resistance (shear) forces. The gravity-driven forces are partly dependent on the cross section area of the flow. The resistance forces are partly dependent on the perimeter of the channel in contact with the flow. The hydraulic radius is a length term derived by dividing the flow cross section area by the wetted perimeter when solving for flow velocity through the force balance. It approximates the average flow depth in wide channels.

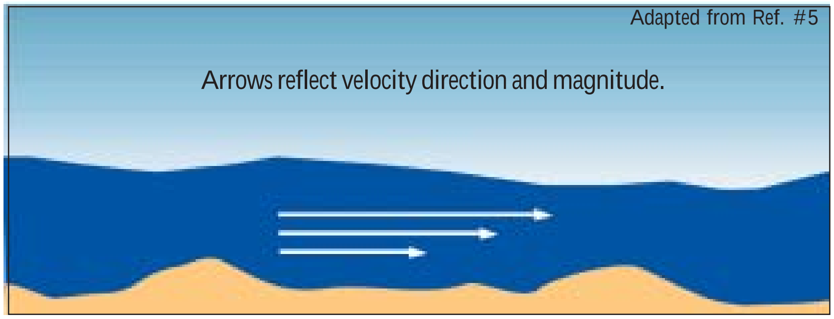
The hydraulic radius of a channel has relevance to flow resistance because water flowing against the bed and bank surfaces experiences energy-robbing friction. The further the flow is from the sources of friction, the faster it moves downstream *(figs. 22-23)*. The term "relative roughness" is used to describe the relationship between stream bottom roughness and the depth of the flow. A shallow flow in a stream with large stones or boulders will experience greater resistance from the channel bottom compared to deep flows moving over a relatively smooth sand bed. Similarly, the larger the sources of friction on the stream banks, the greater their influence on the flow over the channel width.

LWAD, MDDNR

Sources of resistance from vegetation and debris in Deep Run, Anne Arundel County.

The average flow velocity in a stream is roughly 0.80 to 0.90 times the velocity observed at the water surface.

If a stick were traveling on the water surface at 5.0 ft/s, the average velocity of the water flow may actually be 4.25 ft/s.



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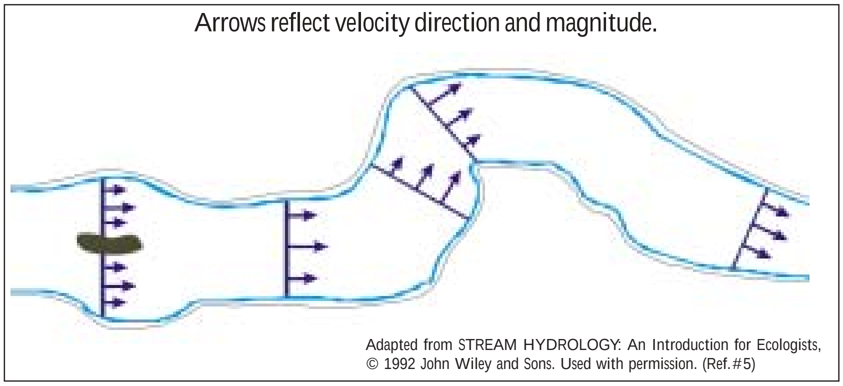
Arrows reflect velocity direction and magnitude.

Figure 22: Velocity distributions in the longitudinal perspective.

Arrows reflect velocity direction and magnitude.



Adapted from STREAM HYDROLOGY: An Introduction for Ecologists, © 1992 John Wiley and Sons. Used with permission. (Ref.#5)

Figure 23: Generalized velocity distributions in the planform perspective.

CHANNEL ADJUSTMENT: THE RESPONSES TO STREAM FLOWS

Geomorphologists and engineers have studied channels, their rates of change, and the processes influencing their shape for centuries. Despite this attention, two seemingly simple questions are still difficult to answer:

* When can a stream channel be called stable?
* What discharges have the greatest influence on the channel form?

The answers to these questions can be complex and site specific due to the variable characteristics of streams and the extraordinary complexity of how water and sediment flow through them.

EQUILIBRIUM CONDITIONS: DO THEY EXIST IN STREAMS?

The term "equilibrium", more accurately stated as "steady-state equilibrium", is often used to describe the condition under which a stream's average shape and dimensions are maintained over a period of time, such as several decades or a century. Under this definition, channel changes occur in response to changes in sediment supply, but they are localized in a reach and last for relatively short periods of time. Short-term widening and contraction of channels in response to floods are good examples of this variability.

The perpetuation of an equilibrium condition requires consistent watershed conditions. Watershed changes that alter the frequency and magnitude of water and sediment discharges make it difficult to obtain consistent channel conditions over time. Most of Maryland's watersheds have experienced numerous changes in land use over the past century. As a result, there are few streams that exist under a constant steady-state equilibrium.

WHICH FLOWS SHAPE A CHANNEL?

The shape and dimension of a stream channel are influenced by the frequency, magnitude, and velocity of the flows conveyed by the channel, the type and amount of sediment supplied to the channel, and the structural characteristics of the stream bed and banks.

In the absence of structural controls, the factor having the greatest influence on the channel shape and dimension is the capacity of the reach to move the sediment supplied to it. A reach that receives excessive sediment loads from agricultural fields or urban construction may not be capable of transporting all of the materials that it receives. This can result in the temporary build up of sediments and braided conditions within a reach that was previously characterized by a meandering planform. Conversely, a channel that receives increases in flow without simultaneous increases in sediment supply can rapidly degrade due to a net export of sediment.

There are three terms (bankfull, dominant, and effective discharge) that have been used by engineers and geomorphologists to describe the flows that have the greatest influence on the channel dimensions. These are broadly defined here and in the glossary. Currently, there are discussions within the scientific communities as to how these terms should be applied in stream channel assessments and designs.

Dominant Discharge	This is a conceptual term that describes the discharge that has the most influence on the channel dimension. This concept was historically derived from engineering criteria for canals that were designed with the goal of requiring little or no maintenance.
Bankfull Discharge	This is the discharge that fills the stream to the top of the channel banks formed by water flow and sediment deposition. This discharge has been correlated with a return frequency of 1-2 years in several of Maryland's Piedmont and Coastal Plain watersheds.
Effective Discharge	This term describes the flow that transports the most sediment over an extended period of time. Effective discharge is often correlated with the dominant discharge because of the link between sediment and the channel dimension. However, it is important to note that there are other measures of the effectiveness of a discharge in the shaping of a channel, such as parameters related to channel erosion.

CHANNEL CHANGES

Stream channels respond to the amount, frequency, and duration of water and sediment moving through them. Changes can occur in the cross-section dimension, planform shape, longitudinal slope, and the arrangement of the bottom substrate and topography. The hydrology, surrounding land use, topography, rocks, soils, and trees determine the modes and magnitudes of adjustment.

Stream channels often maintain constant positions in the landscape where they are controlled by bedrock formations that are resistant to erosion. In places not controlled by bedrock and characterized by low to moderate slopes, streams can migrate back and forth across channel valleys. The average cross section dimensions can be maintained over time as the channel position changes if the water and sediment supply remain consistent.

Channel migration can occur in several different ways. In sinuous or meandering channels operating under natural conditions, bank erosion on the outside of a meander bend is compensated by the accumulation of deposited materials (bank rebuilding) on the inside of the bend *(fig. 24)*. This process of erosion and aggradation is how channels migrate across their valleys. If the rates of erosion and aggradation are similar, the channel will change its position but maintain its cross-section dimension. This condition is sometimes called a "dynamic equilibrium" because it is a form of stability.

In urbanized and agricultural watersheds, stream bank erosion can exceed sediment accumulation and bank rebuilding. This results in the enlargement of the channel. Within a meander, erosion on the inside of a bend that normally aggrades with sediment can result in an increase in the channel width and depth. This will continue until the hydraulic forces on the channel banks are sufficiently reduced so as to limit further expansion, or until resistant bank materials are encountered. Examples of these processes can be clearly seen in channels in the urbanizing areas of the Coastal Plain and Piedmont near Washington, D.C. and Baltimore.

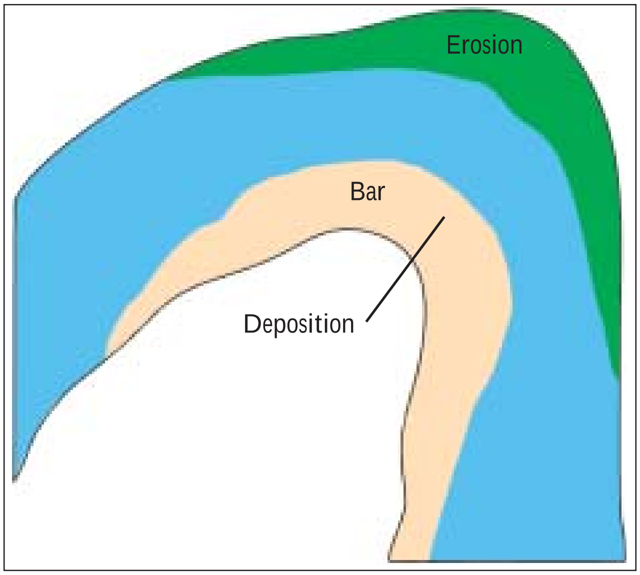
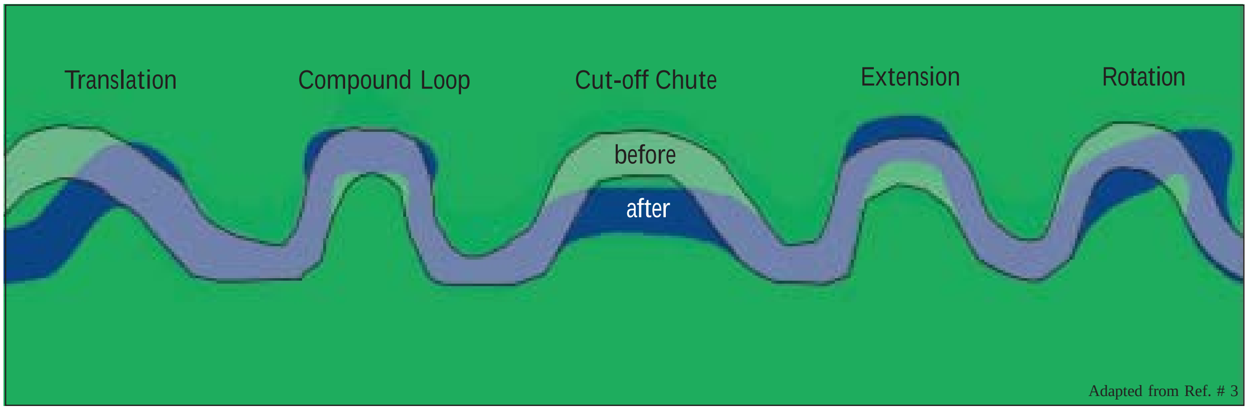


Figure 24: Lateral bank migration shown with erosion of the outside bend balanced by sediment deposition on the inside of the bend.

The appearance of individual meanders can change over time as a result of different rates of outer bank erosion through a bend. The varied rates of erosion can result in different modes of planform adjustment *(fig. 25)*. In extreme cases, entire meander bends can be abandoned by the formation of a cut-off channel through a narrow section of land at the base of a bend. Meander bends prone to this mode of adjustment are called oxbows (*see photo series, page 27-top left*). The abandoned feature, called an oxbow lake, will remain as a pond until it fills in with sediment carried by flood flows.



Adapted from Ref. # 3

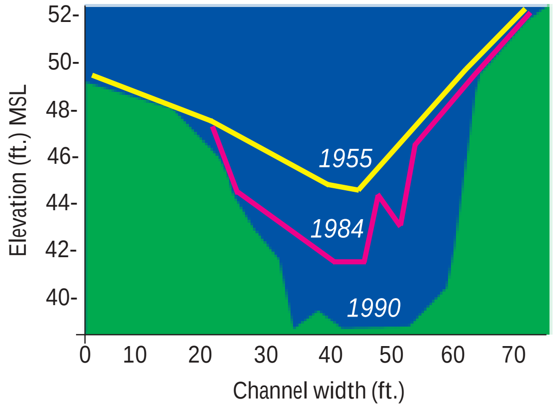
Figure 25: Generalized modes of meander bend migration in the planform perspective (light green alignment = before migration; dark blue alignment= after migration).

USDA

Aerial photographs taken over Little Pipe Creek in Carroll County show the formation of a large oxbow lake. These pictures were taken from 1963 (top), 1970 (middle), and 1997 (bottom).

Channel incision is another form of adjustment that often occurs in streams with moderate to steep slopes and composed of easily erodible materials. Channels cut downward if the export of sediment out of a reach exceeds the sediments imported into a reach. First and second order channels on the western side of the Coastal Plain are often prone to incision because they are steep enough to generate erosive flows and composed of highly erodible materials, such as sand. These headwater channels receive limited sediment contributions to compensate for channel erosion, particularly when the contributing watersheds are urbanized. Evidence of channel incision can often be seen around urban infrastructure in developed areas *(figs. 26 and 27)*.

Geomorphic processes associated with incision can vary with the landscape setting and climatic conditions. Steeply sloped first order channels in western Maryland are also susceptible to incision; however, bedrock prohibits down-cutting over short time scales. Hillslope processes that move large amounts of sediment over short time periods, such as debris flows and landslides, can affect the appearance of channels on steep slopes during extreme precipitation events. However, such events are rare in Maryland.



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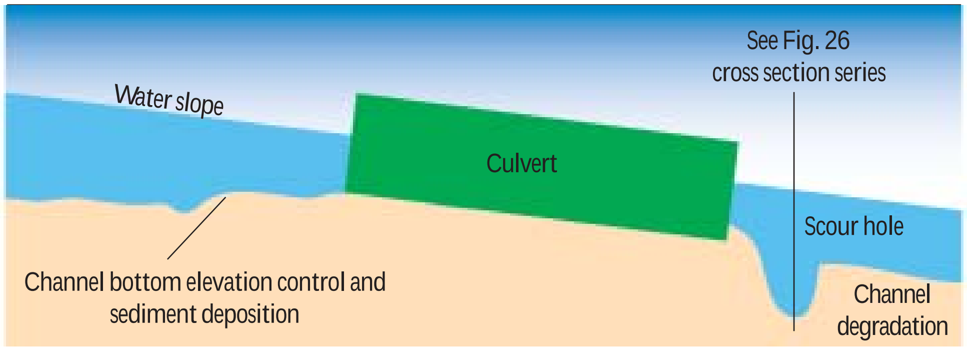


Figures 26 (above) and 27 (below): Urban infrastructure can influence vertical erosion rates in localized areas and mark the effects in the longitudinal profile. In this case, high velocity flows produced by a road culvert carrying Muddy Bridge Branch under I-97 in Anne Arundel County enlarged the channel on the downstream side by creatng a scour hole. The structure also stopped the progression of channel incision upstream. Culverts like this one cause opposite effects on the upstream side, causing sediments to build up and preventing channel incision.

THE SEDIMENT ENVIRONMENT

Sediment is a term used to describe the geologically derived particles found in stream channels that vary greatly in size and shape. The sizes are generally divided into clays(<0.004mm), silts (0.004-0.062mm), sands (0.062-2mm), gravels (2-64mm), cobbles (64-256mm), and boulders (>256mm). Shapes of the particles can range from spherical to platy geometries.

Sediment particles move because water flowing in the channel pushes them downstream. Channels act as sediment conveyor belts, transporting materials from the first order channels to the higher order channels. However, the rate of transport is not constant over time or consistent through a drainage network. The amount of sediment that moves through a reach depends on the amount of sediment input, the magnitude, frequency, and duration of flows, and the hydraulic geometry of the channel.

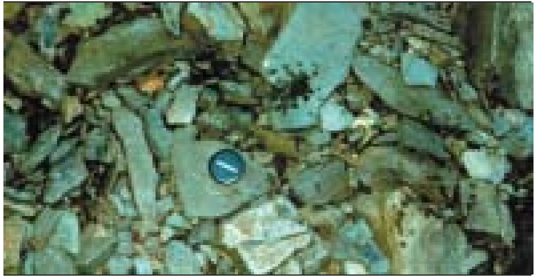
Individual sediment particles move by either rolling or hopping along the bottom of the channel as bedload; or, by traveling in complete suspension in the water column. The amount of force required to move a particle depends on its size, density, shape, and position relative to other particles.

FOUR FACTORS AFFECTING SEDIMENT MOVEMENT

- The larger the particle mass, the more force that is required to move it.
- Particles with more surface area exposed in the water column experience more force from the water flow, which increases their susceptibility to movement.
- Particle shape affects movement, with round shapes being more susceptible to rolling.
- Small particles surrounded by larger particles are more resistant to moving because they have to climb out from the shadow of the larger particles.
- Cohesion between particles increases resistance to the initiation of motion

LWAD, MDDNR

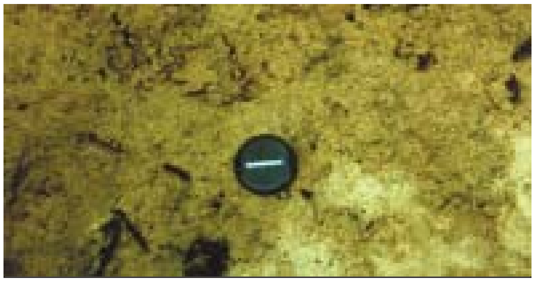
The bed of Bear Creek contains cobble and boulder sized particles derived from siliciclastic bedrock formations in the Appalachian Plateau Province.



Fifteen Mile Creek contains platy gravel and cobble sized particles derived from siliciclastic bedrock formations in the western portion of the Ridge and Valley Province.

Grave Run sediments are dominated by gravel, with some cobble sized particles derived from crystalline bedrock formations of the Piedmont Province.

The bed of Marsh Run is dominated by silty materials derived from the carbonate-dominated Great Valley in the eastern portion of the Ridge and Valley Province.



The bed of Severn Run has a mixture of sand and small gravel sized materials derived from unconsolidated Coastal Plain sediment formations.

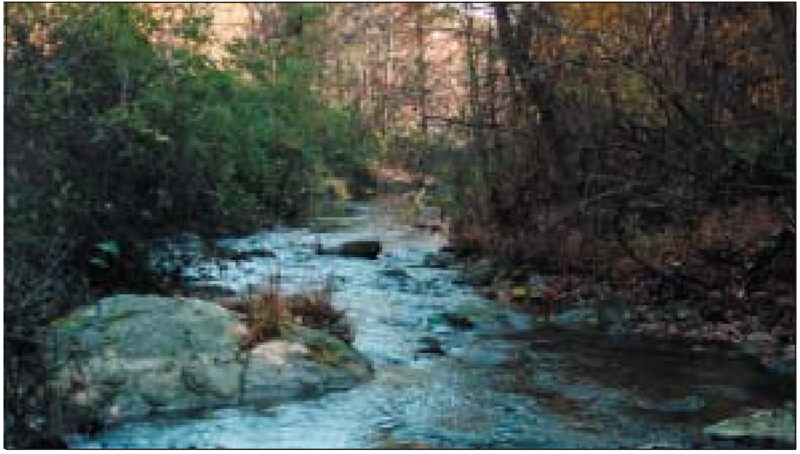
REACH - SPECIFIC SEDIMENT TRANSPORT CHARACTERISTICS

Sediment movement is not constant over time or consistent throughout a watershed because each individual reach within a drainage network has physical characteristics that create unique flow characteristics and sediment transport capabilities. For example, incising channel reaches associated with low order streams often release more sediment than they receive. This sediment can become stored in bars and adjacent floodplains in downstream reaches. In some locations, pulses of sediment from upstream are conveyed through a reach in waves that coincide with high flows.

LWAD, MDNR

Sediment production reach in the Grave Run headwaters

LWAD, MDDNR



Sediment transport reach in the Grave Run mainstem.

LWAD, MDDNR

Sediment deposition reach at the downstream end of Grave Run in Pretty Boy Reservoir

Grave Run, located in the Piedmont, provides an example of a drainage network with distinct segments that have different sediment flux characteristics. The top photo shows an area of sediment production in the headwaters. This supplies sediment to the mainstem of Grave Run, which acts as a transport reach (middle photo). Although sediment deposition occurs within the transport reach, it is balanced with sediment losses. The lower-most reach of the Grave Run mainstem (bottom photo) receives the sediment transported from upstream, but is incapable of passing most of the load further downstream. In this example, the lower depositional reach is a large delta located in the Pretty Boy Reservoir. Sediment derived from years of erosion in the upper portion of the watershed has accumulated in this delta.

SEDIMENT STORAGE

Sediment stored in stream channel bar formations and on floodplains can provide a history of a changing land use activities. Distinct changes to the morphology of the active channel and floodplain have been observed in response to alterations in watershed hydrologic conditions and sediment supply. Many Piedmont floodplains were formed over long periods of time by the settling of fine sediment in the wooded areas adacent to active stream channels. Following European colonization of the land, the widespread establishment of farming caused dramatic increases in sediment supply. This change resulted in the accumulation of significant layers of sediment in floodplain areas over a relatively short period of time. In recent years, reductions in agricultural activities and improved sediment controls have resulted in a decrease in sediment supply from over-land sources.

Coincident with the decreases in watershed sediment supplies, urbanization has increased the magnitude and frequency of discharges associated with small to moderate rainfall events (see *fig. 10*, p.16). Piedmont streams respond to these changes by eroding into the fine sediment stored on the floodplain, thereby remobilizing it for downstream transport. The coarser materials are reworked into bar features within the channel. These types of observations demonstrate the role of watershed processes in the evolution of stream channels, as well as the relevance of geomorphic history to the explanation of appearance and behavior of streams *(fig. 28)*.

Original graphic by R.B. Jacobsen and D.J. Coleman. Reprinted with permission from the American Journal of Science. See Ref. #43

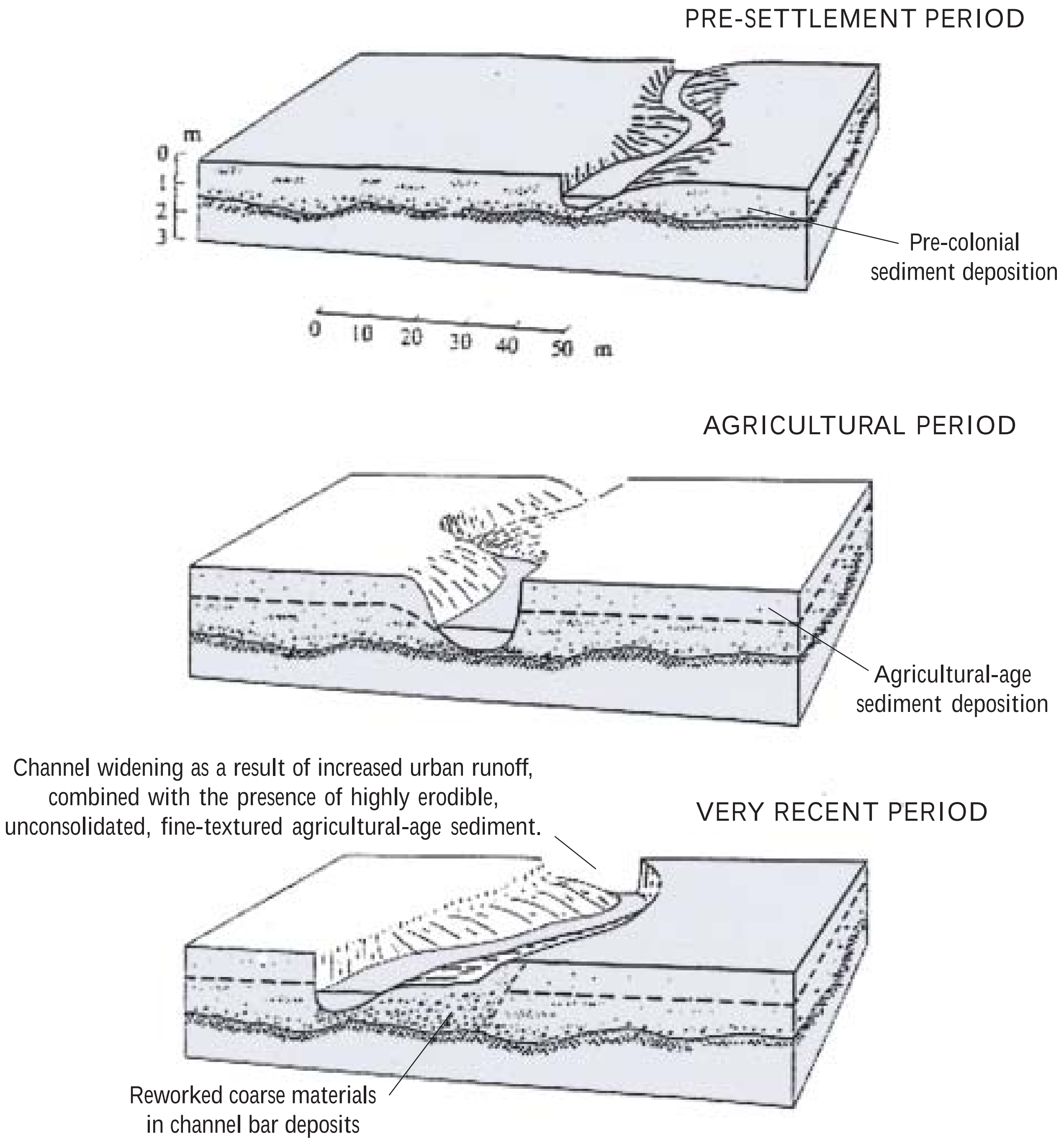


Figure 28: Three periods of land use influencing floodplain stratigraphy and channel characteristics in Maryland's Piedmont Province, as described by Jacobsen and Coleman (1986).

FLOODPLAINS: THEY ARE ALSO PART OF THE STREAM

Stream flows are not always carried solely within the confines of the active channel. During floods, the width of the stream extends beyond the banks of the active channel. The area accommodating this expanded flow is called the floodplain.

FLOODPLAIN MORPHOLOGY

Floodplain limits are often delineated relative to the area known to convey the 100-year discharge. The actual limits of inundation can vary with the watershed size, local geology, and land-use history. The structure and form of the floodplain also vary. Even though the path of the floodplain can be sinuous, it is usually not as meandering as that of the active channel. The width of the floodplain affects the depth of flood flows and the ability of the active channel to laterally migrate.

In some areas, the boundaries of the floodplain are well defined by steep slopes *(fig. 29)*. The valley dimensions in these areas are narrow and confining relative to the width of the active channel. Confined valleys often form through long-term geologic processes or where channels have slowly eroded into the landscape. Streams in the Appalachian Plateau, western mountainous sections of the Ridge and Valley, and Blue Ridge Province provide good examples of these conditions. The valleys associated with many Piedmont streams are also confined, particularly in headwater areas. In the Coastal Plain, the most notable confined valleys can be seen in the “knobby” upland landforms in Calvert County.

In other parts of the state where the valleys are broad and relatively flat, flood discharges can expand laterally over significant distances and have limited depths (*fig. 30*). The most striking examples of broad valleys can be found in the areas underlain by carbonate bedrock, including extensive portions of the Monocacy River watershed in the Piedmont and the Great Valley near Hagerstown. The Coastal Plain also has characteristically unconfined floodplain valleys in many areas. A 100-year storm on the Eastern Shore can inundate areas far outside of the active channel. Within these settings, flood flow velocities are much lower than in confined valleys because of the low gradients, shallow flow depths, and the larger cross-section available for conveyance.

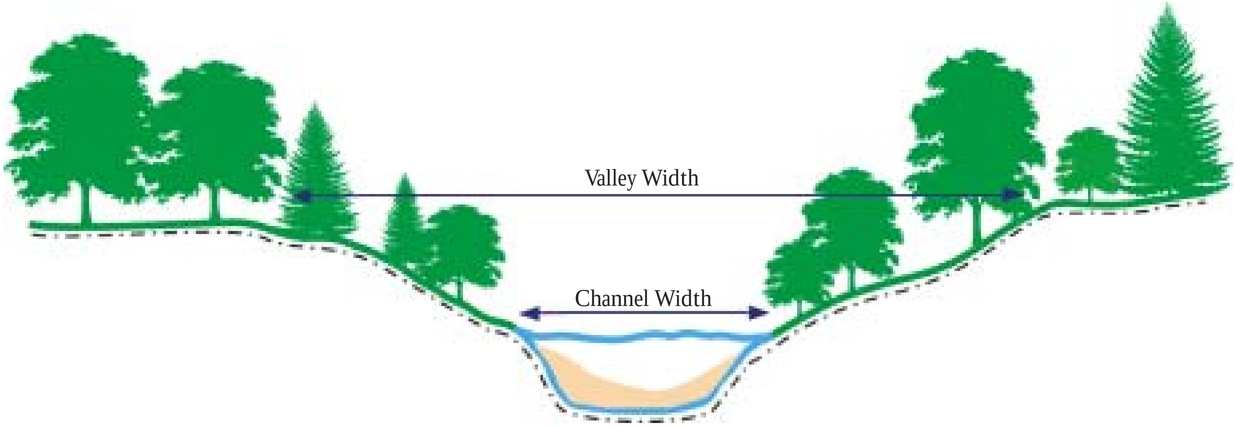


Figure 29: A confined valley.

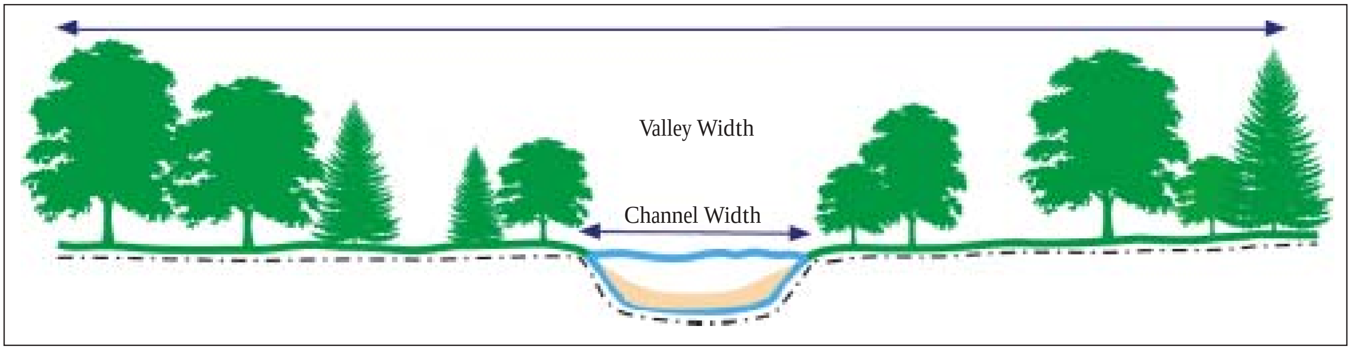


Figure 30: An unconfined valley.

FLOOD DEFENSE AND CHANNELIZATION

The limits of the floodplain can be influenced by the land uses that surround the stream corridor. In many areas of the state, development has occurred without proper consideration of the floodplain and its association with the active channel. In some cases, development and agricultural activities have resulted in the reshaping of the floodplain. These modifications can change the depth and rate of flood flows moving through the valley.

Constructing buildings and roads in the floodplain can result in costly and hazardous conditions. In urbanized areas where development has occurred in the natural floodplain, levees are often constructed parallel with the active channel. While the levees may reduce the impacts from flooding over the short term, it is generally less costly and more ecologically beneficial over the long term to avoid development in these areas rather than attempting to artificially control the stream system.

The photo below shows the 100-year floodplain boundaries for the Severn Run watershed in Anne Arundel County. This type of demarcation is determined by hydraulic studies and flood documentation in order to provide guidance for developers and planners. Knowledge of this boundary is important because it can help minimize impacts to areas that receive flood flows, thereby protecting areas that are essential for the maintenance of stream stability and habitat.

LWAD, MDDNR

Northeast Branch in Prince George's County has been channelized with levees in order to promote the rapid movement of flood flows downstream within a narrow corridor with little hydraulic resistance.

LWAD, MDDNR

Many Eastern Shore streams, like Beaver Dam Ditch in Queen Anne's County, were channelized and deforested for agricultural drainage, which can negatively affect the stability and ecology of the system.

MDDNR

The floodplain limits of Severn Run. Note the reduced width of the floodplain as it passes under the I-97 highway (lower right). These types of constrictions can cause water to back up on the upstream side and increase flow velocities immediately downstream during flood events.

THE RIPARIAN ZONE

The riparian zone is the land adjacent to streams that provide the transition between the terrestrial and aquatic environments. Water flowing off the land and within the stream channel interact in the riparian zone. This hydrologic interaction makes the riparian zone important to the stability and ecological integrity of streams and their aquatic habitats. Historically, forests have been the naturally occurring ecosystem along Maryland's streams. Streamside forests generally provide a tremendous range of benefits to water quality improvement, streambank stabilization, habitat, and flood defense.

WATER QUALITY IMPROVEMENT

Riparian forests have the potential to provide water quality benefits in several ways. Streamside forest vegetation provides shading, which regulates water temperatures that are critical for the health of aquatic organisms, particularly cold-water fisheries. Riparian vegetation also increases the potential to trap sediments, remove pollutants, and take up nutrients, such as nitrogen and phosphorus, from surface runoff and shallow ground water. The ability of riparian vegetation to perform these functions has made their restoration and protection a key part of the Chesapeake Bay restoration effort.

The amount of sediments and nutrients that can be removed from surface and ground water depends on how long the water stays in the riparian zone and how much contact there is with the vegetation. The residence time and interactions with the vegetation are determined by geology and topographic setting. In this regard, Maryland's diverse physiographic settings not only influence the appearance and stability of streams, but also the effectiveness of a streamside forest in performing water-quality functions.

For example, consider the conditions in the western Ridge and Valley Province *(fig. 31)*. In areas with sandstone and shale bedrock, there is a high potential for nitrate removal because the bedrock keeps the water above it and flowing laterally towards the stream, forcing it to pass through the forest buffer. This potential for nutrient uptake is reduced in low-order streams if the steep topography of the stream valleys causes surface releases of ground water on the valley hillslopes prior to reaching the channel.

In contrast, groundwater flow paths can completely bypass streamside forests in limestone bedrock areas of the eastern Ridge and Valley by seeping through the porous rock into deep aquifers. The potential for nutrient removal is reduced in these areas where the ground water flows into deep aquifers rather than through the riparian zone. Similar interactions occur in areas of the Piedmont Plateau that are underlain by carbonate bedrock formations *(fig. 32)*.

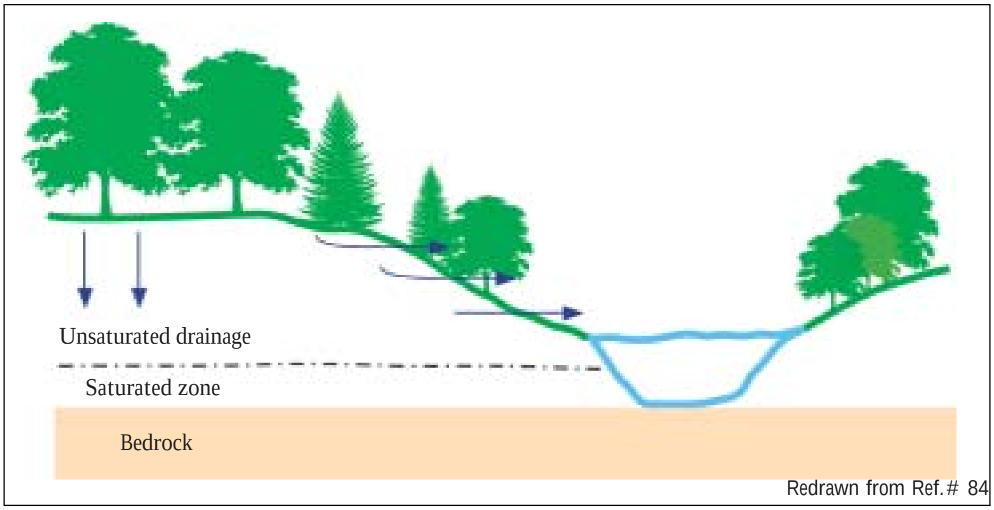


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Figure 31: Generalized flow paths through riparian forests adjacent to low-order streams in the western Ridge and Valley Province.

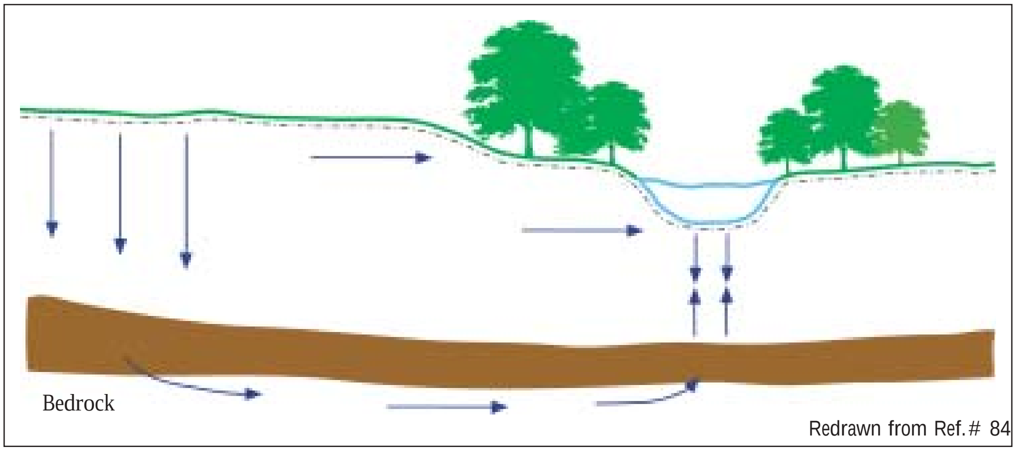

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Figure 32: Flow paths through a streamside forest in the carbonate bedrock formations of the Piedmont and eastern Ricge and Valley Provinces.

The effectiveness of a riparian forest at removing nitrogen depends, in part, on the bedrock composition, depth of the soil, and presence of organic materials. The Piedmont Plateau contains many areas with deep rich soils. The ability for forest vegetation to uptake excessive nutrients in groundwater varies with the depth of soils over the bedrock. In areas with a shallow bedrock layer, ground water is forced to flow directly to the stream over a shorter path close to the surface, thereby allowing more interaction with the roots of the vegetation. Areas with greater depths to bedrock produce longer groundwater flow paths and less potential for interaction with the root network of streamside forests.

The Coastal Plain Province typically does not have bedrock close to the land surface. The effectiveness of streamside forests at the removal of pollutants from subsurface flows depends on the dominant soil drainage characteristics and occurrence of impermeable soil layers below the surface (typically a clay formation). Well-drained soils can create ground-water flow paths that bypass the root zone of streamside forests. Soils with poor drainage capacity can extend the residence time of ground water near the root zone by reducing flow velocities in all directions. In areas where impermeable soil layers confine ground-water movement close to the land surface and the root zone, the opportunity for uptake by vegetation is enhanced *(fig. 34)*.

Figure 33: Generalized flow paths through streamside forest in the schist/gneiss bedrock formations of the Piedmont Plateau.

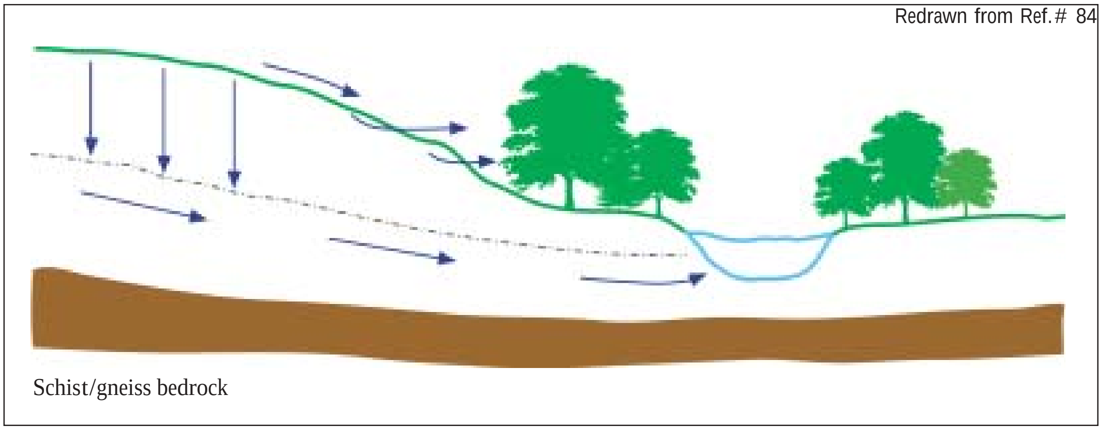
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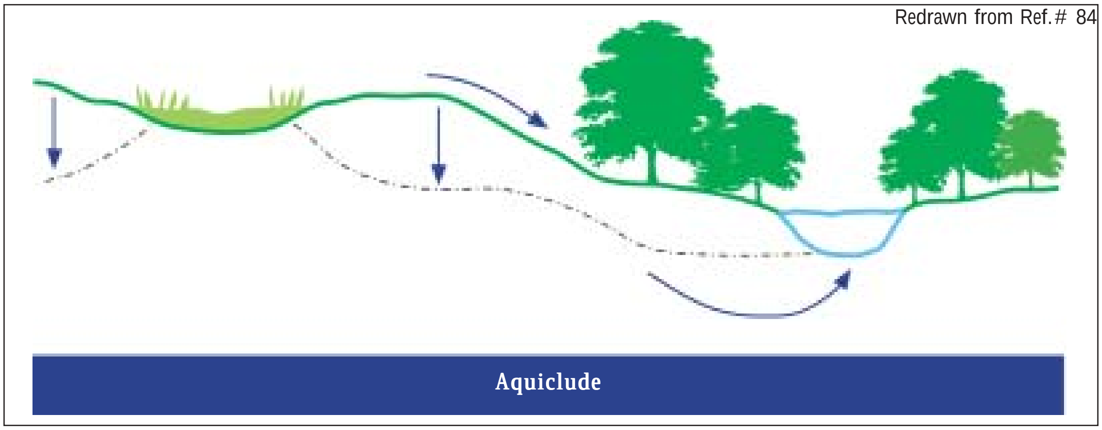
Figure 34: Generalized flow paths through streamside forest in the well-drained soil formations of the Coastal Plain.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STREAMBANK STABILIZATION

Riparian forests can enhance stream channel stability by providing structure. The roots of trees bind the soil along the bank and serve as hard points that are resistant to erosion. Roots projecting into the stream also create a source of friction that slows water flow and provides unique habitat for aquatic organisms.

MITIGATION OF FLOOD FLOWS

The influence of riparian forests on flood flows is often overlooked. Under natural conditions, stream flows usually move faster in the active channel than on the floodplain because vegetation in the floodplain provides "roughness" or resistance to flow. The removal of riparian forests promotes higher flow velocities in the floodplain, which can cause instability in both the floodplain and active channel. The increased flow velocities also reduce the opportunity for sediment storage and nutrient retention in the floodplain.

LWAD, MDDNR

Structural bank reinforcemnent from a streamwide root network in Marsh Run in Washington County.

LWAD, MDDNR

Out-of-bank flows in Deep Run in Anne Arundel County during the January 1996 flood.

LWAD, MDDNR

High flow velocities in an unforested floodplain, such as that characterizing Deep Run in 1996, are able to move larger sized materials that are normally only transported within the active channel.

PUTTING OUR UNDERSTANDING INTO PRACTICE

Evaluating channels for the purpose of management and/or restoration starts with the investigation of the factors operating at landscape and watershed scales. The examination of the reach itself primarily involves an analysis of the response of the channel to these influences.

HYDRAULIC GEOMETRY RELATIONSHIPS

The relations between flow discharge and cross section width, cross-section depth, and flow velocity can be used to describe the hydraulic characteristics of the active channel. These relations can be used for the development of detailed channel engineering plans or for the evaluation of channel changes over time.

MARYLAND EXAMPLE

The at-a-station hydraulic geometry data taken from Deep Run in Anne Arundel County shows the differences in channel conditions that can occur within one short reach of a drainage network. Regional downstream hydraulic geometry relationships that are based on drainage area and partitioned by physiographic province can also be generated using USGS gage data and cross-section information from nearby "reference" reaches.

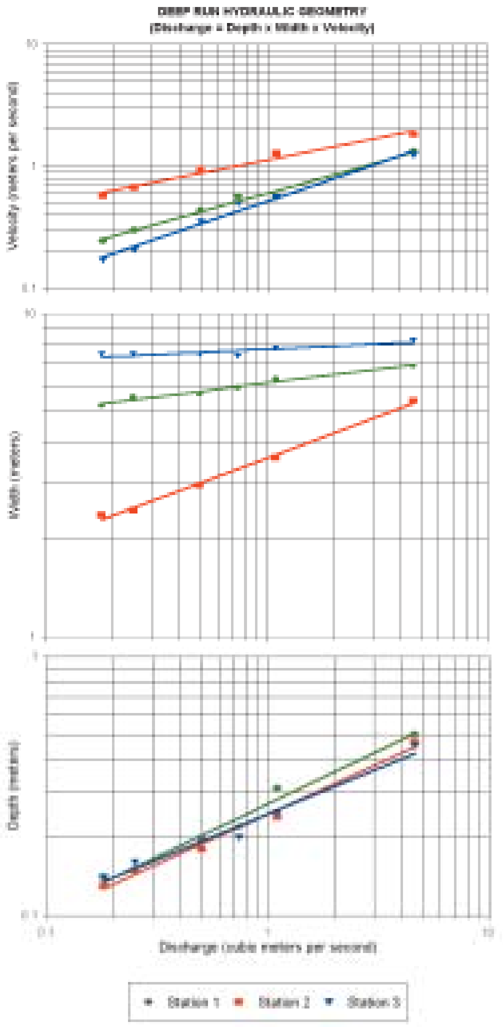


Figure 35: Hydraulic geometry relationships in Deep Run.

RIPARIAN CORRIDOR BENEFITS

The reestablishment of streamside forests can restore the natural geomorphic characteristics of the channel and in-stream aquatic habitat by simultaneously addressing factors related to water quality, flood hydraulics, physical habitat, and bank stability. These multiple benefits, combined with a low cost of implementation, makes riparian reforestation a great approach to restoration in areas where the stream corridor has been disturbed by agriculture or development.

MARYLAND EXAMPLE

In many cases, riparian restoration can be limited to the termination of vegetation management activities such as mowing or other institutional landscaping practices, thereby allowing streamside forest growth through natural recruitment.

LWAD, MDDNR

Little Paint Branch with active vegetation management in the riparian corridor (1990).

LWAD, MDDNR

Little Paint Branch five years after vegetation management was discontinued (1995).

FEATURE LEVEL

At the Reach Level, the focus is on the stream channel itself, including its shape, dimensions, and immediate surroundings. The Feature Level goes a step further by looking at specific physical elements within the channel. It is the closest level of examination in the heirarchy and focuses on discrete parts of the channel formed by the movement of water and sediment. A drainage network within a watershed can be measured in hundreds of miles and a reach in hundreds of feet, whereas features can be measured in tens of feet or less. Some common examples of features that can be found within a channel include sand bars, gravel riffles, boulder cascades, and woody debris. Even small features, such as individual rocks, can create localized changes in flow patterns that affect the physical characterstics of a stream reach. Each feature may be relatively small in size, but collectively influence the stability characterstics of a reach and create a diversity of habitat for a variety of aquatic organisms during different stages of their development.

B. Bachman

Features such as cool deep pools and conglomerations of coarse bottom sediments are characteristic of the high quality brook trout habitat that can be found in some areas of central and western Maryland.

WHAT ELEMENTS ARE VISIBLE AT THE FEATURE LEVEL?

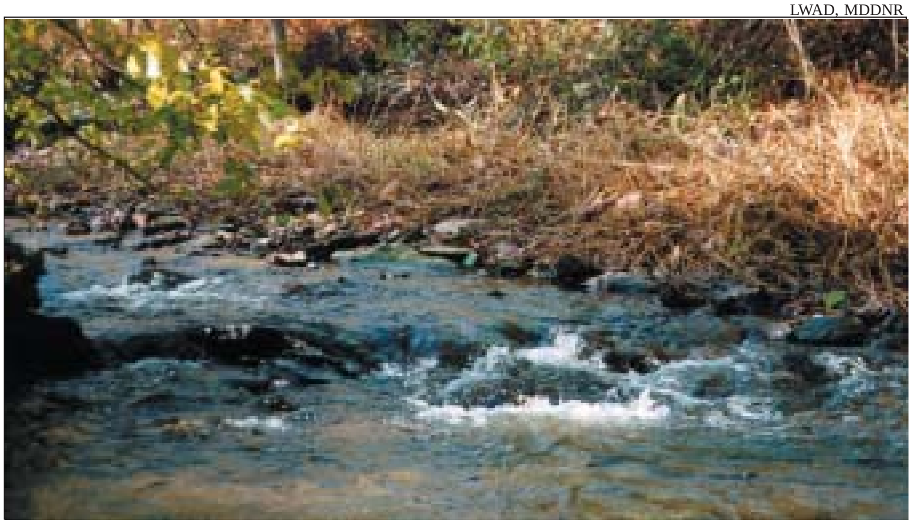
CHANGES IN WATER DEPTHS AND VELOCITY

The most obvious features within a stream reach are often associated with variations in the slope of the channel bottom. These undulations create riffles, pools, and runs during periods of low flow. These characteristics influence the channel appearance, hydraulic condition, and types of aquatic organisms found within a stream reach.

Riffles

Riffles appear in a stream reach as conglomerations of coarse gravel or cobble that can be easily observed during periods of low flow when water depths are shallow and turbulent flows rapidly traverse over them, creating localized "white-water" conditions. Their formation usually depends on the supply of coarse materials delivered from upstream. Consequently, riffles may be absent in carbonate or sand-bed streams due to the scarcity of gravel and cobble materials.

LWAD, MDDNR



A riffle in Grave Run during a period of low flow.

In meandering streams, riffles generally occupy segments between alternating meander bends. In straight reaches, riffles occur between runs or pools with deeper, slower-moving flows. The spacing and size of riffle features are generally governed by the local channel width, presence of structures, location of meander bends, and supply of coarse materials during high discharges. The spacing of riffles has been found to be consistent over extended lengths in some streams.

Riffles can provide several important functions within a reach. The local topographic changes from riffle formations can create sources of flow resistance that can reduce the average downstream water flow velocity during high discharges. The interstitial spaces between the loosely aggregated materials that compose them provide habitat for fish and invertebrates during different stages of their development.

Pools

Pools are found where the stream bottom has a low or reversed longitudinal slope. Water depths in pools are the deepest of anywhere in a reach and the flow velocities are low in comparison to other areas of the channel during periods of low discharge. Pools are typically found along the outside banks of meander bends or between riffles in straight reaches. Sediments in pools are often fine-grained because the low flow velocities promote the settling of fine-grained silt and sand

LWAD, MDDNR

A pool in Bear Creek.

materials. The organic detritus and fine sediments that settle out in pools can provide food sources and habitat for some fish and insect species.


LWAD, MDDNR

A run in Grave Run.

Runs

Runs are intermediate features with moderate depths and flow velocities. They are typically found in straight segments that share some of the flow and sediment characteristics of both riffles and pools. Runs often separate riffles and pools in gravel-bed streams. They often occupy extensive lengths of higher-order streams in Coastal Plain and carbonate bedrock environments due to the combination of relatively low gradients and the small supply of coarse gravels and cobble sediments that would otherwise promote the formation of riffles. Extended runs can be formed through artificial channelization that creates straight channels without riffle and pool features.

LOCAL HYDRAULIC CONDITIONS

General variations in water flow velocities that can occur across a channel and vertically through the water column were described in the Reach Level. More localized variations in flow conditions can be found within a reach due to the effects of structures and abrupt channel transitions. Structures that cause perturbations in the flow can include large rocks, root materials that project into the channel, and even large sediment conglomerations that create hummocks (riffles) in the channel profile. The variations in flow can create localized changes in stability and unique habitat conditions for aquatic life.

LWAD, MDDNR


LWAD, MDDNR

A hydraulic jump (top) and circulating eddy (bottom)observed in Deep Run, Anne Arundel County.

Eddies

Abrupt changes in the channel alignment and presence of structures such as rocks or tree roots can deflect flows horizontally in a manner that creates swirling flow conditions into or away from the channel banks. If projected into the banks, eddies can cause accelerated bank erosion in localized areas. Turbulence created by the eddies can also slow the downstream movement of water by deflecting flows across the channel.

Hydraulic jumps

A hydraulic jump is a term used to describe the transition from “super-critical” to “sub-critical” flow. Stream flows are normally sub-critical. Super-critical flow exists when the velocity of the water flow exceeds the velocity of a wave being propagated downstream. The conditions necessary for the formation of super-critical flows usually coincide with abrupt steepening or narrowing of the channel so as to result in dramatic increases in flow velocity. This high energy condition is unstable and usually does not persist for long distances, returning to sub-critical conditions through the expenditure of energy in the form of turbulence. The location of energy expenditure is called a “hydraulic jump”, which appears as a localized standing wave in the channel.

BAR FORMATIONS

Localized accumulations of sediment, usually sand, gravel, and cobble materials, promote the formation of bars. Bar formations can have a variety of shapes and be positioned in different locations in a stream reach. The size, height, and position of bars has significant effects on the way water is conveyed through the reach during periods of low flow. Although bars can maintain a constant position within a reach, the sediment materials composing them can be removed and replaced over time. In this way, bars act as temporary sediment storage areas. Four types of bar formation are commonly found in streams *(fig. 36)*.

Alternating Bars

Alternating bars are sediment deposits found on the sides of stream channels in sinuous reaches. These features alternate between the left and right banks, creating lateral shifts in the direction of the low flow channel. Alternating bars often form in channels that have been artificially straightened and widened.

Point Bars

Point bars are found on the inside of meander bends. Over time, point bars can increase in size as the opposite stream bank erodes, which allows the channel to maintain a consistent cross section. The shape of a point bar, particularly its slope, can affect water movement across the channel and the patterns of channel adjustment.

Transverse Bars

Transverse bars form in the cross over reaches of meandering channels. The cross section geometry of these bars change as the channel planform alignment transitions from a right to a left (or left to right) meander bend orientation with downstream distrance.

Mid-Channel Bars

Mid-channel bars are deposits formed away from the channel banks. These island formations cause the channel flow to split during periods of low discharge. The bars vary in stability depending on whether they are composed of loose gravels or organic matter. The presence of multiple mid-channel bars corresponds with braided or anastomosed channel planform conditions.

SEDIMENT FACIES

Stream bottoms have different assemblages of sediments that can be described as “facies”, or unit areas of the stream bottom comprised of a characteristic sediment grain size distribution. The types and sizes of sediment facies witin a reach depend on the geology of the contributing watershed. Facies may be limited to assemblages of sand and gravel in the Coastal Plain, but may also include cobble sized materials in the Piedmont Plateau and western provinces *(fig. 37)*. Coarser facies are typically found in association with riffle features. Facies composed of finer materials spatially correlate with pools and runs. Facies are often stable in position even though the material composing them changes over time.

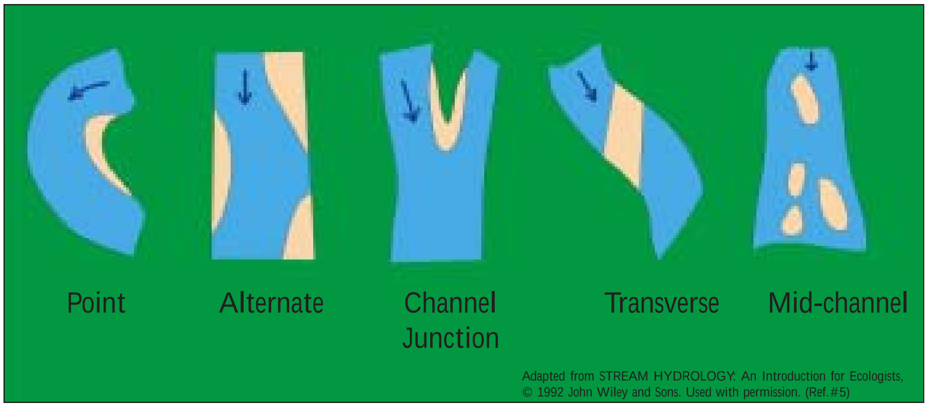


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Figure 36: Generalized bar types.

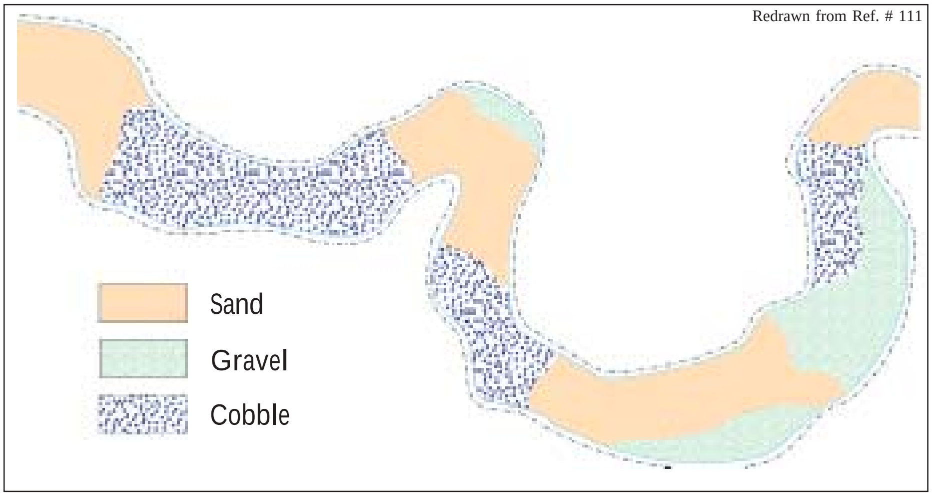

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Figure 37: Sediment facies found in Deep Run at the Piedmont / Coastal Plain boundary.

CHANNEL BANKS

The composition of a stream's banks and corresponding erosion characteristics can significantly influence channel stability and appearance. Bank characteristics can vary through a drainage network and even within a single reach. Hard rock banks found along many mountain streams in western Maryland do not erode very easily. In contrast, stream banks in areas like the Great Valley near Hagerstown are composed of silty materials that are easily scoured. Similarly, sandy bank materials found in the Coastal Plain are highly susceptible to erosion, particularly in the absence of binding roots from riparian vegetation.

Bank erosion generally occurs as a result of direct scour from the water flow and/or mass wasting through mechanical failures of the soil materials. The type and magnitude of erosion is influenced by historic channel adjustments and the orientation of flows through a reach. Areas that are hit more directly by high velocity flows can experience greater hydraulic forces. Banks often experience greatest erosion where they come in contact with the channel bottom, where hydraulic forces are at a maximum. This causes the upper portions of the bank to overhang and eventually fall into the channel under the influence of gravity. This can result in large episodic inputs of sediment.

Stream banks in Bear Creek (top), are naturally protected against short-term erosion by rock outcrops. Localized rocks and trees along Marsh Run (middle) minimize erosion in some areas; however, many reaches are free to erode (bottom), thereby allowing the planform alignment to change over time.

LWAD, MDDNR

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This section of Little Gunpowder Falls shows evidence of erosion from eddy circulation within a tight meander bend.

LWAD, MDDNR

Another section of the same reach of Little Gunpowder Falls shows evidence of mass wasting of the upper soil layers after erosion occurred along the toe of an unforested bank.

HABITAT: HOW FEATURES AFFECT AQUATIC COMMUNITIES

The health of a stream's aquatic community depends on the habitat conditions within a reach, which depends, in part, on the physical features within a reach. The primary biological communities in a stream ecosystem are bacteria, algae/diatoms, macroinvertebrates, and fish. These communities form a food pyramid with bacteria at the bottom and fish at the top. The physical features within a stream play an important role in the food web by influencing the spatial and temporal availability of habitat for food supply, reproduction, and predation avoidance.

THE MICROSCOPIC COMMUNITY

Bacteria are decomposers that break down the organic materials derived from plants and animals into nutrients that fuel the algal and diatom community. If a stream does not retain organic material and make it available to bacteria, the aquatic community will be very poor. To trap organic debris, a stream must have appropriate physical features that establish the hydraulic conditions necessary to retain materials imported into the channel.

Algae and diatom communities tend to use the hard substrates found in streams. Cobble and gravel in riffles, bedrock in runs and pools, woody debris, and even stable sands are all suitable substrates for colonization. The more surface area that is available within a reach, the greater the potential for species diversity. Algal and diatom community richness is vital to other components of the food web, such as the benthic macroinvertebrates.

THE MACROSCOPIC COMMUNITY

A large portion of the aquatic life in streams is composed of benthic macroinvertabrates, including clams, crayfish, worms, and aquatic insects. The term "benthic" refers to the bottom of a water body. "Macroinvertebrate" refers organisms that lack an internal skeleton and are larger than five microns (about the size of the head of a pin). Like bacteria, these organisms are important for processing and transforming organic matter into sources of food for other aquatic life. Macroinvertebrates have a variety of lifestyles and feeding modes. Shredders decompose large organic particles from leaves and twigs that fall into the stream. Grazers scrape algae and diatoms from rocks and other substrates. Collectors filter fine particles transported from upstream. Predators feed on animal matter. The more diverse the features of a stream, the more diverse the macroinvertebrate community.

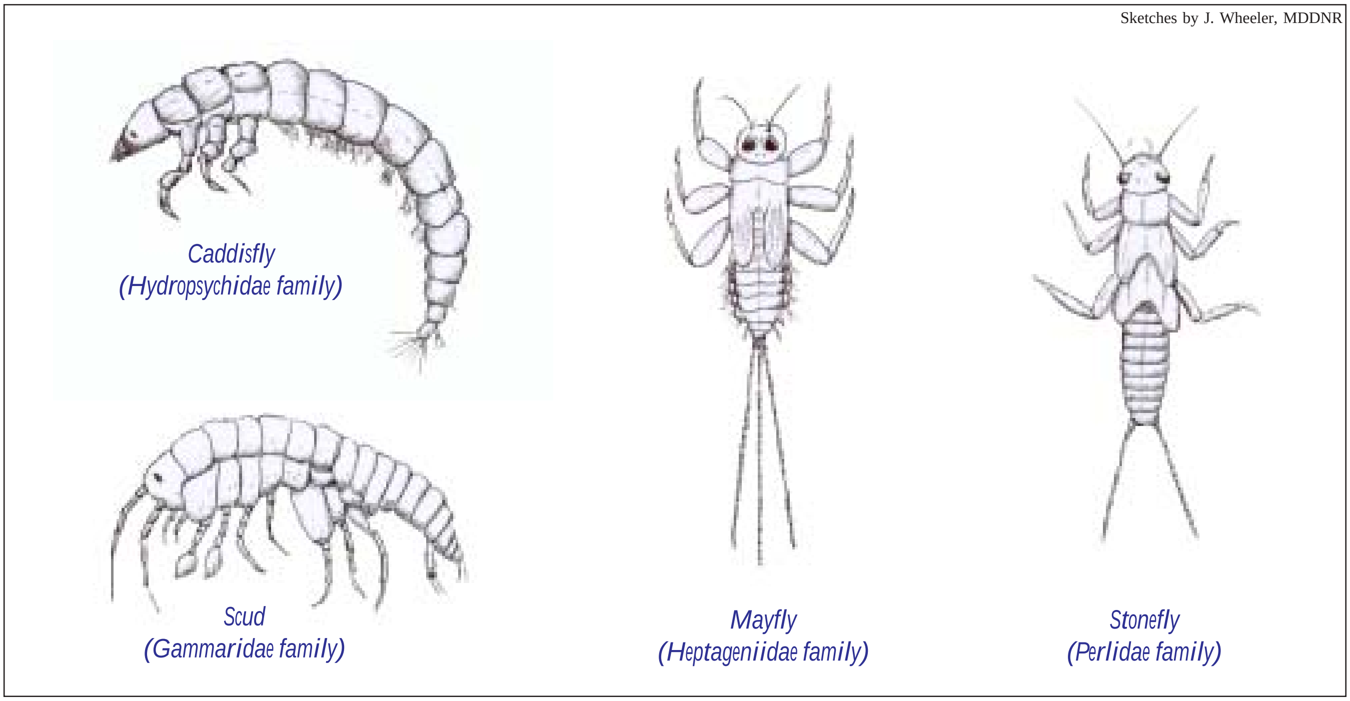

Figure 38: The species composition of the macroinvertebrate community found in a channel reach depends on the water quality, sediment facies that are present on the stream bed, and the availability of features such as riffles and woody debris that correlate with the geomorphic setting.

Healthy stream systems generally have species from several feeding groups and lifestyle modes that inhabit different stream features available within a drainage network. Active filtering collectors, such as clams and several species of mayflies, are found in pools and runs. Passive collectors, such as the net spinning caddisflies, are found in riffles. Leaf litter in pools harbor shredders such as amphipods. Shredding stoneflies inhabit leaf packs trapped in riffles and runs. The slow-moving water of pools is home to predatory dragonfly larvae, while predatory stoneflies inhabit riffles and runs. Scrapers, such as snails and many mayfly species, exist where there is a hard substrate colonized by algae and diatoms.

Increases in fine sediments that fill pools and clog the interstices in coarse bottomsediments reduce habitat diversity. As the diversity of physical habitat features decreases, the diversity of the macroinvertebrate community decreases. Bottoms composed of fine sediment generally have lower species diversities and larger populations of worms and midge larvae.

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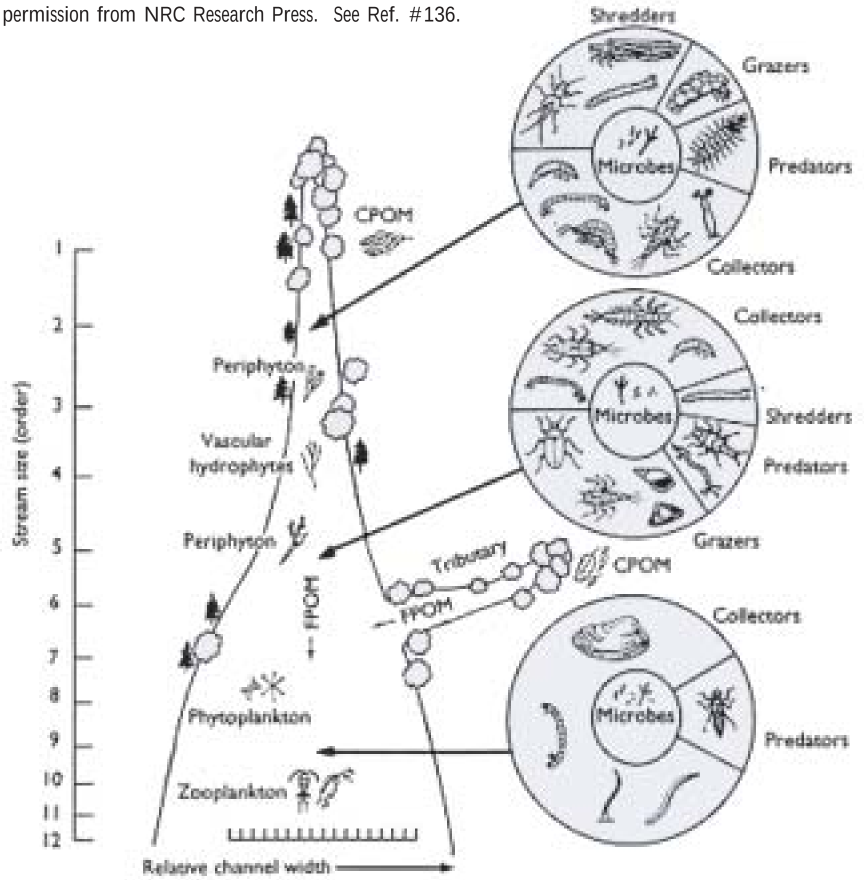

Figure 39: This diagram describes the conceptual relations between macroinvertebrate communities and the physical environment. In this simplified model, physical channel conditions in a drainage newtork change with stream order, thereby influencing food sources (i.e.; coarse particulate organic matter, fine particulate organic matter) that are available. The changes in food sources influence the composition of the macroinvertebrate community at different locations within a watershed.

THE FINFISH COMMUNITY

The physical habitat characteristics of a streamalso influences the fish community. Like macroinvertebrates, fish species have adapted to specific habitats by using different feeding methods and other morphological characteristics. A number of species, such as sculpin, have evolved attributes, such as stiff pectoral fins and flat profiles, that allow them to survive well in the fast flows associated with riffle features. Other species, such as white suckers, have evolved specialized mouths to take advantage of the food sources in the soft sediments of pools and runs. Large predators, such as trout and bass, optimize the use of hiding places in order to ambush their prey while avoiding the main stream flow, thereby conserving energy. Boulders and logs in the channel or undercut stream banks with extensive root mats can create these kinds of habitat conditions.

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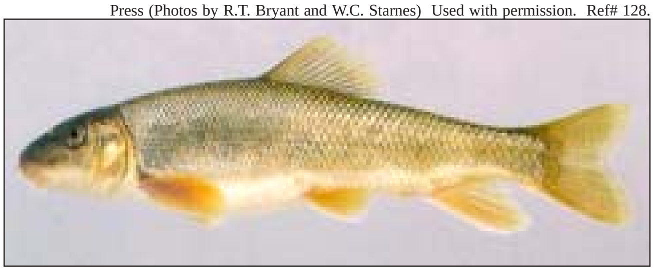

White suckers (Catostomus commersoni) have mouths that are adapted for bottom feeding in soft and gravelly sediments.

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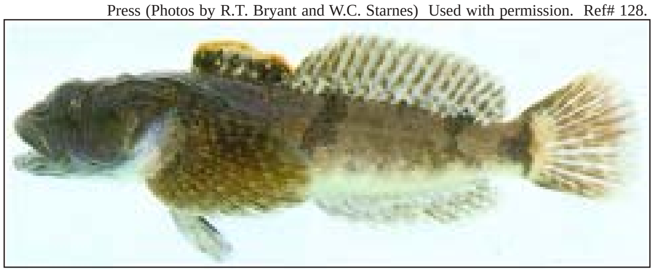

Mottled sculpin (Cottus b. bairdi) have a body morphology that allows them to survive well in moderate to high gradient streams.

WHAT ARE REFUGIA?

Refugia is a term used to describe features and factors that provide organisms or entire aquatic communities with mechanisms to withstand environmental stresses. They can have a significant role in the regulation of overall species diversity and the maintenance of aquatic communities. Refugia can be considered in several dimensions. The spatial dimensions can be measured longitudinally through a drainage network at the Watershed Level, transversely from the channel into the floodplain at the Reach Level, or vertically through the stream bottom at the Feature Level. Time scales can also be associated with refugia, including the consideration of hydrologic events that occur seasonally, annually, or over longer time scales. The types of refugia available for aquatic life in an area can change with the physiographic region because of the changes in the physical environment, including bottom substrate materials, floodplain width, and factors such as watershed slope that have secondary affects on the flow in the channel.

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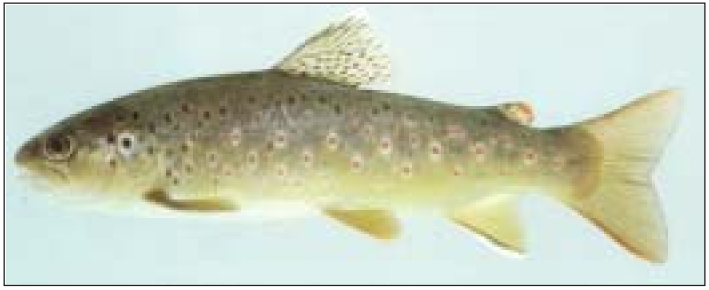

Brown trout (Salmo trutta) live in cold water streams with interspersed riffle and pool features that provide variations in bottom substrate and flow conditions.

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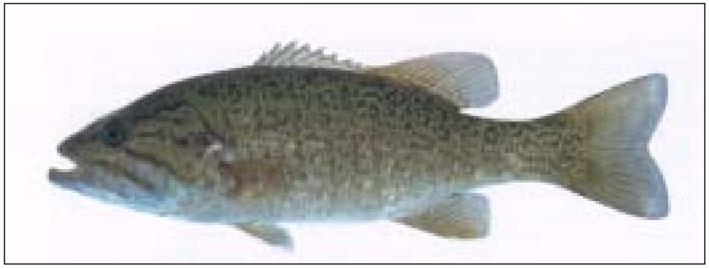

Smallmouth bass (Micropterus dolomieu) are commonly found in warm water streams with extensive deep pools.

Scale	Refugia
Watershed Level	Drainage network-wide distributions of floodplain vegetation and riparian wetlands, location and magnitude of ponding in the floodplain, hydraulic transition areas(abrupt valley slope and width changes)
Reach Level	Local distributions of streamside vegetation, spring seeps, and ponded areas (such as abandoned channels or oxbows)
Feature Level	Presence of physical cover from overhanging vegetation and structures, variations in water depths (shallow/deep), presence of large woody debris, distinct sediment facies, and organic material

Figure 40: Examples of the types of refugia at watershed, reach, and feature levels.

Examining the physical effects of features within a reach can involve the consideration of ecology, channel hydraulics, and geomorphology over different time scales.

HABITAT

Assessment techniques, called rapid bioassessments, have been developed to determine the specific habitat elements that are present within a reach using standardized approaches that are adapted to distinct geomorphic settings. The elements that are commonly considered are primarily related to the physical characteristics and flow conditions within the channel that affect habitat for aquatic organisms. Although the approach is qualitative, rapid biassessments can provide some indications of habitat impairment and a framework for comparisons to healthy reference streams. It is important to note that the surveys only provide a “snapshot” of the conditions that existed at the time of observation. However, repeated surveys at the same location with the same criteria can be used to document changes over time.

MARYLAND EXAMPLE

Physical features considered in habitat assessments have been adapted to evaluate the success of stream restoration projects in Maryland. Habitat variables used in the evaluations focus on the physical channel features that affect different life stages of aquatic organisms or that are thought to be indicators of stability.

A habitat assessment survey was used in a tributary (Tributary 9) of Sawmill Creek in the Coastal Plain to evaluate the effectiveness of recent stream restoration activities that attempted to stabilize the channel and improve habitat. The results were compared to those obtained from a healthy reference reach at another location in the Coastal Plain.

Habitat Parameters	Reference (Healthy) Stream	Trib. 9 (pre-restoration)	Trib. 9 (post-restoration.)
Substrate & Cover	80	50	75
Embeddedness	65	25	60
Flow	60	45	30
Channel Alteration	93	13	67
Scouring & Deposition	67	40	60
Pool/Riffle/Run Ratio	87	47	87
Bank Stability	80	30	70
Bank Vegetative Stability	90	40	90
Streamside Cover	80	60	50
Total Score (%)	78	39	65
# of Fish Species	9	1	6

Figure 41: Habitat asssessment scores for the reach of Tributary 9 in the Coastal Plain before and after restoration activities were completed. The reference scores are for another stream in the Coastal Plain known to have good aquatic habitat conditions.

BANK STABILIZATION

Stream channel bank stabilization activities have historically been conducted with the single objective of preventing channel erosion and migration into adjacent properties or infrastructure. Common practices often included the use of concrete liners and/or rock revetments. In recent years, multiple objectives, including stability, safety, aquatic habitat, and natural aesthetics, are often pursued in single projects.

MARYLAND EXAMPLE

Objectives that are now often considered in bank stabilization projects include the creation of features that provide areas for feeding, predation avoidance, or natural refugia for the indigenous aquatic organisms. In Trib 9, Anne Arundel County, stream banks that were encroaching into adjacent properties were reinforced using strategically placed rocks, logs, and native vegetation to meet stabilization and habitat goals.

LWAD, MDDNR

Bank stabilization activities in Tributary 9 during construction.

LWAD, MDDNR

Bank stabilization in Tributary 9 during the growing season after construction.

CONCLUSION

The conceptual framework that we have used in this document, including the Landscape, Watershed, Reach, and Feature levels, provides perspectives for the assessment of stream channels at different spatial scales. The Landscape and Watershed levels of consideration provide information regarding the factors influencing the stream channels over long (i.e., thousands of years) and intermediate (i.e., decades to centuries) time scales. Regional characterizations, drainage network descriptions, and land use considerations are relevant at these relatively broad levels of investigation. The Reach and Feature levels focus on the physical characteristics and behavior of the channels themselves. Relatively short time scales (i.e., instantaneous to a century) are generally appropriate for the evaluation of stream channels at these levels. The intention of this heirarchy is to provide organization to the thought processes that should be involved in the investigation of stream channels for the purpose of resource assessment, the development of management plans, and the design of stream channel engineering and rehabilitation projects.

For example, if you are standing in a stream and you notice a pile of flat, cobble-sized rocks under your feet, think of that pile as a *feature* in the channel. There is a physical reason that material of that size landed in that position in that *reach* of the drainage network. The stability of the pile of rocks under your feet is influenced by the frequency and magnitude of the flows moving through the reach. The frequency and magnitude of the flows moving through the reach are influenced by the shape, slope, and land-use characteristics of the surrounding *watershed*. The size, shape, and composition of the rocks in the pile are also influenced by the local geologic conditions within the contributing drainage basin. The watershed configuration and local geologic conditons are influenced by the regional *landscape* history, including the processes that created the subsurface geologic materials and surface topography.

Thinking about the many physical processes at the appropriate temporal and spatial scales of resolution helps explain why streams look the way they do, how they have changed in the past, and how they might change in the future. Understanding these processes is where the science of fluvial geomorphology can help integrate the disciplines of aquatic resources management, civil engineering, and environmental management and restoration. Simply put, when you are investigating a specific stream resource, think about the physical processes that influence the appearance of the stream system, then take a closer look at the channel itself and the aquatic community within it.

Intentionally Blank

GLOSSARY

(* Note that many of the definitions have been adapted from reference No. 20)

Accretion: The gradual addition of new land to old by the deposition of sediment carried by the water of a stream.

Aggradation: The process of building up a surface by deposition.

Alluvial: Pertaining to or composed of alluvium, or deposited by a stream or running water.

Annual flood: The arithmetic mean of all the annual maximum discharges.

Anticline: A fold, generally convex upward, that has a core containing stratigraphically older rocks.

Aquiclude: A body of rock that will absorb water slowly but will not transmit it fast enough to supply a well or spring.

Aquifer: A water-bearing stratum of permeable rock, sand, or gravel capable of providing a consistent supply of water.

Bankfull discharge: The flow at which water just fills the channel without over-topping the banks. The bankfull stage can be significant because it represents a break-point where processes governing channel and floodplain formation occur in alluvial valleys. In stable self-formed channels, bankfull discharge may correspond closely with the effective discharge.

Base flow: Water that percolates into the ground and is conveyed to the stream slowly over long periods of time, thereby sustaining streamflow during periods without rainfall.

Channel capacity: The maximum flow that a given channel is capable of transmitting without overtopping its banks.

Channel: A landscape element consisting of two banks and a bed that is capable of conveying confined surface flows downstream in a watershed. The morphology of a channel can be formed and maintained by incision associated with hillslope erosion or by processes of erosion and deposition within alluvial valleys.

Discharge: The rate of stream flow at a given instant in terms of volume per unit time.

Dolomite: A sedimentary rock that is commonly associated with limestone and consists of more than 50% by weight of the mineral dolomite ($CgMg(CO_3)_2$).

Drainage basin: The land area that drains water, sediment, and dissolved materials to a common outlet. The term is synonymous with watershed and catchment.

Drainage density: Ratio of the total length of all streams within a drainage basin to the area of that basin.

Drainage network: The hierarchical pattern of channels that drains a watershed. These patterns can be described as dendritic, parallel, trellis, rectangular, radial, annular, multi-basinal, or contorted, depending on the overall pattern of connectivity and shape of the network form.

Equilibrium: Conceptual term used to describe landform behavior over cyclic time spans (See definition for graded time span). The adjective "dynamic" is used to describe the progressive long term change in the landform, such as reduction in longitudinal slope, over a cyclic time span. "Equilibrium" refers to the steady state condition in which the landform fluctuates around an average condition over a graded time span within the longer cyclic time span. Accordingly, the term describes a condition under which a landform fluctuates around an average rate of change over a long period of time. The term was modified after its original conception to "dynamic meta-stable equilibrium" to account for the influence of thresholds that result in abrupt changes to landforms during cyclic time spans (See Ref. #63).

Eddy: A circular current of water running contrary to the main current, such as a whirlpool.

Effective discharge: The discharge that transports the most sediment in a channel reach over an extended period of time, usually considered to approximate a 100 year time span, thereby conforming with the concept of a graded stream (see definition below). Conceptually, infrequent discharges (i.e., 100-year recurrence interval) affecting a graded stream channel transport more sediment, but seldom occur over a 100 year period. Frequent discharges (i.e., less than the 1 year recurrence interval) occur often over a 100 year period but are incapable of transporting significant quantities of sediment. Accordingly, the effective discharge of some alluvial streams has been found to be correlated with moderate discharges (i.e., 1 to 2 year recurrence interval) in regions with temperate humid climates.

Eutrophication: A process through which excessive plant growth, typically algae, induced by excess nutrients is followed by the decomposition of vegetative material and the depletion of the water's oxygen supply.

Facies: A term used in fluvial geomorphology with respect to sedimentary facies, which are designated spatial units on the stream channel bottom that exhibit sediment size distribution characteristics significantly different than those in other parts of the channel.

Fault: A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

Floodplain: The portion of the river valley adjacent to the active channel that is built of sediments deposited during the present regimen of the stream and is covered with water when the river overflows its banks at flood stages.

Fold: A bend or plication in bedding, foliation, cleavage, or other planar features in rocks.

Geomorphology: The science that treats the general configuration of the earth's surface, including the classification, description, nature, origin, and development of landforms and their functional relationships to underlying structures.

Graded stream: A stream that has a slope and dimensional characteristics adjusted to provide, with available discharge, just the velocity required for the transportation of the sediment load supplied from the drainage basin over a period of years (See Ref. # 48).

Graded time span: One of three time spans used to conceptually describe landform evolution (See Ref. #63). "Cyclic" time spans encompass major periods of geologic time under which a stream system undergoes a progressive change, such as a reduction in longitudinal slope. "Graded" time spans refer to a relatively short periods (i.e., approximated by 100 - 1000 year periods) on the cyclic time scale during which an equilibrium condition is approached. "Steady" time spans refer to very short periods characterized by static equilibrium during which a landform does not change.

Hydraulic jump: Term used to describe flow conditions characterized by a stationary, abrupt turbulent rise in water level in the direction of flow. See definition for "super-critical flow".

Hydrograph: A graph showing stage, flow, velocity or other characteristic of water with respect to time. A stream hydrograph commonly shows the rate of flow over time.

Hydrology: The science of the distribution and effects of water in the atmosphere, soils, and rocks.

Igneous rock: Rock that solidified from molten or partly molten material, such as volcanic magma.

Infiltration: The flow of a fluid into a solid substance through pores or small openings.

Intermittent stream: A stream that does not have a continuous flow throughout the year.

Lithology: The description of rocks on the basis of such characteristics as color, minerologic composition, and grain size.

Mass wasting: Term used to describe the downslope movement of soil and rock material under the direct influence of gravity.

Meander: One of a series of sinuous curves or loops in the course of a mature stream.

Metamorphic rock: Rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to changes in temperature, pressure, shearing stress, and chemical environment.

Morphology: The study of structure or form.

Nutrients: The elements required to support the bodily structure and metabolism of biological organisms. These elements include nitrogen and phosphorus, which can become pollutants if present in excessive quantities or result in the generation of adverse secondary effects, such as eutrophication in slow moving or standing water.

Oxbow: A closely looping stream meander having an extreme curvature such that only a neck of land is left between two parts of the stream.

Permeability: The capacity of porous rock, soil, or sediment for transmitting a fluid.

Perennial stream: A stream that flows continuously throughout the year.

Physiographic province: A region of which all parts are similar in geologic structure and climate and which has had a unified geomorphic history. Its relief structures are different from those of adjacent regions.

Reach: An uninterrupted length of stream channel with similar physical characteristics, including discharge conveyance capacity, cross section geometry, and slope.

Roughness: Features that create resistance to the downstream movement of water in a channel. The features may include sediment particles, sediment deposits, bank irregularities, the type, amount, and distribution of living and dead vegetation, and other obstructions to flow. The term is modified to "relative roughness" when the scale of the roughness elements to the water depth is considered.

Relief: The physical configuration of a part of the earth's surface with reference to variations of height and slope or to irregularities in the earth's surface.

Riparian: Pertaining to or situated on the bank of a body of water, usually a river.

Runoff: The part of precipitation appearing on the land surface or in streams.

Sediment: Solid, fragmented material that is transported and deposited by wind, water or ice, chemically precipitated from solution, or secreted by an organism, that forms in layers or a loose unconsolidated form.

Sedimentary rock: A layered rock resulting from the consolidation of sediment.

Self-formed channel: A stream channel formed by processes of erosion and deposition of sediment over graded time scales of several decades or a century. Channels that are not self-formed include incised channels created by progressive erosion or hillslope processes, steep bedrock channels that are hydraulically incapable of creating an adjacent floodplain or bar features, and artificial (engineered) canals created with a single uniform channel cross section to convey all flows.

Shear stress: The force per unit area acting parallel to a surface. In the case of stream flow, reach-averaged shear stress [$\boldsymbol{\tau}$ (M/LT^2 or N/m^2)] can be defined using the product of the density of water [$\boldsymbol{\rho}$ (M/L^3)], the acceleration of gravity [$\mathbf{g}$ (L/T^2)], the hydraulic radius associated with the flow [$\mathbf{R}$ (L)], and the average water surface slope [S (L/L)], where the dimensions include: M = mass, L = length, T = time). That is, $\boldsymbol{\tau = \rho\, g\, R\, S}$. (See Ref. # 4)

Sinuosity: The amount of curvature in a channel defined as the ratio of the active channel length to the valley length.

Stage: The height of the water surface above an established datum plane.

Stream order: A classification of the relative position of streams in channel network, assigning each link an integer order number determined by the pattern of confluences in the tributary network.

Stream power: Stream power is the amount of work performed by the stream flow per unit time, which can be expressed relative to a unit of stream bed area or length of channel. Power is traditionally expressed in watts, which ultimately can be expressed as ML^2/T^3, where the dimensions include: M = mass, L = length, T = time.
a) Stream power per unit area [$\boldsymbol{\omega_a}$ (M/T^3 -or- watts/L^2)] can be defined as a product of the shear stress [$\boldsymbol{\tau}$ (M/LT^2)] and average velocity [$\mathbf{V}$ (L/T)]. That is, $\boldsymbol{\omega_a = \tau\, V}$.
b) Stream power per unit length of channel [$\boldsymbol{\omega_l}$ (ML / T^3 -or- watts/m)] can be defined as a product of the water density [$\boldsymbol{\rho}$ (M/L^3)], acceleration of gravity [$\mathbf{g}$ (L/T^2)], discharge [$\mathbf{Q}$ (L^3/T)], and water surface slope [$\mathbf{S}$(L/L)]. That is, $\boldsymbol{\omega_l = \rho\, g\, Q\, S}$. (See Ref. # 51)

Structure: The attitude and relative positions of the rock masses of an area, the sum total of structural features resulting from such processes as faulting, folding, and igneous intrusions.

Super-critical flow: Flow condition that occurs when the velocity of the flow exceeds the velocity of a gravity wave propagated in the same medium. Flow conditions can be characterized using a dimensionless ratio of intertial to gravitational forces called a Froude number (**Fr**) that is defined as the average velocity [$\mathbf{V}$ (L/T)] divided by the square root of the product of acceleration of gravity [$\mathbf{g}$ (L/T^2)] and the flow depth [$\mathbf{d}$ (L)], where the dimensions include: M = mass, L = length, T = time. That is, $\mathbf{Fr = V / (g\, d)^{1/2}}$. Flow is described as “super-critical” where **Fr** > 1, “sub-critical” when the **Fr** < 1, and “critical” where **Fr** = 1. (See Ref. # 4)

Terrace: A relatively level bench or step-like surface breaking the continuity of a slope.

Transpiration: The process by which water absorbed by plants is evaporated into the atmosphere from the plant surface.

Watershed: The land area that drains water, sediment, and dissolved materials to a common outlet. The term is synonymous with drainage basin and catchment.

Wetland: Term used to describe areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions, including swamps, marshes, bogs, and other similar areas.

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