WATERSHEDS AND STREAMS

2.0 – Introduction

From the time the last glaciers receded from the North American continent, up until the early colonial period, most of the country’s landscape was in a relatively stable condition. Although the native people worked the land, clearing forests for villages and cultivating fields, their numbers were relatively few and their settlements were widely dispersed over millions of square miles. Consequently, extensive forests and prairie grasslands characterized the country. With the exception of brief catastrophic natural events, this was an environment in which changes occurred very gradually. Natural stream ecosystems evolved under these relatively stable conditions.

When European settlers came to America, large tracts of forest were cleared for farms and pastures. European forests had made the transition to fields over a thousand years, but the North American forests fell in a much shorter time. Although sediments and nutrients had always entered aquatic systems from adjacent land, the rate at which they entered was now greatly accelerated, as thousands of acres of land poorly suited for cultivation were laid bare. Soil erosion, which formerly progressed at relatively low rates, suddenly increased dramatically. As sediment yields in watersheds rose sharply, stream channels began to fill with fine sediments, channels became wider and shallower, and in-stream habitat was reduced.

In a short time, the poor farmlands of the eastern seaboard were abandoned and farmers moved west to New York, then Ohio, Indiana and Illinois. Vacating farms with poor or depleted soils became a common pattern in the settlement of North America, especially in the South.

As former farmland reverted to old-field and then to forest, watersheds entered a new phase of adjustment. Sediment yields decreased and stream channels scoured, stabilizing over time at a lower base elevation, abandoning former floodplains. The westward expansion carried these same changes to watersheds dominated by prairie grasslands as they were plowed for the production of crops, or heavily grazed by livestock. Many of these activities occurred in the fertile floodplains of streams and rivers. Throughout this country, thousands of acres of bottomland forest were cleared, drained, and converted to crops or pasture. Severe flooding prompted measures to protect towns and farms that were situated in low-lying areas. Dams were built to control flooding and levees were constructed to separate the river from its developing floodplain.

The building boom which began shortly after World War II and which has continued virtually unabated to the present has resulted in a radically altered landscape. This construction activity has promoted the clear-cutting of millions of acres of forests. It has resulted in the draining and filling of thousands more acres of wetlands and the damming and diversion of miles of rivers to provide drinking water and hydroelectric power to cities that continue to grow in population. Lawns, concrete, and asphalt have replaced forest, cropland, and pasture.
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In this section, you will learn the basic characteristics of watersheds and streams, the dynamic processes that form and maintain them, as well as how changes in land use affect them.

2.1 – The Watershed Perspective

Because streams are landscape features that interact with the surrounding land areas it is appropriate to start with a discussion of streams at the watershed level. Watersheds are the landscape units that provide the most relevant basis for understanding natural stream systems, their components, and the physical processes that form and maintain them. They are also the most appropriate landscape unit for managing and restoring streams.

2.1.1 - What is a Watershed?

*Watershed* can be most simply defined as an area of land that drains water, sediment, and dissolved materials into a particular stream. A watershed or drainage basin boundary can be determined at any point along any stream or river by delineating the points of highest elevation in the surrounding land area that drains to the selected point on that stream. Watersheds can range in size from less than an acre to thousands of square miles. Each stream and its contributing watershed are part of an increasingly bigger drainage area.

Figure 2-1. North Carolina’s major watersheds (NCDENR, 1998).

For example, the Salem Creek watershed is part of or a subwatershed of the Muddy Creek watershed, which is a subwatershed of the Yadkin River watershed, which is a subwatershed of the Pee Dee River watershed. The Pee Dee River eventually flows into the Atlantic Ocean.

The major portion of Forsyth County’s 424 square mile land area lies within three subbasins of the Yadkin River watershed. The largest percentage is situated in the High Rock Lake - Muddy Creek sub-basin, a 4,000-square mile watershed that includes Winston-
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Salem, numerous smaller municipalities, and significant rural land area. A relatively small area on the eastern side of the county drains to the Abbotts Creek sub-basin, and a portion of the western side of the county contains tributaries that drain directly to the Yadkin River. About one-fifth of the County’s land area drains to the Dan River watershed, which is a sub-basin of the Roanoke River.

Examining streams from a watershed perspective allows us to see the “big picture” and to appreciate the fact that almost everyone lives downstream of someone else.

Figure 2-2. Abbotts Creek Watershed and Upper Yadkin River Watershed.

2.1.2 - Watershed Hydrology

Understanding how water flows into and through streams is critical to making management and restoration decisions. Decision-makers must know how much, how fast, how deep, how often, and when water flows in order to implement appropriate management and restoration measures.
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2.1.2.1 - Hydrologic Cycle

The hydrologic cycle describes the continuous cycling of water from atmosphere to earth and oceans and back again. The cycle is powered by solar energy, which drives evaporation and transpiration, transfers water from the surface of the land, from plants, and from oceans, lakes and rivers into the atmosphere. Precipitation, primarily as rain and snow, transfers water from the atmosphere to the land surface. A portion of the precipitation evaporates directly to the atmosphere. A portion of the precipitation infiltrates the land surface, is absorbed by plants and transpired to the atmosphere. A portion flows downslope rather quickly as shallow subsurface flow or throughflow. The rest percolates deeper to become part of the groundwater reservoir, which moves downslope very slowly. That portion of the precipitation that does not infiltrate is stored in surface depressions or runs off quickly downslope as overland flow.

![Hydrologic cycle diagram]

Figure 2-3. Hydrologic cycle.

2.1.2.2 - Streamflow and Flow Regimes

Streamflow is that portion of precipitation which reaches the stream channel from shallow subsurface flow, groundwater, or overland flow. Streamflow is subdivided into two components: baseflow and direct runoff or storm flow. It is conventionally referred to as discharge (i.e., volume of water passing through a channel cross-section per unit time). In the United States, discharge is measured in cubic feet per second (cfs).
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Figure 2-4. Streamflow diagram showing pathways precipitation follows to become stream discharge as baseflow or direct runoff.

*Baseflow* is that streamflow that originates from groundwater. This component is influenced by climate and watershed characteristics that affect infiltration and storage capacity. Because groundwater moves very slowly, its discharge lags well behind precipitation and tends to vary slightly for streams with good groundwater reserves. Where groundwater reserves are naturally low, or they have been reduced by drought or land use changes, baseflow can be extremely variable. The variability associated with baseflow can best be characterized by describing three distinct flow regimes: *perennial* (i.e., carry water year-round, fairly stable groundwater flow), *intermittent* (i.e., carry water part of the year, receiving groundwater discharge when the water table is high), or *ephemeral* (i.e., carry water only during or immediately after a storm, no baseflow component).

*Direct runoff* consists of overland flow and a substantial portion of subsurface flow. This component is influenced by climate, watershed characteristics that affect the storage capacity, timing, and volume of runoff, and the intensity of individual storm events. The variability associated with direct runoff can best be characterized by describing two distinct stormflow regimes: bankfull flow and flood flow.

*Bankfull flow* is that streamflow when the channel is flowing at or near capacity and the water surface is just at floodplain level but has not overtopped the stream banks. Nearly all stream channels, whether large or small, will contain without overflowing that discharge that occurs about once a year. Higher flows, occurring on average once in 2 years or once in 5 years or more, will be too large to be contained in the natural channel and will overflow the banks.
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Flood flow exceeds the capacity of the stream channel, overtops the stream banks and moves out onto the adjacent land surface. In confined streams, this land surface may be an adjacent hillslope or terrace. In unconfined streams, this land surface is most often a floodplain. Although a stream is considered at flood stage once its banks have been overtopped, the extremely high discharge events only occur on average once in 50 years or once in 100 years or more.

Figure 2-5. Regimes that characterize streamflow.

2.1.2.3 - Describing Flow Variability

- Hydrographs

Hydrologists routinely measure and record streamflow. They use hydrographs to show how streamflow varies with time. The portion of the hydrograph that lies to the left of the peak is the rising limb and shows the time that elapses as streamflow increases from baseflow discharge to its peak or maximum discharge in response to a precipitation event. The portion of the hydrograph to the right of the peak is the recession limb and shows the time that elapses as streamflow decreases from the peak discharge returning to baseflow conditions after the precipitation event has passed.
Figure 2-6. A hypothetical hydrograph showing amount of rainfall (blue bar graph) and discharge (purple line) measured over time. (FISRWG, 1998)

Although hydrographs can illustrate how a stream’s discharge varies for an individual storm, shown above, they can also be utilized to show how streamflow varies daily, monthly, yearly or over a longer time period.

• Flood Frequency and Probability of Exceedance

Flood frequency and recurrence interval are terms hydrologists use to refer to extremes of streamflow. Flood frequency indicates how often a discharge of a given magnitude or volume will be exceeded during a given time period. Recurrence interval indicates the average interval of time within which a given discharge event, such as a flood, will be equaled or exceeded one time. For example, when Winston-Salem experienced flooding associated with Hurricane Fran in 1996, news reports characterized the event as a 50-year flood. Although such a flood might have occurred again the following year, or the year after, on average the frequency with which a 50-year flood would be expected to occur is once in 50 years.

Discharge extremes can also be referred to in terms of their probability or likelihood of being exceeded. For example, a 50-year flood of 1000 cfs means that discharge has a 1 in 50 chance, or 2 percent probability of being exceeded in any given year. At the opposite extreme, a 10 year low flow of 5 cfs means that a discharge of less than 5 cfs has a 1 in 10 chance or 10 percent probability of being exceeded in any given year. More simply stated,
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a discharge of less than 5 cfs will occur as an annual minimum flow on the average once in 10 years.

The two flow variability descriptors most commonly used by hydrologists in dealing with high flows include peak flows and flood volume averages. Peak flows describe the maximum instantaneous flow rates that will be equaled or exceeded with specified frequencies (i.e., 2-yr, 10-yr, etc.). For example, if the 100-year peak discharge is determined to be 10,400 cfs for Salem Creek at Main Street in Winston-Salem, this means that a peak of 10,400 cfs will be exceeded at that site once every 100 years (on average). This peak flow data can be used in the planning and design of bridges, culverts, and channel modifications.

Flood flows are also described by maximum average flow rates over designated time periods. The average discharges are anticipated to increase above these flow rates with specified frequencies (i.e., 2-yr, 10-yr, etc.). For example, at the same location on Salem Creek, a 7-day 10-year flood volume discharge of 6500 cfs (average over the highest 7 consecutive days in the year) means a discharge of 6500 cfs will be exceeded at that site once every 10 years (on average). This flood volume data can be used in developing estimates of flood-storage capacity for a flood mitigation project.

Similarly, low flows can be described by minimum average flow rates over designated time periods. The average discharges are anticipated to decrease below these flow rates with specified frequencies. For example, a 7-day 10-year low flow discharge of 10 cfs (average over the lowest 7 consecutive days in the year) at a site means a discharge of less than 10 cfs should be expected at that site once every 10 years (on average). Low flow data is used in the design of wastewater treatment plants, determining time of travel and dilution for toxic spills, evaluating streamflow-temperature degradation, and evaluating water withdrawal and diversion proposals. For example, the City of Winston-Salem is proposing a new water intake on the Yadkin River to meet water demands. In order to protect aquatic habitat in the river, the North Carolina Division of Water Resources recommended that the City be required to maintain the 7Q10 (i.e., 7-day 10-year low flow discharge) streamflow target for the gage site at Enon, North Carolina.

2.1.3 - Watershed Processes and Channel Formation

2.1.3.1 - Surface Runoff and Erosion

Most streams originate on newly formed land surfaces and carve their own channels and valleys. This process is initiated by surface runoff and erosion. Surface runoff begins when the rainfall or snowmelt rate exceeds the infiltration rate and all depression storage is filled. The erosive potential of this flowing water depends on its velocity, depth, turbulence, and the type and amount of material it transports. Soil erosion by water involves the detachment of soil particles and their transport. This is a mechanical process that requires energy. Energy is supplied directly by falling raindrops and by the runoff moving downslope creating a shear stress. Runoff moving downslope concentrates into rivulets and depressions where it gains depth and velocity. The concentrated runoff
removes enough soil to form small, well-defined channels called rills. Continuous erosion of these rills results in the development of gullies. These gullies, in turn, increase in width, depth, and length, forming larger channels.

2.1.3.2 - Drainage Networks

At the watershed level, stream systems are described in terms of drainage networks. These networks formed as channels were eroded in the landscape. When observed from an airplane or shown on a topographic map, these networks have different drainage patterns. The patterns reflect the surface topography and underlying geology. Dendritic or branched patterns indicate land surface of uniform resistance to erosion. Channels tend to form along joints in weaker bedrock layers where erosion resistance is not uniform. Under these conditions rectangular or trellised patterns develop.

Figure 2-7. Drainage Patterns typical of natural drainage networks.

Stream size and location in the drainage network can be characterized by use of a ranking method called stream ordering. A smaller order number indicates a smaller stream and a location closer to the watershed boundary. The most common method of stream ordering is shown in the watershed diagram below. You can see that first order streams have no tributaries. A second order stream has only first order streams draining to it, and so on.
2.1.4 - Effects of Watershed Characteristics

Flowing water and the materials carried by that water form stream channels. Regional climatic conditions and watershed geology, soils, topography and land cover have a significant effect on the volume, timing and routing of water and sediments from adjacent uplands into a stream, and along the stream to the outlet of the watershed. These factors interact to profoundly affect the nature of stream systems and how resistant they are to disturbance.

2.1.4.1 – Climate

Climate refers to the prevailing weather conditions in an area, which affects the flow, pattern, and shape of streams by influencing:

- Amount and type of precipitation
- Timing of runoff
- Evaporation rate
- Vegetation type
- Erosion rate
- Groundwater recharge rate
Because climate influences the amount and seasonal distribution of precipitation, it determines which processes (rain, snowmelt, rain-on-snow) are most important in controlling the current hydrologic regime of a stream and its watershed. For example, floods associated with hurricanes or violent thunderstorms periodically affect the Southeastern region of the United States. These storms tend to occur during summer months in this region. On the other hand, mountainous areas of the Northeast and Pacific Northwest sometimes experience flooding that results from rain events that occur during late winter or early spring when there are large accumulations of snow at higher elevations.

Climate also affects stream flow and sediment by influencing the type and density of watershed vegetation. In the humid southeastern United States, more vegetation grows than in the arid Southwest. The increased vegetative cover in the southeast reduces runoff by increasing transpiration losses and developing soil conditions that favor infiltration and help bind the soil. This increased vegetative cover also reduces erosion by intercepting rainfall and slowing the downslope movement of water where runoff is generated. Although the volume of rainfall that occurs in those southeastern watersheds during intense summer thunderstorms can be substantial, the presence of dense vegetative cover and low antecedent soil moisture conditions typical for this time of year serve to reduce runoff potential to some degree.

In addition, climate has a significant effect on the chemical characteristics of streams. The chemical composition of streams derives from atmospheric, soil and rock sources. Chemical and physical weathering of rock and soil contribute the greatest proportion of dissolved and suspended material to natural stream systems.

North Carolina has four distinct seasons, each with its characteristic climatic patterns. Summers are generally warm to hot, and humid. Winters are cool, mild, with little snow, except in the western mountains. Spring and fall usually provide pleasant weather. More specifically, the climate of Winston-Salem and Forsyth County is warm and humid. Winter lows average right around freezing (32°F), and summer highs average in the upper 80s. Temperatures above 90°F can occur from late April through September. There are an average of 35 days above 90°F each summer.

The weather of North Carolina is dominated for most of the year by that portion of the global air circulation known as the Westerlies (i.e., a broad band of eastward-moving air that encircles the globe throughout the latitudes 30 to 60 degrees north). This general flow is characterized by waves of air currents, the best known of which is the Jet Stream. These waves are responsible for the movement of rain-bearing atmospheric depressions. The moisture from such depressions is commonly widespread, prolonged, and fairly gentle, giving the good soaking rains that farmers prefer. Several depressions pass over North Carolina in any winter, and the precipitation in them is relied on to fill reservoirs and recharge groundwater supplies.

In summer, when the Jet Stream tends to be further to the north, North Carolina’s weather is dominated by air masses that originate over the tropical Atlantic Ocean, drifting in from a southerly direction. These warm, moist air masses bring the hot, humid, hazy conditions...
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with afternoon thunderstorms, typical of summer. These thunderstorms produce intense, short duration rain events that are highly localized and often widely scattered. As a consequence they do not provide a reliable source of precipitation for agriculture or water supply purposes. However, there is a strong correlation between the outbreak of these storms and the number of flash floods experienced in the region. The majority of these thunderstorms develop between May and August.

Winston-Salem and Forsyth County are situated in a region of North Carolina where the average annual precipitation is less than 46 inches. With the exception of an area that includes parts of Madison, Haywood and Buncombe Counties, this region has the lowest average annual precipitation in the state. Average monthly rainfall ranges from 2.8 inches in the winter, to 4.6 inches in the summer. In spite of this rainfall deficit, the U. S. Geological Survey rates the streams in this area as having at least a moderate potential for maintaining year-round baseflow.

The increased precipitation during the summer months is due primarily to the thunderstorms noted above. Historic stream flow records indicate that Winston-Salem and other areas of Forsyth County have experienced periodic flash flooding associated with intense thunderstorms. However, the tropical storms from the Atlantic Ocean and Gulf of Mexico that cause significant damage along the North Carolina coast are usually weakened by the time they move as far inland as Forsyth County. The notable exceptions were Hurricane Hugo in September 1989 and Hurricane Fran in September 1996.

Average total winter snowfall is about nine inches. Generally, only one to two inches of snow accumulate at any given time, and melt within a few days. As a consequence, snowmelt is not a significant contributor to baseflow maintenance or peak flood flows.
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2.1.4.2 - Physiographic Regions

Traveling from east to west, the North Carolina landscape transitions from the flat terrain at or near sea level along the Atlantic Coast, to the rolling hills of central Carolina, to a mountainous region that includes Mt. Mitchell, which is the highest peak in the eastern United States. North Carolina’s landscape has been divided into three major physiographic regions based on geologic and topographic characteristics.

![North Carolina's physiographic regions](image)

Figure 2-10. North Carolina’s physiographic regions (NCDENR, 1998). Forsyth County is highlighted in red.

The Coastal Plain forms the eastern edge of North Carolina, comprising about 45 percent of the state’s total land area. To the east is the Atlantic Ocean and to the west is the Fall Line, a broad zone where the soft sedimentary rocks of the Coastal Plain meet the hard crystalline rocks of the Piedmont region. The Coastal Plain is further subdivided into two subareas. The Tidewater, closest to the ocean, is an extremely flat, poorly drained, low-lying area characterized by swamps and lakes. The Inner Coastal Plain is higher in elevation and better drained. Locally there are distinctive wetlands or upland bogs known as pocosins or Carolina Bays (elliptical lakes of unknown origin). Steep river gradients and rapids characterize the boundary between the Coastal Plain and Piedmont (i.e., Fall Line). Downstream of the Fall Line, low gradient streams meander across broad, low valleys carved in the soft, easily eroded sediments.

The Piedmont is a geologically ancient region situated west of the Fall Line that is underlain by a complex of metamorphic and igneous rocks. The rolling plateau of the Piedmont formed as ancient mountains were worn down by erosion. As the mountains were worn down, areas of more resistant rock formed hills known as monadnocks. Pilot Mountain, in Surry County, is a sandstone-capped monadnock. The Piedmont covers about the same amount of land area as the Coastal Plain, but is higher in elevation, ranging from 300 feet at the Fall Line to 1500 feet at the foothills of the Blue Ridge Mountains. Seven major rivers and their tributaries (Dan, Tar, Neuse, Cape Fear, Yadkin, Catawba, and Broad) drain the eastern slopes of the Blue Ridge, carving narrow, deep valleys in the hard rocks of the Piedmont.
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The Appalachian Mountains begin abruptly at a major fault line, west of which rises a steep escarpment, the edge of the Blue Ridge Mountains. The escarpment is visible at places such as where Interstate 77 crosses into Virginia and where Interstate 40 crosses the Blue Ridge Mountains and enters the Asheville Basin. These mountains are underlain by a variety of rock types, the predominant being metamorphic rocks, which are relatively resistant to erosion. The Blue Ridge Mountains form the eastern continental divide, with streams draining the eastern slopes flowing to the Atlantic Ocean and streams draining the western slopes flowing to the Mississippi River system.

Winston-Salem and Forsyth County are located in the northwestern part of the Piedmont physiographic region. The topography is gently rolling to steep, with sharp breaks in topography occurring along the edge of floodplains. Generally, the floodplains are broad along the mainstem of streams such as Muddy Creek, Salem Creek, Silas Creek, Monarcas Creek, and Mill Creek. Tributary streams are numerous and have steep gradients and relatively narrow floodplains.

2.1.4.3 – Geology and Soils

Geology refers to the bedrock underlying an area, while soil is the material that develops as a result of weathering or wearing away of the bedrock or parent material. These characteristics affect streams by influencing:

- Permeability and porosity
- Infiltration rate
- Groundwater recharge rate
- Volume of water stored
- Rate of water movement through the watershed
- Erosion rate
- Sedimentation
- Stream bank material
- Water chemistry

When we discuss the geology of a watershed, we are referring to the type of rock or mineral formations (i.e., igneous, sedimentary or metamorphic) that underlie the area. These bedrock formations developed as a result of geologic processes (e.g., volcanic eruptions, mountain uplift and erosion, tectonic forces, and deposition of sediments in alluvial, coastal and shallow marine environments) that have operated over a span of more than a billion years. Soil consists, at least in part, of material weathered in place from the underlying parent material (i.e., bedrock) and mixed with organic material near the surface. As such, a soil’s character is related to the interaction of the parent bedrock material from which it derived, climate, and biotic and climatic factors.

Geology and soils help to define the nature of watersheds and streams by affecting the quantity and quality of both groundwater and stream water, as well as the stability of landscape features such as hillslopes, terraces, floodplains and stream channels.
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During rainfall and snowmelt, water may flow rapidly to a stream over the ground surface (i.e., overland runoff), through the soil laterally as throughflow, or downward as recharge for groundwater. To a large extent the pathway taken is determined by characteristics of the geology and soil.

Bedrock formations vary in physical characteristics such as permeability, porosity, and resistance to erosion, as well as in their mineral and chemical composition. In addition, watershed runoff characteristics are greatly influenced by the predominant type of soil because of differences in infiltration and water storage capacity and transmissivity.

For example, streams draining watersheds of the Coastal Plain region of North Carolina are all underlain by sedimentary formations and the soils that weather from these formations (i.e., clay, silt, sand and gravel). Those watersheds with clay soils have high runoff potential and very low potential for sustaining year-round baseflows. In these watersheds rain and snowmelt do not readily infiltrate and percolate through the low permeability soils. These watersheds tend to generate more overland runoff and contribute less water to baseflow. Therefore, stream flow is highly sensitive to rainfall inputs. Conversely, watersheds in the Sand Hills area of the Coastal Plain with sandy soils have low runoff potential and the highest potential for sustaining year-round baseflows in the State. The precipitation that falls on these watersheds will readily percolate through the highly permeable soil and into the underlying rock formation generating less overland runoff. They have significant groundwater storage capacity and the volume and rate of water movement through the rock sustains reliable baseflows.

A soil’s characteristics also determine how susceptible it is to erosion by rainfall and overland runoff. A soil’s structure, texture, and the percentage of organic matter influence its erodibility. The most erodible soils generally contain high proportions of silt and very fine sand. The presence of most clay minerals or organic matter tends to decrease soil erodibility. Clay tends to bind particles together, while organic matter helps maintain stable aggregate structure.

While a soil may be fairly resistant to erosion by surface runoff, this does not guarantee that it will be stable and resistant to some type of mass wasting or slippage. Soil moisture can have a significant influence on the stability of some soils. For example, the addition of water to clayey soils can transform them from solid to plastic and liquid states, thereby reducing their resistance to displacement. In addition, groundwater seepage can result in undermining of hillslopes by sapping and piping, and pore water pressure near seepage zones may weaken the skeletal strength of soil materials within a slope.

The structural stability of soils also relates to the steepness of the hillslope on which they formed. For any earth material there is a maximum angle, called the angle of repose, at which it can be safely inclined and beyond which it will fail. The angle of repose varies widely for different materials, from 90° in strong bedrock to less than 10° in some unconsolidated materials. In unconsolidated materials, it can vary substantially with changes in water content, vegetative cover, and the internal structure of the particle mass. This is especially so with clayey material: a poorly compacted mass of saturated clay may
give way at angles as low as 5°, whereas the same mass of clay with high compaction and lower water content may be able to sustain angles greater than 100°.

The nature of the geologic formations and soils in a watershed also influence stream channel stability. For example, granitic, metamorphic rock and consolidated sedimentary bedrock are relatively resistant to the hydraulic forces of flowing water. Channel shaping and migration are very slow processes in these formations. On the other hand, unconsolidated alluvium (i.e., silt, sand and gravel material deposited by streams) is particularly susceptible to scour and lateral erosion. Where unstable conditions exist due to man-made channel modifications, rapid channel adjustment and lateral migration can occur in response to high discharge, high sediment transport flow events.

Basin geology also has a significant effect on surface water quality. Chemical and physical weathering account for a significant proportion of dissolved and suspended material in natural systems.

As pointed out previously, Winston-Salem and Forsyth County are in the northwestern Piedmont region. Primarily gneiss and schist underlie the watersheds in this area, with granite occurring in localized areas. These materials are generally low in permeability and porosity. Consequently, water doesn’t flow easily through them and they have relatively low capacity to store water. The U. S. Geological Survey characterizes most of the watersheds in this area as having an intermediate potential for sustaining year-round baseflows. The dominant soils, weathered from these formations in upland areas are well-drained, moderately permeable loamy soils with clayey subsoil. These soils have moderate to slow infiltration rates and surface runoff is medium to very rapid depending on slope. The erosion hazard for these upland soils is moderate to severe. The dominant floodplain soils of the area formed from alluvium. They are poorly drained loamy soils with loamy subsoils. These soils generally have a low permeability, moderate infiltration rates, slow surface runoff, and moderate to high erosion hazard. They also have a high seasonal water table and are subject to frequent flooding.

2.1.4.4 – Landscape Topography

Landscape topography is comprised of the natural and man-made features that characterize the surface of the land. Topography affects streams by influencing:

- Surface storage of precipitation
- Infiltration rate
- Runoff rate
- Erosion rate
- Sedimentation
- Vegetation type
- Flood storage and conveyance
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Topography is a product of the underlying geologic formations and the geologic history of an area, as well as human activities that alter the natural landscape. The topography or terrain of an area has a significant influence on runoff and erosion processes, valley and stream morphology, stream energy, and conveyance of floodwaters.

Natural storage of water in depressions on the ground surface during rainfall reduces surface runoff volume and velocity. On relatively flat terrain, precipitation stored in surface depressions has the opportunity to infiltrate the soil. Depending on soil characteristics and vegetative cover, the rainwater may be taken up by plants and transpired back to the atmosphere, flow subsurface down the slope, and/or percolate to the groundwater. Unfortunately, natural surface depressions, while highly effective on flat areas, diminish rapidly in volume and effectiveness as the surface slope increases. In small watersheds on steep hillslopes, most surface depressions are filled to capacity very quickly, reducing opportunities for infiltration and increasing overland runoff.

Increasing surface slope not only decreases surface storage and infiltration, but also increases the velocity of overland runoff generated. Increased runoff velocity means that erosion rates increase as soil particles are more easily detached and transported down the slope. The terrain adjacent to the stream also influences sedimentation rates by providing opportunities for water-borne soil particles to settle out prior to reaching the stream channel.

The topography of the watershed determines the character of the stream valleys as well as the streams themselves. For example, the steeper, headwater areas of a watershed tend to have steeper stream channels confined by adjacent hillslopes, while lowland areas downstream tend to be flatter, with broader valleys. As a result, headwater streams generally have more energy available to erode and transport stream bank and streambed materials. They also have relatively few areas to store flows that overtop the stream banks. As a consequence, floodwaters are conveyed quickly to downstream reaches. On the other hand, unaltered streams flowing across broad, flat valleys tend to have less energy available for erosion and transport of materials, while they usually have significant areas available for storing and slowing the downstream conveyance of floodwaters.

In Winston-Salem and Forsyth County the topography is gently rolling to steep, with broad, gently sloping ridges, and smooth side slopes. Sharp breaks in topography occur along the edge of floodplains. Generally, the unaltered floodplains are broad along the mainstem of streams such as Muddy Creek, Salem Creek, Silas Creek, Monarcas Creek, and Mill Creek. Tributary streams are numerous and have steep gradients and relatively narrow floodplains.

The Upper Salem Creek watershed is a typical example. It is characterized by moderately steep terrain, with slopes in some areas in the 5-10% range. Many of the headwater tributaries of Salem Creek are moderately steep with relatively narrow valleys confined by adjacent hillslopes. Kerners Mill Creek, a tributary upstream of Salem Lake, is an exception with a relatively broad floodplain. Long stretches of the mainstem through Winston-Salem are relatively flat. The overall slope of the upper mainstem of Salem Creek is approximately 0.5%. Areas along the mainstem Salem Creek, upstream and downstream
of the Gorge, as well as the reaches through Civitan, Central and Washington Parks have broad floodplains. Some of these areas currently support or historically supported wetlands.

2.1.4.5 – Land Cover and Land Use

*Land cover* refers to the types of vegetation found in an area. A related factor is *land use*, which refers to the types of activities which people conduct on a given land area. Together, land cover and land use influence:

- Streambank stability
- Stream temperature
- Nutrient and sediment inputs to the stream
- Stormwater runoff quantity, quality, and rate
- In-stream and riparian habitat

Land cover and land use are major factors controlling the volume and rate of runoff from a watershed, soil erosion and sediment loadings, the stability of valley hillslopes, stream channel morphology, and overall water quality. The location and intensity of a particular land use activity will determine its effect on the watershed.

The vegetation that covers the land surface of a watershed is a major factor influencing the amount of surface runoff generated and the amount of sediment eroded and transported from upland areas. Interception on leaves, stems, and surface litter allows water to be retained during smaller storms, evaporating back into the atmosphere without ever reaching the ground. It also lessens the impact of raindrops by preventing the dislodgement of soil particles.

Where there is appreciable vegetative cover, and especially where there is a humus or litter layer, overland flow generally occurs only during larger storms due to increased infiltration rates. Vegetation aids infiltration by preserving loose soil structure and diffusing the flow of water where runoff is initiated, thereby increasing infiltration opportunity. Vegetation also depletes soil moisture to greater depths, increasing available water storage and allowing more water to infiltrate. These effects are more pronounced under forest cover where roots penetrate deeper and transpiration rates are greater. Forest cover, litter, and lower vegetation also moderate soil microclimate, in particular the depth and frequency of soil frost. Thus infiltration may occur even during colder months when the ground may be frozen elsewhere.

All of these mechanisms tend to increase infiltration rates and capacity and thereby reduce the volume of runoff generated. Once runoff has commenced, vegetation interrupts overland flow, slowing the velocity, physically binding the soil and inhibiting erosion. Land use and land cover in Winston-Salem and Forsyth County spans the spectrum from forested open space, to agricultural croplands, to manicured and landscaped residential properties, to asphalt-dominated commercial centers and industrial complexes. The Legacy Comprehensive Plan describes the pattern of development in Forsyth County as a central
downtown in Winston-Salem, older close-in neighborhoods, new suburban residential and commercial development, small towns, and rural areas. Winston-Salem forms the geographic core of the county, with development radiating out along key transportation corridors. Rural areas are situated primarily in the northeast, southeast, northwest, and southwest corners of the county.

The headwaters of Muddy Creek and its upper tributaries flow from the rural parts of the Forsyth County in the Tobaccoville and Rural Hall areas. As it flows south across the county, Muddy Creek is joined by Mill Creek, which drains the suburban areas in northwest Winston-Salem; Silas Creek, which drains the suburban/urban areas of west-central Winston-Salem; Salem Creek, which drains the Kernersville town center and surrounding rural area, the suburban areas in northeast Winston-Salem, and the urban areas of central Winston-Salem; and the South Fork Muddy Creek, which drains the suburban and rural areas of southeast Forsyth County.
2.2 – The Stream Reach Level

Now that we have looked at streams from the watershed level, we can shift our focus to the stream itself and its immediate surroundings. Our goal is to become familiar with the characteristics used to describe streams and evaluate their condition or overall health, and to develop some understanding of how channels change over time.

2.2.1 - Stream Channel Morphology

The stream channel presents a three dimensional form defined by its cross-sectional geometry, meander pattern, and longitudinal profile.

![Characteristics of Channel Morphology](image)

Figure 2-11. Stream channel morphologic characteristics.

2.2.1.1 - Cross-sectional Geometry

One of the characteristics of streams is that each *cross-section*, on any stream, has been shaped and dimensioned over time to convey a range of flows. The size and shape of a stream’s cross-section is a function of its flow regime, the quantity and type of sediment transported through the section, and the character or composition of the materials that make up the streambed and banks. The size and shape of the channel cross-section determine how energy is distributed within the channel and how sediment and other material are...
transported. Streams in cross-section tend to be trapezoidal in straight reaches and asymmetrical at curves or bends.

Figure 2-12. Stream channel cross-sectional geometry.

Channel cross-section shape and size is described by a number of terms:

* width \( (W) \) - the horizontal distance across the channel at a given discharge

* depth \( (D) \) - the vertical distance between the water surface, at a given discharge, and some point on the streambed

* width:depth \( (W/D) \) - describes the dimension and shape of the channel as the ratio of channel width to mean depth

* cross-sectional area \( (A) \) - the area of water across a given section of stream, at a given discharge; \( W \times D \)

* wetted perimeter \( (P) \) - the distance along the streambed and banks at a cross-section where they contact the water; a close approximation is \( W + 2D \)

* hydraulic radius \( (R) \) - the ratio of the cross-sectional area to the wetted perimeter; \( A/P \)

* thalweg - the path of the deepest thread of the stream
2.2.1.2 - Meander Pattern

A stream’s *pattern* or plan form describes the form of the channel one might observe from an airplane. Natural streams are seldom straight for more than a relatively short reach of stream; most have curves, bends, or meanders. *Sinuosity* is a way of describing how much meandering a stream exhibits. The straighter the channel, the greater the energy available to erode the stream’s bed and banks.

![Stream channel meander geometry – sinuosity.](image)

Streams in mountainous areas where the channel is confined by the adjacent hillslopes have naturally low sinuosity, while streams flowing through broad, flat valleys are highly sinuous.

Channel pattern is also described by a number of other terms:

- **meander wavelength** - twice the linear distance between successive inflection points
- **radius of curvature** - the radius of the central portion of a channel bend
- **meander amplitude** - distance between tangents drawn on the convex sides of successive bends
Although most streams have a single channel, two or more channels, divided by bars or islands characterize braided streams. Braiding generally indicates that the stream has lost its ability to transport its sediment load. Braided channels are very unstable. Significant bank erosion and rapid lateral migration is common. The exceptions are the heavily vegetated, very stable anastomosed braided channels, which are usually associated with riverine wetland systems.
2.2.1.3 - Longitudinal Profile and Streambed Forms

The *profile* of a stream describes the way in which a stream’s elevation changes as it flows in a downstream direction. A stream’s overall slope or gradient is a measure of that change in elevation and refers to the steepness of the channel. The steeper the channel, the greater the energy available to erode the stream’s bed and banks.

For many streams, slope decreases continuously from headwaters to mouth, forming a characteristic concave shape. Local topography, bedrock features, and bed materials...
modify the profile. Harder rock (e.g., granite) produces steeper profiles, while streambeds that are more easily eroded produce flatter profiles.

![Stream channel longitudinal profile](image)

Figure 2-18. Stream channel longitudinal profile.

A related characteristic is *streambed forms*. Natural streams rarely have flat beds. The energy of flowing water molds streambeds into various forms. The most commonly recognized streambed forms include *riffles*, which are relatively steep areas of fast moving, shallow water formed by the accumulation of coarse materials (e.g., gravels, cobbles, and boulders) and *pools*, which are relatively flat areas of slow moving, deep water formed by scouring of the streambed material. Riffles are usually formed in the crossover or straight reach between successive meander bends, while pools are usually formed in the bends.

In steeper streams, riffles may be replaced by *steps*, which are areas of steep drops or jumps formed by the accumulation of large material such as boulders and fallen trees or logs. The steepest bedforms include *cascades*, dominated by jet-and-wake flow and hydraulic jumps, longitudinally and laterally disorganized bed material of cobble and boulders; and pool spacing less than one channel width.

*Regime* streambed forms are typical of low gradient sand or silt channels. These types of streams exhibit a succession of bed forms with increasing velocity - planar bed, ripples, dunes, and anti-dunes.
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2.2.1.4 - Streambed and Stream Bank Materials

Although streambed and stream bank material is generally a mixture of various size materials, it is common to characterize a stream by describing the most common or average size material present. For example, we may describe a stream as a gravel-bed or sand-bed stream. Stream channel material will usually fall into one of these categories: bedrock, boulder, cobble, gravel, sand, silt, or clay.

The character of these materials determines: erosion potential; ability to support vegetation that stabilizes the stream channel; the amount of roughness to slow the water velocity and reduce its energy; and the physical habitat available to aquatic organisms for feeding, resting, reproducing, and hiding.

Although the size distribution of streambed material may be determined using a variety of streambed sampling techniques, the most commonly used method is called a “Wolman Pebble Count”. This technique provides information that allows characterization of the streambed relative to its dominant particle size ($D_{50}$), degree of fine material ($D_{16}$), and the largest material sizes ($D_{84} - D_{100}$).
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Streambed Materials

Figure 2-20. Bedrock

Figure 2-21. Boulder

Figure 2-22. Cobble

Figure 2-23. Gravel
2.2.2 - Floodplain

The basic geomorphologic unit of the stream corridor is the *floodplain*. The floodplain is the area adjacent to the stream channel that is periodically inundated or flooded with water, when the stream overflows its banks.

Figure 2-26. Floodplains as geomorphologic units of the stream corridor (FISRWG, 1998).
The hydrologic floodplain is that land adjacent to the channel that is situated above the elevation of baseflow but below the elevation of the bankfull stage. It is inundated by storm flows that occur on average every two years out of three (i.e., 1.5 year recurrence interval). Some streams do not have a hydrologic floodplain. This is often the case with urban streams that have incised into the landscape and become isolated from their former floodplain. The topographic floodplain is that land adjacent to the channel that is situated above the elevation of baseflow but below the elevation of a given peak flood stage. For example, the 100-year recurrence interval flood is generally used in flood studies, and cited in planning and regulatory standards.

The presence or absence of a functioning floodplain has a significant effect on how and where floodwaters are conveyed along the stream corridor. The ability of a stream to overflow onto a floodplain decreases the concentration of energy in the channel, thus decreasing the potential for channel down-cutting and bank erosion.

A flood wave moving through a watershed is usually decreased through storage in the floodplain. Storage of floodwaters in natural floodplain areas slows the downstream movement and reduces the risk of flooding in developed areas.

Trees, shrubs, and debris on the floodplain surface create resistance to the movement of floodwaters. As such, they slow water velocity, depositing sediments that build fertile floodplain soils, allow detention and infiltration of floodwaters, thereby slowing the rate at which the flood wave progresses, and reducing the total volume of water that moves to downstream areas. Receding floodwaters carry organic material from the floodplain into the channel that is a critical source of energy for the stream ecosystem.

2.2.3 - Riparian Vegetation

Riparian or streamside vegetation plays many roles in maintaining the health of a stream. Streambank vegetation, especially trees and shrubs, physically hold the stream banks intact. Trees and shrubs also provide shade for the stream, keeping water temperatures cool and increasing the dissolved oxygen in the stream water. Roots and branches that overhang or extend into the stream channel provide habitat for fish and other aquatic organisms. Leaves and twigs are an important food source for aquatic insect larvae, which are an important food source for fish.

Vegetation in the floodplain and on adjacent slopes mitigates the effects of runoff by slowing the velocity of water as it flows over the land, decreasing the potential for erosion to occur. Materials suspended in water and attached to soil particles (e.g., nutrients and toxic chemicals) tend to settle out and may be broken down by soil microorganisms and absorbed by plants, when runoff water is detained by vegetation.
2.2.4 - Groundwater Reserves

Water that is absorbed into the soil through the process of infiltration moves downward through the force of gravity, and in all directions due to capillary action (similar to wicking). Water continues to move downward until it reaches a completely saturated area known as the *groundwater table*. As water continues to collect in the soil, the water table rises until it is exposed in the bottom of the deepest notch or depression in the area, which is usually a stream channel. Thus water flowing in a stream channel long after a rainstorm generally indicates that the groundwater is high enough to enter the channel. For most streams, groundwater enters the channel by seeping through the banks or upwelling through the bed.
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Locations where groundwater and surface water are exchanged are important. An area that freely allows the movement of water into the saturated zone underground is called a recharge area, while localized areas where groundwater emerges are called springs or seeps.

Interactions between groundwater and the channel can vary spatially (i.e., along the stream system throughout the watershed) depending on geology and soils, as well as temporally (e.g., seasonally) as groundwater elevations fluctuate. For example, gravel bed streams with well-developed alluvial floodplains generally have the greatest interaction with groundwater. During wet periods when groundwater elevations are high most, if not all, stream reaches may be functioning as effluent reaches. That is, they are gaining or receiving water from the groundwater aquifer through their banks and bed. During dry periods when groundwater elevations are low, many of those same reaches may be functioning as influent reaches. That is, they are losing water to the groundwater aquifer through their banks and bed.

![Stream cross-sections of influent and effluent reaches](image)

Figure 2-29. Stream cross-sections of influent and effluent reaches (FISRWG, 1998).

2.2.5 - Physical Habitat

The physical habitat available in a given stream reach can be characterized by a variety of interdependent components that include macrohabitat features such as temperature and water quality, as well as channel structure, dimension, pattern, slope and discharge, which influence microhabitat features such as depth, current, surface area, substrate, cover, and pool/riffle ratios. Utilization of the various living spaces created by these features varies diurnally and seasonally by species and life stage, and depends on the activity in which the organism is engaged.

A variety of water quality parameters determine the suitability of water for its intended use, whether by aquatic organisms or by people. These parameters include but are not limited to
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temperature and chemical constituents such as pH, dissolved oxygen, nutrients, hardness, alkalinity, turbidity, suspended sediment, heavy metals, etc. The amount, concentration, or magnitude of each parameter helps determine overall water quality.

Historically, water quality has been defined strictly by physical and chemical characteristics. Although these are important descriptors, they are insufficient to fully describe and understand the ability of water resources to support living systems. For many purposes, especially biological ones, high quality water resources are characterized by stable and natural temperature, high oxygen but low nutrient concentrations, pH within a natural range determined by bedrock and soil weathering, and levels of other constituents that support diverse biological communities including abundant organisms with narrow environmental tolerances.

Channel characteristics such as slope, dimension, pattern, channel structure and bed material size are interdependent and relate to discharge and sediment load. They affect sediment transport processes and how water velocity varies within a channel section. They affect temperature by controlling the amount of surface area and substrate that is directly exposed to sunlight. They also affect the capacity of the channel to detain and cycle organic material (e.g., leaves, twigs, etc.) and nutrients that collect behind boulders and debris jams and settle in pools or in the voids between coarse substrate material.

Discharge directly influences channel characteristics and available habitat. Baseflow is the most critical flow relative to aquatic habitat. The volume of water carried by a stream under baseflow conditions directly influences its habitat features, including surface area, depth, velocity, cover, temperature, and concentrations of dissolved oxygen and carbon dioxide. The overall surface area available as habitat fluctuates with discharge. During periods of seasonal low flow and droughts, very little surface area may be available to stream organisms. As discharge increases during periods of higher baseflow, or during storms, side channels and isolated pools become available even in headwater areas. The timing of discharge has a very strong influence on biological activities, including feeding, spawning and migration of fish, the downstream drift of aquatic insects, and the growth and development of most aquatic organisms. Consequently, two streams with similar channel dimensions but different baseflow regimes will have different habitat characteristics.

Water depth to a large extent determines the amount of space available for organisms to utilize. It limits upstream and downstream movement, determining access to critical areas such as spawning grounds. For example, shallow flow through road culverts can create impassible barriers to migrating fish. Deep water provides overhead cover, protecting large fish from predation by wading birds and mammals. Shallow water protects small fish from predation by piscivorous fish. Depth also influences other parameters such as velocity (relative to the effect of streambed roughness) and temperature (relative to the degree of insolation and vertical variability).

Current influences the character of the streambed or substrate by controlling sediment transport and deposition. It determines the distribution of photosynthetic organisms. For example, periphyton are generally tolerant of swift currents, phytoplankton tolerate
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Moderate currents, and vascular macrophytes are generally found only in very slow moving reaches. Current influences oxygen concentration through physical aeration. It maintains high oxygen levels in spawning gravels and transports metabolic waste products away from developing fish embryos. Current influences the capacity of the channel to retain and cycle organic material and nutrients. Torrential or cascading reaches generally transport material downstream before bacteria, fungi, and aquatic insects process it. Current can function as a barrier to fish movement. This is particularly a problem where road culverts steepen the gradient of the stream reach.

Substrate is one of the most critical habitat features for the benthic community. Macroinvertebrate diversity and abundance are strongly influenced by the substrate size and embeddedness (i.e., the percentage of finer sediments filling the voids around larger streambed material). Studies have shown that the most diverse communities are found in gravel-cobble substrates with a low percentage of fine sediment. Many fish spawn in or on the substrate. Again studies have shown that fish such as trout have a strong preference for gravel-cobble sized material. As embeddedness increases, the suitability of the substrate for fish and macroinvertebrates decreases significantly. For many streams, particularly those with natural sand or silt bottoms, beds of aquatic vegetation and large woody debris (e.g., logs, branches, etc.) provide additional critical substrate to which organisms cling.

For macroinvertebrates living in or on the bottom substrate or in beds of aquatic vegetation, cover from predation is provided. They also avoid swift currents by staying within the boundary layer or beneath the substrate. Fish utilize cover to avoid predation or unfavorable current conditions as well. Fish abundance in streams has been correlated with the abundance and quality of cover available. Large woody debris, undercut banks, overhanging vegetation, water depth, water turbulence, and even turbidity are all forms of cover for fish. The preferred cover varies diurnally and seasonally, and by species and life stage.

Figure 2-30. Typical habitat in a gravel bed stream.
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Figure 2-31. Typical habitat in a sand bed stream

Pools are important resting areas, which provide cover from disturbance and predation and areas for avoiding current. Riffles are generally the major source of aquatic insects for insectivorous fish, and provide critical spawning areas. The ratio of pools to riffles is key to the number of fish a stream can support and how much pressure from predation and competition they will experience.

2.2.6 - Aquatic Organisms

In any ecological community, at the base of the food chain are the plants that utilize the energy of the sun to produce organic compounds for their own growth and reproduction. Headwater streams depend upon terrestrial plants as their primary energy source. Leaves and twigs fall or are blown into the stream and supply food for macroinvertebrates, which are small aquatic organisms such as insect larvae, worms, crustaceans, clams and snails, that live in stream bottoms and along banks. Macroinvertebrates are a critical component in the processing of organic material and nutrients, and they in turn are an important food source for fish.
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Figure 2-32. Food relationships typically found in streams (FISRWG, 1998).

In a healthy headwater stream, there is a great diversity of macroinvertebrates with no single species dominating the community. Organisms found in such streams include stoneflies, caddisflies, mayflies, gilled snails, water pennies, riffle beetles, and hellgrammites. These animals, and the fish that feed on them, such as trout and smallmouth bass, sculpin, and darters require fast flowing, cool water with high dissolved oxygen concentrations. In addition, some of the fish inhabiting these areas need sediment-free gravel streambeds for spawning. The animal community found in healthy headwater streams is usually considered pollution-intolerant because of its very specific habitat requirements.

As we travel downstream in a watershed, stream size increases and a greater surface area is exposed to sunlight. Algae and rooted aquatic plants become the primary source of energy production. The macroinvertebrates inhabiting larger, warmer streams include crayfish, sowbugs, scuds, dragonflies, damselflies, aquatic worms, and snails. The fish found in these streams are those such as largemouth bass, sunfish, catfish, dace, and minnows which are able to tolerate the relatively warmer temperatures and lower concentrations of dissolved oxygen which occur in slower flowing reaches. The animal community found in healthy lowland streams is adapted to the habitat conditions typical of these areas.
2.2.7 - Fluvial Processes

Although all stream reaches are unique, early studies on streams demonstrated that relationships exist between discharge and stream channel characteristics, and between the channel characteristics themselves. These relationships have provided a basis for explaining the apparent similarities from one stream to another and between one reach and another on the same stream. Understanding the processes that shape and maintain stream reaches is more challenging.
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2.2.7.1 - Flow in Channels and Flow Resistance

Water flowing in a stream on a mountain or hill possesses potential energy. The amount of energy is in proportion to the difference in elevation from the top of the mountain or hill to the lowest point to which the water can flow. The water flows downhill under the influence of gravity, converting the potential energy of position into kinetic energy of motion. The flowing water performs work in the form of eroding stream banks and beds, and transporting sediment and debris. Resistance created by bends in the stream channel, changes in channel width, turbulence, friction along the channel boundary (i.e., banks and bottom), and obstructions (e.g., boulders, woody debris, overhanging vegetation, etc.) retard the flow.

This resistance causes the velocity (rate of flow) to vary vertically from water surface to stream bottom, laterally across the channel from bank to bank, and along the channel in an upstream-downstream direction.

Figure 2-34. Flow velocity varies vertically, laterally and longitudinally (Redrawn from Gordon, McMahon, & Finlayson, 1992).

The extent to which obstructions retard the flow depends on the relative roughness of the channel (i.e., depth of the water relative to the size of the obstructions). For example, boulders protruding from a streambed create considerable resistance under shallow, baseflow conditions, while those same boulders offer much less resistance under flood flow conditions.

The relationship between the forces of gravity and the resistance determines the energy available to erode and transport materials, and is therefore the key to the processes that shape and maintain stream channels.
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2.2.7.2 - Sediment Supply and Sediment Transport Processes

• Sediment Supply

The amount of sediment carried through the outlet of a watershed depends on two factors: the amount of sediment eroded and transported to the stream from upland sources; and the ability of the stream to carry the washed in sediments and to rework and transport bed and bank materials.

The first factor is dependent on climate, land use, and the geology and topography of the watershed. The second factor is dependent on the hydraulic and hydrologic properties of the channel and the erodibility of its bed and banks. Streams may be either supply limited or capacity limited, depending on whether their ability to carry sediment exceeds the amount available or vice versa.

• Sediment Transport

Sediment movement consists of three stages - initiation of motion, downstream transport, and sedimentation. Flowing water exerts a force on the streambed and banks. Tractive force and shear stress are the most common expressions for the force exerted. Critical shear stress is that force initiating motion for a particle of a given size. Once in motion, particles continue to be transported until velocity drops below the threshold of motion.

Figure 2-35. Velocity required to erode and transport various sizes of material.
Sediment is transported downstream as *dissolved load* (consisting of material transported in solution), *wash load* (comprising small particles, primarily clays, silts, or fine sand, readily carried in suspension), and *bed material load* (including material in motion which has approximately the same size range as streambed particles). Bed material load may be transported as *bed load*, when particles move by rolling, sliding, or saltation (hopping) or *suspended load*, when particles are transported and maintained in suspension by turbulent eddies, but settle out quickly when velocities drop.

Figure 2-36. Modes of sediment transport (Adapted from Abbott and Francis, 1977).

**2.2.7.3 - Channel Erosion Processes**

Stream channel erosion occurs because water flowing in the channel exerts a force that exceeds the critical shear stress for erosion. Stream channels erode in different ways depending on their location in the channel, the direction of flow, and the characteristics of the bed and bank material. For example, tractive forces undercutting or eroding the toe of a bank initiate the adjustment process. This causes the upper part of the bank to overhang. The weight of the overhanging bank can exceed the shear strength of the bank material causing the bank to fail, falling into the channel under the influence of gravity.
2.2.7.4 - Depositional Processes

A stream carries its load until it lacks the energy to do so. Bed load materials deposit when they stop rolling, sliding, or saltating. Suspended materials settle out of suspension. Three major processes lead to deposition: a particle’s orientation in the flow changes, thereby increasing resistance; the competence of the stream decreases, meaning the energy available for transport decreases; and the quantity or size of the sediment load suddenly increases.
A variety of depositional features can form as a result of sedimentation. For example, in stable meandering streams, *point bars* generally form on the inside of meander bends. *Alternating or side bars* form along the channel margin in straight stream reaches. They generally alternate from left to right bank creating a sinuous thalweg within the straighter active channel. These features often form in streams that have been artificially straightened and may indicate the early stages of meander redevelopment. *Delta* bars form along channel margins immediately downstream of tributary confluences. *Mid-channel bars* form toward the center of the channel or just off of the channel margin. These features cause the flow to split and may deflect flow towards adjacent banks. Mid-channel bars are usually indicative of a significant loss of sediment transport capacity and channel stability.

Figure 2-39. Typical depositional features (Rosgen and Silvey, 1996).
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2.2.7.5 - Channel Changes

Stream channels change in response to changes in streamflow and sediment supply. The adjustments can include changes in cross-section, planform, and longitudinal profile. Changes in channel form may occur gradually, over geologic time periods. Stream slopes become less steep as uplifted terrain is worn down. Some changes occur abruptly as a critical threshold value is exceeded. A stream with a meander radius that has decreased over a long time period will suddenly cut off that meander bend by forming a chute across the inside of the meander bend or floodplain. Some changes are short term. The streambed may scour as stream power increases with the increasing channel flow in response to a storm, and fill as material transported from upstream deposits due to the loss of stream power when the flow recedes after the storm has passed.

- Lateral Adjustments

Under natural conditions, the erosion of the stream bank on the outside of a meander bend is compensated by accretion (i.e., deposition of material) or the formation of point bars on the inside of the meander bend. A result of this process of erosion and accretion can be the migration of the channel across the floor of the valley. If the rate of erosion and accretion are similar, a channel can completely change its location in the landscape, while maintaining its cross-section dimensions. These adjustments generally occur very gradually.

Over time, meanders tend to become more tortuous. As their radius of curvature decreases some bends become very sharp. The angle at which flow strikes the bank becomes more severe, stress on the bank increases, and the erosion rate accelerates. If the bend becomes tight enough, a cutoff channel may form across the point bar or floodplain on the inside of the bend, abandoning the meander, and creating a relatively straight reach with an adjacent oxbow lake or wetland. The meandering of the stream leaves topographic features that can be observed on the floodplain.

Figure 2-40. Topographic features on the floodplain created by a meandering stream (FISRWG, 1998).
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- Vertical Adjustments

Unstable conditions may result in bed forms that are significantly steeper or flatter than normal. For example, if a stream loses its ability to transport its sediment load it may start filling with sediment. This process is known as aggradation. The slope of the channel section upstream of the filling area will flatten as the upstream/downstream elevational difference decreases. The slope of the channel section downstream of the filling area will steepen as the upstream/downstream elevational difference increases.

Figure 2-41. Aggradation in riffle.  

Figure 2-42. Aggradation in pool.

Figure 2-43. Longitudinal profiles of a natural stable channel and an aggrading channel.
If the energy of the water flowing through a stream exceeds that necessary to erode and transport the sediment carried from upstream the channel may incise or erode downward through the bed material. This process is known as incision. This results in a steeper local channel slope increasing the available energy even more. A knickpoint or abrupt change in elevation can be observed at the point at which the bed erosion was halted. Incision of the streambed may progress further upstream or headward with each successive storm.
2.2.7.6 - Morphological Equilibrium

*Morphological equilibrium* refers to a mean or average channel form about which short/long term and abrupt/gradual fluctuations occur. Consequently, stream channel stability is not a static state. It is a dynamic process in which a stream adjusts its form to maintain a balance between sediment supply and sediment transport. We may refer to a stream as a self-regulating system. In response to changes in streamflow and sediment supply it adjusts local riffle and pool slopes, rearranges bed material, transports more or less sediment, and adjusts its pattern and cross-section. Therefore, a *stable stream* is:

- able to maintain over time, its pattern, profile, and cross-sectional dimensions (shape and size);
- laterally stable, that is, slow rates of bank erosion on the outside of meander bends are matched by slow rates of deposition on point bars and lateral migration (movement back and forth) across its floodplain is gradual;
- vertically stable, that is, it is neither aggrading (filling) or incising (down-cutting);
- able to effectively convey the various flows and sediment delivered to it by its watershed.
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2.2.7.7 - Channel Maintenance and Channel Forming Flows

Channels are formed and maintained over time by flowing water eroding and depositing sediment. The effectiveness of these processes increases with discharge. Low discharges are very common, but not very effective at eroding and transporting sediment. On the other hand, high discharges erode and transport the most sediment during a given event, but are not very common. However, there is an intermediate range of discharge events that occurs frequently enough and has enough energy to erode and transport sediment such that, over time, they actually accomplish more work than the higher, less frequent discharge events. Studies have demonstrated that for most stable streams, the effective discharge, that is, the discharge that carries the largest amount of sediment over a long period of time, is equivalent to the bankfull discharge.

You will recall that the bankfull flow is that streamflow when the channel is flowing at or near capacity and the water surface is just at floodplain level but has not overtopped the stream banks. The size channel that is formed and maintained by the bankfull flow is not large enough to convey unusually high discharges. Nearly all stream channels, whether large or small, will contain without overflow approximately that discharge that occurs about once or twice a year, approximately the 1.5-year discharge. Higher flows, occurring on average once in 2 years or once in 5 years or more, will be too large to be contained in the natural channel and will overflow the banks.

Bankfull flow is a key parameter in determining the relationship between the volume of sediment transported and stream flow and is critical in evaluating stream channel stability. Field identification of channel features associated with this flow (e.g., top of point bars, scour marks along the outside bank, etc.) and accurate estimates of this discharge are essential in stream assessment and restoration work, since the cross-sectional geometry and meander pattern of the stable channel form are closely linked to it. Because this range of flows directly influences channel characteristics (e.g., shape, size, streambed material size and distribution, etc.) it directly influences habitat features as well.

Flood flows exceed the capacity of the stream channel, overtop the stream banks and move out onto the adjacent land surface. These large volume flows also have geomorphologic significance in that they actually build adjacent landforms by carrying sediment from upland and upstream areas and depositing it along the stream corridor. Although most sediment leaving a watershed is transported by the more frequent bankfull flow, higher volume storm events can carry very large amounts of suspended and bedload material that significantly alter the stream channel and floodplain characteristics.
2.3 – Components of a Healthy Stream System

The major components of a healthy stream system are:
- a stable stream channel
- an active floodplain
- healthy streamside vegetation
- adequate groundwater reserves
- high quality physical habitat
- abundant and diverse living organisms

Stable stream channels have:
- constant width and depth over time
- vegetated, stable banks
- sufficient slope to transport materials delivered to it, neither aggrading (filling in) nor incising (downcutting)

Groundwater is the water contained below the land surface, in the pores between soil particles. Groundwater is the primary source for streamflow between periods of precipitation and is critical for sustaining abundant year-round baseflows.

Floodplains are areas of land adjacent to streams where water overflows during floods, allowing settling of materials and the return of water to the ground and the stream.

High quality physical habitat means cool temperature, good water quality (i.e., high dissolved oxygen, proper amounts of nutrients and minerals, little to no pollution), adequate surface area, clean substrate free from fine sediment, highly varied and abundant cover, and appropriate pool/riffle ratios.

Streamside vegetation is important for:
- physically holding streambanks in place
- providing food and habitat for aquatic and terrestrial animals
- moderating water temperature

An abundance and diversity of living organisms indicates that the other pieces of the puzzle are in place.
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2.4 – Healthy Stream Types in North Carolina

Mountain Streams

- steep slopes
- V-shaped valleys
- narrow floodplain and riparian area
- narrow, deep channels
- straight to slightly sinuous
- cascading riffles, step-pools, and falls
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Foothill Streams

- moderate to steep slopes
- U-shaped valleys
- moderate floodplain and riparian area
- moderate width and depth channels
- slightly sinuous
- riffle-pools, and step-pools
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Piedmont Streams

- moderate to relatively flat slopes
- U-shaped to broad valleys
- moderate to broad floodplain and riparian areas
- narrow to wide, deep to shallow channels
- slightly sinuous to meandering
- riffles and pools
Coastal Plain Streams

- very flat slopes
- very broad, flat valleys
- very broad floodplain and riparian areas
- narrow, deep channels
- highly sinuous
- runs, glides, and pools
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2.5 – Effects of Land Use on Watersheds and Streams

Like many other urbanizing areas of this country, the Winston-Salem and Forsyth County area has undergone dramatic change and growth since the German Moravians first settled it in 1753. In fact, the Piedmont Triad (Greensboro, Winston-Salem and High Point) along with Charlotte/Mecklenburg County is part of the Piedmont Crescent, one of the most rapidly developing regions in the country. It is anticipated that this growth will eventually result in a solid band of urbanized counties from Raleigh to Charlotte. The population of Forsyth County alone is expected to increase as much as 20 percent by 2020. Unmanaged, this growth has the potential to significantly impact the region’s natural resources.

Stable watersheds are generally characterized by forest vegetation, a thick humus layer that protects the soil from the impact of precipitation, high infiltration rates, low runoff rates, and low soil erosion and sediment transport rates in upland areas, a stable stream channel, high quality water, and a healthy aquatic community.

Disturbance of a forested watershed leads to a chain of interrelated events that can destabilize the stream ecosystem. Most stream water quality, channel stability, and habitat problems can be traced to a change in the supply of water or sediment in the stream, or to alterations of the stream channel and banks. Every activity undertaken by people to render the landscape more suitable to a specific purpose begins with the removal of native vegetation and the disturbance of the soil.

2.5.1 - Changes in Watershed Hydrologic and Sediment Regimes

By altering the structure of plant communities and soils, human activities often conflict with the hydrologic and geomorphic functions of stream corridors. Land clearing activities, which precede all other land use activities (e.g., agriculture, mining, urban land development, etc.), influence the hydrologic and sediment regimes of watersheds in the following ways:

- Vegetation removal decreases the volume of rainfall intercepted and transpired back into the atmosphere.
- Soil disturbance and compaction reduce the volume of water infiltrated into the soil and stored in surface depressions.
- The volume of water conveyed as overland runoff directly to the channel increases significantly.
- Soil erosion and sediment transport increase significantly.
- Stream channels, adjusting to the increased runoff and sediment inputs, become unstable and contribute additional sediment from streambed and stream bank erosion.

Although these processes occur to varying degrees in all disturbed watersheds, streams in urban watersheds undergo the most dramatic changes. For urban streams, the degree of stream degradation is directly related to the amount of impervious cover (hard surfacing) and storm drainage.
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Impervious cover and storm drainage:

- Decrease the volume of water infiltrated into the soil;
- Decrease groundwater recharge;
- Decrease stream baseflow;
- Increase the volume of direct runoff;
- Decrease the time it takes to convey runoff from streets, sidewalks and parking lots to the nearest stream channel; and
- Increase the energy available to erode the stream channel.

Figure 2-47. Relationship between percent impervious surface and runoff (FISRWG, 1998).
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As a consequence, urban streams tend to have flashy hydrologic regimes. Many urban streams experience a significant reduction in baseflow. Streams that were perennial prior to development of the watershed may become intermittent or ephemeral. Conversely, even moderate rainfall events can generate a noticeable increase in stream flow volume and velocity.

Figure 2-48. Effect of urbanization on storm hydrographs – increased peak discharge and decreased lag time or time of concentration (FISRWG, 1998).

Smooth, hard pavement and storm drain systems route urban runoff rapidly to nearby streams. As a result the rising limb of the storm hydrograph shifts to the left reflecting the decrease in lag time. In addition, the peak is higher reflecting the greater volume of water entering the stream as direct runoff.

2.5.2 - Impacts on Stream Channels and Floodplains

2.5.2.1 - Channel Stability

We can expect that stream channels will react to alterations in the watershed’s flow and sediment regimes, especially changes in the frequency and magnitude of the bankfull and higher discharges. These alterations in flow and sediment load do not necessarily produce an immediate change in the stream channel but initiate a response that may extend over a period of time. The situation is further complicated by the fact that the changes in flow and sediment yield may not occur simultaneously. As a consequence, it has not been
determined with certainty how much alteration in the rainfall-runoff-erosion relation is necessary to cause a given type and amount of channel change. However, studies suggest that as little as 10% impervious cover within a watershed can cause significant channel stability problems.

We do know that urban channels adjust over time, eroding and enlarging in response to increased storm flow volume and velocity. A typical channel evolution sequence following the development of a watershed includes:

*Initial bed degradation* - particularly in channels with fine-grained bed material, the bed provides little resistance to the increased stream energy that develops as a greater volume of runoff is conveyed rapidly to the channel. This situation usually causes the channel to incise with a subsequent lowering of the bed elevation. As the degree of incision increases, the stream becomes entrenched and disconnected from its floodplain. Flood flows, which normally overtopped the banks, become increasingly confined to the channel. Stream energy and stress on the banks increase as depth of flow increases in a confined channel.

![Figure 2-49. Bed degradation resulting from changes in watershed hydrology associated with urbanization exposed this sanitary sewer line.](image)

*Lateral adjustment* - lowering of the streambed due to incision increases bank height confining the channel even further and places additional stress on the banks. Hydraulic forces eroding the toe of the banks result in steeper bank angles with increased susceptibility to gravitational failures. As these failures become common the channel adjusts laterally, becoming wider.
2.5.2.2 - Riparian and Streamside Vegetation

Riparian and streamside vegetation is routinely impacted by mechanical removal and spraying with herbicides for: preparation of riparian land for cultivation or grazing; maintenance of power line, utility, and road rights-of-way; maintenance of public parks, recreation and open space areas; maintenance or expansion of residential recreation facilities and yard areas. Overgrazing by livestock can either eliminate streamside vegetation altogether or significantly reduce the vigor and density of more palatable plants. Under all of these circumstances the effects are similar:

- Increased bank erosion and lateral migration
- Increased channel width, decreased depth
- Increased water temperature
- Lowered water table
- Increased velocity of flows in overbank areas
- Reduced trapping of sediments
- Increased damage to property and adjacent utilities
- Increased maintenance costs
- Increased loss of land
- Decreased fish and wildlife habitat
2.5.2.3 - Floodplain and Channel Alterations

As noted previously, a flood wave moving through a watershed is usually attenuated (decreased) through storage in the floodplain. Filling of floodplains to accommodate new development, channelization and/or construction of flood dikes to protect existing properties in the floodplain, channel straightening to eliminate channel migration and overbank flows can result in a loss of flood storage capacity and channel instability. These channel and floodplain “improvements”:

- Eliminate access to the floodplain
- Convey passing floodwaters more rapidly to downstream areas
- Increase peak flood stage
- Increase the energy of the flood downstream
- Decrease sediment transport capacity under bankfull flow conditions
- Decrease channel stability
- Increase channel migration
- Increase bank and bed erosion on neighboring properties
- Lower water tables
- Increase loss of riparian wetlands
- Decrease recharge of groundwater aquifers
- Degrade in-stream habitat
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Figure 2-52. Channelized reach with concrete revetment.

Figure 2-53. Channelized reach with gravel berms.
Figure 2-54. Channelized reach with timber walls on left bank and sheet piling on right bank.

Figure 2-55. Channelized reach with riprap on banks.
2.5.3 - Impacts on Physical Habitat and the Biotic Communities

The most significant influences on water quality, in-stream habitat, and biotic communities are the land use activities conducted in the adjacent floodplain and throughout the watershed.

Since the Clean Water Act was passed, significant progress has been made in reducing point-source pollutants (i.e., discharges that come from a fixed location, usually through a pipe) from industries, sewage treatment plants, large livestock feedlots, mine sites, and other sources. Although point-source discharges can still have dramatic and deleterious effects on stream systems they are generally few in number and localized within a given watershed. On the other hand, non-point source pollutants come from diffuse sources, such as runoff from cropland and grazing land, forestry operations, construction sites, urban land, highways and landfills. Progress has been made on controlling non-point pollutants as well. However, these types of land disturbing activities are generally widespread and can affect significant land area within a given watershed. As a consequence, they have the greatest potential to negatively affect our streams.

Figure 2-56. Impacts due to vegetation removal and livestock grazing.

Removal of streamside and stream bank vegetation can result in increased erosion, lateral migration, channel widening, loss of stream bottom habitat due to sedimentation, and increased water temperature due to increased insolation.
Stream channel alterations (e.g., channelization and/or channel straightening) associated with flood mitigation and stabilization projects create channels that are virtually devoid of habitat and ultimately unstable. These situations are commonly associated with engineered channels, which are relatively straight, wide, trapezoidal channels, with uniform profiles. They are generally designed to convey all flows (baseflow, bankfull flow, and flood flow). As a consequence, baseflow is usually very shallow or may actually flow beneath the substrate because it is spread out over such a large surface area. The uniform profile replaces the typical riffle-pool sequence with a continuous riffle that provides no cover from predation or strong flushing currents. Vegetation on the banks is replaced with riprap or gabions (concrete revetment in more urbanized areas) in an effort to maintain the engineered form, and grade control structures may be installed to maintain bed stability.

Because the channel is oversized for bankfull flows as well, its sediment transport capacity is significantly reduced. This results in increased substrate embeddedness and ultimately aggradation, which reduces flow conveyance capacity. Because these channels are generally designed to convey the 50-year or 100-year flood, the larger flows are confined, creating significant stress on the bed and banks that leads to channel instability.

Development and its effects on hydrologic and sediment regimes can have an effect on the physical habitat by causing streambed and bank erosion and sedimentation that alter channel characteristics (e.g., dimension, pattern, slope) and microhabitat features (e.g., depth, substrate, cover, and pool/riffle ratios).
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Channel instability and sediment is a significant problem for urban streams. During the development phase most sediment enters streams from construction sites in upland areas. Post development sources of sediment are primarily from within the channel as streambeds and stream banks are eroded by increased runoff from compacted soils and paved areas. Sedimentation causes substrate embeddedness and aggradation, which reduces the flow conveyance capacity of the channel. Stream bank erosion and flooding can significantly affect water quality by exposing or inundating private sewage disposal systems, public sanitary sewer lines, underground and above ground fuel storage tanks, and landfills.

Figure 2-58. Urban runoff and sewage spills impact water quality.

Sewage spills that occur when septic systems or sanitary sewer lines are exposed and damaged by channel erosion contribute oxygen consuming organic wastes, nutrients, and pathogens associated with human waste that have serious health consequences for aquatic life and humans.

Runoff from urban land contains a variety of pollutants from trash to toxic compounds. The ubiquitous shopping carts, bicycles, soda cans, and plastic containers some how manage to find their way into most urban streams. Rain falling on streets, sidewalks and parking lots washes particulate material worn from automobile tires and brake linings, as well as waste oil, antifreeze, and road salts into storm drain inlets for conveyance to the nearest stream. Pesticides, fertilizers, and pet wastes washed from lawns, golf courses, and parkland are also common contributors to the degraded water quality typical of urban streams. During the hot days of summer, runoff from heated paved surfaces can significantly increase stream temperature. The biological availability of many toxic pollutants is enhanced as water temperature rises.
Refuse and other waste products such as old batteries, paints and solvents, and pesticides discarded by homeowners usually end up in a sanitary landfill. When precipitation falls on a landfill it percolates through the layers of refuse and waste, where it picks up pollutants. Many newer landfills have drainage systems and clay and/or plastic liners designed to collect and contain this contaminated rainwater or leachate. Unfortunately, older landfills or dumps usually did not have leachate collection or containment systems. Plus, landfill liners degrade and can eventually develop leaks. As a consequence, leachate from sanitary landfills and dumps may percolate into groundwater and eventually reach nearby streams, where it can be toxic to aquatic organisms.

As noted previously, healthy fish and macroinvertebrate populations in headwater streams depend on relatively cool water temperatures and high levels of dissolved oxygen. Some species of fish, such as trout, are especially intolerant to increases in water temperature above natural background levels. Because dissolved oxygen levels are a function of water temperature, a stream warmed due to the loss of streamside vegetation and channel widening will have lower dissolved oxygen levels than a stream with tree cover. Increased insolation due to loss of vegetation plus an influx of nutrients from fertilizers and manure washed into a stream can stimulate massive blooms of algae. As the algae die, they are broken down by bacterial decomposition, which consumes what little oxygen may be available. The further depletion of oxygen levels can severely stress resident aquatic organisms. This stress can affect the ability of less tolerant aquatic organisms to survive.

Sediment in runoff from cropland and construction sites, and eroded from banks damaged by livestock grazing and urban runoff deposits on the streambed, smothering bottom
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dwelling insects and fish eggs buried in the gravel substrate. Sediments carried in suspension can irritate or clog the gills of adult fish.

![Image of a sediment-laden tributary entering a less turbid mainstem.](image)

Figure 2-60. A sediment-laden tributary entering a less turbid mainstem.

The effects of land use activities have been documented for the streams of Forsyth County. The North Carolina Department of Environment and Natural Resources indicated in the Yadkin-Pee Dee River Basinwide Water Quality Management Plan that Muddy Creek and Salem Creek have been impacted by urban runoff, permitted wastewater discharges, and agricultural land uses. As pointed out at the beginning of this manual, NCDENR has identified the majority of the streams in the High Rock Lake – Muddy Creek sub-basin as being support threatened.

The Forsyth County Environmental Affairs Department has been conducting physical and chemical monitoring of Muddy Creek and its tributaries since 1988. Results of their efforts indicate elevated levels of total phosphorus throughout the Muddy Creek watershed. In addition, they found elevated levels of heavy metals (e.g., lead and cadmium), especially at the more urban sites such as Peters Creek and Salem Creek in Winston-Salem. Although most streams sampled were very turbid, low dissolved oxygen did not appear to be a problem. Most streams in agricultural areas, including the South Fork of Muddy Creek and Salem Creek above Salem Lake, were assigned a good-fair rating, although severely degraded habitat is typical. Their report indicates that the cobble/gravel substrate typical of Piedmont streams has been significantly embedded by massive inputs of coarse sand, thereby reducing available habitat for benthic macroinvertebrates and fish.
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Macroinvertebrate and fish community studies conducted by the North Carolina Division of Water Quality in 1996 demonstrated that water quality problems still exist in parts of Muddy Creek and Salem Creek. Their results suggest that improvements in wastewater treatment and/or control of urban runoff have reduced the severity of the problems.

2.5.4 - Impacts to Property, Infrastructure and Water Supplies

Channel instability caused by changes in watershed hydrology, vegetation removal, and/or channel alterations impact property, infrastructure and water supplies with significant economic and public safety consequences.

Channel erosion and sedimentation damage public and private property resulting in a loss of land, lower property values, and increased maintenance costs. Erosion of streambeds and banks exposes and damages underground utilities (e.g., septic systems, sanitary sewer, water, gas lines, communication cables) and undermines and damages above ground utilities and infrastructure (e.g., telephone and power poles, transmission and distribution towers, bridge piers and abutments). Sediment eroded from upland and in-channel sources deposits at culvert and bridge openings and clogs storm drains. The cost of protecting and maintaining utilities and infrastructure can be considerable for homeowners, and private utility companies, as well as state and local highway and public works departments.

Figure 2-61. Bridge footers exposed by streambed degradation.
Figure 2-62. Sanitary sewer line exposed by streambed degradation.

Figure 2-63. This incised stream is experiencing significant lateral erosion. Note remains of undermined and broken concrete channel.
Figure 2-64. Lateral adjustment and property damage resulting from historic channelization work.

Figure 2-65. Bed degradation, failure of gabions, subsequent lateral adjustment and property damage resulting from historic channelization work.
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Maintenance dredging of navigation channels is another costly item. A study conducted in the mid-1970’s estimated that the cost of dredging sediment eroded from in-channel sources alone, ranged from $55,000 per square mile to $229,000 per square mile (1976 dollars) of watershed. Add to this sediment eroded from upland sources and the frequency and cost of maintenance dredging increases dramatically.

Throughout this country public water supplies have been significantly impaired and reservoir capacities reduced by sedimentation. For example, studies on siltation rates for three water supply reservoirs in the Baltimore, Maryland region showed that all three reservoirs had lost considerable capacity due to sediment deposition. In fact, the newest reservoir had lost nearly 20 percent of its capacity over a thirty-year period. A study conducted in the early 1980’s indicated that the cost of removing sediment from the nation’s reservoirs to maintain their storage capacity would be approximately $1 billion (1983 dollars).

Many municipalities that historically relied on high quality lakes and reservoirs have been forced by population growth and the loss of reservoir capacity to draw water from regional sources, such as streams and rivers. Because many streams and rivers have impaired water quality, water treatment costs can be substantial. The higher treatment costs are passed on to domestic and industrial users of the water supply system. High quality water supply reservoirs are an exhaustible natural resource and many are threatened by poor land use practices. Preservation of existing water supply capacity and quality is critical.

The main sources of drinking water for Forsyth County residents are the Yadkin River and Salem Lake, which provide 65-70% and 30-35% of the water needs respectively. As indicated previously the Yadkin-Pee Dee River Basinwide Water Quality Management Plan prepared by NCDENR has documented the effects of land use activities on the water quality of the Yadkin River and its tributaries. Although that same study found Salem Lake is fully supporting its uses, sedimentation and runoff from urban development and agriculture has raised concerns about the future water quality of the lake.