Riparian Forest Handbook 1

Appreciating and Evaluating Stream Side Forests

VIRGINIA
DEPARTMENT
OF
FORESTRY

Riparian Forest Handbook 1

Appreciating and Evaluating Stream Side Forests

written by
Samuel H. Austin

photography by
Jim Mehring
Samuel H. Austin

special thanks to
The Chesapeake Bay Restoration Fund
The USDA Forest Service
The Alliance For The Chesapeake Bay

published by
The Virginia Department of Forestry
900 Natural Resources Drive, Suite 800
Charlottesville, Virginia 22903
www.dof.virginia.gov
(434) 977-6555

with funds from the sale of
Chesapeake Bay License Plates

Table of Contents

List of Figures

List of Tables

1. How To Use This Booklet

This handbook is organized to help you appreciate the importance of stream side forests, and to guide you as you evaluate a portion of a stream you may hope to restore. We begin with a discussion of why riparian forests are important. We then describe ways to evaluate the health of a riparian forest, and suggest methods for restoring a riparian forest.

A companion computer disk is available. It contains computer programs that help you organize information and compute the hydraulic geometry and sediment relationships that characterize your stream. Contact the Virginia Department of Forestry at (434) 977-6555, for more information.

We hope you enjoy reading and using this handbook and software. Armed with new information and insights into your stream, we encourage you to organize yourself and others to take positive steps to restore and protect the waters and riparian forests of Virginia!

Figure 1: *Forests are important to watershed health*

2. Why Riparian Forests Are Important

2.1 Riparian Forests Sustain the Stream Environment

By controlling water temperature, light, habitat diversity, channel morphology, food webs, and the species diversity of stream systems, riparian forests sustain the stream environment.

Temperature and Light

Maintenance of consistent daily and seasonal fluctuations in water temperature and ambient light levels is crucial to the viability of plant and animal populations.

Riparian forests dampen fluctuations in stream water temperature; blocking out heat to keep water cool during hot times, and capturing heat as it radiates from the soil and water to keep the stream environment warmer during cold times. The net effect is an environment more conducive to life, with less tendency for wide fluctuations in stream temperature.

Light levels are regulated in similar fashion. Brighter areas in small openings and at the tops of tree canopies contrast with shaded areas in lower portions of the forest stand, and on the forest floor. The result is a stable and varied habitat conducive to diverse plant and animal life.

Habitat Diversity and Channel Morphology

Biological diversity depends on available habitat. Available aquatic habitat depends, in large part, on the woody debris available to streams. Upon entering the stream channel, woody debris creates unique and diverse habitat for aquatic organisms, at many scales. As it slowly decomposes, woody debris releases nutrients that sustain aquatic life. The roughness and structural integrity created by woody debris act to stabilize the stream environment by absorbing the energy of water, and reducing the severity of erosive influences of stream flow. Debris dams formed by woody debris accelerate organic decay rates, making nutrients more available to aquatic organisms.

Absence of streamside forest can fundamentally change channel morphology (the dimension, pattern, and profile of a channel) resulting in habitat loss. Without trees a channel may become unnaturally wide, as stream banks erode. Water velocities may increase as water moves without the energy absorbing benefits of woody debris. Faster water combined with altered channel form can cause bank scour, stream straightening, and excess sediment deposition in the stream bed. Each of these affects can create a degraded environment that supports fewer aquatic plant and animal species.

Links between the presence of large woody debris in streams and abundant fish habitat are well documented in scientific literature. The surfaces of submerged logs and roots provide habitat that may support aquatic insect (macroinvertebrate) densities far higher than those supported on the stream bottom. Macroinvertebrates provide food for fish. Pools created by woody debris provide pockets of habitat otherwise unavailable to fish. In undisturbed forests, large woody debris create most of the pools formed in streams. Removal of woody debris by deforestation typically results in loss of pool habitat. Even when selective timber harvesting is done along streams, the removal of older trees causes a decline in aquatic habitat because of diminished inputs of large woody debris.

Food Webs and Species Diversity

Litterfall and algal production are the two primary sources of food energy inputs to streams. Both are intimately tied to the presence of riparian forest.

Litterfall, (leaves, twigs, fruit seeds, and other organic debris), is most abundant when riparian forests are present. Studies note that "streams flowing through older, stratified forests receive the greatest variation in quality of food for detritus-processing organisms."[1] Because large pieces of litter do not travel very far away from their origin, a stream side forest is needed along the entire length of a stream to ensure a balance of food inputs appropriate to the food chain of native species. Macroinvertebrate populations are affected by changes in litter inputs. The metabolic activity of some of these organisms may increase as streamside plants are removed. This allows woody material to be decomposed more quickly, making nutrients in this material less available to fish and other aquatic species.

The type and amount of algae produced in a stream is affected by the amount of light striking the water surface. Studies show that the algal community of a stream well shaded by older trees is dominated by single celled algae (diatoms) throughout the year. Streams in deforested areas often contain many thread like (filamentous) green algae, and few diatoms. While some macroinvertebrates such as crayfish and waterboatmen insects readily consume filamentous green algae, most herbivorous species of stream macroinvertebrates have evolved mouth parts specialized for scraping diatoms from the surfaces of rocks and wood. They cannot eat filamentous algae. Macroinvertebrate diversity tends to decline if a stream side zone is deforested.

2.2 Riparian Forests Remove Non-point Source Pollutants.

Riparian forests remove, sequester, or transform nutrients, sediments and other pollutants. Pollution removal depends on (1) the capability to intercept surface water and groundwater borne pollutants, and (2) the activity level of certain pollutant removal processes.

---

[1] Chesapeake Bay Riparian Handbook, NA-TP-02-97, Section III.

Nitrate Removal

The mechanisms that remove nitrate from forest riparian zones are *denitrification and plant uptake*.

Denitrification is the biochemical reduction of nitrate to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen. As nitrogen in soil water is changed to a gas, it leaves the riparian zone and moves into the atmosphere. Forests act to facilitate this process, by stimulating microbial activity and contact between biologically active soil layers and groundwater.

Plant uptake is the movement of soil nutrients into a plant. Nitrate can be collected from soil water and sequestered in plant tissue. Active nitrate uptake by forest vegetation throughout the biologically active soil layers can provide long term sequestering of nitrate and other nutrients in woody biomass. Since the growth rate of a forest tends to be nitrogen limited, forests can respond to a nitrogen subsidy in the soil by both increased growth rates and the "luxury" of increased nitrogen uptake. Such a response will reduce the amount of nitrogen available to enter stream water.

Flood tolerant plant species, such as those found in many riparian forests, are adapted to process nitrogen and other nutrients in low oxygen environments. Flooding can enhance the nutrient uptake and growth of some species. Flood tolerant species often have unique metabolic responses, adapted to low-oxygen conditions. During flooding, for example, roots may become thicker, increasing porosity and allowing downward diffusion of oxygen. When selecting vegetation for restoring or managing a riparian forest, it is important to consider the ability of species to process and store nutrients under site specific conditions.

Microbial Processes

Microbial processes also immobilize pollutants in riparian forest buffers. Microbes may take up dissolved nutrients as do plants. Later, these nutrients may be mineralized following the death and decomposition of microbial cells. This process is similar to the release of nutrients by plants following litterfall. Over time, a net storage of immobilized nutrients occurs in forest ecosystems that are accumulating soil organic matter. If managed to encourage the accumulation of soil organic matter, riparian forests can support significant long-term nutrient storage by immobilization.

There are many different microbial degradation mechanisms that operate in forests, these including: aerobic, anaerobic, chemoautotrophic, and heterotrophic pathways. The wide ranging and diverse environments in riparian forests can support these mechanisms at many locations.

Removal of Surface-Borne Pollutants

Riparian forests trap sediment as surface runoff is intercepted by forest litter, organic soils, and tree roots. Water is slowed and sediment particles are deposited in the forest before they can enter the stream.

Nutrient runoff is controlled by riparian forests in similar ways. The sediments carrying nutrients may be deposited on the forest floor and erosive processes may be reduced. The high infiltration rates characteristic of forest soils allow runoff to move into groundwater, eliminating surface movement of nutrients to the stream. Nutrients borne in surface runoff may be diluted by incoming rainfall and throughfall beneath the forest canopy. Nutrients my be adsorbed in reactions with forest litter and forest soil.

Figure 2: *Healthy forest soils store nutrients*

2.3 Riparian Forests Provide Many Natural Benefits[2]

Leaf Food

Leaves fall into a stream and are trapped on woody debris (fallen trees and limbs) and rocks where they provide food and habitat for small bottom dwelling creatures such as insects, amphibians, crustaceans, and small fish. Survival of these creatures is critical to the aquatic food chain.

---

[2] Adapted from Alliance for the Chesapeake Bay source materials published in 1996.

Canopy and Shade

The leaf canopy of a mature forest provides shade that keeps the water cool during warm times, and insulation that keeps soil and water warmer during cool times. It also retains dissolved oxygen and encourages the growth of diatoms, beneficial algae, and aquatic insects. The canopy improves air quality by filtering dust from wind erosion, construction, and farm machinery.

Nutrient Uptake

Fertilizers and other pollutants that originate on land are taken up by tree roots. Nutrients are stored in leaves, limbs, and roots instead of reaching the stream. Through a process called "denitrification," bacteria in the forest floor convert harmful nitrate to nitrogen gas, which is released into the air.

Filtering Runoff

Rain and sediment that runs off the land in sheet flow can be slowed and filtered in the forest, settling out sediment, nutrients, and pesticides before they reach streams. Water infiltration rates in forest soils are often 10 to 15 times higher than grass turf and 40 times higher than a plowed field.

Fish and Wildlife Habitat

Wooded stream corridors provide the most diverse habitats for fish, mammals, and other wildlife. Woody debris provide cover for fish while preserving stream habitat over time. Forest diversity is valuable for birds.

Water Quality

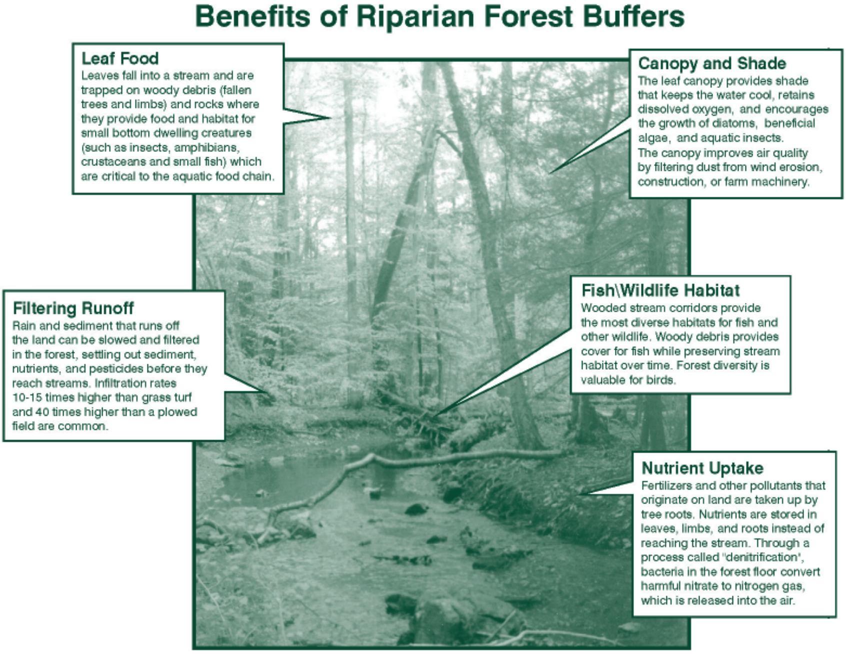
Riparian forests create conditions that lead to sustained yield of higher quality water. By shading streams, filtering runoff, enhancing stream habitat, and stabilizing stream hydro-dynamics, riparian forests allow the healthy natural tendencies of the stream system to take hold and function. Improved water quality is achieved as fundamental reorganization of the ecosystem occurs, creating healthy natural tendencies over time.

Hydrologic Functions

Riparian forests create conditions that lead to natural, stable, stream systems. Natural, stable stream systems have less volatile hydrologic functions.

Riparian forests help dampen peak water discharges during storms, while maintaining more baseline water flow during dry times. Forests help create stable channels that carry water more efficiently while reducing suspended sediment loads. Improved hydrologic functions are achieved as stable, natural stream channel dimension, pattern, and profile are restored over time.

Figure 3: *Benefits of riparian buffers (reprinted with permission)*



Benefits of Riparian Forest Buffers

Leaf Food
Leaves fall into a stream and are trapped on woody debris (fallen trees and limbs) and rocks where they provide food and habitat for small bottom dwelling creatures (such as insects, amphibians, crustaceans and small fish) which are critical to the aquatic food chain.

Canopy and Shade
The leaf canopy provides shade that keeps the water cool, retains dissolved oxygen, and encourages the growth of diatoms, beneficial algae, and aquatic insects. The canopy improves air quality by filtering dust from wind erosion, construction, or farm machinery.

Filtering Runoff
Rain and sediment that runs off the land can be slowed and filtered in the forest, settling out sediment, nutrients, and pesticides before they reach streams. Infiltration rates 10-15 times higher than grass turf and 40 times higher than a plowed field are common.

Fish\Wildlife Habitat
Wooded stream corridors provide the most diverse habitats for fish and other wildlife. Woody debris provides cover for fish while preserving stream habitat over time. Forest diversity is valuable for birds.

Nutrient Uptake
Fertilizers and other pollutants that originate on land are taken up by tree roots. Nutrients are stored in leaves, limbs, and roots instead of reaching the stream. Through a process called "denitrification", bacteria in the forest floor convert harmful nitrate to nitrogen gas, which is released into the air.

3. Evaluating the Health of Your Riparian Forest

3.1 The Essential Parts of a Healthy Riparian Forest

The essential pieces of a healthy riparian forest are not difficult to define, they are the fundamental natural "building blocks" that allow forests to function. Of equal importance is the way in which these pieces are put together. A riparian forest can serve as a *catalyst for proper ecosystem organization*, if all the pieces are assembled in proper proportion. A discussion of how to evaluate your streamside forest, and choose a good mix of restorative interventions, is found in the next section. Several of the most important of these pieces are described below.

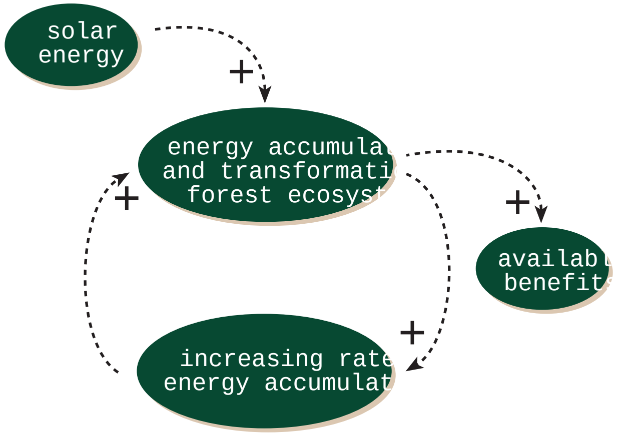
Solar Energy

The forests of the earth are solar collectors. Energy from the sun is accumulated (delayed) by forests, combined with carbon, minerals and nutrients, and transformed into richly diverse states of plant and animal organization, (ecosystem organization), creating conditions that reinforce, sustain, and cultivate life. Energy delay and transformation in a forest ecosystem is a *process* that does not begin or end, but accelerates as accumulations of biomass within a forest system increase, and slows down as these accumulations within a forest system decrease or are removed. Energy from the sun is piped to plants by photosynthesis. Energy in plants is transformed into energy stored in animal tissue and in soil through detritus. Energy in plant and animal tissue changes form and is further delayed as plant and animal species diversify. Over time, species richness increases and the web of links among forest plants and animals on land and in water becomes more complex.

The *available benefits* of forests result from the accumulated stock (delay) of solar energy and the associated transformations (plants, animals, and landscape organized as an ecosystem) that are in place at any moment in time. As forests evolve they develop diverse, complex, rich, and resilient states of ecosystem organization. These processes of forest transformation are self-sustaining (generative). As forest systems age and more solar energy is collected and stored, availability and diversity of benefits tend to increase. This “virtuous cycle” is illustrated below.

Riparian forests act as solar energy collectors and pumps, collecting and transforming this energy into useful forms and “spreading it around” the ecosystem.

Figure 4: *A generative cycle of solar energy accumulation and transformation in forests*



Forest

Structure

Structure is the spatial organization of forest communities. Natural forests evolve complex and diverse structural patterns. These patterns are a key part of a vital ecosystem. Among plants, horizontal and vertical diversity are two important components of habitat structure. Horizontal diversity or “patchiness” refers to the complexity of the arrangement of plant communities and other habitats across the landscape. Vertical diversity refers to the extent to which plants are layered, or form “vertical strata” such as in a stand of trees.

The degree of layering is determined by the arrangement of plant growth forms, by distribution of trees, shrubs, and herbs of varying heights and crown characteristics, and by plants of the same species but different ages. Diverse forests often have multiple vertical layers with overlap among herbaceous, shrub, small tree, and large tree species.

A forest with rich structural diversity is resilient. Changes may occur within animal and plant communities, but the entire ecosystem tends toward a certain stability or “dynamic equilibrium.” This richly dynamic stability evolves as links among species become more numerous and tightly woven, and plant and animal species become more diverse. Perturbations among small groups of individuals are held in check, with less tendency of disrupting the larger ecosystem.

Species Diversity

Riparian forests with rich structural diversity provide habitat for a rapid increase in plant and animal species diversity. As a riparian forest evolves through time, the increase in species diversity can advance exponentially. This exponential increase in diversity is caused by the expansion of reinforcing “virtuous” cycles of individual and species interaction, as solar energy continues to be made more available in many forms of plant, animal, and insect.

This expansion of diversity occurs over multiple scales and is readily observed in the field. A glimpse of the evolving dynamic complexity of the forest floor can be obtained by carefully examining the leaf litter of this biotic community, or by turning over a rotten log. A variety of insects, isopods, spiders, and myriapods (millipedes and centipedes) are exposed as evidence of the diversity accumulating in the rich “forest soil - forest air” interface.

These creatures, easily seen, represent but a fraction of the total community. They interact with smaller creatures such as springtails, mites, and nematodes. They are part of the food chain of vertebrates such as salamanders, frogs, snakes, shrews, mice, and ground dwelling birds. Larger mammals such as beaver, bats, bear, birds, weasel, shrew, raccoon, otter, and opossum, rely on these animals, in turn, for food.

Such diversity is equally evident and important in the plant community of a healthy riparian forest.

Temporal and Spatial Integrity

A diverse forest with rich structure has temporal and spatial integrity. The ecosystem is dynamic and resilient over time. Predators and prey are better balanced and species are mixed, making it more difficult for a single species to dominate the landscape. Small disturbances are less likely to create large scale or catastrophic changes. Such integrity occurs over time and throughout the horizontal and vertical dimensions of a forest.

Figure 5: *Structure, species diversity, and temporal and spatial integrity are important forest "building blocks"*

Stable Stream Channel Geometry

Healthy forest streams have a stable dimension, pattern, and profile that fits the natural geomorphology (land form) of the surrounding landscape. Stable natural channels tend to be sinuous and relatively narrow with little exposed or eroding stream bank, and access to an active flood plain.

Dimension

Dimension refers to the shape of a forest stream channel when viewed in cross-section. Research of the natural geomorphology of stream systems has identified cross-sectional shapes associated with stable and unstable stream channels. Examples of these shapes are shown in Figure 6.

This information can be used to determine the health of a riparian stream, and will be discussed in the section titled: *Benchmarks to compare against.*

Pattern

Pattern refers to the shape of a forest stream channel when viewed from above. Stable, naturally occurring stream patterns tend to be sinuous, or S-shaped. The S-shape is actually a sine generated curve, created naturally as the most efficient and effective way for a stream system to evenly distribute the energy carried by water along the entire length of the stream channel.

A sine-generated curve provides the most effective reconciliation of two fundamentally opposing tendencies in the physics of water flow: (1) the need to move water energy efficiently through the landscape, and (2) the need to evenly distribute the energy of water along the entire length of the stream channel.

A sine-generated curve shape accomplishes this task mathematically, as shown in Table 1. The total variance from the down stream direction is least for a sine-generated curve shape than for any other waveform. Nature, by design, has chosen the most efficient and effective conduit possible for moving water!

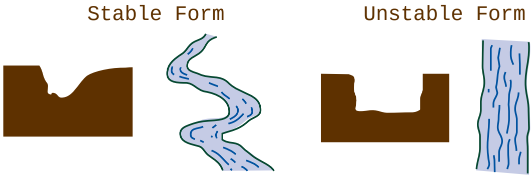
Profile

Profile refers to the shape of a forest stream when viewed from the “side” along its gradient. Nature has evolved stable profiles that involve “pools” and “riffles” alternating at consistent intervals. In stable streams the number of alternating pools and riffles is well correlated with stream pattern and bankfull width. Usually, 2 to 3 pools and 2 to 3 riffles alternate over one meander wavelength. Pools and riffles are spaced at a distance that is equal to about 2.5 times the bankfull width of the stream, regardless of the size of the channel.

The slope of a stream channel, identified in its profile, is related to the sinuosity of the stream pattern. All streams flow in an s-shaped pattern, but streams on steep slopes, with significant vertical fall, have only a slightly s-shaped curve. Curves associated with streams on more gradual slopes have a pronounced s-shape. Such streams are often said to be highly sinuous.

Lack of a predictable pool-riffle sequence is a signal of stream system instability.

Figure 6: *Examples of stable and unstable cross section shapes.*



Wildlife

Ample wildlife is in many ways a manifestation of adequate structure, diversity, and integrity in a riparian forest. Large fluctuations in wildlife populations and shifts in dominant species can be symptoms of inadequate structure, diversity or integrity.

Natural riparian forests are inherently productive and should provide ample opportunities for wildlife to thrive. Riparian forests in Virginia can be home to many plant and animal species. Plant species that grow well in riparian areas are listed in Table 2. Many plant species provide food and habitat particularly important to riparian wildlife. Table 3 lists the native plants used by common songbirds for food, cover, and nesting. Table 4 lists some significant wildlife food plants.

Table 1: *Total variance of a sine-generated curve, compared to other curve shapes*

Units of distance along curve	Deviation of path from downvalley direction (degrees)			Square of deviation		
	Sine ated curve	Circle	Sine- gener- curve	Sine curve	Circle	Sine-generated curve
0				0	0	0
5	0	0	0	2,809	529	576
10	53	23	24	3,844	2,116	2,209
15	62	46	47	4,624	4,761	4,489
20	68	69	67	4,761	8,464	7,056
25	69	92	84	4,761	9,604	8,100
30	69	98	90	4,761	8,464	7,056
35	69	92	84	4,624	4,761	4,489
40	68	69	67	3,844	2,116	2,209
45	62	46	47	2,809	529	576
50	53	23	24	0	0	0
			Sum:	36,837	41,344	36,760

Smallest ! ↗

Table 2: *Plant species that grow well in riparian areas and their value to wildlife*

Common Name	Vegetation Type	Wildlife Value
River birch	tree	good, cavity nesting
Black willow	tree	high; nesting
American beech	tree	high
Eastern cottonwood	tree	low
Green ash	tree	low
Silver maple	tree	moderate
Red maple	tree	high, seeds/browse
Sweetgum	tree	low
Sycamore	tree	low, cavity nesters
American hornbeam	tree	low
Bitternut hickory	tree	moderate, food
Flowering dogwood	tree	high, food (birds)
Persimmon	tree	extremely high, mammals
Box elder	tree	low
Baldcypress	tree	low
Black locust	tree	low
Pawpaw	tree	high, fox & opossum
American holly	tree	high, food, cover-nests
Black walnut	tree	high
Eastern red cedar	tree	high, food
Yellow-poplar	tree	low
Sweetbay	tree	very low
Blackgum or sourgum	tree	moderate, seeds
Hophornbeam	tree	moderate
Swamp tupelo	tree	high
Red bay	tree	good, food (quail/ bluebirds)
Loblolly pine	tree	moderate
White oak	tree	high, food, well drained
Overcup oak	tree	high
Swamp chestnut oak	tree	high
Water oak	tree	high
Cherrybark oak	tree	high
Willow oak	tree	high, mast
Eastern hemlock	tree	good, nesting
Southern wax myrtle	shrub	moderate
Common spicebush	shrub	high, songbirds
Winterberry	shrub	high, cover & fruit-(birds) Holds berries in winter

Table 2 (continued)

Common Name	Vegetation Type	Wildlife Value
Pussy willow	shrub	moderate, cover-(birds) & nectar-(butterflies)
Sweet pepperbush	shrub	high
Red-osier dogwood	shrub	high
Silky dogwood	shrub	high, mammals & songbirds
Witch-hazel	shrub	moderate
Hackberry	tree	high
Buttonbush	shrub	moderate, (duck/shore birds) & nectar (hummingbirds)
Gray dogwood	shrub	moderate
Hawthorn	shrub	moderate
American elderberry	shrub	high, food
Arrowwood viburnum	shrub	high
Switch grass	grass	good, cover
Reeds canary grass	grass	good, cover, drought tolerant
Little or big blue stem	grass	good, cover
Eastern gamagrass	grass	good, cover
Weeping love grass	grass	good, cover
Indian grass	grass	good, cover
Coastal panic grass	grass	good, cover

NOTE: (Table is for use with the three-zone riparian forest buffer system)

1. Zone 1 has the greatest potential for annual inundation of water and the least moisture stress.

2. Zone 2 has the potential for the greatest moisture stress during the summer, because it could be a steep area subject to rapid drying.

3. Zone 3 has the greatest variability, because some plant species have naturally adapted to these areas, and the width could vary greatly.

Table 3: *Native plants used by common songbirds for food, cover, and nesting*

Plant	Bird												
	Bluebird Thrush	Bunting	Cardinal Grosbeak	Catbird Thrasher	Finch Siskin	Jay	Mocking-bird	Oriole Tanager	Robin	Sparrow Junco	Tit Nuthatch	Towhee	Waxwing
Ash			•	•	•			•					•
Bayberry	•		•	•			•			•	•		
Bittersweet	•	•	•	•			•		•				•
Blackberry	•	•	•	•		•	•	•	•	•	•	•	•
Blueberry	•	•	•	•		•	•	•	•	•	•	•	•
Cedar	•		•	•	•		•		•	•			•
Cherry	•		•	•	•	•	•	•	•	•		•	•
Crabapple	•		•	•	•	•	•	•	•		•	•	•
Dogwood	•		•	•	•		•	•	•	•		•	•
Elderberry	•	•	•	•	•	•	•	•	•	•	•	•	•
Grape	•	•	•	•	•	•	•	•	•		•	•	•
Hawthorn	•	•	•	•	•	•	•	•	•			•	•
Hickory			•			•							
Holly	•	•	•	•	•	•	•		•	•	•	•	•
Honeysuckle	•	•	•	•	•		•		•	•			•
Maple					•			•	•	•			
Millet		•	•		•	•				•	•	•	
Mulberry	•		•	•	•	•	•	•	•	•	•	•	•
Oak			•	•	•	•	•	•	•	•	•	•	
Pine	•		•	•	•	•			•	•	•	•	•
Plum			•	•		•	•	•	•			•	
Pokeberry	•		•	•			•	•	•	•			•
Pyracanthia	•	•	•	•	•	•	•		•	•			•
Rose	•		•	•	•		•		•	•			•
Sassafras	•			•			•		•			•	
Serviceberry	•	•	•	•	•	•	•	•	•	•	•	•	•
Spicebush	•		•	•					•	•			
Spruce			•		•	•	•		•	•	•		•
Sumac	•		•	•	•	•	•	•	•	•	•		•
Sunflower		•	•		•	•				•	•	•	
Viburnum	•	•	•	•	•	•	•		•	•			•
Virginia Creeper	•	•		•	•	•	•	•	•		•		

Table 4: *Significant wildlife food plants.*

Plant Species	Wildlife Species Using Plants for Food Available	No. of Species Using Plants	Seasons
Ash	cardinal, purple finch, evening grosbeak, pine grosbeak, cedar waxwing, yellow-bellied sapsucker, wood duck, bobwhite quail, black bear, beaver, porcupine, white-tailed deer	20	W
Blackberry	brown thrasher, chipmunk, gray catbird, rabbit, ring-necked pheasant, robin, white-tailed deer	56	S, F
Cherry	black bear, cedar waxwing, raccoon, red squirrel, rose-breasted grosbeak, ruffed grouse, white-footed mouse	56	S, F
Grape	black bear, cardinal, fox sparrow, gray fox, mockingbird, ruffed grouse, wild turkey	53	S, F, W
Ragweed	dark-eyed junco, goldfinch, horned lark, mourningdove, red-winged blackbird, sparrows	49	F, W
Dogwood	bluebird, cardinal, cedar waxwing, rabbit, ruffed grouse, wild turkey, wood duck	47	S, F, W
Oak	black bear, blue jay, raccoon, ruffed grouse, white-tailed deer, wild turkey, wood duck	43	Sp, F, W
Sedge	horned lark, ruffed grouse, sparrows, wild turkey	43	Sp, S
Serviceberry	beaver, bluebird, cardinal, cedar waxwing, gray catbird,red squirrel, scarlet tanager, white-tailed deer	39	Sp, S
Blueberry	black bear, gray catbird, rabbit, rufous-sided towhee, skunk, white-footed mouse, white-tailed deer	37	S, F
Elderberry	bluebird, brown thrasher, cardinal, indigo bunting,rabbit, rose-breasted grosbeak	36	S
Pine	beaver, black-capped chickadee, brown creeper	33	W
Panic grass	dark-eyed junco, sparrows, red-winged blackbird, wild turkey	32	F
Beech	black bear, blue jay, chipmunk, porcupine, ruffed grouse,squirrels, tufted titmouse, white-tailed deer, wild turkey	31	Sp, W

Continued on page 18

Table 4 (continued)

Plant Species	Wildlife Species Using Plants for Food Available	No. of Species Using Plants	Seasons
Poison Ivy	black-capped chickadee, gray catbird, downy woodpecker, flicker, hairy woodpecker, hermit thrush, wild turkey	28	F, W
Sumac	bluebird, cardinal, black-capped chickadee, hermitthrush, rabbit, robin	28	F, W
Maple	beaver, chipmunk, porcupine, rose-breasted grosbeak, squirrels, white-tailed deer	27	S, F
Pokeweed	bluebird, cedar waxwing, gray catbird, gray fox, mourning dove, raccoon, red fox	25	F
Greenbriar	gray catbird, hermit thrush, mockingbird, raccoon, ruffed grouse	23	F, W
Birch	black-capped chickadee, beaver, porcupine, rabbit, ruffed grouse	22	Sp, S
Virginia creeper	bluebird, great-crested flycatcher, pileated woodpecker, red-eyed vireo	22	F, W
Hickory	chipmunk, red-bellied woodpecker, rose-breasted grosbeak, squirrels, wood duck	19	Sp, S, F, W
Aspen	beaver, porcupine, ruffed grouse, white-tailed deer	17	Sp, S, F, W
Hawthorn	fox sparrow, gray fox, raccoon, ruffed grouse	15	S, F
Hemlock	black-capped chickadee, porcupine, red squirrel, ruffed grouse, white-footed mouse	13	F, W
Walnut	red-bellied woodpecker, beaver, fox squirrel, gray squirrel, red squirrel	7	F, W
Yellow-poplar	redwing blackbird, cardinal, chickadee, purple finch, goldfinch, hummingbird, yellow-bellied sapsucker, beaver, red squirrel, fox squirrel, gray squirrel, white-tailed deer	14	Sp, S F, W
Alder	beaver, goldfinch, ruffed grouse	11	Sp, S,

Source: Adapted from Martin, A. C. et al. 1951.
SP = spring, S = summer, F = fall, W = winter.

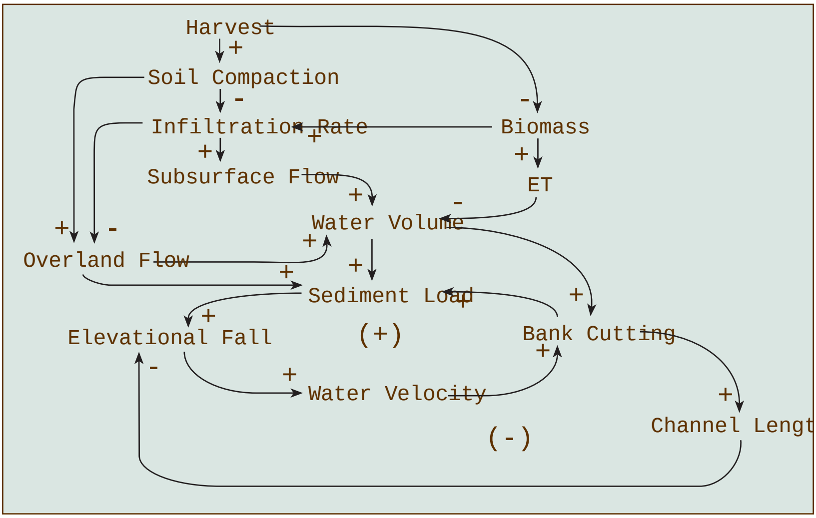
3.2 Evaluating Present Conditions: "The Past is Prologue"

Departures from stability and health

Certain physical and biological laws are universal
Water flows downhill. The potential energy of elevation changes to the kinetic energy of motion as water travels form the mountains to the sea. Over geologic time, stream systems evolve a stable dimension, pattern, and profile that allows the most efficient transfer and uniform distribution of energy over the distance traveled from mountains to sea. Stream systems change, and are dynamic, but change in stable stream systems occurs *very slowly*, at a geologic pace, within the context of the landscape. In the past the landscape in Virginia was almost completely forested.

Stream systems achieve a dynamic equilibrium, balancing changes among eight key hydrologic variables. These are: *water discharge*, *water velocity*, *channel width*, *channel depth*, *channel slope*, *channel material roughness*, *suspended sediment load*, *bedload*. These variables are all linked. Each influences the others. Over time, significant changes in one variable can have profound effects on the entire collection of variables that comprise the stream system.

Figure 7: *Some of the variables and dynamic links in a watershed system ('+' means reinforcing influence, '-' means compensating influence)*



The effects of past land use

In Virginia, stream systems evolved a stable geometry over millions of years, before human beings occupied the landscape. The land was almost completely covered with mature forest. Erosion and sedimentation did not occur at the scale and rate we are accustomed to today.

As humans occupied the landscape, dramatic and instantaneous changes began. Forests were burned, forests were cleared, soils were laid bare, soils were compacted, roads were constructed, ditches and canals were dug, natural water courses were diverted. All of this change had profound effects on the landscape, streams, and rivers. The balance among hydrologic variables and the links among them was fundamentally altered, and continues to change today, throughout the landscape and over time. Large scale *adjustment processes* were initiated in stream and river systems. Sections of streams and rivers within many watersheds shifted from a stable geometry to an unstable geometry. These adjustments continue today.

The effects of active change within the watershed

The landscape effects of human activity within the watershed are pronounced and visible on the landscape. As land is cleared the hydrologic regime changes. Stream systems become more entrenched, with steep vertical banks and reduced access to the active flood plain. Entrenchment limits natural pattern, known as sinuosity. Restricted access to the flood plain ensures sediments stay in the channel, causing the stream profile to flatten. A flatter profile reduces efficiencies in water movement, allowing more sediments to settle and creating a tendency for the stream to cut into its banks. This further reduces efficiencies and increases sediment loads. A cycle of events evolves that continues to degrade the stream system.

Measuring the departure from desired conditions

Benchmarks to compare against

The benchmarks as they relate to the historic forests of Virginia

The historic forests of Virginia were diverse, abundant and productive. Many plant and animal species thrived in dense, unbroken woodland. The stock of natural resources and myriad interconnections among species is hard to imagine in today's remnant timber stands.

The three benchmarks we must use, therefore, represent perhaps less than we would hope for but certainly more than we currently have. They are benchmarks that define an appropriate stream system and landscape geometry; a dimension, pattern, and profile that will allow development of healthy riparian forests and improved aquatic habitat if given enough time.

In any investigation of the departure from desired conditions, it is important that measurements be made and compared for all three benchmarks.

Benchmark 1: The 3 zone riparian buffer

The 3 zone riparian buffer is an accepted minimum standard for vegetation adjacent to streams and rivers. It helps ensure that the structural, temporal, and spatial diversity and stability of plants, animals, and landscape pattern will remain intact. Without adequate buffering using the 3 zone concept or something more extensive, the integrity of the river landscape and vegetative community is lost.

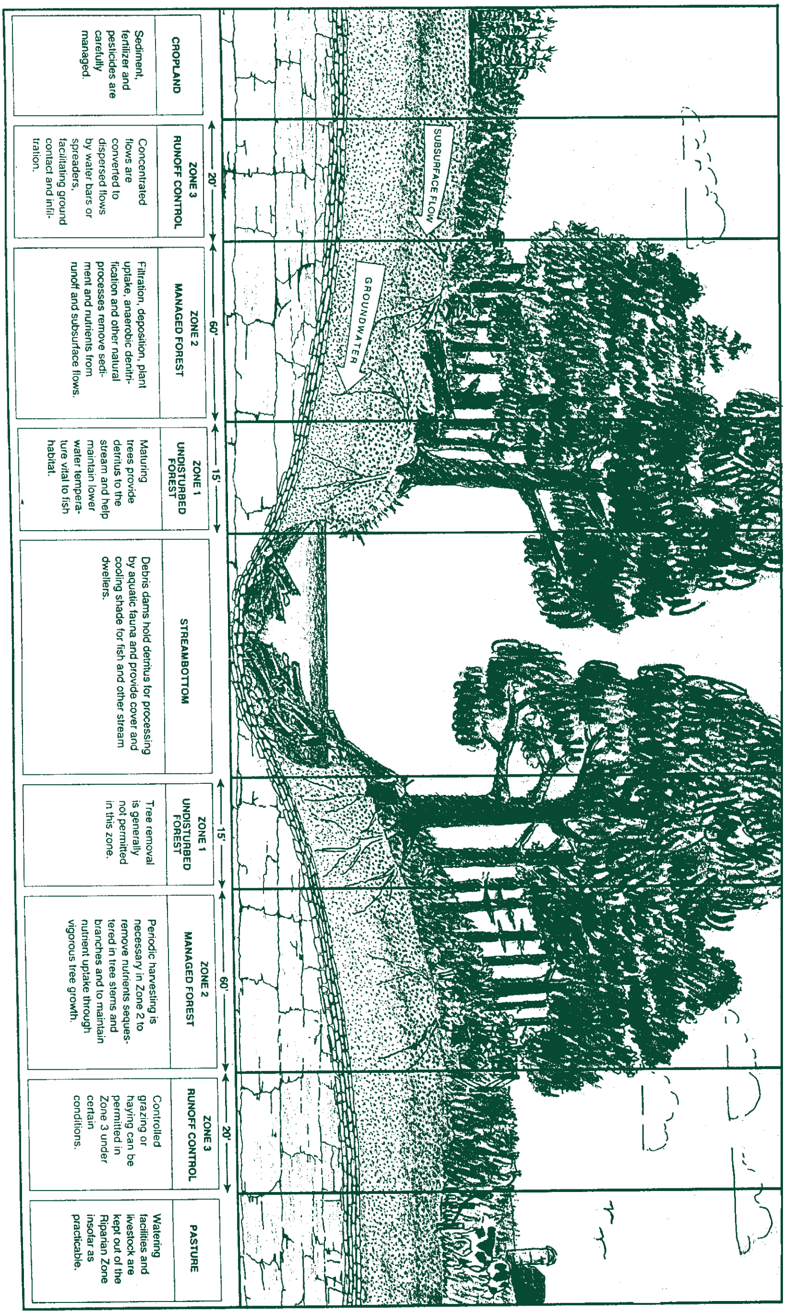
The 3 zone buffer is illustrated in cross section in Figure 8. The area immediately adjacent to the stream channel, Zone 1, is comprised of larger woody plants and tree species. The boles and roots of these plants provide structural integrity to the stream system. Fallen large woody debris is an essential food source for aquatic life as well.

Zone 2 is an area of contiguous forest at least 60 feet wide. The trees in this section store nutrients and filter sediments and pesticides while shading stream water, providing animal habitat and cover, and regulating storm water.

Zone 3 should be contiguous forest, but may included perennial grasses or other non-woody plants if desired. This zone is a “first defense” against the accelerated run-off of water, sediment, pesticides, herbicides, and toxic chemicals that may be bi-products of adjacent land use.

A first step in measuring the departure from desired conditions is comparing your restoration site against the 3 zone riparian buffer standard. Does your site contain a contiguous buffer that meets or exceeds the vegetation and width criteria of the three zone standard? If not, how significant are the deviations from the standard? What is the extent of contiguous forest? Is soil within the buffer zone compacted? What are the size and type of plant species occupying the site as compared to those in the standard?

Figure 8: *The three zone buffer system (reprinted with permission from USFS)*



Benchmark 2: Normal values of stream dimension, pattern, profile

Measurements of stream dimension, pattern, and profile are used to determine if a stream you are evaluating has a stable "hydrology" and "geology." A stable stream has a naturally occurring sediment load. A stable stream also migrates slowly across its valley over thousands of years (geologic time). Having evolved slowly in an undisturbed landscape, the dimension, pattern, profile, and water regime of a stream achieve a dynamic equilibrium within the surrounding environment. This equilibrium is an integration of the landscape and historic rainfall patterns upstream. In equilibrium, a stream follows a path that has evolved as the best compromise between (1) *efficient movement of energy*, and (2) *uniform distribution of energy* along the entire length of the stream system.

Relative to geologic time, human induced changes occur quickly, upsetting the dynamic equilibrium that has evolved over many years. Abrupt changes in vegetation, land surface features, water pathways, or length, width, depth and shape of portions of stream channel cause streams to adjust width, depth, and position, as means to re-capture a stable shape and dynamic equilibrium. These adjustments will cause increased bank erosion and sediment deposition at various points along a stream channel until stable dimension, pattern, and profile are restored.

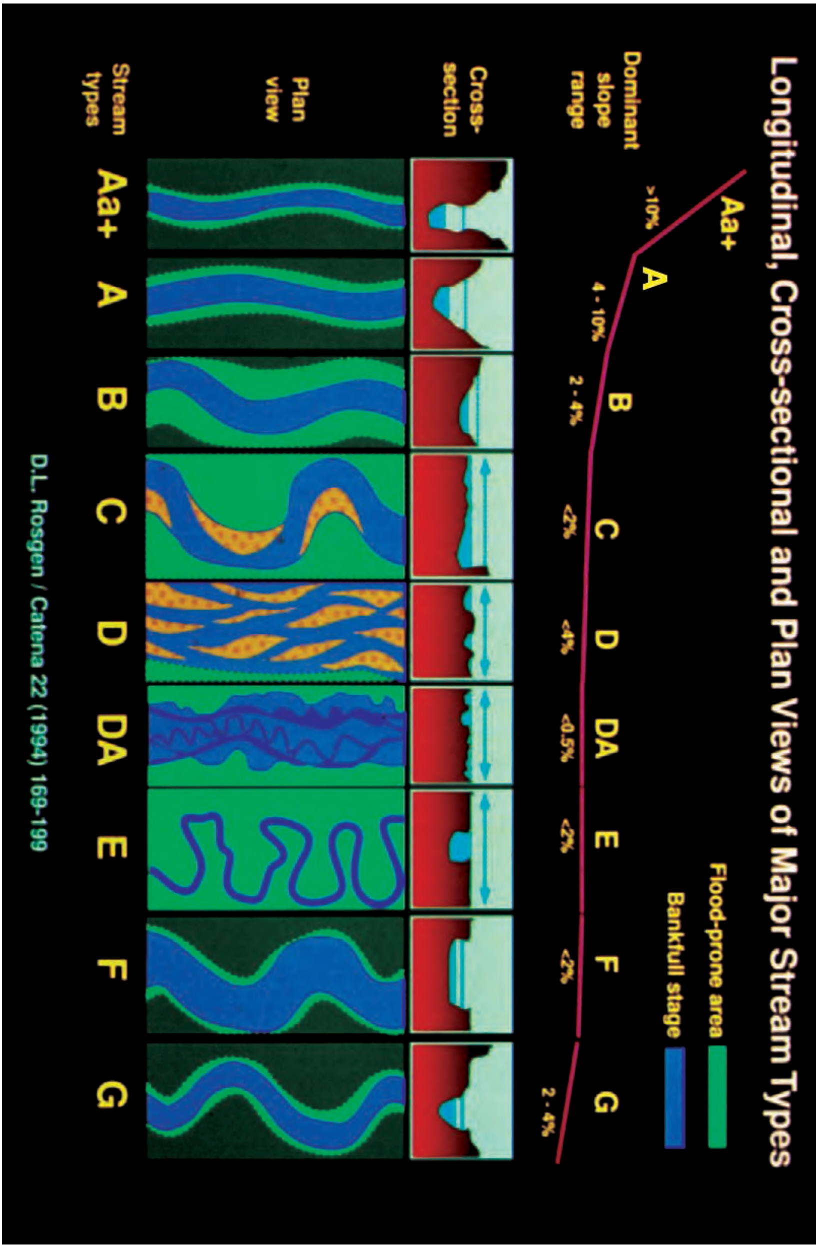
Consequently, measuring the dimension, pattern, and profile of a stream system is a useful way to determine if its "hydraulic geometry" is stable or unstable.

Benchmark 3: Normal values of stream particle size and distribution

In addition to streamside vegetation and hydraulic geometry, the sediment load of a stream is a useful benchmark of stability. As a stream system evolves over geologic time, it develops a characteristic set of sediment particle sizes in the stream bed (some combination of silt, sand, pebbles, gravel, and larger stones). These particles move through the channel over time. The quantities of each size of material depend on the geology of the watershed and the energy of water flow in the system. In an undisturbed stream system the distribution of particle sizes indicates the natural sediment load of the stream bed (known as "bed load").

Any abrupt change in vegetation, land surface features, water pathways, or length, width, depth and shape of portions of stream channel can cause

Figure 9: *Rosgen stream types in cross section and plan view (reprinted with permission from Elsevier Science)*



streams to adjust width, depth, and position, as means to re-capture a stable shape, and dynamic equilibrium. A frequent consequence of these adjustments is a shift away from the normal sediment particle size distribution. Consequently, measurements of this distribution, when compared to normal values for a given stream type, are a useful benchmark of the extent of deviation from normal sediment loads. Prior to restoration of a disturbed stream they may be compared with normal values to determine the shift in bed load. They may also be compared with normal values to project the change in bed load expected after restoration.

What to measure and how to measure it

Selecting a site for measurements

The process of deciding where to actually collect measurements along your stream, takes careful thought. Ask yourself:

1. What do you want to know about this stream or drainage?

2. How do you plan to restore the stream?

3. How will your measurements contribute to existing or planned restoration efforts?

4. How much can you accomplish with available resources?

It is often helpful to research existing information about your stream before collecting your measurements. Find out what has been done in your area. Often benchmarks, gauges, or references sites already exist and have been measured.

Document what has been done. Contact persons working in your area. Valuable studies may have been done by a local planning district or as part of a fisheries project. Agencies such as the U.S. Geological Survey, or the Department of Forestry may have studies in place that can be expanded or extended for your purposes. Take time to review regional climate data, geology, land types, vegetation, historic land use and any forest plan guidance. A day spent with files, in a library, or contacting others, may reward you with useful information.

Measuring Benchmark 1: streamside vegetation in the 3 zone riparian buffer

Measuring streamside vegetation in the 3 zone riparian buffer may be done as follows.

First, define the upstream and downstream boundaries of your stream reach. Then,

For each of the three zones, determine:

1. The dominant type of plant cover.

   While walking the site, with the aid of a recent aerial photograph if available, visually determine the dominant type of plant cover, (trees, shrubs, or grasses) in each of the 3 riparian zones. Estimate the percent of each plant cover type in each of the three zones. Write down your results. The 3 x 3 matrix below illustrates a useful way to organize these numbers. Draw a sketch map to scale, illustrating the relative area of each type.

Figure 10: *A 3 x 3 matrix for determining dominant plant cover types in riparian zones*

	riparian zone 1	riparian zone 2	riparian zone 3
percent grass and herb cover			
percent shrub cover			
percent tree cover			

2. The extent of contiguous cover along the stream.

   While walking the site, determine the extent to which the dominant cover type in each zone is "contiguous" (of at least minimum width, without breaks or gaps, along the entire stream reach you are interested in.) If the vegetation in a portion of a zone becomes too narrow, or gaps are found, note these areas on your sketch map.

3. The density of cover.

   The density of cover is determined for each zone by organizing riparian vegetation into three groups: Trees, Shrubs, and Grasses, and estimating the density in each group.

   Density of *trees* may be determined by calculating tree basal area. Commonly used in forestry, basal area is the average cross sectional area of the tree bole(s) at 4.5 feet above the ground per unit area. It is often expressed in square feet per acre and may be calculated using a 10 basal area factor (BAF) prism. Additional discussion of proper methods for determining basal area can be found in forestry text books, and other references to forestry field methods. A riparian forest should have no less than 50 square feet of tree basal area per acre.

   Density of *shrubs* may be determined by defining a circle ten meters in diameter and estimating the fraction of ground surface covered by shrubs. Coverage includes the area of ground shaded by the leaves of a shrub.

   Density of *grasses* may be determined by defining a circle one meter in diameter and estimating the fraction of ground surface covered by grasses. Coverage includes the area of ground shaded by the leaves of a grass.

Measuring Benchmark 2: stream channel dimension, pattern, and profile

Measurements of the stream channel dimension, pattern, and profile define the *hydraulic geometry* of the stream. Hydraulic geometry is the second useful benchmark of stream stability.

Using the Rosgen stream classification system

Stream channels may be classified in terms of eight major variables: width, depth, velocity, discharge, slope, roughness of bed and bank materials, sediment load, and sediment size (Leopold et al. 1964). Streams are not random in their variation, but tend to organize themselves around the most likely combinations of variables based on physical and chemical laws. This tendency to seek a dynamic equilibrium lends itself nicely to classification.

When any of the factors controlling stream classification changes, other factors will adjust along with it toward a new, balanced state. Because change is continuous, this process of adjustment is continuous. Under normal circumstances change and adjustment take place **very** slowly, over geologic time. Water quality problems arise when humans induce rapid change.

In streams the dominant physical medium for adjustment is the flowing water. In adjusting, the stream will show measurable change along the continuum determined by this flow (Rosgen 1994). The Rosgen stream classification system is well suited to identifying the changes in streams and recognizing stable (normal) and unstable (problem) conditions.

The Rosgen system lets you group streams that have similar configurations. This allows you to:

1. predict a streams behavior from its appearance
2. compare data among streams of similar type
3. accumulate measurements that allow consistent and uniform tracking of status and change in stream system conditions

Rosgen's method organizes streams into seven major stream types that are closely associated with particular landscape shapes. These are labeled A through G. Streams are classified from the headwaters to the lowlands as follows:

A = headwater stream
B = intermediate stream (step-pool channel)
C & E = meandering stream (riffle-pool channel)
D = braided stream
F = entrenched stream
G = gully

Next, the Rosgen system organizes these seven major types into subtypes based on dominant channel material particle size. The subtypes are:

1 = bedrock
2 = boulder
3 = cobble
4 = gravel
5 = sand
6 = silt/clay

Classifying streams in this way, helps distinguish among variations due to stream type, landscape, and site conditions.

The measurements collected for Benchmark 2 and Benchmark 3, allow you to identify stream type using the Rosgen method. Comparing the benchmark measurements listed in this guide to your collected measurements enables you to determine the "physical health" of your stream.

Measuring Hydraulic Geometry

Measuring hydraulic geometry requires measuring a cross-section and a longitudinal profile of the stream channel, using surveying equipment. Ratios developed from these measurements can then be used to determine stream pattern and Rosgen classification.

Bankfull stage (BKF) is perhaps the single most important parameter used in calculating hydraulic geometry. Correct and reliable interpretation of the interrelationships among dimension, pattern, profile, and stream flow depend upon an accurate field identification of bankfull stage. The stage of bankfull discharge is related to channel dimensions such as width, and channel patterns such as meander length, radius of curvature, belt width, meander width ratio, and amplitude. Two of the key hydraulic geometry indicators, entrenchment ratio and width / depth ratio, require an accurate estimate of the bankfull channel width.

Bankfull discharge is the upper level of the range of channel-forming flows which transport the bulk of available sediment over time. Because of this, it is possible to identify the bankfull stage using key bankfull discharge indicators. The appropriate use of these indicators relies on four basic principles:

1. Look for indicators in the locations appropriate for specific stream types.

2. Know the recent flood and drought history of the area to avoid being mislead by spurious indicators.

3. Use several indicators when possible to secure identification of a common stage or elevation.

4. When possible, calibrate field determined bankfull stage elevations and corresponding bankfull discharges at gauging stations.

The key indicators of bankfull stage are physical differences in the stream channel that are interpreted in the field. These include:

1. The presence of a flood plain at the elevation of incipient flooding.
2. The elevation associated with the top of the highest depositional features such as: point bars and central bars within the active channel. These depositional features are especially good stage indicators for channels in the presence of terraces or adjacent colluvial slopes.
3. A break in slope of the banks and/or a change in the particle size distribution; since finer material is associated with deposition by over-flow, rather than deposition of coarser material within the active channel.
4. Evidence of an inundation feature such as small benches.
5. Staining of rocks.
6. Exposed root hairs below an intact soil layer indicating exposure to erosive flow.
7. Lichens and, for some stream types and locales, certain species of riparian vegetation.

Measuring the channel cross-section

A cross-section lies across the stream, perpendicular to the direction of stream flow. Generally, the cross-section is central to the survey area. Locate a good site for the cross-section before making measurements.

1. Find a site with well defined bankfull indicators.
2. Anchor each end of a measuring tape, at bankfull height, across the channel, with the zero end of the tape on the left bank facing downstream. Adjust the tape until it is level. A carpenter's line-level is often helpful.
3. Measure the area of the channel cross-section. To do this, measure the vertical distance from the bottom of the stream channel to the tape, at one foot intervals along the tape. Use a measuring stick or surveying rod to make these measurements. Begin measurements at the left stream

bank when facing downstream. At each station, record the distance on the tape, and the height measurement from stream bottom to tape.

4. Measure the flood prone area width (FPA), a horizontal distance at an elevation of 2 times the maximum bankfull depth of the channel.

Measuring the longitudinal profile

A longitudinal profile survey is important for measuring the slope of the water surface, channel bed, floodplain, and terraces. The elevations and positions of various indicators of stream stage and other features are recorded and referenced to a benchmark.

Measuring a longitudinal profile requires some familiarity with using a surveying level and stadia rod, to perform differential leveling. Taking the measurements is not difficult. (For additional information see the surveying references listed at the end of this handbook.)

1. Define the length of stream you want to survey. Generally this corresponds with the distance of stream you hope to restore.

2. Review how to recognize floodplain and bankfull indicators. Walk the channel and assign various colors of flagging to mark the indicators of channel-forming flow and to identify terraces. Place flags where it is possible to sight with a surveying level.

3. Set up the surveying level so that most of the site is visible. The best locations are often on a low stream terrace. Consider setting up in the stream channel if visibility is limited elsewhere and conditions allow it.

4. Select a starting point at the upstream end of the reach, then select stations for measuring elevations. Number and mark the stations using surveying stakes.

5. Measure elevations of important channel features. Using the marked stations as reference points, place the surveying rod and measure individual elevations of the channel bottom at the center of the stream. Measure elevations of the bankfull indicators, flood plain, and terraces as flagged in step 2. Record distances and elevations in a field notebook. Move the instrument as needed.

6. Plot your survey in a field notebook. Do this while you are in the field. Fit a series of straight lines to the longitudinal profile by eye for the present water surface conditions, bankfull, and terrace elevations. Connect the points identifying the channel bottom. The lines of slope for the entire reach should closely parallel each other.

Calculating hydraulic geometry

After making the measurements of your reference stream, you can use them to calculate your stream's "hydraulic geometry." The numbers that describe hydraulic geometry may then be used to place the stream in an appropriate class using the Rosgen stream type classification method.

Width-depth ratio (W/D) is calculated as the ratio of bankfull width over average channel depth at bankfull. For your cross section this can be computed as the "width measured with the tape" divided by the "average of the depth measurements made along the tape."

Entrenchment Ratio (ENT) is the ratio of the width of the flood-prone area to the surface width of the bankfull channel, (or FPA/BKF). The flood-prone area width is measured horizontally, in a manner similar to bankfull width, but at the elevation that corresponds to twice the maximum bankfull depth of the channel.

Sinuosity (SIN) is the ratio of stream length to valley length. It can also be described as the ratio of valley slope to channel slope. Meander geometry is directly related to sinuosity.

To measure sinuosity, determine the length of the stream reach along the thalwag for at least one meander wavelength of your stream. Then, divide this figure by the straight line distance between the same two starting and stopping points.

Sinuosity measurements should be collected as part of the longitudional profile survey, or from aerial photography, or a topographic map. With the exception of large rivers, however, measurements from topographic maps may underestimate actual channel sinuosity since sinuosity is not accurately transposed in the process of map construction.

Slope of the water surface is a major determinant of river channel morphology and the related sediment, hydraulic, and biological functions. It is determined as part of the longitudinal profile survey by measuring the change in water surface elevation per unit stream length. Slope measurements should be taken over a distance of at least two stream meander wavelengths. The water surface slope should be measured by taking the difference in elevation from one stream bed feature, such as the top of a riffle, to the same stream bed feature either upstream or downstream.

Identifying Rosgen stream type:
Once calculations are complete, the numbers may then be used to determine the hydraulic geometry of the stream by "keying out" the classification using the values shown in Table 5. Determine which stream type has the *entrenchment ratio*, *width-depth ratio*, *sinuosity*, *and slope* that most closely matches your measured results.

The companion Microsoft Excel spreadsheet titled *Reference Reach Geometry*, will do all of these calculations for you! Directions are included with the spreadsheet.

Figure 11: *Measuring bankfull stage*

Measuring Benchmark 3: stream channel particle size distribution
The particle size distribution (size of the rocks, gravel, sand, and silt) in the stream bed, is another useful indicator of stream stability. A *pebble count* can be used to determine this particle size distribution. The size distribution is then compared to a distribution graph from a reference stream to determine if the particle size distribution is "normal" indicating channel stability, or "abnormal" indicating channel instability.

Table 5: *Average values for entrenchment ratio, width/depth ratio, sinuosity, and slope, organized by Rosgen stream classification*

Stream Type	Entrenchment Ratio (FPA/BKF)	Width Depth Ratio (W/D)	Sinuosity (SIN)	Slope
A	<1.4	<12	1 - 1.2	0.04 - 0.099
B	1.4 - 2.2	>12	>1.2	0.02 - 0.039
C	>2.2	>12	>1.4	<0.02
D	n/a	>40	n/a	< 0.04
Da	>4.0	<40	variable	<0.005
E	>2.2	<12	>1.5	<0.02
F	<1.4	>12	>1.4	<0.02
G	<1.4	<12	>1.2	0.02 - 0.039

A pebble count consists of selecting at least 100 particles located by the toe of the observer's boot as he/she walks along a transect in the stream from bankfull to bankfull stage. The particle is picked up (if possible) and the length of the intermediate axis is measured in millimeters using a metric ruler or calipers.

A particle has three axes that are mutually perpendicular. These are: long, short, and intermediate in length. The intermediate axis of each particle is measured. Pebbles as small as 2mm can be easily measured. Smaller sizes are judged by feel, using soil classification methods, to determine if they are mostly sand, silt, or clay.

Particle sizes are tallied by the following classes: <2mm, 2-4mm, 5-8mm, 9-16mm, 17-32mm, 33-64mm, 65-128mm, 129-256mm, 257-512mm, 513-1024mm, 1025-2048mm, >2048mm. A cumulative size distribution curve is created by plotting the cumulative "percent finer than" over particle size class. The *Reference Reach Geometry* spreadsheet makes this easy.

The sampled data are compared to a reference curve to determine if the collected measurements indicate channel stability or instability. A statistically *normal distribution* of particle sizes, matching reference conditions, indicates stability. A bi-polar or skewed particle size distribution indicates stream system instability resulting from stream bed *aggredation* (sediment deposition) or *degradation* (sediment scour).

Other useful measurements

(1) If you have aerial photographs you can determine the *land cover mix* in your watershed. Use a photo marking pen to delineate the polygons representing crop-

land, forest, pasture and urban areas. Use a dot grid or planimeter to calculate the acreage of each cover type. Represent each cover type as a percentage of total land area in the watershed.

Understanding the mix of land classes in your watershed can help you identify areas that may be impacting your stream. Comparing these numbers over time allows you to determine a rate of change in land use among the land use categories in your watershed.

(2) With knowledge of the land cover mix you can estimate the *extent of soil compaction and impervious area* in your watershed. This is done by determining an average "C" or cover factor for your watershed. Higher "C" values indicate increased runoff rates, and suggest more soil compaction and impervious area. "C" values and methods for using them are explained as part of a companion *Rational Runoff Method* Microsoft Excel spreadsheet available from the Virginia Department of Forestry. Directions are included with the spreadsheet.

(3) By making careful observations along the stream corridor, you can determine the *extent of channelization or water diversion* occurring upstream of your stream reach. Any human alteration of the natural dimension, pattern, and profile of a stream system can have dramatic effects downstream.

Tools to measure with

The following tools are useful when collecting channel measurements.

- an auto level and tripod
- an inexpensive calculator
- a 35mm camera
- a canvas tote bag
- a field note book
- flagging and flagging pins
- insect repellent
- maps (USGS 1:24,000 scale, and county map)
- pencil
- rod for auto level
- ruler (mm scale)
- sun screen
- tapes (100' to 300', plastic coated: graduated to 0.1 feet)

Table 6: *Stream characteristics and expected channel response to forest vegetation: organized by Rosgen stream type*

Stream type	Sensitivity to disturbance (a)	Recovery potential (b)	Sediment supply (c)	Streambank erosion potential	Riparian vegetation controlling influence (d)
A1	very low	excellent	very low	very low	negligible
A2	very low	excellent	very low	very low	negligible
A3	very high	very poor	very high	very high	negligible
A4	extreme	very poor	very high	very high	negligible
A5	extreme	very poor	very high	very high	negligible
A6	high	poor	high	high	negligible
B1	very low	excellent	very low	very low	negligible
B2	very low	excellent	very low	very low	negligible
B3	low	excellent	low	low	moderate
B4	moderate	excellent	moderate	low	moderate
B5	moderate	excellent	moderate	moderate	moderate
B6	moderate	excellent	moderate	low	moderate
C1	low	very good	very low	low	moderate
C2	low	very good	low	low	moderate
C3	moderate	good	moderate	moderate	very high
C4	very high	good	high	very high	very high
C5	very high	fair	very high	very high	very high
C6	very high	good	high	high	very high
D3	very high	poor	very high	very high	moderate
D4	very high	poor	very high	very high	moderate
D5	very high	poor	very high	very high	moderate
D6	high	poor	high	high	moderate
DA5	moderate	good	very low	low	very high
DA5	moderate	good	low	low	very high
DA6	moderate	good	very low	very low	very high
E3	high	good	low	moderate	very high
E4	very high	good	moderate	high	very high
E5	very high	good	moderate	high	very high
E6	very high	good	low	moderate	very high
F1	low	fair	low	moderate	low
F2	low	fair	moderate	moderate	low
F3	moderate	poor	very high	very high	moderate
F4	extreme	poor	very high	very high	moderate
F5	very high	poor	very high	very high	moderate
F6	very high	fair	high	very high	moderate
G1	low	good	low	low	low

Table 6 (continued)

Stream type	Sensitivity to disturbance (a)	Recovery potential (b)	Sediment supply (c)	Streambank erosion potential	Riparian vegetation controlling influence (d)
G2	moderate	fair	moderate	moderate	low
G3	very high	poor	very high	very high	high
G4	extreme	very poor	very high	very high	high
G5	extreme	very poor	very high	very high	high
G6	very high	poor	high	high	high

a. Includes increases in streamflow magnitude and timing and/or sediment increases.

b. Assumes natural recovery once cause of instability is corrected.

c. Includes suspended and bedload from channel derived sources and/or from adjacent slopes.

d. Vegetation that influences width/depth ratio-stability.

4. Choosing How to Restore Your Riparian Forest

4.1 Three ways to intervene

Simply put, there are three categories of action that may be taken to Restore a Riparian Forest. These are:

1. Exclusion: Limiting activity near the stream, using fencing or other methods.

2. Planting: Establishing trees and shrubs in the riparian zone.

3. Channel Modification: Using knowledge of hydraulic geometry and bioengineering techniques to change the shape of the channel, restoring its natural meander, width, and depth.

Each of these actions has associated benefits and costs. Each may be done alone, or in combination with one or two of the others. Information from your stream measurements can help you select an appropriate combination of actions.

4.2 Interpreting the results of your measurements

Stable vs. unstable stream type

The Rosgen stream classification method lets you quickly identify whether the hydraulic geometry of the stream reach you hope to restore is stable or unstable. In Virginia, a stream reach that falls into the A, B, C, or E categories identified by Rosgen is in most cases relatively stable. A stream reach that falls into the D, F, or G categories is in most cases a relatively unstable reach, see Table 5.

Using stream type to guide restoration decisions

Streams that are relatively stable (A,B,C,E) respond well to exclusion and planting, and do not need channel modification. Streams that are relatively unstable (D,F,G) will benefit from exclusion and planting, but may need additional channel modification. Use Table 6 as a guide. It lists stream characteristics and expected channel response to forest vegetation, organized by Rosgen stream type.

Natural vs. accelerated sediment loads

Your stream's sediment load can alert you to land use problems upstream that are affecting your stream reach. All streams have a natural sediment load. If measurements indicate a suspended sediment load matching the load indicated by the sediment load reference curve, then the sediment regime is fine. On the other hand, if measurements indicate a suspended sediment load exceeding the load indicated by the sediment load reference curve, you should consider these affects when developing your restoration plan.

Using sediment load to guide restoration decisions

Excess sediments originate as a consequence of land disturbance, resulting in erosion or a change in the water regime upstream. Even a seemingly small change, such as a new field or parking lot, can accelerate water flow, increase peak water discharge, and cause sediment loads to increase dramatically.

A first step in restoring your stream is to identify the critical areas upstream that are helping to create the excess sediment, then organize interventions to fix these areas. If sediment loading is severe channel modifications may be needed along your stream reach, in addition to planting and exclusion, to create a natural channel geometry that is stable and more efficient at handling the increased sediment loads. This should be a geometry that closely approximates that natural dimension, pattern, and profile of one of the stable stream types (A, B, C, E).

Particle size distribution can be an important indicator of recent disturbance, or pending channel instability, particularly when Rosgen stream classification indicates a stable stream form. Often relatively new disturbances upstream will cause particle size distributions to change, but will not have progressed enough to change the stream type of your reach.

If you observe skewed or bi-polar particle size distributions (from your pebble count) and stable Rosgen stream type, carefully investigate upstream disturbances. Determine likely causes of a sudden shift in sediment bed load or particle size. Channel restoration may require additional channel protection or modifications upstream.

Suspended sediment curves from reference streams combined with turbidity data collected at your site, can tell you if suspended sediment levels are within or beyond natural limits. If suspended sediment levels are beyond natural limits, significant land use changes in the upstream watershed may have occurred. Investigate the upstream watershed to determine the likely cause of a sudden change, and if it may be corrected or not. Land clearing or urbanization will create fundamental changes in water regime and peak water flows. In these circumstances, any channel modifications as part of a restoration should be made based on calculations of hydraulic geometry that account for these new conditions.

Suspended sediment curves from a forested C4 reference stream are shown here. Reference curves for other Rosgen stream types are being developed and will be made available periodically. The companion *Reference Sediment* Microsoft Excel spreadsheet can be used with data collected at your stream, to determine if your stream's suspended sediment load is within or beyond normal natural limits. Instructions for using the spreadsheet are included with the spreadsheet.

If the stream reach you are investigating turns out to be type “C4,” you may use Figure 12 and Figure 13 to determine the normal sediment load for your stream, as follows:

Using Figure 12:

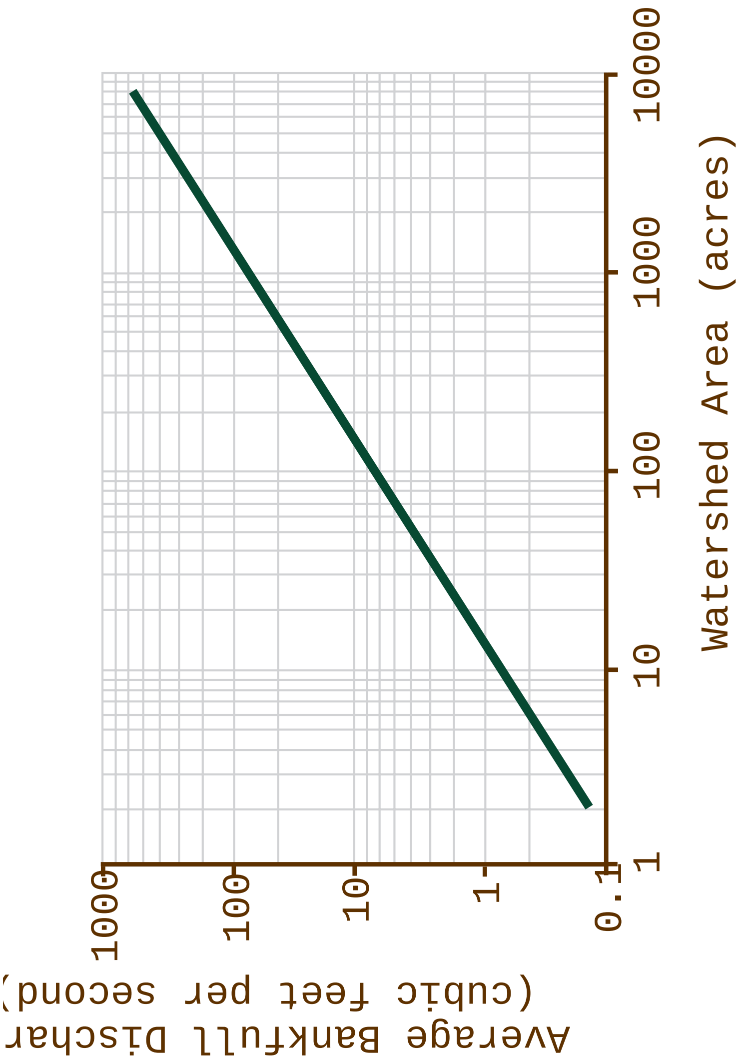
1. Determine the watershed area upstream of your stream reach.
2. Find this quantity on the “watershed area” axis of Figure 12 (the x-axis).
3. Read up to the solid black line, then across to the y-axis.
4. Read the “average bankfull discharge” on the y-axis.

Using Figure 13:

5. Find the x-axis quantity on Figure 13 equal to the y-axis quantity from Figure 12.
6. Read up to the solid black line on Figure 13, then across to the y-axis.
7. On the y-axis read the normal “suspended sediment load” for your C4 stream in pounds per day.

If you are lucky enough to have a turbidity meter that measures stream water turbidity in NTU’s (Nephelometric Turbidity Units), you can determine the amount of suspended sediment in your stream and compare it to your stream’s normal value, using the companion *Reference Sediment* Microsoft Excel spreadsheet.

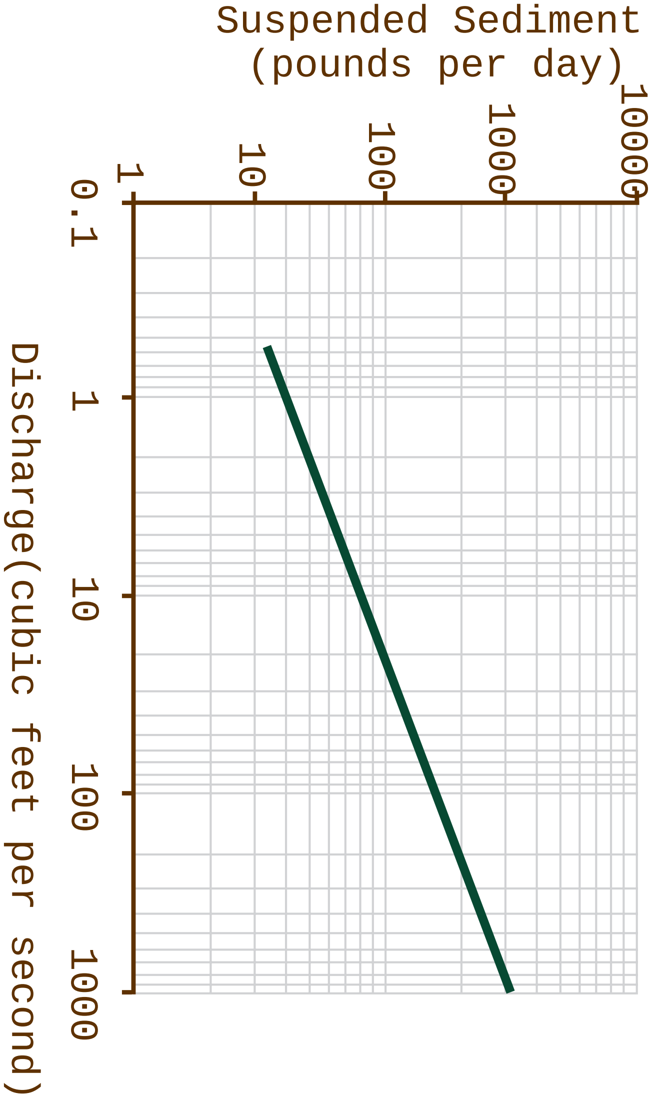
Figure 12: *Average bankfull discharge as a function of watershed area*[3]



---

[3] discharge (Q) = 0.065(acres) - (2.617 x 10^-7)(acres^2)

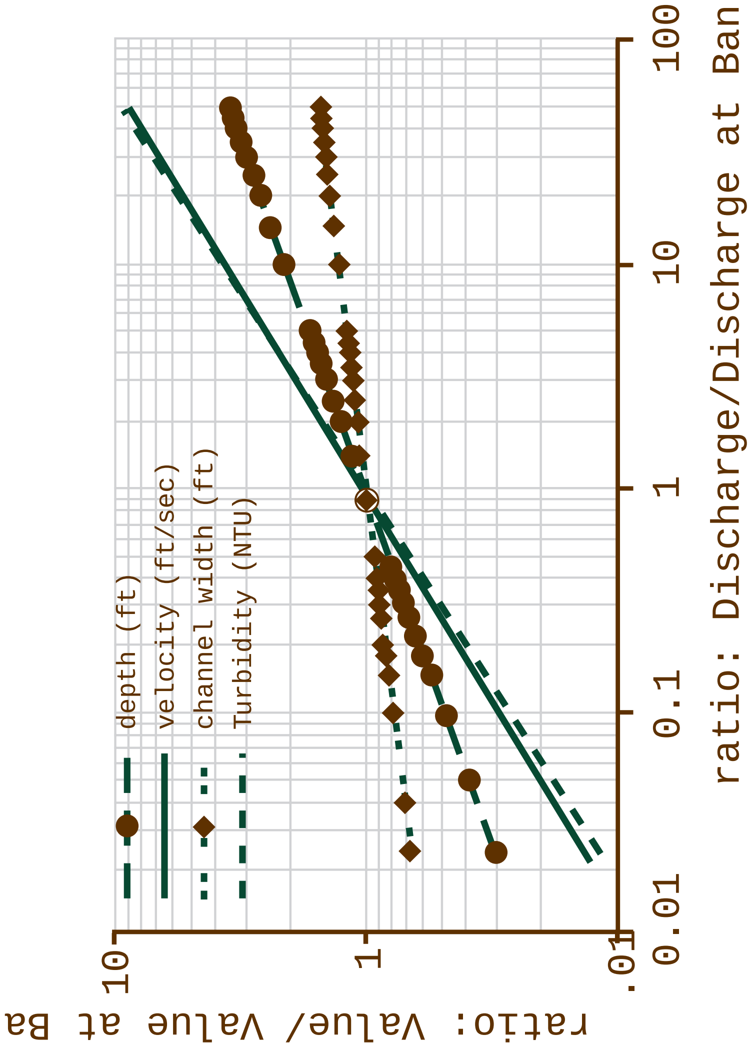
Figure 13: *Normal suspended sediment load as a function of bankfull discharge: Rosgen C4 stream type in Virginia*[4]



---

[4] Virginia C4 suspended sediment = 18.45(Q^0.58)

Figure 14: *Reference values for hydraulic geometry expressed in dimensionless ratios: Rosgen C4 stream type in Virginia*[5]



---

[5] dimensionless depth ratio = (0.43Q^ 10.32)/depth at bankfull stage expressed in feet
dimensionless velocity ratio = (0.44Q^ 57)/velocity at bankfull stage expressed in feet per second
dimensionless channel width ratio = (5.29Q^ 0.11)/channel width at bankfull stage expressed in feet
dimensionless turbidity ratio = (1.83Q^ 0.58)/turbidity at bankfull stage expressed in NTU

5. Using The Companion Computer Programs

Three companion computer programs are available from the Virginia Department of Forestry.

The program titled *Reference Reach Geometry* will make all the calculations necessary to characterize your stream using the Rosgen stream classification method, and more. You enter the data you have collected in the field. Particle size distributions and stream flow calculations are also included.

The program titled *Reference Sediment* allows you to determine if the suspended sediment load you observe is within or beyond the normal natural limits of your stream type. You input: average bankfull depth, average observed water depth, upstream drainage area, and measured turbidity. The program does the rest!

The program titled *Rational Runoff* allows you to determine stream discharge estimates using the mix of land uses (and associated "C" values) in your watershed. The Rational Runoff method is widely used by conservation professionals.

Instructions for using each program are included with the program.
To obtain these programs contact the Virginia Department of Forestry Central Office at (434) 977-6555. Ask for the "Riparian Forest Handbook 1 Companion Programs."

6. Further Reading

Many excellent resources are available to help you understand stream systems and work to restore them. Several of the best are listed below. *A View of the River* provides an excellent **synthesis** of the concepts of morphology and hydraulic geometry in a style that is easy to read. *Applied River Morphology* is **the** reference to the Rosgen stream classification system, written by "the man" himself. *Fluvial Processes in Geomorphology* is the **landmark** book by Leopold, Wolman, and Miller that started it all! It lays out the theory and science of stream systems and geomorphology and is an excellent reference. *Stream Channel Reference Sites: An Illustrated Guide to Field Technique* is a wonderful yet inexpensive guide to proper field methods for making stream measurements. *Water in Environmental Planning* is another classic from Dunne and Leopold. A practical reference to understanding water from a resource manager's perspective. If you find a copy of this book, hang on to it! *Water, Rivers, and Creeks* is an excellent, **easy to read** introduction to hydrology, geomorphology, and stream systems, from the "master" himself.

Additional resources, including updated water resource computer programs and stream geometry reference curves, are available from the water quality section of the Virginia Department of Forestry web page. The address is: www.dof.virginia.gov

We encourage you to obtain these and other resources that may be helpful, and to use them.

We welcome any comments or feedback you may have. To contact us, call or write: Samuel H. Austin, Forest Hydrologist, Resource Information Team, Virginia Department of Forestry, 900 Natural Resources Drive, Suite 800, Charlottesville, Virginia, 22903 (434) 977-6555.

References

A View of the River, by Luna B. Leopold, 1994 Harvard University Press, Cambridge, Massachusetts, USA. ISBN number: 0-674-93732-5

Applied River Morphology, by Dave Rosgen, 1996 Wildland Hydrology, 1481 Stevens Lake Road, Pagosa Springs, Colorado, USA.
ISBN number: 09653289-0-2

Fluvial Processes in Geomorphology, by Luna B. Leopold, M. Gordon Wolman, John P. Miller,1962 W. H. Freeman and Company, 1995 Dover Publications, Inc., 31 East 2nd Street, Mineola, N.Y. 11501 USA
ISBN number 0-486-68588-8 (pbk.)

Stream Channel Reference Sites: An Illustrated Guide to Field Technique, by Cheryl C. Harrelson, C. L. Rawlings, and John P. Potyondy, 1994 USDA-Forest Service General Technical Report RM-245, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, USA.

Water in Environmental Planning, by Thomas Dunne and Luna B. Leopold, 1978 W.H. Freeman and Company, New York, USA
ISBN number 0-7167-0079-4
Water, Rivers and Creeks, by Luna B. Leopold, 1997 University Science Books, 55D Gate Five Road, Sausalito, California 94965
ISBN number 0-935702-98-9

Notes:

Notes: