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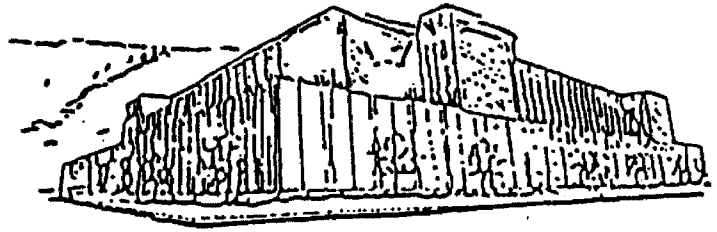
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**A WATERSHED ASSESSMENT GUIDE  
FOR CITIZEN MONITORS**

by

**Daniel Pierre Moffroid**

**B.A. The University of Vermont, 1992**

**presented in partial fulfillment of the requirements**

**for the degree of**

**Master of Arts**

**The University of Montana**

**1998**

Approved by:



Chairperson



Dean, Graduate School

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A Watershed Assessment Guide for Citizen Monitors (181 pp.)

Director: Jeffrey A. Gritzner



### ABSTRACT

This document is intended to orient the beginning water quality citizen monitor. A citizen monitor is someone who is willing to volunteer time and effort to the community and to the stream. This person is assumed to want to protect and promote the health of a particular stream, and to be interested in involving the public, both in actively assessing the watershed and in sharing the knowledge gained with the rest of the community. It is further assumed that this "beginning" monitor has little or no prior experience in the field of stream ecology.

This orientation is accomplished by providing the reader with a general understanding of how a stream functions, and how the different components of a stream are interrelated (stream dynamics), and by describing the process involved in conducting a watershed assessment. The document further lists specific watershed inventories for the reader to obtain, as well as additional sources and organizations to contact for when the reader is ready to go to the field and begin a detailed watershed assessment.

The stream dynamics section is broken up into thirteen parameters: sinuosity; slope; substrate; width-to-depth ratio; pool-to-riffle ratio; discharge; velocity; temperature; turbidity; riparian vegetation; dissolved oxygen; pH; and macroinvertebrates. The discussion for each parameter includes a definition, ways that each is measured, the significance of each, how each is altered, what the effects of these alterations are, and additional sources to which the interested reader can refer to learn more about a specific subject.

The watershed assessment section instructs the reader as to what steps need to be followed in order to carry out a watershed assessment. These steps are: conducting a background investigation; choosing a study area; identifying specific issues; finding the source of each issue; determining if each issue should be addressed (with available resources); deciding upon the proper action to take; and establishing a monitoring program.

This document also includes a case study of Freeman Brook in central Vermont. The purpose of this study was to apply the process listed above to "the real world."

## ACKNOWLEDGEMENTS

I would like to say a special thank you to Dr. Jeffrey Gritzner for repeatedly demonstrating his understanding of the trials and tribulations of the life of a graduate student, and for allowing me to stray from the traditional protocol of graduate work in order to structure my own education. I would also like to thank my other committee members, Dr. Vicki Watson and Dr. Eric Edlund, for their input and guidance. Other helpful contributors included Kinny Connell, Richard Czaplinski, and Geoff Dates, without whom the practical applications of this document and this education may have been lost on the author. Finally, I could never have successfully completed a project of this scope without the support and encouragement provided by my parents. Thank you.

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## CHAPTER ONE

### INTRODUCTION

I imagine there is a stream near you that has affected some parts of your life. This stream has seemingly been there forever, and you have used it in many ways, on occasions too numerous to recount. Perhaps you have gone swimming in it on a hot day, or cast a fishing line or two into its life-filled waters. Maybe you have even kayaked or canoed down it. Maybe you have gone bird-watching or hunting along its corridor, or just picnicked on its shores. It is also possible you get your drinking water from it and that, perhaps unknowingly, you flush your sewage into its seemingly endless flow. I suppose that after realizing all of these uses, multiplied by your many neighbors, you began to realize that your local stream is a resource which is in need of proper management and protection. After all, it would be unfortunate if your children and grandchildren could not drink from it, or picnic alongside it, just as you have. Therefore, you have decided that you would like to take an active role in protecting your local stream from further degradation, as well as to try and fix any problems that have already occurred. This essay is designed to help you get started.

The first step is to realize that you can make a difference. Citizen monitors are the members of a community who take an active role in protecting their local **watershed\***, and they are increasing globally in both numbers and importance. In 1988, the first edition of a United States Environmental Protection Agency (EPA) directory of citizen volunteer monitoring groups listed eighty-eight such groups, and the 1994 edition listed 517 groups. It is estimated that there are at least 1000 such groups today (Behar

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\* Words in bold-face type appear in the glossary beginning on page 166.

and Dates 1995, 1). Most projects enacted today with the purpose of protecting water quality actually begin as voluntary programs (Terene Institute 1993, 33).

What has worked best in the past has been citizen groups working in conjunction with local governments. Only thirty-six percent of America's rivers are monitored by the government, so additional information provided by citizens can be vital (Kellogg 1994, 1). The help of citizens has become increasingly important to the cause of protecting rivers for a variety of reasons. For example, the use of citizen monitors ensures that those who are likely to be most familiar with a watershed, its problems, and possible solutions play a major role in its stewardship (EPA 1995, 841-R-95-004, 1-5). It enables more frequent sampling because citizen monitors have easier access to sampling sites, thus allowing them to be "watchdogs" for compliance monitoring and enforcement. They also have a better opportunity to respond quickly to episodic events such as storms (Armitage 1989, *cited in* Campbell and Wildberger 1992, 12). Finally, citizen involvement leads to an increased understanding and respect for the stream system by the members of the community. River Watch Network (RWN) of Vermont goes so far as to say "it is essential that citizen groups are the ones to implement the projects from their monitoring efforts" (River Watch Network 1995).

The work most commonly performed by citizens is collecting water quality samples, identifying water quality problems, surveying fish and wildlife habitat, gathering photographic documentation, and staying updated on land uses affecting the entire watershed (EPA 1995, 841-R-95-03, 8-4; Murdoch, Cheo, and O'Laughlin 1996, x).

The importance of involving the community is invaluable. The Terene Institute of Washington, D.C., maintains that “public support is an essential step (in carrying out a successful watershed protection effort), and educating the public and local government is the key to gaining this support” (Terene Institute 1993, 12). After all, in the end we will conserve only what we love, we will love only what we understand, and we will understand only what we are taught (*cited in Texas Natural Resource Conservation Commission 1997, 26*).

The recruitment of community volunteers, however, can be a difficult process. This is sometimes the most time-consuming step for the citizen monitoring leader. When beginning to organize community support, it is best to begin with personal contacts, such as friends and family. Further recruitment involves contacting organizations, such as schools and churches, and placement of advertisements in the local media. In the case of recruiting, persistence usually pays off. The main issue though, regardless of who is being approached, is to convince the potential volunteer that this effort advances *their* goals. This means finding out what their goals are, and convincing them that their volunteer efforts will help them reach these goals. (An excellent source to help understand this process is: Buskirk, Jr., E. Drannon, Dennis Auker and Irving Hand. 1981. *Public participation: Citizen handbook*. Working for Clean Water. Pennsylvania State University Institute of State and Regional Affairs. Middletown, Pennsylvania.)

By now the reader may be wondering why it might be necessary to carry out this work. Perhaps the common belief within your community is that your stream is healthier than most and, being a part of nature, will be fine on its own. Unfortunately, this is probably not the case. A 1982 study by the Nationwide Rivers Inventory on the lower



forty-eight states, performed by the National Park Service to assess rivers for possible inclusion under the National Wild and Scenic Rivers Act, found that fewer than two percent of the streams were of “high natural quality” (Karr 1993, *cited in* Murdoch, Cheo, and O’Laughlin 1996, 249). The EPA estimates that about thirty percent of U.S. waters are impaired in one way or another, about two-thirds of that resulting from **non-point source pollution (NPS)**, which is pollution entering the stream over an area rather than at a point (Chesapeake Bay Program 1995, 2).

Unfortunately, the pressures are only increasing. Of all the resources found on this planet, the EPA (1991, 440/5-91-005) declares that water is the most limiting to human development since the demand for it continues to grow while the amount in existence will always remain constant. Problematically, not only is more and more water being used, mostly in our homes and factories, but it is also becoming more and more polluted. Almost every gallon used is polluted before being released back into the hydrological system (DePew, Reed, and Gleason 1993, 18).

(If you would like to look up available information for your local watershed, there is a site on the Internet maintained by the EPA called “Surf Your Watershed.” This site may help you find information on the watershed in which you live, but beware that not all watersheds are included in the database. To locate this site go to <http://www.epa.gov/surf>.)

To effectively combat this problem of degrading water quality, it is necessary to understand what is happening within the entire watershed, for stream degradation is largely a result of watershed land use. As H. Borland once stated, “any river is really the summation of the whole valley. To think of any river as nothing but water is to ignore

the greater part of it” (*cited in Friends of the Mad River 1996, 1*). Every person on earth lives within a watershed. Our challenge is to balance the human uses of a river with its overall health.

This document attempts to lead to an understanding of the elements of a river, and how they are interconnected. Chapter Two lists some ideas of how humans affect water quality and overall stream health. The ways in which these changes are brought about are numerous. A stream may be altered by dredging, **channelization**, diversions, dams, weirs, dikes, garbage/litter, toxic substances, sewage, bridges, roads, culverts, pipes, detention ponds, and storm drains. Some of our land uses which lead to decreased stream health include residential, commercial, industrial, forestry, mining, recreation, grazing, crops, and irrigation (Murdoch, Cheo, and O’Laughlin 1996, 95). The list can go on.

Chapter Two examines many of these agents of stream alteration in the context of stream parameters. The chapter is divided into thirteen different parameters, separated into three categories. The physical parameters included are sinuosity, slope, **substrate**, width-to-depth ratio, pool-to-riffle ratio, discharge, velocity, temperature, **turbidity**, and **riparian** vegetation. The chemical parameters included are dissolved oxygen (DO) and pH, and the only biological parameter discussed is **macroinvertebrates** (aquatic insects, snails, worms, etc.). These categories are discussed below. For each of these parameters, a definition is given, followed by common methods of measurement for each, the significance of each, common ways each is altered, and the effects of these alterations.

Chapter Three discusses the importance of understanding the history and current state of a stream (reconnaissance survey), followed by guiding the reader to answer some specific questions concerning the particular stream in question (site-specific survey). The

purpose of watershed analysis is to answer the following: What are we doing and how is it affecting the stream (Texas Natural Resource Conservation Commission 1997, 5)? As pointed out by the Friends of the Mad River (FMR) of central Vermont, a volunteer group organized to protect the Mad River, “not knowing how the river works, and how we contribute to the river's problems through our everyday activities, may be the biggest threat to the river” (Friends of the Mad River 1995, 20).

Chapter Four is a discussion of some field work carried out on Freeman Brook, a tributary of the Mad River in central Vermont. This chapter provides examples of the practical applications of the information provided in chapters one, two, and three.

Appendix A is provided to give the reader a sense of the various watershed inventories being used today, Appendix B provides examples of previous successful citizen monitoring efforts, and Appendix C provides a list of resources to help the reader continue on to the next step required to carry out a successful watershed analysis.

## CHAPTER TWO

### UNDERSTANDING STREAM DYNAMICS

#### CHANGING AND CONNECTED COMPONENTS

“A river is a dynamic system of inter-related physical, chemical, and biological characteristics” (Behar and Dates 1995, 9). Since one cannot measure every single aspect of a river, water quality indicators are used. These are selected characteristics that “tell us what we need to know” (Dates 1992, 3): When professionals refer to water quality, they usually mean those characteristics which make the water suitable or unsuitable for the uses that people wish to make of it (Texas Natural Resource Conservation Commission 1996, 3).

The physical component of a stream is often the most neglected because the measurements, although usually simple to make, are often difficult to interpret. For example, whereas a pH reading of 6.8 has a specific meaning in terms of its effect on aquatic life, a velocity reading of 3.4 feet per second does not necessarily indicate good or poor water quality. The physical component, however, is often directly altered by human actions, and this has a subsequent impact on the chemical and biological components. The physical component is shaped by the flow of water and the **sediment** load it carries, which depends on the climate and geology of the area (Montana Department of Environmental Quality 1995, 3).

The chemical component of water quality includes parameters in the **water column**, such as DO and pH which, as mentioned above, are discussed in this document. Other chemical parameters are acidity, alkalinity, salinity, **biochemical oxygen demand (BOD)**, and the concentration of certain chemical pollutants, such as heavy metals or nutrients. These measurements are almost always quantitative, making the chemical

component of a stream one of the easiest to study and to regulate. For this reason, analyses of these parameters are most common among volunteer groups, although the results produce a limited view of the overall health of the stream's ecosystem.

The biological component is difficult to quantify because it includes plant and animal life, and their respective habitats, both within the stream **channel** and along the riparian corridor. Aside from macroinvertebrates, which have been mentioned, other biological parameters include the vegetation within the **riparian zone**, the **algae** found on rocks along the stream bottom, bacteria, plankton and, of course, fish. The biological component is usually assessed according to the presence or absence of **indicator species**, as well as species density and habitat quality.

As noted previously, a stream is a dynamic system, meaning it is both changing and connected. Any one part is dependent upon all other parts. It is therefore important to emphasize the relative arbitrariness of this classification system of a stream into three components. Let us use riparian vegetation as an example. The riparian vegetation is biological in nature, but it has such a large impact on the physical component that, for the purposes of this document, it has been included with the other physical parameters. For that matter, it also has a large impact on the chemical and other biological parameters. The point is that it is difficult to divide such an interconnected and complicated system into three distinct subsets. This division into these three components helps us visualize the complexities and different parameters acting upon a stream, and facilitates discussion and a common understanding of the system as a whole. It is important, however, not to view this division as *de facto*. It needs to be understood that the system is ever-changing and complexly interconnected, so that any measurements taken only shed light on the

state of the stream at the particular time and place when and where the measurement was taken. Any singular measurement does not necessarily indicate good or poor water quality. For example, imagine taking a patient's pulse and temperature. These measurements may indicate that the patient is sick, but it will take many other tests to determine why.

As in any system, the parts work together to provide common functions. Stream systems conduct water and sediment runoff from an area toward the oceans (Dyckman, Way, and Kelly n.d., 147). Unfortunately, as streams concentrate flowing water, they also concentrate watershed pollutants (EPA 1994, *910/B-94-05*, 11), and humans contribute to this pollution in a myriad of ways. Typically, the headwaters of a stream are high-quality water, but this deteriorates downstream because of human land uses. In most cases, a stream will recover if left alone, but the healing process can often be shortened with some help from human intervention. This leads to the concept of **dynamic equilibrium**.

Natural systems, including streams, are in a constant state of change. A stream system changes dramatically from its headwaters to its mouth, from season to season, and from year to year (Dates 1990, 14). Even different **reaches** of the same stream may respond differently to the same activity, depending upon the natural characteristics of the site (Montana Department of Environmental Quality 1995, 1). This constant change occurs because the stream system is continuously attempting to establish an equilibrium, a "balance between the shape of its stream channels and the amount and force of water running off from its hillslopes" (Murdoch, Cheo, and O'Laughlin 1996, 63).

There are many ways in which a stream can lose this balance, not all of them the result of human action. Some of these causes and their effects are discussed here in Chapter Two. A greater question, however, may be how does one know if a stream has achieved dynamic equilibrium.

For the sake of simplicity, let us say a stream in dynamic equilibrium is one in which “the amount of sediment and water that enters the (stream) equals the amount that leaves it” (Murdoch, Cheo, and O’Laughlin 1996, 63). As the hydrologist Luna Leopold puts it, “each stream balances erosion, transport, and deposition in the context of its climate and landscape” (Leopold et al. 1964, *cited in* Harrelson, Rawlins, and Potyondy 1994, 3). This means that the overall stream is neither accumulating sediment or losing it (**aggrading** or **degrading**), although this may be occurring, in a balanced fashion, from one reach to another. Because of the ever-changing nature of stream systems, virtually none will be found in a state of dynamic equilibrium, but all will be in a state of transition as they perpetually strive for it.

Whether a stream reaches equilibrium depends upon its age, or maturity. In a mature stream, “no energy is wasted as the stream performs its function of transporting water and sediment through the system from the watershed to the ocean” (Leopold and Maddock, Jr. 1953, 51). What this means is that the river has attained a gradient and channel morphology which have adjusted to provide just the velocity required to transport this water and sediment load (Mackin 1948, *cited in* Leopold and Maddock, Jr. 1953, 51). It therefore has no excess energy to erode the channel banks and bottom. A stream in dynamic equilibrium is an example of a highly efficient system.

## MEASURES OF PHYSICAL INTEGRITY

### **Sinuosity**

*Definition:* Sinuosity is a measure of how much a stream meanders along its course. Left to natural forces, a stream will develop a series of alternating **bars**, resulting in a meandering channel. By so doing, “the erosive force of the flow is dissipated as the water travels a longer distance through the bends and curves. This results in a more stable system than a channelized (straight) stream whose erosive energy accumulates as it funnels straight downstream” (Murdoch, Cheo, and O’Laughlin 1996, 63). These meanders tend to form in a length that is seven to ten times the width of the channel (Leopold et al. 1964, *cited in* Swanson 1988, 97).

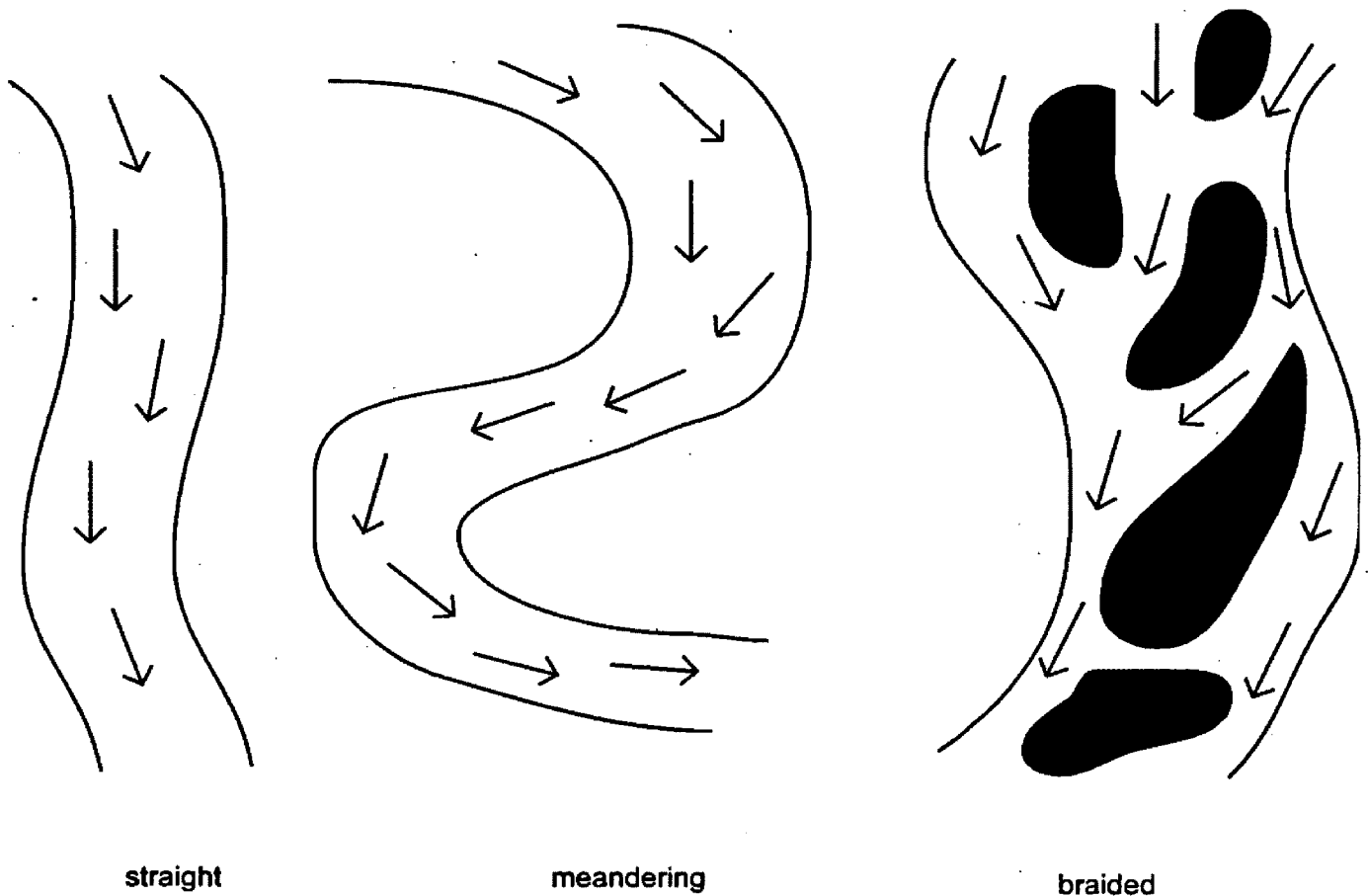
Even if a stream appears to be relatively straight, the **thalweg**, or the deepest part of the channel, has a meandering pattern (Government of Canada 1980, 47). This meandering has two functions: it slows down the stream as contact with the bottom and sides of the channel is increased, and this increased contact gives the stream more time to soak into the ground water supply (DePew, Reed, and Gleason 1993, 77). Streams are generally characterized as being straight, meandering, or **braided**, where braided means the stream has multiple channels. See *figure 1* for illustrations of these stream channel types.

*How Sinuosity is Commonly Measured:* The most commonly used measure for sinuosity is the Sinuosity Index (SI), determined by dividing the thalweg distance by the valley length (Leopold and Wolman 1957, *cited in* Gordon, McMahon, and Finlayson 1992, 312). A SI less than 1.5 is classified as straight (Government of Canada 1980, 48). Anything else is considered meandering, with a SI of 4 considered highly meandering.



Braided channels are more a result of heavy sediment loads and low discharges than they are of a high Sinuosity Index.

## CHANNEL TYPES



(figure 1)

On a large stream, one can accurately measure sinuosity on a United States Geological Survey (USGS) 7.5-minute topographic quadrangle map (see *Appendix C* for how to obtain a USGS topographic map), but a small stream would have to be measured in the field (Hansen et al. 1996, 15). The easiest way to gain an understanding of a stream's sinuosity is to fly above it. In fact, sinuosity was not even noticed as a parameter of streams "until the advent of air travel" (Langbein and Leopold 1966, H1).

*Significance:* An important function of a stream is the transport of sediment and water. Transport is most efficient when channels are as close to a semicircular shape as possible (Heede 1980, 8). To alter this shape is to reduce the stream's ability to perform its functions. Langbein and Leopold (1966, H8) declare that meandering is a characteristic of a stream in equilibrium since straight reaches are rare and meanders are common. If a stream is straightened, either by human action or **flooding**, it will begin to deposit sediment on one side of the channel and erode it on the other. This process creates meanders and continues until the meanders are so extreme they are eventually cut off, leaving remnant channels such as **oxbow lakes**. Once the channel is cut off, the process begins again. In this way, a stream is constantly changing, although within its own limits. This is an example of dynamic equilibrium and, just like any other system, a stream will work to reestablish equilibrium once it has been lost.

As the stream goes through this process of reestablishing equilibrium, the aquatic habitat may be drastically diminished. This occurs because sinuosity helps regulate velocity and therefore the erosion potential of a stream. If the velocity is too high, the banks will erode and the riparian vegetation will be altered. Also, if a stream is straightened, flooding will increase because the capacity of the **floodplain** to absorb water is reduced. These actions help the stream establish a new channel, but degrade aquatic habitat in the process.

Another feature of sinuosity is its use by watershed managers as a comparative indicator. The general morphology of a stream can be estimated from its SI. "In general, low sinuosity suggests steeper channel gradient, fairly uniform **cross section** shapes, limited bank cutting, and limited **pools**. High sinuosity is associated with lower

gradients, asymmetrical cross sections, overhanging banks, and bank pools on the outside of curves” (Platts, Megahan, and Minshall 1983, 15).

*What Alters Sinuosity:* The sinuosity of a stream is mainly altered by channelization. Streams are commonly channelized to “control flooding and flood damage, increase available land for agriculture, improve navigability,...maintain hydraulic efficiency of streams” (USDOI 1982, *FWS/OBS-82/24*, iv), and reduce the number of highway and railroad crossings. Other ways in which stream sinuosity is commonly reduced are in-channel gravel mining (another form of channelization), damming, or reduction of flow which indirectly alters sinuosity. Changes in flow can alter sinuosity because the rate of flow is the most important natural contributor to channel migration (Nanson and Hickin 1986, 503). If a stream has less water in its channel, it has less erosive energy available for migration as it seeks equilibrium.

*Effects of Alterations:* By decreasing a stream's sinuosity, we increase the stream velocity, which increases the erosive energy. This translates into erosion of the streambanks, which increases the rate of **sedimentation**, or the process of sediment being deposited into the stream channel. This has profound impacts on the aquatic habitat for the biological community.

Another effect of decreased sinuosity is an increase in flood potential. If the length of the channel is decreased, and the flow of water remains the same, the depth must increase. When coupled with the decreased storage capacity of the floodplain, owing to less contact between the stream and its surrounding riparian **wetland**, it becomes evident why many stretches of channelized streams are equipped with levees that are built higher and higher with each successive flood.

Streambank erosion associated with channelization results in the loss of riparian vegetation and associated stream shading, thus increasing stream temperature. This, accompanied by the increase of sediments from sloughing banks and the resulting infilling of pools and riffles, degrades available fish habitat (Beschta and Platts 1986, 377).

Finally, decreasing sinuosity reduces the ability of the stream to soak into the ground water, since the stream will move along its channel more quickly. This results in higher **peak flows** and lower **base flows**. During wet times, the flow in a channelized stream will be higher because of less water soaking into the floodplain, resulting in more water remaining in the channel. During dry times, the flow in a channelized stream will be lower because the stream relies on the influx of ground water to replenish its flow. If the amount of ground water available is reduced, then the result may be lower flows and, thus, higher temperatures, which pose a danger to the aquatic biota.

*Additional Source:* For more information regarding sinuosity, see Leopold, Luna B. and M. Gordon Wolman, *River channel patterns: Braided, meandering and straight*, Geological Survey Professional Paper 282-B, U.S. Department of the Interior (USDOI), Washington, D.C., 1957.

## **Slope**

*Definition:* Slope, or gradient, is the degree of steepness or flatness of the water surface. Technically, it is “the drop in water surface elevation per unit length of channel” (Platts, Megahan, and Minshall 1983, 14). A gradient below 1.5 percent is considered low (Potyondy and Hardy 1994, 517), with other classifications being moderate or high. These terms are used to help managers discuss stream characteristics by using a common

classification system. A stream with a low gradient is not necessarily in better or worse condition than one with a high gradient. Streams are different, and so demonstrate different characteristics. A stream with a low gradient, however, most likely has similar characteristics to other streams of low gradient.

The overall slope of a channel is called the **longitudinal profile**. (See *figure 2*, which shows the longitudinal profiles of the Eel River and its major tributaries, which drain the Pacific Coast Ranges in northern California. Note how the longer the stream, the greater the tendency toward a concave-upward profile (USGS, *adapted from Muller and Oberlander 1984, 382*.) A stream's longitudinal profile can be described as either convex or concave. A convex shape typifies a young stream as it is still in the process of carving the ideal channel to fit its flow, whereas a stream with a concave shape signifies maturity as it has produced a stream that no longer changes so rapidly. Such a stream has a smooth transition from the un-channelized headwaters to the channel and, largely because there are no sudden drops in the stream, sediment production is negligible (Heede 1980, 7). Once again, this refers to the concept of dynamic equilibrium. It must be understood, however, that it is natural for a stream system to change. It is an unnatural rate of change, or change resulting from unnatural causes, of which all watershed managers, including the citizen monitor, need to beware.

*How Slope is Commonly Measured:* The overall slope of a stream can be measured on a USGS 7.5-minute topographic map if one can determine the elevation of the river at the source, the elevation at the mouth, and the length of the channel. Slope is simply the difference in elevation divided by distance (Gordon, McMahon, and Finlayson 1992, 109). If this data cannot be accurately determined from a map, one must use either

a clinometer or rods and measuring tape. (See *Additional Source* below for sources with details on how to carry out these methods.) The measurement of slope has no units. It can be expressed as feet per feet, meter per meter or, more commonly, as a percentage.

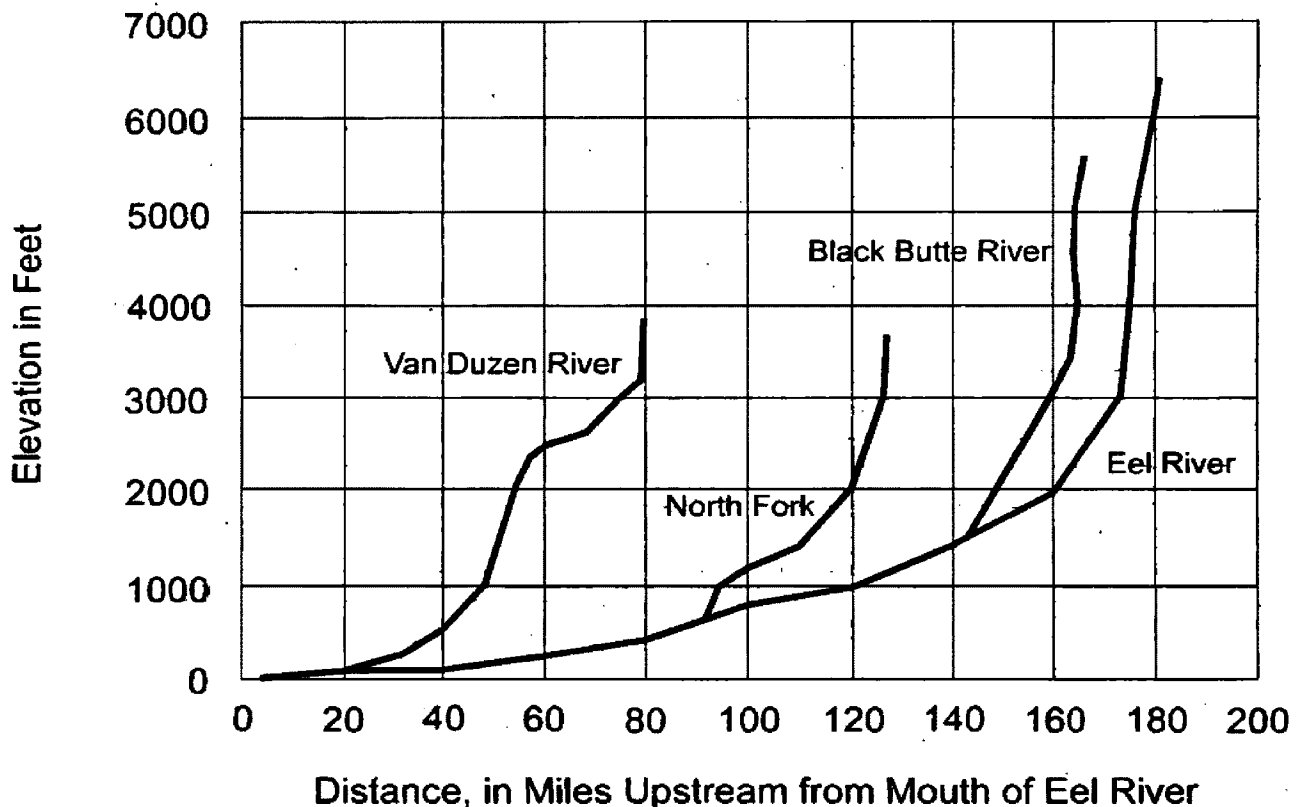
*Significance:* The slope of the land determines the route of the stream since “water will always flow along the line of steepest slope” (Texas Natural Resource Conservation Commission 1996, 12). Velocity is thus largely dependent upon slope. As stated earlier, a stream's velocity helps determine erosive energy, sometimes called stream power. The slope of the land therefore partially determines the amount of erosion occurring, and thus the composition of the **substrate**, which in turn determines the in-stream habitat of the aquatic biota.

As one travels along a stream from its headwaters to its mouth, the slope usually gradually decreases (see *figure 2*). Because of this, the average size of the sediment pushed along the bottom of the stream, called the **bedload**, will decrease, the channel width will increase, the frequency of side channels, such as oxbow lakes, will increase, and the frequency of pools will decrease (Government of Canada 1980, 6).

Like sinuosity, slope is commonly used to compare streams. Stream ecologist Kenneth Cummins distinguishes between four different stream categories related to gradient: mountain, piedmont, valley/plains, and coastal (*cited in EPA 1991, 440/5-91-005, 27*). In this way, managers discussing a stream of a certain slope can assume certain characteristics without actually seeing the stream. They can do this because the slope is dependent upon the topography, landform, and elevation, which contribute to the determination of the on-site vegetation. Cummins goes on to categorize habitat types according to gradient by dividing streams into either high or low gradient. A high

gradient stream has a prevalence of fast water, characterized by riffles and **runs**, whereas a low gradient stream has a prevalence of slow water, characterized by pools and **glides**. In this way, Cummins uses slope as the primary factor to determine what habitat is available in the stream.

## LONGITUDINAL PROFILE



(figure 2)

*What Alters Slope:* Slope is a function of two factors, elevation change and distance, so altering either of these alters slope. Changing the elevational difference requires either a lot of time or a lot of money. Typically, mountains are raised by Mother Nature and worn down by weathering, sometimes by mining companies. Sometimes the

elevation of the source of a stream is increased as a result of **headward erosion**, which is the cutting of a **streambed** in an uphill direction. This type of erosion commonly occurs at sharp drops in the streambed. Floods and dams can change the elevation of the mouth of a river. This change occurs as sediments build up at the delta and slowly raise the **base level** of the stream, thereby slightly reducing the elevational difference. However, the elevation change is minimal when looked at over the entirety of the stream's length, although the alteration of the slope of a specific stream reach can profoundly affect the stream quality of that particular reach and of the reach just downstream.

A much more common method of altering slope involves altering the length of the channel. Shortening a channel increases its slope, and vice versa. Channel length is altered by increasing or decreasing channel sinuosity, usually through channelization.

*Effects of Alterations:* As previously stated, slope largely determines velocity. If a stream's slope is decreased, the increase in velocity may result in problems such as increased erosion, scouring of aquatic habitat, an increase of sediment in the channel, a decrease of riparian vegetation density (and the resultant decrease in stream shading), and an increase of stream temperature. To decrease slope generally results in **suspended sediment** (sediment suspended in the water column) settling out onto the streambed, which reduces areas of spawning. This often results in an increase in the width of the stream, the depth of the stream, or both. Either way, the stream's habitat characteristics will be altered.

*Additional Source:* For more information on measuring stream slope, see Gordon, Nancy D., Thomas A. McMahon, and Brian L. Finlayson, *Stream hydrology: An introduction for ecologists*, 1992, pp.109 and 132-135.



## **Substrate**

*Definition:* Substrate is the material that makes up the bed of a stream. It includes both organic and inorganic material. Substrate size varies naturally from bedrock down to boulders, cobbles, gravels, sand, and very fine sediments such as clay particles. (See the classification scale in *How Substrate is Commonly Measured and Assessed* for numerical ranges for each substrate category.) This variation mostly depends upon the regional geology and topography of the landscape (Terrell and Perfetti 1989, 17), but it also depends upon the characteristics of each stream reach.

Substrate particle size typically decreases in the downstream direction. In its steep mountain headwaters, a stream may have carved down to bedrock as it cascades rapidly down the hillside. As it flattens out in the valley, the sediment it has picked up settles out of the water column and gradually builds on the channel bed. In this way, streams act as an integral component of the shaping of the earth's surface, slowly bringing material down from the mountainsides and depositing it in broad floodplains, estuaries, lakes, and oceans.

The substrate particle size also varies within a single reach of a river. Riffles and runs are areas of relatively high velocity, and therefore the finer sediment particles are washed downstream from these areas. Riffles and runs are thus typically predominated by gravel, cobble, and sometimes boulder substrates. On the other hand, pools and glides, areas of slow-moving water, commonly have a bed consisting of small particles, which settle in the slower flow. In fact, one can estimate the velocity of a stream by examining the substrate (Government of Canada 1980, 49).

*How Substrate is Commonly Measured and Assessed:* The three most common methods of measuring substrate size are cobble **embeddedness**, percent surface fines, and the pebble count (EPA 1994, 910/B-94-05, 27). The first two are used to determine the effects of sedimentation on aquatic organisms, and the third uses various methods to categorize substrate particles.

Cobble embeddedness is calculated to determine the degree of **siltation** of a cobble stream. A cobble stream should not have a large percentage of fine sediments, but if these fines reach the stream because of erosion, and the stream velocities are not high enough to lift them up (**entrainment**) and carry them downstream, they will settle and embed the cobbles they settle around. To measure embeddedness, one can pick up a cobble partially embedded in fine sediments and either note the line of color differentiation on the rock or, with a finger, mark the spot on the rock up to which the rock was buried. The embeddedness is the percentage of the rock's vertical rise that was buried in sediment. This method is seldom used by professionals, however, because the results are largely subjective and it is difficult to be precise. It is a common method, on the other hand, in watershed inventories designed for citizen monitors.

Percent surface fines is another method used to assess the impact sedimentation has on aquatic habitat. Percent surface fines is simply a visual estimation of the percentage of the stream bottom within a chosen reach covered with fine sediments. It is therefore also subjective in nature, and so not often used by professionals in the field.

The pebble count is the most common way to measure substrate particle size, especially for citizen monitors. The usual method is the Wolman pebble count, which consists of randomly selecting at least one hundred particles from the streambed and

measuring them. This selection process can be done using grids, transects, or the random step-toe procedure. The random step-toe procedure involves standing in the stream, moving the finger down toward the big toe, and picking up the first particle touched (Harrelson, Rawlins, and Potyondy 1994, 49). When measuring the particle, one should look at its length, width, and depth, and use the one of intermediate dimension (Stream Systems Technology Center n.d., 1). Once at least one hundred particles have been measured, they need to be classified to determine the percentage of the streambed falling within each category.

The classification system most often used in the United States is that of the American Geophysical Union (AGU). This system builds upon the Wentworth scale, a convenient classification system because the sizes correspond closely to United States standard sieve mesh openings. The Wentworth classification scale is as follows (*adapted from* Gordon, McMahon, and Finlayson 1992, 196):

Inorganic Materials (classified according to size)

Bedrock	
Boulder:	>256mm (10")
Cobble:	64mm - 256 mm (2.5" - 10")
Gravel:	2mm - 64mm (0.1" - 2.5")
Sand:	0.06mm - 2mm (gritty)
Silt:	0.004mm - 0.06mm
Clay:	<0.004mm (slick)

Organic Materials (classified according to type)

Detritus:	sticks, wood, coarse plant materials
Muck/Mud:	black, very fine organic materials
Marl:	gray, shell fragments

Furthermore, aside from bedrock, each of the above inorganic categories can be further subdivided. For example, gravel, which covers a wide range from two

millimeters to sixty-four millimeters, is often broken down to include categories of very coarse, coarse, medium, fine, and very fine gravel.

*Significance:* The life on the bottom of the stream is called the benthos. Much of a stream's production is concentrated on the bottom, where **benthic** algae, bacteria, and fungi grow, and where aquatic insects and other macroinvertebrates feed and grow, supplying food for fish. It is also here where fish reproduce, egg development takes place, and where we see the rearing of fish, frog, and salamander juveniles (Murdoch, Cheo, and O'Laughlin 1996, 100). In fact, because substrate particle size affects availability of detritus (the primary food source for many macroinvertebrates) (Rabeni and Minshall 1977, *cited in* USDOI 1982, *FWS/OBS-82/24*, 47), it was found that "macroinvertebrate distributions (are) more closely related to substrate than to water quality" (Ruggiero and Merchant 1979, *cited in* USDOI 1982, *FWS/OBS-82/24*, 47). If the water quality is extremely poor, however, macroinvertebrate distributions will be governed by the water quality. A greater substrate diversity will therefore typically lead to a greater diversity of organisms, which is an indicator of a healthy stream. For all of these reasons, the stream ecologist Kenneth Cummins determined that "no single factor has greater biological significance in the stream than the physical nature of channel substrate" (Cummins 1974, *cited in* Beschta and Platts 1986, 374).

*What Alters Substrate:* The alteration of the channel substrate is generally a result of sedimentation, primarily owing to erosion. Sedimentation can occur in the uplands as sediments wash downslope, on the streambanks when sediments fall directly into the stream, or on the channel bed as a result of **downcutting** (erosion of the streambed). Human actions, of course, can contribute a large percentage of sediments to the stream.

Over geologic time, however, sedimentation is “dominated by rare, extreme natural events” (EPA 1994, 910/B-94-05, 44). These might include wildfires, large floods, or landslides.

Human actions such as upland logging and riparian zone disturbance generally lead to sedimentation. With the removal of vegetation, the rootless soil only needs an agent, such as rain or wind, to dislodge it and allow it to travel according to gravity and end up in the stream channel. Other human actions which can deposit large amounts of sediment to the channel are construction and road-building. The building and subsequent lack of maintenance of logging roads, for instance, is a primary source of sedimentation to streams in much of the mountainous areas of the western United States.

Flow is yet another factor affecting substrate composition. An increase in flow translates to an increase in velocity which, in turn, translates to a greater capacity of the stream to transport larger particles, termed stream **competence**. If a stream is able to move the larger particles, it can be assumed that the smaller particles will wash out of the system. The average particle size left behind will therefore increase. One usually finds these larger particles during or soon after the annual peak flow, called the **channel maintenance flow**. This relationship of flow to substrate size is of especial significance when one considers that “the sediment-carrying **capacity** of a stream increases exponentially as a function of discharge. A tenfold increase in discharge may increase the sediment load a hundredfold to a thousandfold” (Platts et al. 1987, 39). Another effect of high flows, however, is scouring and cementing of a stream bottom. These effects leave little or no habitat available for macroinvertebrates or fish spawning (Murdoch, Cheo, and O’Laughlin 1996, 100).

There are two other significant ways of altering substrate. The first is dam failure. As flow slows down or ceases at a dam, the suspended sediments settle out of the water column and accumulate at the bottom of the reservoir. In the case of dam failure, this buildup of fine sediments, defined as particles less than six millimeters in diameter (Potyondy and Hardy 1994, 510), will be washed downstream, resulting in a dramatic reduction in size of the average substrate particle at downstream locations. Beaver dams trap sediment in the same way as manmade dams, but fail much more often. The problem with dam failure can be compounded as the high flow released from one broken dam can result in the destruction of successive dams downstream. This release of fine sediments back into the system is not unique to dams. The removal of any object that traps sediment, be it a boulder or a log, will result in a release of fine sediments downstream.

The second significant method of substrate alteration is that of gravel removal. In many states it is legal to extract a limited amount of gravel directly from the stream channel. Gravel removal alters the substrate in many ways: the heavy machinery usually required to remove it damages the riparian zone, resulting in increased sedimentation to the stream; the actual removal of the gravel often leaves behind a greater percentage of fine sediments; the process of extraction usually results in the stirring up of fine sediments, some that wash out of the system and some that re-settle on the streambed; and submerged aquatic vegetation commonly takes hold on gravel bars and traps sediment behind it, so as this vegetation is removed along with the gravel, this trapped sediment is released back into the system.

*Effects of Alterations:* The primary concern of substrate alterations is the effect of fine sediments, often simply called “fines”, on aquatic habitat. Commonly used thresholds by watershed managers deem that areas with less than five percent fines allow for optimal habitat, while degraded habitat may occur when fines are greater than thirty percent (Raleigh et al., *cited in* Friends of the Mad River 1995, 62; McNeil and Ahnell 1964, *cited in* Platts n.d., 249). As this percentage of fines increases, spawning areas are buried and the interchange between the ground water and the surface water is blocked, reducing DO levels in the spawning gravels. If the sediments are then disturbed after the streambed has been effectively sealed, the water may seep into the ground water at a high rate, possibly causing the stream to go underground for a while, with obvious impacts to aquatic life (Montana Department of Environmental Quality 1995, 25).

The ideal aquatic habitat has a substrate composed of diverse particle sizes (EPA 1983; Ball 1982; Hamilton and Bergersen 1984, *cited in* EPA 1991, 440/5-91-005, 29). This habitat is optimal for benthic macroinvertebrates, the primary food source for many fish. A study conducted by G. Wayne Minshall found that increased deposition of silt, resulting in the burial of stream cobbles, resulted in a reduction of insect species diversity (Minshall 1984, *cited in* EPA 1991, 440/5-91-005, 30). This then correlates to a reduction in fish species diversity. The Fish and Wildlife Service (FWS) took it one step further to say that “if permanent alteration of the substrate occurs, a shift in species composition, diversity, density, and biomass can be expected” (USDOI 1982, 49).

The Government of Canada’s *Stream Enhancement Guide* also points out that a diversity of particle sizes on the streambed results in a more stable stream system. They do so by explaining how the smaller particles can fill the voids between larger particles.

This results in the larger particles being locked into place, thus solidifying the streambed (Government of Canada 1980, 49).

*Additional Sources:* For different classification systems used to categorize substrate particles, see Stream Systems Technology Center, *Ask Doctor Hydro*, Denver, Colorado. This article includes the Wentworth Scale and the classification systems used by the American Geophysical Union, the United States Geological Survey, the American Society for Testing and Materials, and the United States Department of Agriculture.

For a description of various methods used to sample, measure, and categorize substrate, consult: Platts, William S., Walter F. Megahan, and G. Wayne Minshall, *Methods for evaluating stream, riparian, and biotic conditions*, USDA Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-138, Ogden, Utah, May, 1983, pp.15-20.

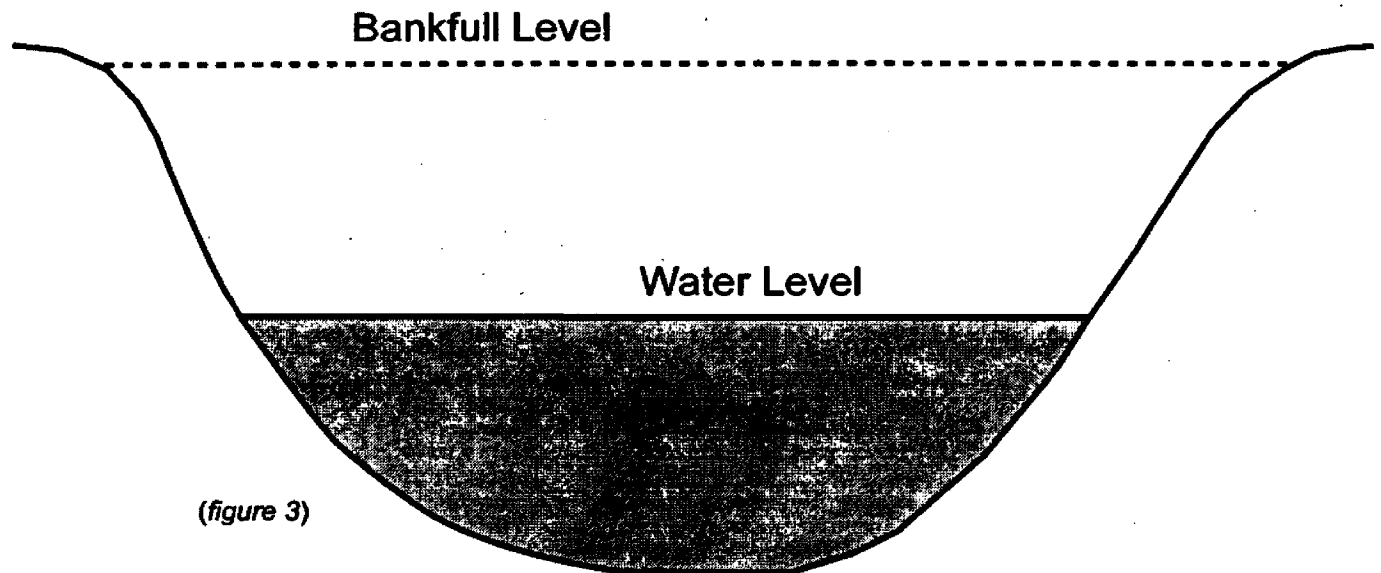
### **Width-to-Depth Ratio**

*Definition:* A stream's width-to-depth ratio describes the shape of its channel at a given cross section. The ratio is simply a measure of the width of the channel in relation to the mean depth of the channel, based on the stream's depth at **bankfull stage** (here used interchangeably with "bankfull level," which is the level at which water fills the entire channel). See *figure 3* for an illustration of bankfull level.

The ratio of width to depth varies naturally, of course, depending upon the discharge of the stream and the morphology of the channel. It also depends upon the location of the cross section at which the measurement is taken. For example, cross sections in straight reaches usually have higher width-to-depth ratios than those in bends. This is because bends are associated with pools, and the deepness of these pools lowers

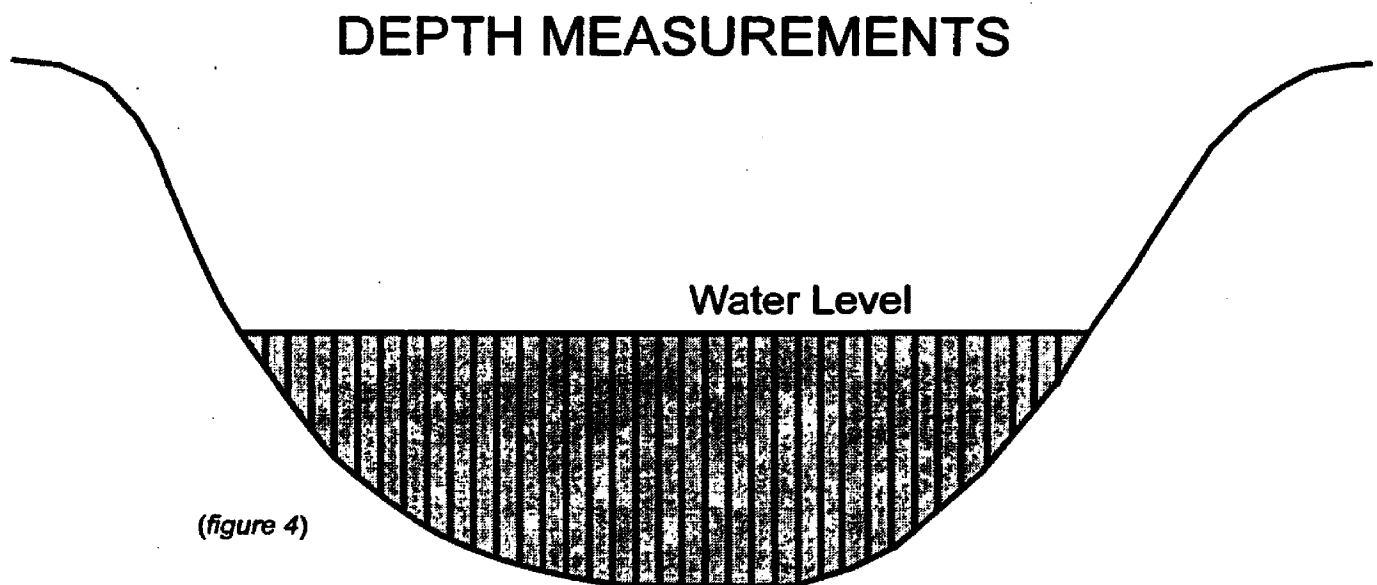


the width-to-depth ratio. In fact, “the sharper the bend, the deeper the pool, and the smaller the ratio” (Heede 1980, 16).



*How Width-to-Depth Ratio is Commonly Measured:* As mentioned, the measurement of the width-to-depth ratio is determined according to the bankfull stage. Measurements can be taken during low flow, however, if the bankfull level is identified and marked with a string. The bankfull level, however, can be difficult to identify, especially in steep streams normally found in mountainous areas. There are a couple of different methods to measure bankfull level. One is to identify the slope break on the streambank, and another is to notice the vegetation change on the bank. (See *Additional Source* for where to find more information on identifying the bankfull level.) Once bankfull level has been determined, the width can be measured simply by running a measuring tape across the channel, from the level of bankfull stage on the left bank to that on the right bank. Be sure the line of measurement is perpendicular to the stream channel.

The measurement of mean depth is slightly more complicated. The mean depth is defined as the cross sectional area divided by the width (Heede 1980, 16). To determine this requires taking multiple measurements of channel depth across the stream channel (see *figure 4*). Harrelson, Rawlins, and Potyondy (1994, 46) suggest taking at least twenty-five to thirty measurements. According to them, the discharge “lost” at the edges is considered negligible. (See *Additional Source* for further references on measuring cross-sectional area.)



*Significance:* The width-to-depth ratio can be used to determine the relative stability of a stream system. World-renowned hydrologist Dave Rosgen considers streams to be unstable if the width-to-depth ratio is greater than twelve-to-one. It is important, however, to know whether this ratio is in the process of increasing or decreasing. If livestock grazing in the riparian zone has recently been eliminated, a stream may be in a stage of recovery. In this instance, a ratio of fifteen-to-one may show the stream to still be unstable according to Dave Rosgen, but data acquired over time will

show that the system is recovering, and therefore does not necessarily need active management.

The width-to-depth ratio is basically a function of the discharge of the stream and the erosional rate of the streambanks or channel bed. A stream with a low ratio usually has a healthy riparian zone, which prevents the streambanks from eroding, allows a stable substrate to prevent channel **incisement**, or downcutting, and an adequate flow which provides sufficient depth to keep the ratio low.

Many other measures of stream health are related to this ratio. A high ratio is often associated with low flows, warm temperatures, and a significant impact by sedimentation. All of these can adversely affect the biological component of the stream. On the other hand, a low ratio is often associated with adequate flows, a healthy riparian zone, a diverse substrate, and a pool-to-riffle ratio representative of a healthy stream habitat. Each of these indicates a system that balances stability and change to support a diverse aquatic biota.

The velocity of a stream and the erosional force it exhibits can also be estimated from the width-to-depth ratio (Leopold and Maddock, Jr. 1953, 52). A high ratio indicates a relatively low velocity since the flow is spread out over a larger area. This correlates to a smaller erosional force, but it can still lead to significant streambank erosion if the riparian zone has been denuded. It is this loss of riparian vegetation that generally leads to the widening, and therefore the decreasing depth, of a stream.

*What Alters Width-to-Depth Ratio:* The width-to-depth ratio can be altered by changing either the width or the depth of the channel. The depth may be altered by altering the flow of the stream, perhaps decreasing it by building a dam or extracting

water for irrigation, or increasing it by eliminating vegetation within the watershed and paving over a portion of the surface. However, the width-to-depth ratio is generally altered by the widening (or narrowing in the case of recovery) of a stream. As the width changes, the depth is altered as the water is either spread out over a wider channel or confined to a narrower one.

The width of a stream increases as a result of the erosion of streambanks. Streambank erosion, however, is sometimes the end result of downcutting. Let us first examine what often leads to the direct erosion of the streambanks, then discuss how downcutting eventually leads to the rapid erosion of streambanks.

The two main ways to widen a channel by eroding a streambank are to remove the riparian vegetation, and thus allow the force of the stream to erode the bank, or to actively erode the bank by direct impacts, such as trampling by livestock. The riparian vegetation is sometimes directly removed by logging activities. More often, however, this vegetation is removed by more subtle methods. For example, the stream's power may be increased to a point where the existing riparian vegetation can no longer withstand the force. Stream power is determined by a combination of the water discharge, the sediment load, and the velocity. If any of these increase, the result may be streambank erosion, and thus channel widening. These can all come about from vegetation removal (including upland vegetation removal) and channelization. Removal of riparian vegetation also results in colder stream temperatures in winter owing to the decrease in forest insulation, and thus lower ground water temperatures. This can lead to increased damage from ice scour.

Another form of channel erosion is incisement, or the downcutting of the stream through the channel bed. This is a natural problem which is sometimes brought about, and oftentimes compounded, by human interference. Channel incisement usually leads to massive streambank erosion and commonly occurs when the banks are armored by **riprap**. If the banks are armored, virtually all of the erosive energy of the stream is used to erode the channel bed. Channel incisement often occurs as a result of stream channelization, an increase in stream flow, or a decrease of the sediment supply.

Reduction of the sediment supply, accomplished by the building of a dam, for example, creates "hungry water." This is water that has lost its upstream sediment load. A given flow of water at a given velocity is capable of carrying a given sediment load. This sediment load will vary depending upon the soil characteristics of the region, but if the sediment load is unnaturally decreased, the stream will pick up more sediment as it travels downstream so as to replace the lost upstream sediment (Heede 1980, 5).

Once a stream is incised, there is no known route to recovery other than allowing the stream to follow its own course of seeking equilibrium. This process involves phases of erosion, widening, and deposition (Swanson 1988, 96). The erosion phase consists of downcutting until it reaches a permanent feature, such as bedrock. In the widening process, the stream rapidly erodes its banks as it tries to establish a new floodplain, which it will do until it is once again capable of transporting the water and sediment its flow tends to carry. The deposition phase is the deposition of the sediments it has collected, thus rebuilding the channel bed.

Streams also widen if they receive a sediment load in excess of their ability to transport sediment, called their carrying capacity. When this happens, the sediment will

settle out of the water column and slowly fill up the channel. The result is a smaller channel trying to transport the same amount of water. The stream must therefore become wider. In extreme cases, a stream in these circumstances will become braided (form multiple channels). Braiding allows the stream to have a lower width-to-depth ratio in its primary channel, while several other channels crisscross this primary one.

Sometimes a stream may become narrower. If streamside trees are removed, grassy vegetation, which is normally shaded out by the trees, “develops a sod that gradually encroaches on the channel banks” (Zimmerman 1967; Sweeney 1992, *cited in* Chesapeake Bay Program 1995, 10). This stream narrowing can be detrimental to aquatic organisms because the loss of stream width equates to a proportionate loss of habitat (Chesapeake Bay Program 1995, 10). In other words, the widening of a channel is detrimental to the system because it adversely impacts the riparian vegetation, which regulates much of the activity within the system. The narrowing of a channel can also be detrimental to the system because it reduces aquatic habitat. If the stream is recovering from earlier widening, however, the lost habitat is considered to already be poor quality habitat.

*Effects of Alterations:* The widening of a stream often continues until a barrier is reached or active management is begun. As a stream widens, it destroys the riparian vegetation and deposits more sediment into the stream. This increased sediment load increases the stream power, which leads to more erosion downstream, and the destruction of the riparian vegetation leaves the streambanks vulnerable to still more erosion. Also, if this persists until the channel is so wide that the stream only fills a small percentage of it (an incised stream occupies about five percent of its channel, compared to an average

of twenty percent for non-incised streams) (Shields et al. 1994, *cited in* Shields, Knight, and Cooper 1995, 975), the water table will be drawn down, making it more difficult for riparian vegetation to colonize the new streambanks.

All of these impacts, of course, have grave effects on the aquatic habitat. The increased sediment, as has been discussed, will fill in pools and smother spawning areas. The decreased depth will lead to warmer temperatures in the summer and cooler temperatures in the winter. The decreased depth will also cause once existent pools to disappear, thereby reducing the habitat diversity so essential to a healthy stream system.

In addition to the effects on the biological component of a stream, the alteration of the width-to-depth ratio by way of channel incision can lead to instability for the entire watershed drainage system by lowering the base level for all of the **main-stem's** tributaries. (The main-stem is the largest river of the watershed and the tributaries are the feeder streams to that river) (Shields, Bowie, and Cooper 1995, 971). Lowering the base level alters the system both upstream and downstream of the affected site, as the stream adjusts its physical characteristics to be in harmony with its new shape.

Another significant impact of concern is that of channel braiding, mentioned earlier. Any stream cross section reflects the amount of water and sediment the stream is accustomed to carrying. By altering the width of the stream, the ability to transport the water and sediment load is effectively altered (Montana Department of Environmental Quality 1995, 21). The stream will therefore attempt to break up into smaller channels to afford it some depth and velocity (within the primary channel) so that it can once again effectively transport this water and sediment (Heede 1980, 16). This results in "extreme channel instability (and) frequent lateral migration," as well as the continuing "inability

to effectively convey upstream inputs of water and sediment” (Jackson and Van Haveren 1984, 695).

*Additional Source:* For more information on how to determine cross-sectional area and the line of bankfull stage, consult: Harrelson, Cheryl C., C.L. Rawlins, and John P. Potyondy, *Stream channel reference sites: An illustrated guide to field technique*, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-245, Fort Collins, Colorado, April, 1994.

### **Pool-to-Riffle Ratio**

*Definition:* Pools are areas of relatively deep, slow-moving water. They are scoured as water flows over a log or boulder, as it flows underneath a log or other fragment of **large woody debris (LWD)** (also called coarse woody debris (CWD) or large organic debris (LOD)), or as water is deflected by a boulder or other large outcrop (Beschta and Platts 1986, 372). As the water is forced into a localized spot by these actions, the increased turbulence scours out a hole, or pool. Pools are also formed by channel blockage caused by debris jams, landslides, and dams made by both man and beaver.

Riffles are areas of shallow, fast-moving water. They are characterized by gravel bottoms and whitewater. Riffles are formed by high flows accumulating bedload in the channel, but they can only be seen during low flows. At higher flows, the physical character of the stream is dominated by runs and pools.

“Natural channels characteristically exhibit alternating pools (and) riffles regardless of the type of pattern” (Leopold and Wolman 1957, abstract). This alternating pattern is generally spaced at a regular interval, with an interval distance five to seven



times the width of the channel (Leopold et al. 1964, *cited in* Heede 1980, 10; Winborne 1989, 2; Keller and Melhorn 1978, 1802). The relationship of pools to riffles, be it by number, percentage, or length (see *How Pool-to-Riffle Ratio is Commonly Measured*), is called the pool-to-riffle ratio. The optimal pool-to-riffle ratio given by most ecologists is one-to-one. The total number of pools and riffles, however, can be more important than the ratio of one to the other. If there is a low number of pools and riffles, the ratio may still be one-to-one, but the habitat diversity will be low (Murdoch, Cheo, and O'Laughlin 1996, 89). Raleigh *et al.*, for example, state that the optimal brown trout habitat is found in streams consisting of 50-70 percent pools and 30-50 percent riffles/runs (Raleigh et al. 1986, *cited in* Friends of the Mad River 1995, 61).

*How Pool-to-Riffle Ratio is Commonly Measured:* There are three common ways to measure the pool-to-riffle ratio, each done within a single stream reach. All three are expressed as a ratio and therefore have no units. One involves counting the number of pools and comparing the result to the number of riffles. Another is to calculate the overall percentage of stream area occupied by pools and compare the result to the same figure for riffles. The third is to measure the combined length of pools and compare the result to the combined length of riffles. Remember, as a preliminary assessment, a ratio of one-to-one is optimal. To further assess the habitat diversity, the individual pools and riffles will need to be examined, and macroinvertebrate samples will need to be taken (see *Macroinvertebrates* section for more information).

*Significance:* Pools and riffles are important components of the aquatic habitat. Runs and glides also play important roles but, without adequate pools and riffles, the habitat will be relatively poor. Alternating pools and riffles at an interval of five to seven

channel widths can signify stable channel geometry (Langbein and Leopold 1966, H1). The ideal diversity of habitat, however, comes not in just having alternating pools and riffles, but in having pools of varying width, depth, and type.

Pools provide resting and feeding areas for fish and, if deep enough, can provide cover. A pool at least eighteen inches deep can provide shelter for fish from high velocities, high temperatures, and predators (Friends of the Mad River 1995, 62). Pools also help dissipate a stream's energy during times of high flow (Beschta and Platts 1986, 372). Riffles produce food (especially aquatic insects) for fish, and are good spawning areas, because it is here that velocities are high enough to flush fine sediments downstream, thus "cleaning" the substrate. This increased velocity is also important for the transport of DO. For these reasons, the pool-to-riffle ratio is used as a measure to predict the potential for the rearing of fish (Platts, Megahan, and Minshall 1983, 8-10). Another significant element of alternating pools and riffles is how the pattern serves to dissipate stream energy by causing the stream to vertically meander. This is similar to the effects of lateral meandering described in the *Sinuosity* section.

*What Alters Pool-to-Riffle Ratio:* The pool-to-riffle ratio is partially dependent upon flow and velocity. An increase in either will decrease the number of pools, and sometimes eliminate the riffles.

The pool-to-riffle ratio can also be affected by the widening of a channel. This might happen when a channel erodes its banks, which mainly occurs when the riparian vegetation has been removed. A wider channel results in a shallower stream, which can diminish the number of both pools and riffles along the longitudinal profile (Montana Department of Environmental Quality 1995, 22; Dyckman, Way, and Kelly n.d., 147).

The ratio can also be changed by removing LWD from the channel (Lisle 1995, 1803). This was a common practice, until recently, because it was thought that these “obstructions” hindered a stream from functioning properly. Large woody debris was also removed to prevent blockage of culverts and irrigation pipes, to lessen the sediment buildup behind dams, and to facilitate navigation. The many benefits of LWD are now better understood, and it has been identified as a necessary component of a healthy stream. Large woody debris within a stream channel can help slow velocity, provide fish with cover and increased habitat diversity, trap sediments, and form pools. As mentioned earlier, a log across a stream can form a pool immediately downstream. In this way, aquatic organisms are provided a more diverse environment in which to survive. Removal of the LWD would result in an alteration not just of pool frequency, but also of pool dimensions.

Yet another way humans alter a stream’s pool-to-riffle ratio is by altering the substrate which makes up the channel bed. Past studies have determined that for “natural” alternating pool and riffle areas to occur, the stream must have “relative heterogeneity in substrate particle sizes” (Hynes 1970; Smith 1974, *cited in* EPA 1991, 440/5-91-005, 32). A common way this heterogeneity is disrupted is streambank erosion. As the sediments enter the stream, especially the fine sediments, they may collect in pools and gradually fill them, for it is in pools where the velocity slows down enough to allow these fines to settle out of the water column. This accumulation of fines may cause problems until the next peak flow occurs, demonstrating the importance of allowing the occurrence of these flows that help shape the channel.

*Effects of Alterations:* The effects of altering the pool-to-riffle ratio are mainly seen within the biological component of the stream. Fish and other aquatic organisms rely upon a diversity of habitats to survive within a stream. Decreasing this diversity and quality of habitat, by decreasing the pool-to-riffle ratio and/or the total number of pools and riffles, results in a decrease in biological diversity. These limitations give aquatic organisms fewer options to survive unforeseen situations.

*Additional Source:* For more information on a stream's pool-to-riffle ratio, see Gordon, Nancy D., Thomas A. McMahon, and Brian L. Finlayson, *Stream hydrology: An introduction for ecologists*, 1992, pp.315-319.

## **Discharge**

*Definition:* Discharge, or flow, is the amount of water flowing past a point over a given period of time. It is therefore a function of the water volume and stream velocity (Murdoch, Cheo, and O'Laughlin 1996, 105). Discharge will usually increase in the downstream direction as tributaries, ground water discharge, and **surface runoff** all contribute flow to the channel. Stream discharge is primarily governed by the amount of precipitation that falls within the watershed, although, as will be discussed below, other factors can also affect the discharge of a stream.

Stream velocity, depth, width, and slope all adjust to accommodate the water and sediment discharge of a drainage basin (Langbein and Leopold 1966, H2). Periodically, these parameters must reach a certain level in order to maintain the stream's dynamic equilibrium. This level is attained by **channel maintenance flows**, sometimes called **bankfull discharge**.

Bankfull discharge “refers to high flows that fill the entire channel up to the tops of the banks, to the level of the floodplain” (Murdoch, Cheo, and O’Laughlin 1996, 96). This level of flow has a **recurrence interval** of approximately 1.5 years (Harrelson, Rawlins, and Potyondy 1994, 35-36), and is usually seen every other year or so during spring runoff. “Channel maintenance flow” is so named because this flow transports the largest amount of sediment under normal climatic conditions, and is therefore most responsible for forming the shape of the bank channel (Harrelson, Rawlins, and Potyondy 1994, 33). Although floods have an extreme amount of energy, they last for too short a time to determine channel morphology. Conversely, although low flows can last for a long time, they lack the necessary energy to determine channel morphology (Swanson 1988, 96). Bankfull flows also remove algae that are able to cling to rocks during periods of low flow, an important feature to the biological community.

**Flushing flows** are another form of channel maintenance flow, but they are specific to human-managed systems. A flushing flow refers to a release of water from a reservoir with the intent of flushing fine sediments out of the system for “the sole purpose of improving fisheries habitat” (O’Neill and Kuhns n.d., 1). Most of the time, however, a stream’s average discharge will be encountered. Average discharge fills approximately one-third of the channel and is exceeded only twenty-five percent of the time (Harrelson, Rawlins, and Potyondy 1994, 33).

Another important type of flow is that of **flood stage**, an event during which the stream overtops its banks. A flooding stream will not only provide the functions listed above, but will also deposit nutrients and soils along the floodplain, preparing the area for the recruitment of riparian species. (For further information on this matter, see the

*Riparian Vegetation* section.) A balance must be found along managed streams, however, to ensure that flushing flows are adequate to remove fine sediments from spawning areas, strong enough to erode streambanks at a natural rate, and small enough so that they do not result in the elimination of deposited sediments accumulated for riparian species recruitment (O'Neill and Kuhns n.d., 3).

*How Discharge is Commonly Measured:* Discharge, symbolized by the letter Q in watershed management equations, is a function of the volume and velocity of water flowing past a point, as mentioned above. The simplest method of measurement is therefore to multiply the cross-sectional area of the **wetted perimeter** by the velocity of the water. (For the measurement of velocity see the *Velocity* section. For the measurement of cross-sectional area see the *Width-to-Depth Ratio* section.)

There are, of course, other methods for measuring discharge, but most of them require building structures such as weirs (or using an existing culvert), or using mathematical equations based upon many years of research. The advantage of these other methods is that the cross-sectional area does not need to be re-measured each time a discharge measurement is taken. The disadvantage is the amount of time and resources they require.

One last note on the measurement of discharge: it is most commonly measured in cubic feet per second (cfs) in the United States and in cubic meters per second (cms) elsewhere. Therefore, when measuring velocity and cross-sectional area, be sure the units match.

*Significance:* Combined with slope and substrate, stream discharge helps establish the physical characteristics of the stream. "Spring high flows influence key

channel morphology features, such as active channel width, gravel bar size, pool depth, (substrate) size, and the frequency of sloughs and oxbows” (Jackson et al. 1989, 125). Discharge also affects the chemical water column parameters, and not just by altering the concentration of pollutants. For instance, high flows can result in whitewater, which helps dissolve oxygen into the stream. Low flows result in higher temperatures, an increase in pollutant concentrations, and more sediments settling out of suspension and onto the streambed. Potyondy *et al.* (1994, 519) have said that fine sediments will remain in the tributaries as a long-term source to the main-stem until a flushing flow washes them downstream. In these ways and others, flow largely determines which plants and animals inhabit a stream.

Stream power is a function of flow and slope (Nanson and Hickin 1986, 497). If flow is increased and the slope is not decreased, one will see a corresponding increase in stream power. This results in more erosion of the streambed and streambanks, resulting in a decrease of both quantity and vigor of the riparian vegetation. This leads to a corresponding decrease in stream shading and recruitment potential of LWD to the channel, and an increase in fine sediments entering the stream.

To emphasize the importance of flow on the survival of many fish species, allow me to quote the Canadian Ministry of Environment:

Stream flow is the major environmental factor affecting the survival and production of coastal anadromous salmonid populations. Flow levels affect salmonids in several ways. Extended periods of low flow can delay the movement of adults into streams, draining their limited energy reserves and affecting upstream distribution and spawning success. High winter flows can cause mortalities of eggs, by scouring the gravel or depositing sediment in the spawning beds. Overwinter survival of juvenile fish may also be reduced by the scouring of shelter and deposition of bedload in their winter habitat. Low winter flows can result in the freezing of eggs or stranding of fry in spawning beds which were used at higher flows in the fall. Prolonged periods of low flow in summer reduce available rearing area for juveniles. Fluctuations in the abundance of adult coho salmon

have been related to stream flow levels during the juvenile stage (Government of Canada 1980, 69).

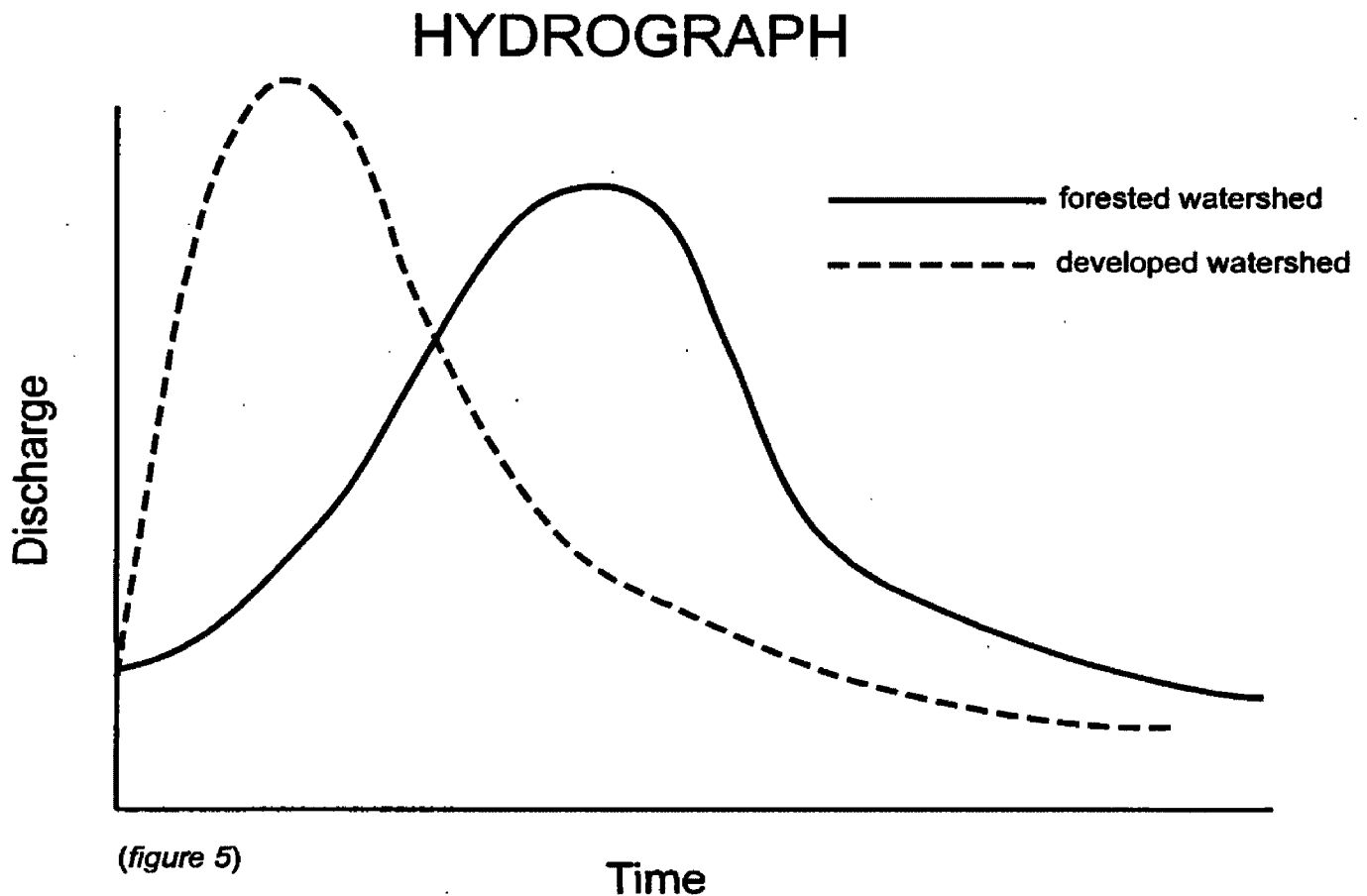
Another feature of flow worthy of mention is its importance on the recreation industry. In many areas, prolonged low flows have eliminated boating activities, angling quality, and swimming possibilities as pollution concentrations are increased. On the other hand, high flows, although they pose wanted challenges to many kayakers, make angling and swimming dangerous or impossible.

*What Alters Discharge:* Some of the ways in which humans alter the discharge of a stream are vegetation removal, the building of dams and diversions, certain agricultural practices, and water extraction for human uses.

Vegetation removal occurs from logging, fire, grazing, disease, erosion, and windstorms (Oregon Department of Fish and Wildlife 1992, 67). The removal of vegetation can alter the stream flow in two ways. First, during wet periods, flow will increase because less water is held by vegetation and returned to the atmosphere (this process is called **evapotranspiration**). As a result, more water runs off the land, and more quickly, increasing a stream's **flashiness** (tendency to flash flood, see *figure 5*). In this case, the peak flow has a short duration, but can be very high and fast. (A flashy stream is typical of an urbanized watershed where much of the vegetation has been removed and much of the land surface has been paved, thus speeding runoff. *Figure 5* compares the runoff rates of an urban watershed and a forested watershed.) Second, during dry periods, flow will decrease because the soil is not capable of storing as much water as it could were vegetation holding the soil in place. This results in a reduction of ground water recharge because plant roots aid the **infiltration** of water, and vegetation creates a layer of duff that is able to absorb and transmit water. During dry periods,



much of the flow of many streams comes from ground water discharge to the stream. If this source is decreased or eliminated, the annual low flows of a stream can become dangerously low for many aquatic organisms. Sometimes the flow may even disappear altogether, in which case the stream will go underground until, at some point further downstream, it has enough flow to once again travel on the surface.



Dams are often built to store water or to harness hydroelectricity, and diversions are usually created for agricultural purposes, especially irrigation. Water is not only diverted from stream channels, but is often directly pumped out of the ground. If the water table is below the level of the streambed, the stream will not receive ground water supplies during dry periods. It is in this way that **perennial** streams (those that flow

year-round) become **intermittent** streams (those that flow for part of the year) or **ephemeral** streams (those that flow only after storm events). Aside from agricultural uses, water may also be extracted for use as an ingredient in manufacturing goods, as a source of drinking water, as a cooling agent in industrial processes, or to be converted to snow at a ski area.

*Effects of Alterations:* Regarding effects of discharge alterations, let us first look at the effects of a decrease in flow. For one, less water in the channel, combined with the same amount of pollutants, makes for a higher pollution concentration. For the most part, it is the concentration of a pollutant that will affect an aquatic organism. Nutrients, such as nitrogen and phosphorous, for example, are essential to plant growth, but at high concentrations nuisance levels of algae may develop. To meet state and federal pollution concentration standards, many industries and sewage treatment plants are permitted to use a **mixing zone** in which to dilute their effluents. Some even discharge only during periods of high flow. During low flows these industries would either have to discharge less effluent or face penalties for exceeding the water quality standard.

Low flows affect aquatic biota in other ways as well. In streams with a flow less than five cfs, water quantity is the most critical parameter to aquatic communities. If discharge exceeds five cfs, the aquatic communities are most affected by velocity and depth (Osborne and Herricks 1983; Oswood and Barber 1982, *cited in* EPA 1991, 440/5-91-005, 31). The reduced water depth associated with low flows affects aquatic habitat by causing higher water temperatures, lower DO concentrations, lower velocity (which results in reduced food drift for fish), and an increase in the formation of anchor ice during winter months (Friends of the Mad River 1995, 89).

An increase in flow can also disrupt an aquatic community. Stream flow is a product of width, depth, and velocity, meaning that an increase in flow will necessarily produce an increase in at least one of these parameters, if not all three (Jones & Stokes Associates 1992, 3). An increase in any of these will alter the habitat of aquatic organisms. An increase in width will usually lead to the flooding of riparian vegetation which, if it dies, reduces the amount of stream shading and the recruitment potential of LWD. Increased flow may also result in an increase in sediment deposition. An increase in depth can result in the alteration of the pool-to-riffle ratio, which will alter the available in-stream habitat. Increased depth does have some advantages, such as increasing the hiding possibilities for fish, but the negative impacts, such as turning riffles into runs, and thus reducing the spawning and feeding areas for fish, outweigh them. Also, the increase in velocity will increase the rate of erosion, thus reducing riparian vegetation and adding more sediment to the stream. This adds stress to fish and may wash some macroinvertebrates downstream.

Generally, there are four categories of optimal velocity/depth relationships for aquatic communities: slow/shallow, slow/deep, fast/deep and fast/shallow (Oswood and Barber 1982, *cited in* EPA 1991, 440/5-91-005, 31). For these categories, slow is calculated to be less than one foot per second, and shallow is calculated to be less than 1.5 feet deep. If any one of these categories is missing from a stream reach, habitat quality will be reduced.

*Additional Sources:* Before physically measuring the discharge of a stream, you may wish to first contact a local USGS office. This federal agency has stream gauging stations on many streams across the Nation, and may have one on your local stream.

Other federal agencies which maintain stream gauges are the United States Forest Service (USFS) and the Bureau of Land Management (BLM), both subsidiaries of the United States Department of Agriculture (USDA).

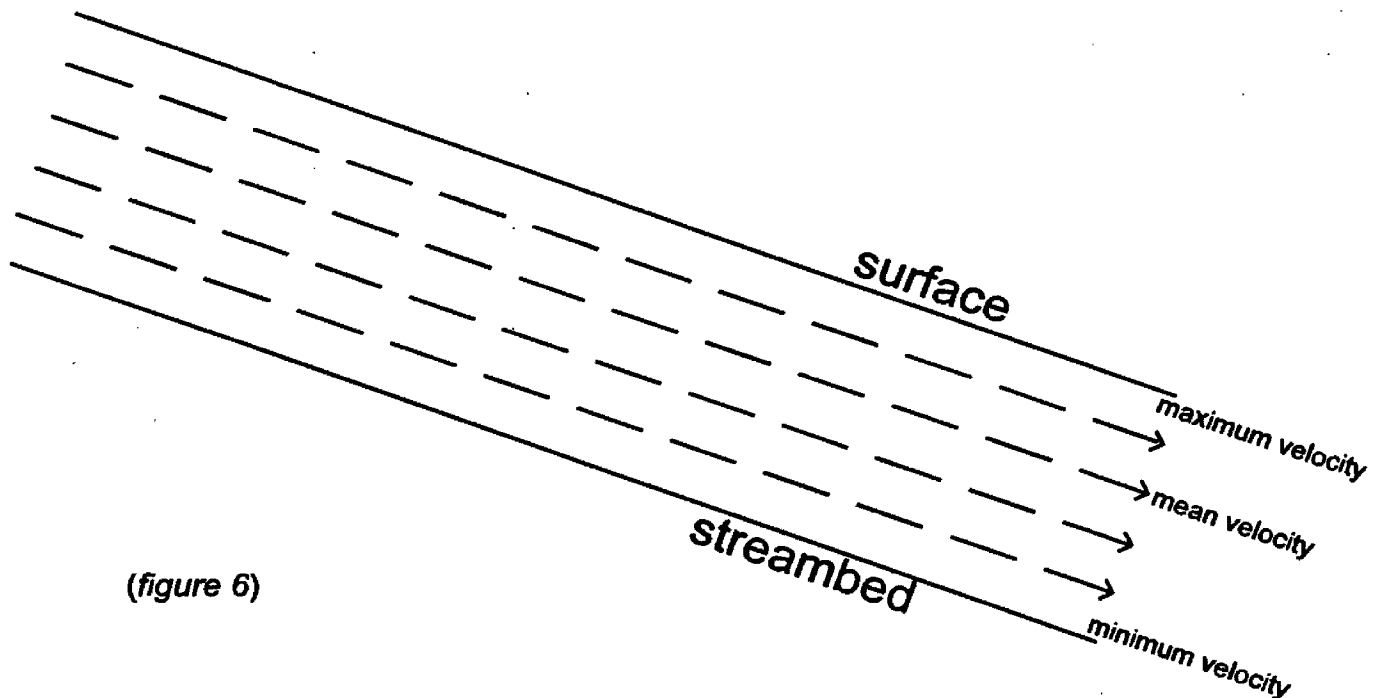
## **Velocity**

*Definition:* The velocity of a stream is the distance covered by the flowing water over a given period of time. This measurement varies both horizontally across the stream channel and vertically within the water column. Horizontally, the lowest velocity measurements are found along the edges, and the greatest velocity can (usually) be found within the thalweg, which is the deepest part of the channel. Vertically, the maximum velocity is found just below the surface of the water, with lower velocities appearing near the streambed where friction is greatest. To account for this, correct velocity measurements are either taken at various widths and depths, and then averaged, or a correction factor of 0.8 is used to determine mean velocity from the surface velocity (Dunne and Leopold 1978, *cited in* Murdoch, Cheo, and O’Laughlin 1996, 112). If only one reading is taken with a current meter, the mean velocity is estimated to be “at a position 0.6 of the distance from the surface to the bed” (Leopold and Maddock 1953, 52). (See *figure 6* for an illustration of stream velocities within the water column.) Velocities are usually recorded in feet per second or meters per second, and they range from slow (0.3 ft/sec) to moderate (0.8-1.6 ft/sec) to swift (3.2 ft/sec) (Terrell and Perfetti 1989, 18).

*How Velocity is Commonly Measured:* The velocity of flowing water is usually measured either by a current meter or by the “float method”. To operate a current meter

requires experience and costly equipment. Current meters have a revolving wheel, and one counts how many revolutions the wheel makes in a given period of time while submerged in the stream. The result can be translated, provided proper calibration of the instrument, into a velocity measurement. The "float method" is a cheap, easy, and effective way to measure velocity. This method involves floating an (organic) object, such as an orange, down a measured stretch of stream, and recording the time it takes to cover a given distance.

## VELOCITY MEASUREMENTS



(figure 6)

**Significance:** Stream velocity directly influences the concentration of DO, as it influences the exchange between the surface of the water and the air above. Velocity helps determine the temperature of the water because it influences evaporation rates. Perhaps most importantly, however, stream velocity strongly influences the types and

number of aquatic organisms (plants as well as animals) that are able to survive within the stream (Terrell and Perfetti 1989, 18). This is because velocity determines the amount of nutrients available to organisms (fast water transports nutrients out of the system, whereas slow water allows it to settle into the stream) and, in the same way, the composition of the streambed (Oregon Department of Fish and Wildlife 1992, 68). Fast water opens up vital spawning areas by flushing fine sediments out of the channel. Extremely fast water, however, can **imbricate** a stream bottom, or armor it by tiling the substrate. This, as previously mentioned, impacts the stream by affecting the exchange between ground water and surface water.

*What Alters Velocity:* There are two major forces acting upon a stream: gravity and friction. There are four factors related to these forces which affect a stream's velocity: channel slope, channel roughness, channel morphology, and channel size. There are other minor factors that influence a stream's velocity, such as total suspended sediment, but they are relatively insignificant, and therefore will not be addressed here.

Channel slope is simply an indicator of the amount of gravitational force acting upon the stream, and has been addressed in the *Slope* section. The other three factors influence the amount of friction acting upon the stream.

Channel roughness is mainly influenced by the size of the substrate, the amount and type of vegetation found along the banks and within the channel, and the amount and type of boulders, LWD, or other obstructions within the channel. An increase in channel roughness usually produces a decrease in stream velocity.

Channel morphology affects friction according to the number of meanders within the stream, and the frequency of pools and riffles. If either the number of meanders or the pool-to-riffle ratio is increased, the stream velocity will decrease.

Finally, in regards to channel size, with all other factors being equal, a large, deep stream will flow faster than a small, narrow stream (Government of Canada 1980, 47). For the most part, a larger stream has a greater volume of flow, and this correlates to a greater velocity. It may not appear so to the human eye, but a large river meandering through a broad valley usually has a higher velocity than a small brook splashing down a hillside. Although it is true a large stream has more surface area, thus increasing the amount of friction acting upon it by the air, the resulting reduction in velocity is relatively insignificant.

With the above in mind, let us address how these factors are commonly altered by mankind. A gradual change of channel slope, as described in the *Slope* section, can occur as sediments accumulate within the river delta, eventually raising the base level of the stream, and thus decreasing the stream's gradient. Slope, as previously stated, is more commonly affected through channelization. When a stream is straightened, it covers less distance (the shortest distance between two points is a straight line), while maintaining its original elevation change. Slope is therefore necessarily increased. This will, of course, lead to an increase in velocity. Marc Reisner, in *Cadillac Desert*, describes the Army Corps of Engineers' (COE) alterations of rivers: "With one hand they dam them; with the other they channelize them; the two actions cancel each other out--the channelized streams promote the floods the dams were built to prevent--and the whole spectacle is

viewed by some as a perpetual employment machine invented by engineers” (Reisner 1986, 307).

Channel roughness can be changed in a number of ways. As we have said, channel roughness relates to the size of the substrate, the amount and type of vegetation found along the banks and within the channel, and the significance of obstructions within the channel. Substrate, as described in the *Substrate* section, is often altered by the process of sedimentation. Many practices, such as logging, agriculture, and the erosion of streambanks owing to the absence of riparian vegetation, increase the percentage of fine sediments found in the channel. If the stream bottom changes from a rough surface of boulders to a smooth surface of sands, the velocity will increase. The removal of riparian or in-channel vegetation, or the replacement of woody species with grasses and forbs, will result in smoother channel banks and bottom, ultimately resulting in greater velocity. Channel roughness can also be reduced by removing obstructions within the channel. This, as stated above, is often done to prevent branches and other debris from clogging irrigation pipes or culverts. However, obstructions are often placed in the stream. Obstructions such as dams, weirs, and bridge abutments can decrease stream velocity.

Channel morphology is commonly altered through channelization, streambank stabilization, and sedimentation. Channelizing a stream allows it to flow straight, rather than around many bends. This, as mentioned before, increases the slope, which necessarily increases velocity, all other factors being equal. We often attempt to reduce streambank erosion with riprap (boulders or broken concrete piled on the bank) or **gabions** (wire mesh or bags of rocks). Riprap is commonly used to protect residential



land and cropland from sloughing into the stream. However, riprapping can accelerate the flow of water as it ricochets off of the hard surface. Riprap and gabions, therefore, may protect a specific streambank from eroding, but the increased erosive energy is sent downstream to a neighbor. As the stream then erodes a downstream bank, it deposits materials, including fine sediments, into the channel. As the percentage of fine sediments in the channel increases, the channel bottom becomes a smoother surface as pools are filled in, thereby increasing velocity.

Channel size is often both increased and decreased by human interference. It is commonly increased through the removal of riparian vegetation. As the vegetation is removed, by logging or urbanization, less water falling as precipitation is taken out of the ground, used by plants, and returned to the atmosphere through evapotranspiration. This results in an increase in surface runoff, which leads to a higher stream discharge (see *figure 5*). Conversely, channel size is often decreased simply through the removal of water from the channel or connected ground water. Examples include irrigators watering their crops and homeowners pumping their drinking water out of the ground. Remember that ground water, unless it is in a confined **aquifer** (meaning there is no outlet for the ground water to seep into the surface water), usually reaches a stream channel, contributing to the flow.

*Effects of Alterations:* If the velocity of a stream is increased, the erosive potential of the stream is also increased. An increase in erosive potential can lead to the cutting away of streambanks which has numerous effects, mainly decreasing the quantity and vigor of riparian vegetation, which then impacts many other stream attributes (see *Riparian Vegetation* section). For example, increased sediment can: clog the gills of

fish; lower the level of visibility in the stream, making foraging more difficult for aquatic organisms; fill in the spaces between gravels, thus eliminating spawning habitat; accumulate in the channel until a braided stream evolves; or cause problems for humans through industrial, agricultural, recreational, and drinking uses. Keep in mind, however, that even though a faster stream erodes more material, it also has a higher capacity to carry sediment. Typically, eroded material settles out of the water column further downstream, causing an increase in the width-to-depth ratio, and often producing braided streams. (See *Width-to-Depth Ratio* section for more information on braided channels.)

An increase in velocity also disrupts fish habitat by making survival more difficult for many macroinvertebrates, such as scrapers which need to hold onto surfaces as they graze a plant or rock covered in algae (see *Macroinvertebrates* section for more information on this subject.) A faster flowing stream can literally wash these creatures downstream. The increased velocity also directly impacts fish survivability. A drastic increase in velocity can prevent a fish from swimming against the current, and a smaller increase will strain the fish as it attempts to fight the current in its everyday life. This is especially true for very young fish.

When velocity is decreased, the effect of greatest concern is that sediments flowing in the stream will settle out of the water column, burying aquatic habitat and biota. For example, silt settles out of the water column when the velocity drops below 0.7 feet per second; sand settles out at velocities between 0.8 and 3.9 feet per second; and gravels settle out at velocities ranging from 3.9 to 5.6 feet per second (Terrell and Perfetti 1989, 18).

*Additional Source:* For more information on measuring stream velocity, see Harrelson, Cheryl C., C.L. Rawlins, and John P. Potyondy, *Stream channel reference sites: An illustrated guide to field technique*, 1994, pp.45-46.

## **Temperature**

*Definition:* Technically speaking, stream temperature is a measure of the average kinetic energy of the water molecules. It varies from stream to stream and from season to season, depending upon the climate of the area, the sources of the water, and the interactions between man and nature.

*How Temperature is Commonly Measured:* Stream temperature is measured by placing a thermometer in the water. The thermometer should remain submerged for at least one minute. Be aware that the temperature of the water will vary within the water column, with warmer temperatures occurring near the surface. It is therefore recommended to take several measurements at different locations vertically. Most data recorded in the United States are measured in degrees Fahrenheit, although most of the rest of the world uses degrees Celsius.

*Significance:* The temperature of a stream “is always included in water quality monitoring because it affects the concentrations and reactivity of many other parameters” (Murdoch, Cheo, and O’Laughlin 1996, 165). Water temperature influences the amount of DO a stream is capable of holding (**saturation**), the rate of all biological processes taking place within the stream, the sediment carrying capacity (as temperature decreases, viscosity increases, increasing carrying capacity) (Colby 1964, *cited in* Heede 1980, 4), and many other factors directly affecting fish and other aquatic organisms.

Most aquatic organisms are cold blooded, which means their body temperature depends upon the temperature surrounding them, whereas warm blooded creatures (including humans) can regulate their own temperature. Stream temperature, therefore, controls the metabolism and reproductive activities of most aquatic species. Furthermore, it influences the sensitivity of these organisms to pathogens (such as disease causing bacteria), and can alter the timing of their reproduction and migration (San Francisco Estuary Institute 1996, 41). Thus, water temperature directly affects the survivability of many species. For example, brook trout become threatened in reaches having prolonged temperatures above 68°F (Byrne 1995, 4).

*What Alters Temperature:* The alteration of stream temperature is called thermal pollution. There are so many origins of thermal pollution that it will be easier to divide them into two groups: how stream temperatures are often naturally altered, and how they are often altered as a result of impacts from mankind (*adapted from* San Francisco Estuary Institute 1996, 41-42; Oregon Department of Fish and Wildlife 1992, 90).

Let us begin with the natural factors affecting stream temperature. The temperature of any given river is determined by the following factors: the amount of energy received by the sun; the direction of stream flow (for example, because of the angle of the sun's rays, southerly flowing streams receive more direct sunlight than streams flowing north, while eastward or westward flowing streams receive shading from adjacent ridges, trees and riparian vegetation); air temperature; **canopy cover** (amount of stream shading); discharge (the larger the water body, the more slowly it heats up); stream depth; stream velocity; ground water temperature; temperature of feeder streams

(tributaries); water color; turbidity (both the amount and the color of the suspended sediment); and substrate composition.

Humans generally alter the above conditions by removing the riparian vegetation, directing stormwater runoff into the stream, changing the stream morphology, altering the flow, discharging cooling water from power plants and other industrial facilities into the stream, and building dams. Now let us briefly discuss the specifics of each of these.

Humans change the temperature of a stream sometimes by adding a new element to it, but usually by altering the stream's surrounding natural ecosystem. The most common way this is done is by removing the riparian vegetation. When the riparian vegetation is removed, the canopy cover (shade) over the stream is reduced, thus allowing more direct sunlight to reach the surface of the water and raise stream temperature. This leads to lower stream temperatures during winter months, as well as causing higher temperatures during summer months. Many studies have been conducted to prove this effect of vegetation removal on stream temperature.

For example, a study found that the removal of riparian vegetation reduced stream temperatures 10°F under winter conditions (Hewlett and Fortson 1983, *cited in* Belt, O'Laughlin, and Merrill 1992, 11), and another study saw temperatures in the Northwest drop 4°F after riparian vegetation removal (Eschner and Larmoyeax 1963, *cited in* Platts n.d., 2). This drop in stream temperature is owing to a decline of the forest insulation, which results in a drop in ground water temperatures.

Studies showing the effects of the removal of riparian vegetation on increasing stream temperatures include one in Oregon which showed an increase from 57°F to 80°F (DePew, Reed, and Gleason 1993, 105). Other studies have shown that maximum

summer temperatures increased by 43°F to 59°F following deforestation (Beschta and Taylor 1988; Lee and Samuel 1976; Brown and Krygier 1970, *cited in* Chesapeake Bay Program 1995, 8).

Compounding the problem, the removal of riparian vegetation also encourages streambank erosion, which leads to stream widening, and thus depth reduction, ultimately raising stream temperature. The accumulating sediment from the eroded banks absorbs heat from the sun, especially if it is dark in color, thus further raising the temperature of the water. It is possible, of course, that lighter-colored sediments will either block or reflect sunlight, thus reducing the effect of the sun on stream temperature. These sediments also accumulate on the stream bottom where, if they are of a dark color, will absorb heat, but they will not absorb as much thermal energy as dark-colored bedrock. In this way, the composition of the substrate can affect stream temperature.

Another source of increased soil erosion is upland clear-cutting within the watershed. This causes more sediment to reach the stream channel, depending upon the distance between the clear-cut and the stream. It also results in higher ground water and tributary temperatures and, as mentioned above, the temperature of the main-stem river is greatly affected by the temperature of its water sources. Tributaries can be 10°F cooler than the main-stem, and therefore serve as important refuge areas for fish (Friends of the Mad River 1995, 54). If the shading of the tributaries is removed or the temperature of the ground water is increased owing to the elimination of vegetation (Chesapeake Bay Program 1995, 9), the temperature of the main-stem will necessarily increase.

Dam building, and the subsequent releasing of water from dams, also results in thermal pollution. As dams, including beaver dams, form reservoirs, they slow the

velocity of the water, prolonging the time that the sun has to heat this water. Man-made dams typically release water from the bottom of the reservoir. This water may come from an area where it received virtually no sunshine, and thus can be very cold, so that the downstream decrease in temperature may adversely impact the aquatic biota. On the other hand, if the water is released from the top of the reservoir, it is generally of a higher temperature than the downstream reaches because it has been virtually motionless while receiving direct sunlight.

Another way to increase stream temperature is by straightening a stream. Channelization alters most parameters, including riparian vegetation, velocity, depth, and stream temperature. The Missouri Botanical Garden states that a channelized stream in Maryland reached a temperature of 98°F one day, while a similar stream nearby, not yet channelized, only reached 74°F (DePew, Reed, and Gleason 1993, 105).

The discharge of cooling water from power plants and other industrial facilities is yet another form of man-induced thermal pollution. Water is an effective coolant because it has a high heat capacity, meaning it takes a lot of energy to raise its temperature. For this reason, it is often used as a tool to reduce the temperatures of manufacturing equipment, and as a coolant in nuclear reactors. The temperature of the discharge from these facilities is sometimes as much as 20°F higher than the stream into which it flows.

*Effects of Alterations:* Thermal pollution, like most forms of stream pollution, is a concern to communities because of how it disrupts the aquatic biota. The main concern of aquatic biota is usually fish species. Fish have an advantage, however, over most other aquatic biota in that they can migrate. During summer months, when flows are low and

temperatures are high, fish will often migrate to cooler tributaries. This emphasizes the importance of tributaries to maintaining a healthy fishery. A phrase heard in the world of stream ecology is "Take care of the tributaries and the rivers will take care of themselves" (Potts 1996). This notion of keeping tributaries cool to allow for migration if it becomes necessary is especially critical for salmonid species.

Trout prefer temperatures between 54°F and 66°F, and can survive temperatures up to 78°F for short periods of time (Friends of the Mad River 1995, 59). If temperatures are sustained above this threshold, and the trout do not have cooler tributaries to migrate to, they will die. This becomes a critical issue in reservoirs where high temperatures are sometimes sustained for several weeks at a time. A problem currently seen in the northwestern United States is the dying of adult salmonids, if they are subjected to extended periods of higher than normal temperatures, before they have a chance to spawn (Dyckman, Way, and Kelly n.d., 66). This causes problems for any cold-water fish, and its severity lies in the fact that stream temperatures only have to be high for a relatively short period of time. If temperatures are normal for the entire year, except for an increase beyond a critical threshold for a week or two, an existing fishery may be ruined. The acceptable temperature range is even narrower for fish larvae and eggs (Campbell and Wildberger 1992, 30).

Some of these problems arise from the fact that oxygen is less soluble in warm water. In other words, a given amount of cold water can hold more DO than can the same amount of warm water. But the problems go beyond that. William S. Platts, a fisheries biologist located in Boise, Idaho, notes that the main effects of high water temperature on fish are "reduced growth, vigor, and disease resistance." To appeal to the



concern of anglers, he points out how this will cause “a shift in composition from game fish to undesirable nongame fish, more tolerant of higher temperatures” (Platts n.d., 247-249).

One last point made clear by a Missouri Botanical Garden study concerns a way in which increased stream temperatures indirectly affect the life cycle of fish. It determined that “an increase of only 2° [it was not mentioned if this was degrees Fahrenheit or Celsius] can cause insects to emerge two weeks early from a winter stream” (DePew, Reed, and Gleason 1993, 105). Aquatic insects make up a large part of a typical fish diet, so this impact, besides possibly killing large insect populations as they emerge into potential freezing temperatures, can greatly affect the dietary patterns exhibited by many species of fish.

*Additional Source:* For a description of various techniques and procedures used to measure stream temperature, consult: Campbell, Gayla and Steve Wildberger, *The monitor's handbook*, edited by Nina Fisher, Marisa Feltham, and Eleanor Ely, La Motte Company, Chestertown, Maryland, 1992. This source also points out significant thresholds, and further explains what one can expect to occur once these thresholds are exceeded.

## **Turbidity**

*Definition:* Turbidity is the measure of how cloudy the water is. This cloudiness is caused by the **total suspended sediment (TSS)** in the water column, which is composed of such elements as algae, suspended sediments, organic matter, and certain pollutants (San Francisco Estuary Institute 1996, 48).

Streams typically have low turbidity. Higher values are found soon after a rain, if there is an erosion problem upstream, or if a specific event (such as livestock standing in the channel) is occurring upstream. The highest natural levels occur in the early spring, when the year's first storms flush out the river system (EPA 1994, 910/B-94-05, 44).

*How Turbidity is Commonly Measured:* The measurement of turbidity, like most water quality parameters, ranges from simple and cheap (and inexact) methods to the more elaborate and expensive (and precise) methods. The former includes dropping a disc (called a secchi disc) into the water and recording the depth at which it is no longer visible. This is more commonly used for measuring lake turbidity, but variations of it can be used in streams. The latter includes machines such as a spectrophotometer which shines a light through a water sample. This machine determines "the clarity of a sample by measuring the intensity of light scattered by particles in the sample and comparing it with that of a known solution" (Dates 1995, 19). Depending upon the method used, the units will be either Jackson Turbidity Units (JTU's) for the former method, or Nephelometric Turbidity Units (NTU's) for the latter method.

*Significance:* The turbidity level of a stream is an indicator of the presence of fine sediments within the water column. It can thus be used to determine the existence or nonexistence of erosion within the stream channel and/or the watershed. Depending upon the level recorded, it may indicate a degraded habitat for fish and other aquatic organisms.

Turbidity is also significant because it affects the amount of light able to penetrate the water column. The higher the level of TSS, the less solar radiation that is able to

reach the channel bed. This translates into a lower rate of photosynthesis, and thus lower DO concentrations, thereby impacting the aquatic habitat.

*What Alters Turbidity:* Fine sediments are the main element making up the amount of total suspended solids within a stream. These generally include substrate particles of clay, silt, and fine organic matter including bacteria, plankton, and other microscopic organisms (Friends of the Mad River 1995, 59). Some of these elements will always be present in any stream. It is an overload of such elements which creates concern. To create an overload of TSS, some sort of a disturbance within the watershed is necessary. This type of disturbance is usually related to the removal of vegetation, either within the riparian zone or in the **upland zone**. Streambank and upland erosion are therefore the primary causes of increased turbidity levels.

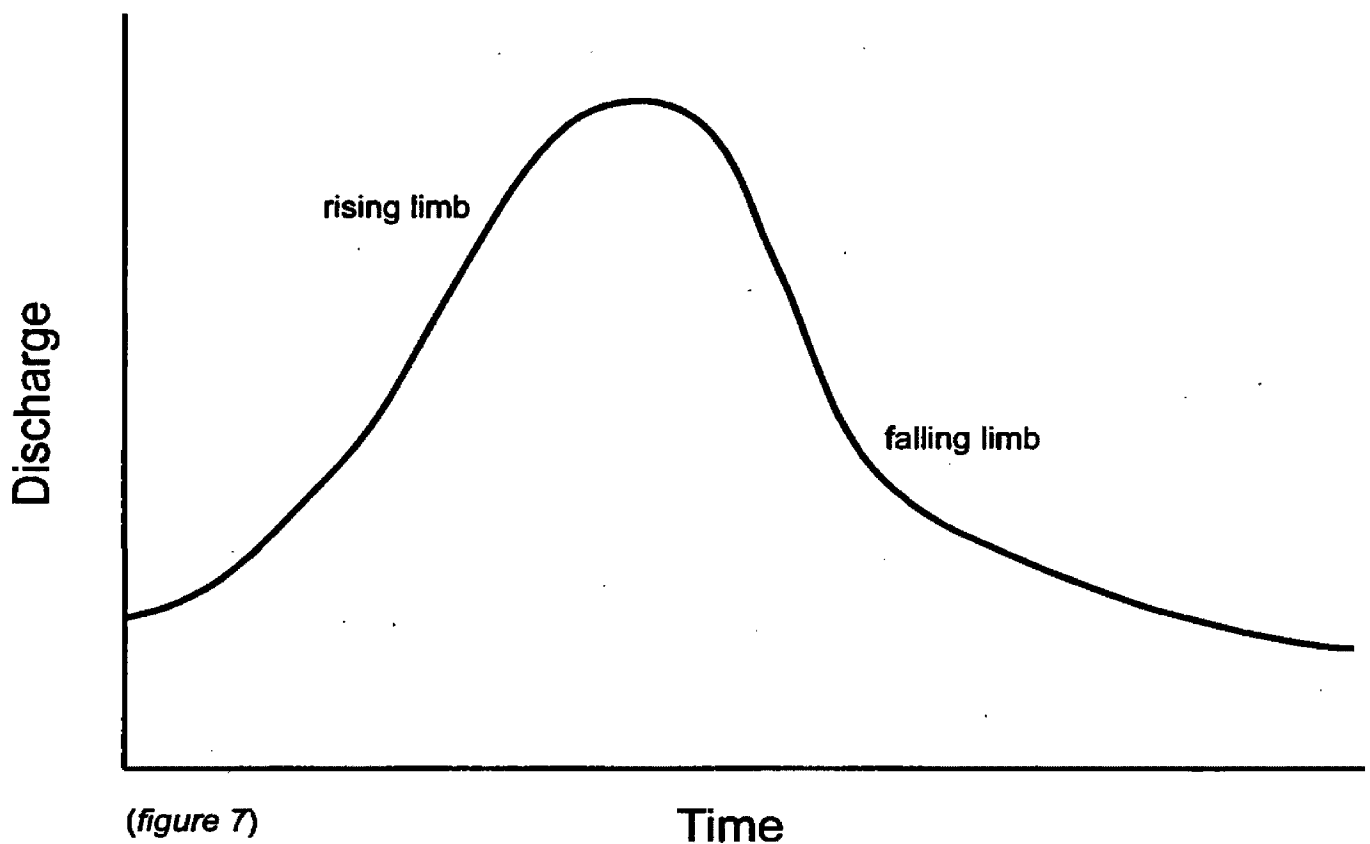
Changes in stream morphology and flow rates can therefore also lead to increased turbidity levels because they generally result in erosion of the channel banks, thus depositing more fine sediments into the water column. Examples include an increase in slope, discharge, or velocity, or a decrease in sinuosity. As explained earlier, any of these changes can lead to an increase in stream power, and will result in a higher rate of erosion.

Humans also affect turbidity by increasing the amount of algae and other aquatic vegetation within the stream. This is commonly achieved by adding nutrients, especially phosphorous, to the water column. The increase in nutrients results in an increase in algal growth, which leads to an increase in turbidity.

Nature, of course, has its own methods of raising turbidity levels, which should not be overlooked. Turbidity will rise and fall with the seasons, varying with the amount

of rainfall or snowmelt occurring in a given period of time. Individual storm events have their own variations. Turbidity levels most often increase on the **rising limb** (while the river is swelling) of the **hydrograph**, and then decrease back toward normal on the **falling limb**. (See *figure 7* for an example of a hydrograph, with illustrations of the rising limb and falling limb.)

## HYDROGRAPH



(figure 7)

Some rivers, however, are naturally turbid. In California, for example, “since the rivers, lakes, bays and ocean waters...are home to small, suspended plants and animals called plankton, turbid water is natural” (San Francisco Estuary Institute 1996, 49). In other areas, a muddy bottom, which can be stirred up by the flow, may lead to high turbidity readings. This does not necessarily mean that this particular stream is unhealthy

or out of balance, but that one of its natural characteristics may be a high turbidity level. As this example demonstrates, regional phenomena must be considered when analyzing water quality measurements.

*Effects of Alterations:* It was mentioned earlier that a high turbidity reading can be an indicator of erosion occurring upstream. As these fine sediments accumulate in the water column, they disturb the life cycle of fish and other aquatic organisms. When turbidity levels are high, fish may have trouble breathing because their gills become clogged with the suspended particles, as was noted previously. Fish may also become more susceptible to infections and diseases because pollutants, nutrients, and pathogens attach themselves to these suspended sediments. Furthermore, as these suspended sediments settle out of the system in areas of slow water, they may cover benthic macroinvertebrates, fill in spawning areas, and bury fish eggs and larvae. Increased turbidity levels also make it more difficult for fish to find food, and add more stress to their environment by lowering DO levels.

As turbidity increases, the amount of DO in the stream decreases, both because stream temperatures are elevated and because the amount of photosynthesis taking place declines. The temperature is increased because the suspended particles near the surface of the water absorb and hold heat from the sun and, as has been stated, stream temperature is inversely related to DO. The amount of oxygen being produced within the stream is reduced because an increase in suspended particles within the water column results in less sunlight capable of reaching the plants on the streambed.

Finally, increased turbidity levels have adverse effects upon the **beneficial uses** of a stream. Beneficial uses are those uses protected by law, such as drinking or swimming.

High turbidity levels result in less aesthetic water, and thus less value placed upon a stream for recreational purposes, and also a reduction in the water's use as a drinking source.

*Additional Source:* For a description of various techniques and procedures used to measure stream turbidity, consult: Campbell, Gayla and Steve Wildberger, *The monitor's handbook*, edited by Nina Fisher, Marisa Feltham, and Eleanor Ely, La Motte Company, Chestertown, Maryland, 1992. This source also points out significant thresholds, and further explains what one can expect to occur once these thresholds are exceeded.

### **Riparian Vegetation**

*Definition:* "Riparian" is defined as "dwelling on the bank of a river." Riparian vegetation, then, is the plant growth along the edges of a stream. The area it defines is called the riparian zone, which is bounded by the terrestrial upland zone and the aquatic zone. The upland zone boundary is identified by a break in slope, with more xeric (dry) species of vegetation occurring in the upland zone. The boundary between the riparian zone and the aquatic zone of the stream channel is identified by the same break in slope used to identify bankfull stage. The easiest way to demarcate these boundaries is to examine the vegetation present.

Paul Hansen *et al.* (1995) use the term "riparian wetland" to combine the stream channel and the riparian zone. They define a wetland as an area where an aquatic zone and a terrestrial zone meet, characterized by **hydric soils, wetland hydrology, and hydrophytic vegetation**. It is this last feature which will be addressed here.

Hydrophytic vegetation is defined as “plant life growing in water or on a substrate that is at least potentially deficient in oxygen as a result of excessive water content” (Hansen et al. 1996, glossary). This means that it is flooded during at least part of the growing season. This feature is what leads to the unique soils present in wetlands, which produces the unique vegetation found within them.

The riparian zone is thus a corridor of land between the stream channel and the upland zone. It is highly diverse in vegetation and in the functions it serves. Because riparian areas are so incredibly diverse, ecologists do not yet fully understand their importance. There is ongoing research today to try to evaluate the effectiveness of these corridors on mitigating some forms of pollution. Unfortunately, much of the damage has already been done so that “few streams today still have pristine riparian areas” (Platts et al. 1987, 93).

What follows is a description of many of the ways healthy riparian areas can benefit a stream system--physically, chemically, and biologically. In the future, there will hopefully be a better understanding of how to protect these areas and, since it is now necessary, of how to restore them.

*How Riparian Vegetation is Commonly Assessed:* Because the functions of a riparian zone are so numerous and diverse, assessing the riparian area is difficult. The assessment will depend upon the particular function being examined. What follows is a list of different methods used to assess the health of a riparian zone.

To determine the potential for recruitment of LWD to the stream channel, one would have to measure the height of the trees, and the distance from the trees to the channel, to understand the possibility of fallen trees reaching the stream. A riparian

assessment may be made according to the possibility of any of this vegetation reaching the channel.

To determine the effectiveness of the riparian vegetation in stabilizing a streambank, one would need to examine the vegetation to understand the root systems present. The primary concern is the density and complexity of the root mass. For this purpose, all woody species are considered to provide a deep, binding root-mass (Hansen et al. 1996, 11). Hansen *et al.* (1996) further say that annual plants lack this binding root-mass, whereas perennial plants vary in their root-mass qualities.

Another important aspect in streambank stability is the diversity of the vegetation. A healthy riparian forest not only has many different species of vegetation, but also has plants of all ages and, of course, these plants must be dense and vigorous. The last factor to study is whether the vegetation present is native or exotic. Native vegetation is preferable, and the species most desired will vary from region to region.

Yet another method used to evaluate a riparian zone is to record the "richness and abundance of bird species observed at specific locations along a creek" (San Francisco Estuary Institute 1996). In the same way that the analysis of indicator species within the stream can shed light on the overall health of the aquatic system (see *Macroinvertebrates* section), an analysis of bird species can shed light on the overall health of the riparian system.

Overall, however, a riparian zone is assessed by determining if it is functioning properly. To give the reader an idea of what this entails, allow me to quote from the BLM's *Riparian area management: Process for assessing proper functioning condition:*

Riparian-wetland areas are functioning properly when adequate vegetation, landform, or large woody debris is present to dissipate stream energy associated with high waterflows,



thereby reducing erosion and improving water quality; filter sediment, capture bedload, and aid floodplain development; improve flood-water retention and ground-water recharge; develop root masses that stabilize streambanks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and support greater biodiversity (USDOI Bureau of Land Management 1993, 4).

Ultimately, it may be the width of the riparian zone that determines how well it performs these functions (Dates 1995, 12). This riparian width varies naturally from stream to stream, depending upon “the size of the stream, its flooding patterns, its interaction with ground water and subsurface drainage, and the slope of its streambanks, floodplain, and valley,” although mankind has altered the riparian width almost everywhere (Murdoch, Cheo, and O’Laughlin 1996, 84). This again brings up the difficulty mentioned earlier of determining the boundary at which the riparian zone ends and the upland zone begins.

Unfortunately, not enough research has yet been done to determine the ideal, or even minimum, width necessary to allow a riparian zone to function properly. For instance, it is commonly accepted that a **buffer strip** (a corridor of land in the riparian zone left adjacent to the channel to lessen the impacts of logging on water quality) should be wider where slopes are steep, but no equation exists to determine a relationship between buffer width and slope (Belt, O’Laughlin, and Merrill 1992, 3). A study by Erman, Newbold, and Roby (1977, 36) showed that streams with buffer strips less than one hundred feet wide showed the same general response as streams logged without buffer strips, and numerical standards vary from state to state. For instance, depending upon the beneficial uses identified for the stream, Idaho requires buffer strips of five feet for Class II waters (a warm-water fishery) and seventy-five feet for Class I waters (a cold-water fishery). For similarly identified uses, both Oregon and Washington have

limits set at twenty-five and one hundred feet, respectively, and California's standards are fifty feet and two hundred feet, respectively (Belt, O'Laughlin, and Merrill 1992, 2, 9).

*Significance:* The list of potential benefits that a healthy riparian zone may have on a stream system is a long one. In an effort to make this reading more clear and concise, this section has been divided into many subsections, each one describing a separate benefit to the stream.

*\*Introduction:* The EPA has divided pollution into two categories, depending upon its origin: **point source pollution** and NPS. Point source pollution can be traced back to a specific location, such as a discharge pipe. Non-point source pollution, conversely, originates over a larger area, making it difficult to specifically identify the source. This makes NPS difficult to regulate. The most common example of NPS is runoff from agricultural fields, which today makes up sixty percent of all the NPS in the United States (Texas Natural Resource Conservation Commission 1997, 9). Other examples include stormwater runoff from urban areas, and industrial discharges into the atmosphere which return as acid rain.

When the EPA began its effort to limit the pollution that reaches surface waters, it began by addressing point source pollution. Since this type of pollution can be easily measured, and therefore regulated, it was the easier of the two to address. The EPA largely did this through its National Pollutant Discharge Elimination System (NPDES). Over the past two decades, this program has been very effective in regulating the amount of point source pollution reaching surface waters.

What remains today is the cleanup of NPS, required by the Federal Government under Section 319 of the Clean Water Act (CWA). This has been brought to the forefront

of today's news as of President Clinton's 1998 State of the Union Address. Non-point source pollution is now considered to be the "major cause of surface water impairment in the United States" (Baker 1992; Long 1991; *cited in Chesapeake Bay Program 1995, 1*). The method most commonly used in the effort to regulate NPS is imposing accepted protocols termed **Best Management Practices (BMPs)**. These protocols, depending upon the type of pollution being created, are voluntary in some states and mandatory in others. There are three types of BMPs: structural, vegetative, and management (Terene Institute 1993, 29). If, for example, farmers, loggers, or miners are operating under established BMPs, it is assumed that the pollution reaching the surface waters as a result of their activities is at a level that is relatively benign to the aquatic system. The riparian zone plays a key role in helping regulate the amount of NPS reaching the stream, in addition to many other functions it serves which help maintain the physical, chemical, and biological integrity of the stream.

**\*Act as a Filter:** The biggest pollutant in the United States, by volume, is sediment (USDA 1979, *14-500/507*, foreword). This problem is compounded by pollutants, such as fertilizers and pesticides, which attach themselves to sediment, and are then carried into the stream. A healthy riparian zone can decrease sedimentation by stabilizing streambanks, as described in the following subsection entitled *Streambank Stabilization*.

Another significant way the riparian zone controls sedimentation, and indeed much of the polluting of a river, is by trapping materials as they flow overland, and thus preventing them from reaching the channel. In this way, maintaining the riparian zone is the most satisfactory practice to protect the aquatic system from NPS. This has been

recognized and utilized for forestry practices, but is still not widely used in agricultural or urban areas, although this seems to be where it is needed most (Comerford et al. 1992; Leopold et al. 1964, *cited in* Chesapeake Bay Program 1995, 1). "Cropland erosion accounts for forty to fifty percent of the approximately 1.5 billion tons of sediment that reaches the Nation's waterways each year (streambank erosion accounts for another twenty-six percent)" (Terrell and Perfetti 1989, 19). Likewise, in urban and suburban areas, construction sites can cause erosion rates 2000 times higher than those in forested lands, and ten times higher than those on utilized agricultural lands (Friends of the Mad River 1995, 139). The rate can be much higher on abandoned agricultural lands.

Sediment and sediment-borne pollutants reach the stream as a result of many cultural activities. For example: during the nineteenth century in Mississippi, owing to heavy deforestation and agricultural production following European settlement, valley bottoms were covered by up to several yards of sediment eroded from hillslopes (Happ et al. 1940; Grissinger and Murphey 1986, *cited in* Shields, Bowie, and Cooper 1995, 971); millions of tons of salt, and even more gravel, are spread on roads in northern states during the winter, often washing downslope into a stream; the susceptibility of dirt roads to **gully erosion** (runoff which forms channels), with the eroded soil often entering a stream channel; the paving of the land, now commonplace in urban areas, which creates impervious surfaces over which pollutants accumulate and flow quickly and easily (in forests approximately half of the rainfall percolates into the ground, compared to less than one third [and often even less] in urban areas) (Texas Natural Resource Conservation Commission 1996); saline irrigation return flows; and many different agricultural activities. Once a field has been tilled, for example, a simple rainstorm can

wash hundreds of tons of topsoil into the streams and, again, this is often accompanied by fertilizer. "Up to half of the artificial fertilizer (usually containing contaminating nitrates) used by today's farmers is washed out of the soil and into rivers" (DePew, Reed, and Gleason 1993, 16).

The main factor limiting the effectiveness of the riparian zone in removing sediment from surface runoff is slope (Chesapeake Bay Program 1995, xiv). The Chesapeake Bay Program proposes three management zones within the riparian zone, with the tightest restrictions placed on the zone nearest the stream, and lessening restrictions occurring as one moves away from the stream. Zone Three, furthest away from the stream, is managed to convert concentrated flow to sheet flow, for a riparian zone cannot effectively filter sediments out of concentrated flow. Moving inward, the primary function of Zone Two would be to trap the sediments, and that of Zone One to stabilize the streambank (Chesapeake Bay Program 1995, 5-6).

Numerous studies demonstrate the effectiveness of riparian zones in combating sediment runoff (Jacobs and Gilliam 1985; Jordan et al. 1993; Lowrance et al. 1983, 1984, 1985; Peterjohn and Correll 1984; and Schueler 1987, *cited in* Belt, O'Laughlin, and Merrill 1992, 16). Two studies, however, are of particular interest because they have quantified results. In one of these studies, dense grass was planted on a section of fill slope (on the edge of a road) at a sixty-seven percent slope and reduced sediment yield to the stream by ninety-seven percent (Burroughs and King 1985, *cited in* Belt, O'Laughlin, and Merrill 1992, 16). In the other study, concentrations of total nitrogen, total phosphorous, suspended solids, and BOD (biochemical oxygen demand, or the amount of oxygen required by all organisms and decomposing material in the stream) were reduced

by up to eighty percent in feedlot runoff by passing it through what was termed “grass vegetated filter strips” ranging in width from 300 feet to 850 feet (Dickey and Vanderholm 1981, *cited in* Chesapeake Bay Program 1995, 17).

**\*Stabilize Streambanks:** The most natural and effective way to stabilize a streambank is to encourage the growth of densely rooted riparian vegetation, as has been described. “A bank knit together with deep, dense roots and fallen logs is less likely to erode during spring runoff and floods than a barren one” (Logan 1994).

The nutrient-rich alluvial soils which are deposited by high flows act as a rooting medium for the riparian vegetation, even on steep slopes. Once this vegetation is established, it can dissipate the stream's energy as the stream is forced to flow over, under, and deflect off of these obstacles. This vegetation, which actively holds the soil in place, can also stabilize the bank by protecting it from the forces of heavy rain, trampling by animals, ice scour, and erosion from overland flow.

The term “buffer strip” is used today to refer to water quality protection from many impacts, not just those resulting from logging activities. A study which examined the effects of a buffer strip on streambank stability found that “streambank erosion was more than 250 percent greater after logging than before in clearcut areas where no buffer strips were left. After clearcutting an area where a buffer strip (fifteen feet wide) or less was used, streambank erosion increased only thirty-two percent over the preharvest rate” (Toews and Moore 1982, *cited in* Belt, O’Laughlin, and Merrill 1992, 14). As mentioned earlier, however, research is still being conducted to determine ideal widths of buffer strips.

**\*Control Floods / Recharge Aquifers:** A healthy riparian zone consists of a thick bed of porous soils, deposited across the floodplain by previous floods. These soils are able to absorb large amounts of moisture, and then slowly release it, just like any wetland. If flood waters are able to overflow the banks (which is not the case in many channelized streams which are often built up with levees), not only is the force of the water spread out over a larger area, but much of the water is absorbed into the wetland and temporarily removed from the channel flow. By temporarily storing much of this excess water, the riparian zone can greatly lessen the flood-related destruction which would occur downstream. Not only will the lowered flow lessen impacts, but the accompaniment of a decreased velocity, resulting from a decrease in flow, will as well.

Riparian zones are also able to moderate floods by slowing down the water with the added friction owing to its dense vegetation. Remember, one of the factors affecting velocity is channel roughness. A stream flowing through a concrete channel will have a much higher velocity than one flowing through a channel of coarse vegetation and substrate along its banks and bed. This decrease in velocity correlates to a decrease in erosion potential.

There is still another advantage to the storing of excess water. A riparian site is a shallow aquifer that recharges during high flows and discharges during normal and low flows (USDOI Bureau of Land Management 1987, 17). This flow augmentation can be critical during dry months when flows can reach levels perilous to aquatic organisms, as described in the *Discharge* section. The amount of water retained, and the duration of the flow back into the channel, will vary depending upon the quantity of water and physical nature (porosity, particle size, etc.) of the soils but, if either is insufficient, the end result

may be either an intermittent stream or one which disappears underground for a stretch (DeBano and Hansen, 146).

**\*Provide Large Woody Debris (LWD) to the Stream Channel:** Several terms are used for large pieces of organic debris which accumulate in the channel, of which large woody debris (LWD), coarse woody debris (CWD), and large organic debris (LOD) are the most widespread. Large woody debris will be used here to refer to all large organic pieces of debris that are deposited into the stream channel from the riparian zone. Organic debris ranges from leaf litter (leaves falling into the channel) to adult trees. Agents that deposit LWD to the channel range from windstorms to wildfires to logging.

The necessary width of the riparian zone for the recruitment of LWD will naturally vary from stream to stream, depending upon tree height, the distance from the trees to the stream, and the slope of the land. Few studies have been done to examine necessary widths, but one in Oregon found that "a ninety-eight-foot buffer strip would supply eighty-five percent and a thirty-three-foot buffer strip less than fifty percent of the (LWD) from a natural stand" (Belt, O'Laughlin, and Merrill 1992, 4). In a separate study in Oregon, it was demonstrated that this natural stand would have to grow for at least fifty years to adequately supply LWD to the stream channel (Andrus 1988, *cited in* Belt, O'Laughlin, and Merrill 1992, 13).

The benefits of LWD to the aquatic environment are many. A watershed management organization in Vermont has said "the importance of (LWD) cannot be overestimated" (Friends of the Mad River 1995, 61-62). This debris tempers the erosional forces of the stream, slowing down the flow by presenting obstacles in its path; increases the amount and diversity of aquatic habitat by creating pools and riffles;



sustains the food chain by providing a source of “slowly decomposable nutrients”; provides protective cover for fish; and controls the flow of sediment by creating a series of **check dams** (a dam to trap sediment to lessen erosion), which increases the substrate diversity and keeps the fine sediments out of spawning gravels (Chesapeake Bay Program 1995, 9; Murdoch, Cheo, and O’Laughlin 1996, 61-62; Lisle 1995, 1805). The Southern Region of the USFS, in trying to improve a fishery, declares that adding LWD to the channel accomplished all of their goals (USDA 1992, 2). The fisheries biologist William Platts undertook a study in Nevada in which he found that when LWD no longer entered the stream, the channel banks became unstable and bank erosion soon followed (Platts 1985, *cited in* Beschta and Platts 1986, 376).

**\*Modify Stream Temperature:** As was described earlier (in the *Temperature* section), the presence of tall trees in the riparian zone helps shade parts of the stream. This function is of greater importance on small streams, but is also significant on larger streams. Again, a shaded stream will remain cooler in the summer and warmer in the winter. This is not only because some of the solar radiation is blocked from reaching the channel, but also because the solar energy is partially blocked from reaching the soils. This helps keep ground water temperatures lower which, in turn, helps keep stream temperatures lower.

**\*Enhance Fish Habitat and Diversity:** A healthy streambank can be vital to the survival of fish, providing them with diverse habitat and, in so doing, allowing for a diversity of species.

The streamside vegetation provides a food supply to fish by providing a habitat for terrestrial insects which make up part of their diet. Not only does the vegetation

provide habitat, but it often serves up the food as well, as insects commonly fall off of the overhanging trees and shrubs into the stream. This source becomes especially important in certain watersheds, such as those with granitic parent material, where soils provide insufficient nutrients to the stream (Platts n.d., 246). In fact, ninety percent of the food in forested streams comes from bordering plants. The figure drops to fifty percent in larger streams (Logan 1994).

The lower stream temperatures allowed by the riparian vegetation also help enhance fish habitat. The suitability of this habitat to fish also depends upon the depth and velocity of the water, which is largely determined by the vegetation lower down on the banks.

Riparian vegetation, along with undercut banks and debris, also provides cover for fish. A study in South Dakota increased trout biomass over two hundred percent by increasing cover in a stream (Boussu 1954, *cited in* Platts n.d., 246). This cover also contributes LWD to the channel, which “create(s) small dams and pools in which fish can breed and hide (from predators)..., rest..., and feed” (Logan 1994).

**\*Enhance Wildlife Habitat and Diversity:** Riparian zones are an integral habitat for the majority of plant and animal species on the planet. “More than eighty-five percent of wildlife inhabit riparian areas at some time during their life cycle” (Murdoch, Cheo, and O’Laughlin 1996, 59). Furthermore, although “riparian forests make up less than five percent of the total forest ecosystem...they contain seventy-five percent of the forest’s plant and animal diversity” (Logan 1994).

The riparian zone is commonly used by wildlife as a corridor for migration, just as it is by humans. To provide wildlife with such a passage can be vital to their survival

in times of catastrophe. Many species migrate as a part of their annual cycle, and many others need to in order to escape unsuspected calamities. To have such a corridor to permit movement allows species to inhabit diverse ecosystems, and even to expand their gene pool, as these corridors can prevent the dangers of excessive in-breeding.

Riparian vegetation also provides valuable cover for wildlife from both weather and predators. In some regions, the trees in the riparian zone are the only trees around. In these cases, their importance as areas to seek protection and hiding cannot be overestimated.

Riparian zones are especially integral for bird species. As floodwaters overflow the banks, the velocity decreases as the flow spreads out away from the main channel. This allows the sediments to settle onto the floodplain while the water slowly filters down through the ground. These sediments are high in nutrient content, and afford a rich feeding ground for birds and other species that feed on the diverse vegetation growing on these soils. Riparian zones are also heavily used by birds for breeding, resting, and nesting.

**\*Modify Channel Morphology:** The riparian zone is also instrumental in maintaining the physical characteristics of a stream. By stabilizing the streambanks, it influences the sinuosity, slope, velocity, width-to-depth ratio, substrate particle size, and pool-to-riffle ratio within the channel. Riparian vegetation is increasingly used as a management tool to help banks recover from erosion. When woody species are planted along the banks of a widened stream, the narrowing process will begin, sometimes taking only a few years for the width-to-depth ratio to return to its natural state (Swanson 1988, 97).

**\*Improve Water Quality:** Riparian vegetation mainly influences water quality by acting as a filter for potential sediments, as described above in the *Act as a Filter* subsection. The functions this vegetation serves, however, can also greatly impact the water chemistry of a stream. It does this by helping control the amount of solar radiation reaching the water body, and thus the rate of photosynthesis. The chain reaction from this largely determines the temperature and the amount of DO in the stream, and thus its biological integrity. Riparian vegetation also affects water quality by modifying stream flow (seen above in the *Control Floods / Recharge Aquifers* subsection), and by governing sedimentation, from both stabilizing the streambank and acting as a filter.

**\*Provide Opportunities for Recreation and Economy:** An aspect of the riparian zone which should not be overlooked is its contribution to human recreation and economy. Not only do people enjoy the improved water quality and fish habitat it provides, but also the beauty and serenity of the riparian zone itself. The picnicking, angling, and swimming opportunities abound, and often there are economic benefits gained by these activities. Also, of course, the timber opportunities of riparian areas sometimes contribute significantly to an area's economy.

**\*Moderate Cumulative Watershed Effects (CWE):** There are many small events which, taken by themselves, may not seem to greatly impact a river. However, examined cumulatively, all of these minor events sometimes combine to create a major impact. This dilemma is referred to as **cumulative watershed effects (CWE)**. Much like NPS, they are often very difficult to quantify, and therefore to regulate. Because riparian zones serve so many functions as the border between the human environment and the aquatic

environment, it is widely believed that they play a large role in moderating CWE. This topic is still in need of much research, however, and so it is only briefly mentioned here.

*What Alters Riparian Vegetation:* Riparian areas constitute only a small percentage of the total land area of the world, but they “are some of the areas most heavily impacted by humans. Water bodies are sites of settlement and sources of water supply for people and domesticated plants and animals, and provide transportation avenues...(The) abundant water, forage, and other amenities attract a proportionately greater amount of use and conflict in riparian areas than their small aggregate area would indicate” (Platts et al. 1987, 36, 93).

Though the figures vary, the fact that most of this Nation's riparian habitat has been altered seems incontestable. The Natural Resources Defense Council (NRDC) maintains that “over fifty percent of the original riparian habitat in this country has been inundated, channelized, damned (*sic*), rippapped, farmed, overgrazed, or altered by other land uses.” Leopold *et al.* put the figure at seventy percent, increasing to ninety-five percent in certain areas, blaming the majority on channelization (Natural Resources Defense Council 1993; Leopold et al. 1964, *cited in* USDO I 1982, *FWS/OBS-82/24*, 1). The only low figure comes from the COE, and that was solely for streambank stability. They estimated that eight percent of streambanks in the United States are experiencing “erosion to some degree,” but the Department of Transportation (DOT) addresses that estimation and states that “it is actually much higher” (USDOT 1982, 26).

Damage to the riparian zone has about as many different sources as there are cultural activities. The greatest impact probably comes from road-building (Oregon Department of Fish and Wildlife 1992, 44). To build a road often includes removal of the

riparian vegetation, use of heavy machinery within the riparian zone, construction of fill slopes, planting of non-native species on these slopes for erosion protection, and stream channelization. Livestock grazing and logging are probably the greatest threats to the riparian zone after road-building.

Livestock prefer riparian areas over upland areas for grazing so, unless livestock are fenced out of riparian zones or managed to occupy them for only very short periods of time, they will adversely affect the riparian vegetation (EPA 1994, 910/B-94-05, 23). As the livestock go about grazing, and periodically making a path down to the channel to drink, they trample the area. This trampling leads to more vegetation destruction, breaking up of the soil, and sloughing of the streambanks. William Platts *et al.* argue that, although damage certainly continues today, most of the damage to riparian zones in this country “was already done by 1900” (Platts *et al.* 1987, 99).

Logging impacts riparian zones by the removal of the vegetation, the use of heavy machinery, and the trampling owing to the building of skid trails. “Research has shown that logging changes basic stream conditions of temperature (Levno and Rothacher 1967; Brown and Krygier 1970), discharge (Rothacher 1973), suspended and deposited sediment (Moring and Lantz 1975), and nutrient concentrations (Fredriksen 1971).” Other studies have shown biological effects of logging on primary producers (Hansmann and Phinney 1973), on invertebrates (Tebo 1955; Burns 1972), and particularly on fish and fish habitat (Burns 1972; Hall and Lantz 1969; Naraver 1972; Moring 1975, *all cited in* Erman, Newbold, and Roby 1977, 1).

Another impact to riparian vegetation comes from the removal of the vegetation, and/or the replacement of woody species by herbaceous species, by farmers and

homeowners. As farmers increase their cropland acreage, and as homeowners extend their lawns, they often clear the riparian vegetation, and plant herbaceous species right up to the river's edge. Woody species, as previously stated, are the best streambank stabilizers because of their dense root system. Many herbaceous species have about the same ability to support a streambank as if there were no vegetation there at all (Hansen 1996). A typical lawn, for instance, "does not provide enough resistance to slow flood flows and prevent bank erosion (and is) sterile habitat, providing little attraction for wildlife" (Logan 1994). This matter is made worse by the amounts of fertilizers, pesticides, and herbicides sprayed onto these lands, which then easily accumulate in runoff and flow directly into the stream. The typical lawn actually has more pesticides per square inch than the most intensely sprayed farmland (Texas Natural Resource Conservation Commission 1997, 11-12).

Some other ways riparian areas are commonly impacted are: the building of dams which floods areas upstream and creates "hungry water" downstream; stream channelization; mining activities; fires; riprapping of streambanks; fallen trees which deflect flows into the streambank; the allowance of invasion of non-native species; debris flows; replacement of deciduous trees by coniferous trees (Government of Canada 1980, 15); and the construction and use of hiking and ATV trails.

*Effects of Alterations:* The above section on the *Significance* of riparian vegetation answers many of the specific questions that one may have as to the effects of altering the vegetation. This section will address some of the general impacts that one may expect to see from riparian vegetation alterations.

The primary effect caused by riparian vegetation damage is an increase of the erosion rate, resulting in an increase of sediment in the stream. Removal of the streambank vegetation renders the banks more susceptible to erosion owing to the flow of water and ice. This increase is often brought about by stream channelization and the creation of impervious surfaces, most commonly the paving of the landscape in urban and suburban areas. Each of these activities, the former by concentrating the flow in a single channel and the latter by creating more surface runoff, increases erosion potential by increasing flow and, therefore, velocity.

Another effect typically seen after riparian vegetation disturbance is increased stream temperature. This is a result partially of the decreased canopy cover, partially of the increased ground water temperature, and partially of the increased width-to-depth ratio. The first two of these impacts have been discussed, and the width-to-depth ratio increases as a result of bank sloughing, which commonly occurs when livestock trample the banks, or when the vegetation is removed and can no longer effectively withstand the erosive energy of the stream.

One may also see dramatic flow fluctuations as a result of riparian vegetation removal. Flood levels will be even higher with the removal of vegetation (see *figure 5*), and flood impacts will be greater as a result of the weakening of the streambanks. On the other hand, low flows will be even lower if there is no riparian zone to store water during periods of high flow, to then be released during dry times.

Another effect of riparian vegetation disturbance is that imposed upon wildlife habitat, both aquatic and terrestrial. The alteration of the riparian zone can mean the elimination of cover and migration corridors for certain terrestrial species, and of feeding



and breeding grounds for many bird species. Vegetation disturbance also results in decreased habitat diversity for fish because it reduces food sources, decreases pool depths and frequencies, raises stream temperatures, increases sedimentation rates, and reduces LWD recruitment to the channel. Furthermore, one must consider the effects associated with pollutants reaching the stream within surface runoff, many of which could be taken out of the system by an effective buffer strip.

To conclude this section, allow me to quote from two publications which succinctly state the effects of riparian vegetation alterations. Taken together, they include a comprehensive list of effects one may expect to encounter once the riparian vegetation has been disturbed or removed:

Effects of impacting vegetation: increases bank erosion and failure; widens channels; decreases depth; disrupts streamside plant communities; increases invasion of non-native plants; lowers water table; makes streambanks more susceptible to livestock trampling and erosion; increases water temperature; speeds runoff; reduces trapping of sediment and other pollutants; reduces livestock forage; increases bank damage due to icing; decreases valuable real estate; decreases fish and wildlife cover (Montana Department of Environmental Quality 1995, 18).

Lack of buffer strips can result in debris damming the stream, fish migration blocks, debris torrents, decreased dissolved oxygen concentrations, increased water temperature, increased nutrient inputs, and increased toxic leachates from decomposing material (Platts n.d., 248).

*Additional Sources:* The following publication includes a description of how to sample a riparian zone to determine its effects on fish habitat: Platts, William S., Walter F. Megahan, and G. Wayne Minshall, *Methods for evaluating stream, riparian, and biotic conditions*, USDA Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-138, Ogden, Utah, May, 1983. This publication includes analyses of the following parameters: streamside cover, vegetation use by animals, herbage production and utilization, vegetation overhang, and habitat type.

Another helpful publication is *the Soil Conservation Service field office technical guide*. This document is a source of conservation technology information helpful in combating soil erosion from agricultural uses (EPA 1994, 910/B-94-05, 19).

## MEASURES OF CHEMICAL INTEGRITY

### **Dissolved Oxygen**

*Definition:* Oxygen is a very soluble gas, meaning that it can readily dissolve in water. Sometimes the water column may even contain more oxygen than the atmosphere (EPA 1991, 440/4-91-002, 16). This oxygen is required for respiration by both aquatic plants and animals, and as an agent in the decomposing process of organic materials. These organic materials may be sewage; dead plants, such as algae; or yard clippings that have been deposited into the stream.

Oxygen is diffused into the stream through aeration, which is increased in turbulent water. It is also produced in the stream by photosynthesis. Therefore, DO concentrations will be higher in the late afternoon and lower in the early morning, since respiration occurs twenty-four hours a day, yet photosynthesis only occurs in the presence of light. Dissolved oxygen levels will also vary vertically within the water column (Dates 1992, 6).

There is a DO saturation level that can be reached within the water column, as previously mentioned. This level is mostly dependent upon stream temperature and the atmospheric barometric pressure (meaning it varies with altitude). Each state has a water quality standard for DO, which varies depending upon the beneficial uses and values identified for a particular stream.

*How Dissolved Oxygen is Commonly Measured:* Dissolved oxygen is commonly measured with a DO meter, which is part of a DO test kit. These can be expensive, depending upon how precise one needs the measurement to be. Because it is so variable, DO should be measured at various times of the day, at different points along the stream, and at different points within the water column. It may also be useful to have samples tested by a professional laboratory, because the narrow range of DO levels sometimes requires a precision of measurement not commonly found with cheaper equipment.

The most common unit for measuring DO is milligrams per liter (mg/l). Its equivalent, parts per million (ppm), is also sometimes used.

*Significance:* The importance of monitoring for DO lies in determining the minimum levels which occur (again, usually in the very early morning), and comparing these to what is required by the in-stream organisms. To give an example of specific DO standards, the states of Montana and Vermont each allow a minimum level of seven milligrams per liter (mg/l) for cold-water fisheries, classified in each state as Class I waters. This may go up to eight mg/l during spawning season and down to four or five mg/l for a warm-water fishery. The Adopt-A-Stream's *Streamkeeper's Field Guide* declares that a stream with DO concentrations above eight mg/l is considered a healthy stream (Murdoch, Cheo, and O'Laughlin 1996, 171). To put this in perspective, saturation levels of DO, which mostly depend upon temperature, are approximately: 14.6 mg/l at a stream temperature of 32°F; 11.3 mg/l at 50°F; 9.1 mg/l at 68°F; and 7.6 mg/l at 86°F (Platts n.d., 247). Therefore, if a stream is at or below a given temperature, and the DO level is below the corresponding saturation level, then another factor aside from

temperature is affecting the DO concentration within the stream, possibly BOD, for example.

*What Alters Dissolved Oxygen:* As mentioned earlier, DO is mostly affected by temperature and barometric pressure. As stream temperature increases, the DO concentration decreases. Likewise, since oxygen is more easily dissolved into water at low altitudes than at high altitudes, the higher a stream's elevation, the lower its DO concentration will be. Thus, the most common way for humans to affect the DO concentration of a stream is to raise the temperature, since we rarely change the altitude of a stream. Raising temperature is important, not just because it is inversely related to DO concentrations, but because higher temperatures increase the metabolic activity of aquatic organisms, so that they require more DO (Campbell and Wildberger 1992, 36). Ways in which humans raise a stream's temperature have been covered in the *Temperature* section. There are, however, other ways humans alter DO concentration.

An increase in gradient usually results in higher turbulence. As the number of riffles then increases, DO levels will increase since re-aeration in riffles is greater than in pools (Anderson et al. 1994; Kilpatrick et al. 1989; Laenen and Woo 1994, *cited in* Tanner and Anderson 1996, 22-24). Channelization, however, although it does increase the gradient, sometimes decreases channel roughness, which could actually result in lower turbulence.

Another way to increase turbulence is by increasing flow. A higher flow corresponds to a higher velocity, which will increase the rate of re-aeration, as evidenced in areas of whitewater. Also, slow moving waters heat up more under the energy of the sun. Thus, sometimes riparian vegetation removal, which results in an increase of flow,

can result in an increase of DO. Usually, however, the other effects of this (such as an increase in temperature) more than offset the difference, so that the end result is actually a decrease in DO levels.

The presence of dissolved or suspended solids also affects DO concentrations. The greater the level of solids present in the stream, the less easily oxygen will dissolve into it. For this reason, saline waters have lower DO concentrations than fresh water. Humans alter this in a number of ways. For instance, we often disrupt the riparian vegetation, thus increasing erosion and causing more solids to enter the stream. Riparian vegetation disruption will also, as has been discussed, raise the temperature of the stream, thus lowering DO levels. When land is irrigated, not all of the water is used by the crops. Some seeps into the ground, picks up salts and other minerals as it travels, and eventually reaches a stream in which it deposits these dissolved solids. One more common way that solids are added to a stream is from daily urban activities. The runoff from urban areas, as it travels over impervious surfaces, picks up many pollutants and carries them to the stream channel.

Aside from raising stream temperature, the most common way to alter a stream's DO concentration is to add nutrients to the stream. A study by Tanner and Anderson (1996, 52) on the South Umpqua River in Oregon found that "algal productivity is the net result of photosynthesis and respiration and apparently controls DO." There are many ways we can promote algal productivity, and there are other things we do to alter the BOD.

Freshwater is typically phosphorous limited, meaning excessive plant growth does not take place because there is a shortage of phosphorous. If phosphorous is allowed to

enter the stream, an **algal bloom** (a sudden explosion of algal growth) will often result, as all of the other necessary ingredients are already present. Phosphorous is directly and indirectly added to a stream through runoff from fertilized agricultural fields or lawns, runoff from livestock feedlots or dairies where manure collects, overflow from failing septic systems (see Friends of the Mad River 1995, 69, for common reasons of sewage system failure), and effluent from wastewater treatment plants. Also, many of these discharges contain ammonia, yet another contributor to decreased DO levels since ammonia in the stream uses up oxygen in the process of nitrification, or the production of nitrate (Tanner and Anderson 1996, 20).

This increase in algal productivity eventually leads to a reduction in DO levels in two ways. First, there are more plants in the stream. Although this does increase photosynthesis during daylight hours, during the night it can consume so much oxygen that levels dangerous to many aquatic organisms can be reached by early morning. Secondly, the decaying process of organic matter requires a lot of oxygen. When these plants die, they consume large amounts of DO from the stream. Nature adds organic material minimally, through falling leaves during autumn and dying trees along the riverbank, but mankind does it in much greater quantities by dumping lawn clippings and raked leaves or twigs into the stream channel.

Another method of decreasing DO levels is the building of dams. As mentioned earlier, water is typically released from the bottom of a reservoir. While this water is generally cold (so that one would assume it to have a high DO concentration), it is generally low in DO content. This is because dead plants floating in the stream are typically trapped by the dam and settle to the bottom of the reservoir. As these materials

decompose, large quantities of oxygen are used up. The water which is then released is therefore not only cold, but also low in DO content (Murdoch, Cheo, and O'Laughlin 1996, 170-171).

*Effects of Alterations:* The main concern of DO levels, as is the case for most water quality parameters, is the livelihood of aquatic organisms. Some species, including salmonids and certain macroinvertebrates, such as mayflies, stoneflies, and caddisflies (see section on *Macroinvertebrates*), require high DO concentrations to survive. This is part of the reason that these species are found in cold waters. If the DO content is low (below six mg/l for trout, and three mg/l for most other aquatic organisms) (Murdoch, Cheo, and O'Laughlin 1996, 171,174), these organisms will either be forced to relocate or die. Levels need to be even higher to ensure the survivability of eggs and larvae. If a **fish kill** results, DO is further reduced because of the oxygen required to decompose the dead fish. As fish either move away or die off, they are replaced by species tolerant of the new conditions. These are usually non-native species, and ones not commonly prized by anglers, such as bass and carp. Fish species also may be replaced since low DO levels reduce fish growth, thereby making it harder for them to compete against invading species.

Yet another problem imposed by decreased DO concentrations is the limited ability to decompose organic wastes. We seem to insist upon using streams as garbage dumps. Streams are naturally able to assimilate a certain amount of waste, but as the DO levels drop, the amount of waste they can effectively assimilate decreases. The problem is like a narrowing tunnel, in that the more waste we dispose of into the stream, the more oxygen it uses up. This eventually reaches a point where the stream can no longer

decompose the waste, and so it just accumulates. In many streams today, even small amounts of organic waste is causing excessively high levels of fecal coliform (bacteria originating in sewage) because the stream cannot adequately assimilate the waste.

*Additional Source:* For a description of various techniques and procedures used to measure DO, consult: Campbell, Gayla and Steve Wildberger, *The monitor's handbook*, edited by Nina Fisher, Marisa Feltham, and Eleanor Ely, La Motte Company, Chestertown, Maryland, 1992. This source also points out significant thresholds, and further explains what one can expect to occur once these thresholds are exceeded.

## pH

*Definition:* pH, or “puissance d'Hydrogène” (strength of hydrogen), is a measure of the acidity or alkalinity of a substance. The scale is logarithmic from zero to fourteen, with neutral, represented by distilled water, being at seven. This means that distilled water is more than ten times more acidic than baking soda, which has a pH of 8.2. Acidic substances have a low pH, such as battery acid with a pH of one, and vinegar with a pH of three. More basic (alkaline) substances are found at the higher end of the spectrum, such as ammonia at eleven, and bleach at twelve.

*How pH is Commonly Measured:* A common pH test kit can be bought which can quickly measure the pH of a stream. There are different types that are distinguished by their level of accuracy. Some kits may measure pH to the nearest integer, some may measure it to the nearest tenth, and so forth. One can also purchase pH paper which is read by color coding and is inexpensive but not very precise. This may suffice, however, depending upon the purpose of data collection.



*Significance:* The pH of a stream can affect the rate of many biochemical reactions occurring in the river. This refers to reactions between the water and inorganic material, between organisms and their surrounding water, and within organisms themselves by altering their cellular metabolism (River Watch Network n.d.).

Most aquatic organisms are reared in a stream within a specific pH range (typically between six and nine) and cannot tolerate too much deviance from this (Murdoch, Cheo, and O’Laughlin 1996, 166). pH becomes toxic to most aquatic organisms below 4.8 and above 9.2. Most freshwater fish comfortably tolerate pH levels between 6.5 and 8.4, and most algae will die at a pH greater than 8.5 (Brooks et al. 1991, 191).

By influencing these chemical reactions within the water column, pH can determine the type and quantity of chemicals and nutrients in the water column, be they at levels desirable by aquatic plants for survival or at toxic levels that can kill entire populations. This is partially true because “toxic metals trapped in sediment are released into the water at lower pH levels” (Campbell and Wildberger 1992, 34). For example, “a decrease in pH may increase the amount of mercury soluble in water, (and) an increase in pH may cause the conversion of nontoxic ammonia to a toxic form of ammonia” (San Francisco Estuary Institute 1996, 44).

*What Alters pH:* “Similar to the daily cycle of DO in relation to photosynthesis, the pH of surface waters is partially controlled by the metabolism of aquatic plants. Consumption of carbon dioxide by photosynthesis raises pH, causing later afternoon maxima; overnight respiration produces carbon dioxide causing early morning pH minima” (Tanner and Anderson 1996, 27). Like most any other parameter, the pH of a

stream can be, and often is, changed both by nature and by humans. Mankind actually sometimes intentionally raises a stream's pH in an effort to lessen environmental impacts.

First, let us see how nature may alter a stream's pH. pH is naturally determined by the minerals and gases within the soil and bedrock through which the stream flows. As the stream washes over, through, and sometimes under these substances, it picks up natural elements which can change the pH. For example, a stream flowing through a coniferous forest will be acidic, whereas a stream flowing through a maple deciduous forest will be basic (San Francisco Estuary Institute 1996, 45). Similarly, a stream flowing through a predominantly limestone area will pick up significant traces of calcium and magnesium, which will increase the stream's pH. pH can also increase as a result of carbon dioxide from the atmosphere dissolving in the water. The presence of algae and other aquatic plants in the stream will therefore increase pH through photosynthesis. Because of this, however, the pH of a stream will vary from daytime to nighttime (a diurnal change), with high pH levels occurring in the late afternoon and low levels occurring late at night. This addition of elements, which causes an increase in pH, is referred to as "buffering". "Buffering" is the ability of the stream to moderate effects caused by the introduction of acidic elements to the stream.

Now let us look at how and why humans intentionally alter a stream's pH. The United States today has thousands of abandoned mine sites. As rainwater and snowmelt flow through these sites, the runoff picks up acidic minerals and heavy metals, eventually depositing them into the nearest stream. These minerals increase the acidity of the river, lowering the pH. One way to combat this is to "reclaim" the site, often done with limestone to buffer the system against any acidic increases.

Other unintended alterations of pH owing to human hands come from surface runoff, effluent discharges, and atmospheric deposits. Surface runoff, especially in urban or suburban watersheds, often contains many substances which can alter pH. A substantial portion of surface runoff also comes from road surfaces, which can contain trace elements of gasoline, motor oil, and many other fluids discharged from automobiles.

Organic effluent discharges also contain minerals and gases that can change the pH of a stream. Sewage, especially, can cause problems. Freshwater streams typically have a limited amount of algae because there is a limited amount of phosphorous, and sometimes of nitrogen. These nutrients are common in discharges from sewage treatment plants, failed septic systems, and fertilizers spread upon agricultural fields. As they are added to a stream, an algal bloom often results. This increase in algae will change the pH of a stream as the carbon dioxide levels are altered through photosynthesis.

One of the main concerns today regarding the acidification of streams, especially in the eastern United States and Canada, is acid rain. Manufacturing plants and other polluters typically discharge industrial waste into the atmosphere, which then adsorbs onto condensed particles. At certain temperatures and densities, this acidic moisture falls to the earth as acid rain, accumulating in streams and lakes. Acid rain typically has a pH around 4.5. The lowest on record in the U.S. is 2.5, which occurred in Wheeling, West Virginia, during the 1970s. Many lakes in the Midwest and New England already have pH levels so low that there are no fish in them at all (The Freshwater Foundation 1985).

Finally, other ways in which humans affect pH include alteration of the type and quantity of sediments in a stream, and by altering the temperature. A large increase in temperature will decrease pH.

*Effects of Alterations:* Concern regarding pH is, of course, for aquatic life. Aquatic organisms are the ultimate indicators of stream health, and they can indicate if a particular stream is suitable for drinking, swimming, fishing, or a number of other uses. As mentioned above, aquatic organisms have adapted to a specific range of pH levels. If pH either rises above or drops below this range, organisms will be stressed, and may begin to die. In *The Adopt-A-Stream's Streamkeeper's Field Guide* it is stated that all fish will be dead at pH levels between zero and four, or between eleven and fourteen (Murdoch, Cheo, and O'Laughlin 1996, 167). If the pH of a stream is altered, the aquatic biota will be affected, which will then change the rest of the physical and chemical components of the stream. If an anthropocentric view is taken, that river systems are to be used for the benefit of humans, then we need to guard against changes that will affect the aquatic biota. For if the stream cannot be used by the plants and animals accustomed to this environment, it will not be able to be adequately used by us.

*Additional Source:* For a description of various techniques and procedures used to measure pH, consult: Campbell, Gayla and Steve Wildberger, *The monitor's handbook*, edited by Nina Fisher, Marisa Feltham, and Eleanor Ely, La Motte Company, Chestertown, Maryland, 1992. This source also points out significant thresholds, and further explains what one can expect to occur once these thresholds are exceeded.

## MEASURES OF BIOLOGICAL INTEGRITY

### **Macroinvertebrates**

*Definition:* "Macro," here defined as large enough to be seen without a microscope, and "invertebrate," meaning animals without backbones, are combined to represent the larvae of insects and other organisms within the aquatic environment. They are often referred to as benthic macroinvertebrates, "benthic" meaning "bottom-dwelling." Macroinvertebrate composition includes insects (such as stoneflies, mayflies, and caddisflies), arachnids (such as spiders and other eight-legged creatures), crustaceans (such as crayfish, crabs, and shrimp), and others (such as worms, snails, clams, and leeches).

These creatures are often subdivided into the following categories: shredders, scrapers (or grazers), collectors (filtering collectors and gathering collectors), and predators. (The following is largely adapted from Murdoch, Cheo, and O'Laughlin 1996, 125-126, with some assistance from Kellogg 1994, 1-2.)

Shredders have chewing mouthparts, enabling them to feed on large pieces of decaying organic matter, such as leaves, algae, and rooted aquatic plants. By processing this coarse organic matter into finer particles, they render it edible by other macroinvertebrates. Shredders tend to inhabit areas with a high percentage of canopy cover, typically exhibited in headwater reaches of a stream. Examples of shredders include certain stonefly and caddisfly larvae, sowbugs, and scuds.

Scrapers, sometimes called grazers, subsist on algae attached to rocks and other surfaces. Many scrapers have a flattened shape to withstand the current as they scrape algae off of a surface, such as a rock. Scrapers tend to inhabit areas where sunlight is

able to reach the stream bottom, permitting algae to grow. Such areas are typically found in the middle reaches of a stream. Examples of scrapers include water pennies, limpets, snails, and certain mayfly larvae.

Collectors eat fine particles of organic matter such as leaf fragments, bacteria, streambed deposits, and waste products from other organisms. They are divided into filtering collectors and gathering collectors. Filtering collectors capture the fine particles from the flowing water, while gathering collectors gather small sediment deposits from the stream bottom. Collectors can be found throughout the stream system, since their food supply is found in all stream reaches. In lower reaches, where fine sediments are more numerous and habitat for shredders and scrapers is limited, however, they tend to make up a larger proportion of the macroinvertebrate population. Examples of filtering collectors are clams and blackfly larvae, and examples of gathering collectors are many mayfly and caddisfly larvae and midges.

Predators consume other aquatic animals, including macroinvertebrates. They are therefore found in all stream habitat types. Examples of predators are dobsonfly larvae, fishfly larvae, watersnipe fly larvae, and dragonflies.

Throughout the stream, the greatest insect production occurs in riffles, especially those with cobbles (rocks six to twelve inches on a side), with a mixture of some boulders and gravel (Terrell and Perfetti 1989, 18). It is also important to keep in mind that "most aquatic insects spend the greater part of their lives as larvae." Therefore, in sampling, it is this larval stage that one is most likely to encounter (Murdoch, Cheo, and O'Laughlin 1996, 123-124).

*How Macroinvertebrate Composition is Commonly Assessed:* One common way to assess biological health is to use visual observation to note the presence or absence of fish. The fish, being at the top of the aquatic food chain, rely upon the rest of the biological community, including macroinvertebrates, for survival. A thorough fish analysis can therefore give a researcher an indication of the aggregate biological health of the entire stream reach. More commonly, however, the density and diversity of macroinvertebrates are measured to indicate stream health.

As noted above, some macroinvertebrates are less tolerant of pollution than others. These less tolerant ones are called indicator species, meaning their presence indicates good water quality and their absence indicates degraded water quality. Those considered largely intolerant are mayflies, stoneflies, and caddisflies. These are summarized as EPT (mayflies are of the Order Ephemeroptera, stoneflies of the Order Plecoptera, and caddisflies of the Order Trichoptera). Chironomids, on the other hand, are more tolerant of pollution. Therefore, a ratio of EPTs (termed “good bugs”) to chironomids (“bad bugs”) is used to determine water quality. A ratio below 0.75 is indicative of “some adverse impact, such as excess sedimentation or poor water quality” (River Watch Network 1991).

There are also many macroinvertebrate assessments available for which the sampler need only collect a sample of the bugs in an area, identify them, and determine the density of each, the density of the total, and the diversity (the total number of species found). From these data, generalizations can be made as to the quality of the habitat. It is important to remember that species diversity is more significant than species density.

A large number of macroinvertebrates is not a sign of good water quality if they are all chironomids.

*Significance:* Many ecologists believe that an assessment of the chemical and physical aspects of a river only gives an indication of what is occurring at that particular moment, whereas the biological community is an indicator of the overall health of the stream. This is because biological parameters integrate both the physical and chemical parameters. In other words, “species can take care of themselves if the ecosystems remain intact” (Rowe 1992, *cited in* EPA 1994, 910/B-94-05, 15). Therefore, biological assessment has become standard in virtually all watershed assessments.

Macroinvertebrates are commonly used for this biological survey for several reasons (*adapted from* Murdoch, Cheo, and O’Laughlin 1996, 119; EPA 1997, 823-R-97-005, 3.1). One, macroinvertebrates are relatively sedentary, so that they are indicative of the pollution in a specific stream reach. This differs from fish which, if able to, will swim away from pollution. Two, they have short life cycles, usually spanning a season or less, all or most of which takes place in the aquatic environment. Using other aquatic organisms, it could take years to determine the effects of pollution, whereas by monitoring macroinvertebrates one can sometimes detect pollution effects in a matter of weeks. Three, some macroinvertebrates are less tolerant than others to pollution. Hence, they can be compared to a “canary in a mineshaft,” their presence indicating good water quality and their absence indicating degraded water quality. Four, they are abundant and easy to collect with inexpensive equipment. Five, they are important links in the food chain. They recycle nutrients to be used by other aquatic organisms, and are a food source for fish. Finally, they are relatively easy to identify. They differ from algae in



this way, which are also indicator organisms but are less commonly studied because they are more difficult to identify.

The best indicator of biological health is species diversity (Erman, Newbold, and Roby 1977, 35; Oregon Department of Fish and Wildlife 1992, 143). When examining macroinvertebrate composition, certain species may indicate relative health or degraded conditions, but a mixture of many species is ideal. "Good water quality is indicated by a variety of different kinds of organisms, with no one kind making up the majority of the sample" (DePew, Reed, and Gleason 1993, 87).

There are, however, some limitations to macroinvertebrate surveys. Most importantly, a biological survey cannot give information as to what is polluting the stream. One can determine that a stream is degraded by examining the macroinvertebrate composition, but (most likely) will not be able to determine the nature of the degradation. Only chemical and physical surveys can identify specific pollutants. Also, whereas the presence of certain indicator species can signify stream health, their absence does not always signify stream degradation (Terrell and Perfetti 1989, 18). There are several reasons that might explain their absence, such as a recent flood, for example. Finally, not only are macroinvertebrates "sensitive to relatively few types of degradation," but "the tolerances of aquatic invertebrates have not been precisely defined in many areas" (Karr et al. 1986, 4).

*What Alters Macroinvertebrate Composition:* The term "pollution," when discussed in the context of macroinvertebrates, usually refers to excessive nutrients or sediments in the stream channel (Murdoch, Cheo, and O'Laughlin 1996, 135). This type of degradation typically occurs owing to the removal of riparian vegetation which, as has

been described, has many associated impacts. This vegetation removal could come about from logging activities, fire, or grazing and trampling by livestock.

Since riparian vegetation stabilizes streambanks and acts as a filter, it can limit the amount of nutrients and sediments that reach the stream channel. If the vegetation is removed, however, the additional inputs can adversely affect virtually every parameter of the stream, including the macroinvertebrates. It has been shown that if buffer strips of at least one hundred feet wide are left along the stream, the invertebrate populations (and physical characteristics of the stream) will be "indistinguishable from unlogged streams" (Erman, Newbold, and Roby 1977, abstract). This particular study also found that on streams logged without protective buffer strips, the invertebrate diversities remained significantly lower than those of unlogged streams ten years after the logging event.

The reasons riparian vegetation removal adversely impacts macroinvertebrate populations are many. One, the increase in nutrients results in an increase in aquatic plants, which ultimately lowers the concentrations of DO (Bormann et al. 1968; Fredriksen 1971, *cited in* Erman, Newbold, and Roby 1977, 29). Two, the canopy cover is reduced. One study found that a reduction in canopy cover from one hundred percent to fifty percent decreased invertebrate production by twenty-eight percent (Belt, O'Laughlin, and Merrill 1992, 4). This is because a reduction in canopy cover results in less food in the form of leaf litter and organic debris reaching the channel; less shade, and thus higher stream temperatures; and more light intensity, resulting in higher algal growth and less DO. Three, the potential for LWD to reach the channel is reduced. This LWD provides a stable habitat for macroinvertebrates (Marzolf 1978, *cited in* USDO I 1982, *FWS/OBS-82/24*, 51). Four, many aquatic insects use streamside vegetation during

emergence and adult stages of their life cycle (Oregon Department of Fish and Wildlife 1992, 144). Finally, the increased sedimentation decreases the "variability in streambed morphology," which results in a decreased macroinvertebrate diversity (EPA 1991, 440/5-91-005, 32).

Mining is another activity which degrades macroinvertebrate habitat. Macroinvertebrates are "very sensitive to acid and toxic metal pollution," as are attached algae, upon which many of them feed (EPA 1994, 910/B-94-05, 27).

There are many other activities that contribute excess nutrients, sediments, and toxic pollutants to the stream, including the agricultural use of fertilizers and pesticides; wastewater treatment plants and other septic systems; industrial discharges; and urban stormwater runoff. Any of these will adversely affect the macroinvertebrate composition.

Finally, for nature's part, the macroinvertebrate composition varies according to the season. As indicated above, these organisms have very short life cycles, and the time of year in which they are sampled can have profound effects on the results. This is true of most parameters, of course. For macroinvertebrates, it is recommended to survey in the spring and in the fall.

*Effects of Alterations:* The primary effect that one will see in the macroinvertebrate population owing to stream degradation is a decrease in diversity. This is not to be confused with a decrease in density, for indeed some organic pollution may result in an increase in macroinvertebrate populations. But this increase is found in those macroinvertebrate communities tolerant of such pollution, such as chironomids and black-flies, while the populations of intolerant species, such as mayflies, stoneflies, caddisflies, water-pennies, and riffle beetles, will decrease.

Regarding specific categories of macroinvertebrates, an increase in nutrients to the water column may result in increased proportions of scrapers, while increased numbers of collectors may indicate organic enrichment (Kellogg 1994, 1-2). Additions of sediment to the stream may result in higher proportions of burrowing organisms, such as worms and midges, but lower proportions of mayflies, stoneflies, and caddisflies, which require higher concentrations of DO. Generally, removal of riparian vegetation will result in an increase of scrapers and a decrease of shredders. Filter collectors may increase in density if organic matter is accumulating in the water column, and predators most likely will not change, unless the overall numbers of macroinvertebrates is reduced. One can see, therefore, that it is possible to relate macroinvertebrate composition to specific forms of pollution. This evidence, however, would be inconclusive without the accompaniment of physical and chemical sampling.

The overall impact of these effects is a detriment to the fish community. Macroinvertebrates make up a large percentage of fish diet, especially salmonids, for which they make up virtually the entire diet. Decreasing the numbers of these organisms, as well as altering their composition, adversely affects fish within the stream. Effects will also be seen in the organic material, be it natural leaf litter or discarded sewage waste, if these organisms no longer exist in populations adequate to break it down. The same is true for the algae that build up on the surfaces of the cobbles.

*Additional Sources:* For a good descriptive sampling technique for macroinvertebrates, consult: Platts, William S., Walter F. Megahan, and G. Wayne Minshall, *Methods for evaluating stream, riparian, and biotic conditions*, USDA Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report

INT-138, Ogden, Utah, May, 1983. This source, however, does not have an identification key. It does contain descriptions, with the pros and cons of each, of many methods used for fish sampling.

Another helpful source is Kellogg, Loren Larkin, *Save our streams: Monitor's guide to aquatic macroinvertebrates*, Izaak Walton League of America, 2<sup>nd</sup> edition, Gaithersburg, Maryland, 1994. This book has an excellent macroinvertebrate taxonomic key prepared for the layperson. It also has identification techniques, pictures, descriptions, habitats required by each, and significance of presence or absence of each species, as well as an inventory to be used to determine relative stream health according to the macroinvertebrate sample.

Valuable sources for identification of aquatic insects are: McCafferty, *Aquatic entomology*, Jones & Bartlett Publishers, 1981; and Merritt, Richard W. and Kenneth W. Cummins, editors, *An introduction to the aquatic insects of North America*, 3<sup>rd</sup> edition, Kendall/Hunt Publishing Company, Dubuque, Iowa, 1996.

For the most recent macroinvertebrate taxonomic key in California, contact the California Department of Fish and Game's Water Pollution Control Laboratory (WPCL) at 916-358-2858 (e-mail address is Jharr@sna.com), or visit the California Aquatic Bioassessment Web Site (<http://www.delta.dfg.ca.gov.cabwpage.html>), as mentioned in San Francisco Estuary Institute, *Volunteer monitoring protocols: A reference guide for monitoring California's rivers, streams and watersheds*, Richmond, California, 1996.

One of the best sources available for understanding sampling techniques of macroinvertebrates is Environmental Protection Agency, *Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish*, EPA 444/4-89-001.

## PRACTICING PREVENTION

The above sections on stream parameters include short descriptions of many of the ways in which humans negatively impact a stream system. There is much research occurring today to help understand the long-term effects of these impacts and how to rehabilitate streams. It is necessary here to mention the importance of preventing these problems from happening in the first place.

First of all, stream degradation is much easier and cheaper to avoid than to rehabilitate (Montana Department of Environmental Quality 1995, 17). The fisheries biologist William Platts has concluded that "a dollar in stewardship is worth \$10,000 in structures" (*cited in* Elmore and Beschta 1989, 119). This emphasis upon prevention is seen to some degree today with disturbances to ground water, because ground water is so expensive and difficult to clean up (EPA 1995, 841-R-95-004, xii), but it is well past the time these same efforts are devoted to preventing the degradation of surface waters.

There are a number of laws and regulations already in place today (*see Appendix C*), which can be used to prevent or control pollution. These are used to varying degrees, but more enforcement is necessary. This is an area in which citizen monitors can be particularly valuable. Government agencies cannot physically test and monitor every reach of every stream. The local community members, however, can get to most sites relatively easily, and coordinate efforts to determine if authorities need to be alerted.

To make accurate determinations of stream degradation, and to effectively prevent detrimental effects to the stream, it is necessary to understand the stream system, and how the actions within the entire watershed are affecting the health of the aquatic life within the channel, as well as the biota of the riparian zone. When undertaking a watershed project, therefore, two types of pollution controls should be included, "those

that clean up existing problems and those that prevent the same problem from recurring (or different ones from happening)” (Terene Institute 1993, 49).

## CHAPTER THREE

### WATERSHED ASSESSMENT

#### INTRODUCTION

Today there is a common belief that watersheds need to be managed holistically, meaning at the watershed level, rather than stream reach by stream reach. Because of the extraordinary dynamic relationships within natural systems, to understand a stream system requires understanding what is happening throughout the entire watershed. A stream, after all, “is only as healthy as its surrounding watershed” (Murdoch, Cheo, and O’Laughlin 1996, 2). To elaborate on this point, allow me to quote from *Clean Water, Streams and Fish: A Holistic View of Watersheds, Secondary Curriculum*:

Salmonids do not live in streams...they live in watersheds. The common assumption that salmonids live in streams has contributed to the loss of fisheries in the Northwest...We do not remember that 99% of what happens to a stream occurs outside of its corridor—in the watershed. We think that we must only protect activities in or immediately along the stream in order to protect salmonid habitat. Similarly, once damage is done to a watershed, we think we need only repair the stream corridor and fish will survive...Until we recognize that every activity in a watershed has the potential to affect the nearest stream, realistic efforts to protect and revive streams and fisheries will not occur (Dyckman, Way, and Kelly n.d., xii).

The EPA uses the term “Watershed Protection Approach” to convey this notion of holistic management (EPA 1991, 503/9-92/002). Similar terms used are “basin-wide approach” and “watershed-based.” This style of holistic management is currently being used by hundreds of government and conservation agencies throughout the country, most notably North Carolina’s “whole basin approach” and the Minnesota Department of Natural Resources’ “integrated resource management approach.” With this concept in mind, one can follow the advice of the Texas Natural Resource Conservation



Commission (1997, 6), and divide a watershed assessment into two parts: the background investigation, and the visual assessment.

The background investigation involves researching the past, present, and future uses and values of a stream. This can be accomplished by reviewing local records; analyzing maps, photographs, and news stories; and speaking with politicians, property owners, and neighbors. As Harrelson, Rawlins, and Potyondy suggest (1994, 3), "before taking to the field, take to the files," although a general stream walk beforehand will be helpful in understanding the relevance of the background information you collect. One must be persistent when gathering data, however, because although a wealth of data exists for most areas, they are often difficult to find and obtain because of the myriad of different agencies which keep such records (USDA 1994).

The visual assessment, on the other hand, involves field work. In this phase, stream reaches are assessed, water samples are taken and analyzed, and the monitoring of stream sites is conducted. It will most likely be found that the background knowledge accrued regarding the stream in question will shed light on what is discovered during the visual assessment.

## BACKGROUND INVESTIGATION

To better understand the background data being collected, it is helpful to first do a reconnaissance walk along the stream (Montana Department of Environmental Quality 1995, 15). This provides a first-hand look at the stream and its immediate surroundings, so that a frame of reference is established for when the maps and other files are examined. The purpose of this walk is not to remember all of the little signs of

degradation along the way, but to provide a general understanding of what is going on within the watershed.

As mentioned above, there may be a vast amount of information available for the watershed in question. The more information that one has, however, the more likely potential threats and subsequent impacts to the stream will be understood. What follows is a list of helpful topics to research when gathering background information (*adapted from Friends of the Mad River 1995; Murdoch, Cheo, and O’Laughlin 1996; Conservation Technology Information Center n.d.; EPA 1994, 910/B-94-05; Harrelson, Rawlins, and Potyondy 1994; and EPA 1995, 841-R-95-03*):

**\*Natural Features:** watershed sizes and boundaries; sizes, locations, and designated uses of all waterbodies within the watershed; topography; geological history; soils; vegetation; fish and wildlife; ground water quality; sediment budget; and climate.

**\*Critical Areas:** floodplain delineations; locations of highly erodible soils; critical riparian areas; critical instream habitat areas; sensitive ground water areas, such as recharge zones; locations and sizes of known pollution sources, such as animal operations and effluent dischargers; and estimates of NPS loadings.

**\*Cultural Features:** settlement history; historical features; current and projected land use; current and projected water use; road inventory; forest plan guidelines; recreational activities; private initiatives to protect land, water, or wildlife; demographics; growth projections; economic conditions, such as income and employment; spiritual and other cultural uses of significance to the area; and political jurisdiction;.

**\*Rules and Regulations:** national and local water quality standards; specific stream-protection regulations; land use plans; public land management plans; zoning

laws; and any other federal, state, and local government acts, laws, policies, regulations, ordinances, and so on, that are on the books that provide protection for aquatic systems and wildlife habitat.

Most of this natural feature information can be found using three basic sources: "a county highway map, a USGS topographical map, and (the) county's soil survey map" (Terene Institute 1993, 15). The county soil survey map can be obtained from the Natural Resource Conservation Service (NRCS) office, formerly known as the Soil Conservation Service (SCS). Unfortunately, this information is usually organized along political boundaries. For simplicity's sake, it may be useful to reorganize the data according to hydrological boundaries. It is easier, after all, to assess a watershed using **subwatershed** boundaries instead of, for instance, those of school districts.

Other sources of background information to consult are: libraries; university faculty; local and state agency personnel; local planning boards and staff; zoning maps; aerial photographs; and other conservation organizations. The best asset, however, is invariably the people who live within the watershed. The property owners are the individuals who make most of the decisions affecting stream health, so it will eventually become necessary to get to know them, and to understand how they are interacting with the watershed. Neighbors who have spent many years within the watershed usually know the most about the history of the area; the historical land and water uses; past problems the river has experienced; and many other insights which may greatly enhance an understanding of the river, as well as what has threatened it in the past, is threatening it today, and may be threatening it in the future.

Aside from the knowledge of the local "old-timer," it will probably be found that the USGS topographic map is the most valuable asset as one begins to understand the processes acting upon a stream. These maps shed light on watershed boundaries and sizes; elevations and slopes; relationships between the tributaries and the main-stem; intricacies of the road system; the proximity of many human-induced features to the stream; and so on. These maps can ordinarily be bought at sporting goods stores for about four to five dollars. See *Appendix C* for information on contacting the USGS.

Other sources of information for soils, water, plants, and animals are the *NRCS Field Office Technical Guides* which are published at the county level. For further assistance on the process of gathering background information, consult: Campbell, Gayla and Steve Wildberger, *The monitor's handbook*, edited by Nina Fisher, Marisa Feltham, and Eleanor Ely, La Motte Company, Chestertown, Maryland, 1992.

## CHOOSE A STUDY AREA

There are two distinct ways of going about assessing water quality. One is to attempt to study all of the impacts affecting an entire stream, the other is to narrow the focus of the study to a specific site and a particular impact. Eventually, a group may wish to attempt to analyze the entire system, as this is the ultimate goal of any watershed protection approach. This may also be useful since studying one small area and a specific pollution source will surely lead to questions regarding other sites and impacts, owing to the interrelated dynamics of a stream system. (It is important to understand that a "pollution source" does not necessarily mean the toxic discharge from a pipe; it also refers to many land and water uses.) However, for a newcomer to the process of watershed assessment, it is recommended to start with a specific focus. "Watershed

assessment is of greatest value when it identifies site-specific remedies for a watershed, improving beneficial uses in a cost effective manner. Similarly, assessing cumulative effects of watershed impacts is most meaningful when specific sources of degradation are tied to specific impacts within a specific frame of time and space” (EPA 1994, 910/B-94-05, 16). In other words, the more specifically the problem and the problem area are defined, the more clearly and easily objectives will be understood and attained.

However, locating a reach which is both interesting and manageable, considering available resources, can be difficult. It is possible that a study of the entire length of the stream is feasible. This usually requires “unlimited time, people power, and resources,” however, unless it is a very small stream (Murdoch, Cheo, and O’Laughlin 1996, 50). If the focus of the project is too large, several problems may result: the resources required to perform an adequate study may not be available; any solutions decided upon may prove to be impractical; it may be difficult to draw accurate conclusions from broad, diverse areas; and the sense of enjoyment for the project may be lost (Winborne 1989, 27).

As The Adopt-A-Stream’s *Streamkeepers Field Guide* indicates, the project focus can be narrowed as follows: “Within a larger watershed, select a subwatershed... Within the subwatershed, select stream reaches... Within each stream reach, select sites” (Murdoch, Cheo, and O’Laughlin 1996, 50). How one narrows the focus to subwatersheds and reaches will depend upon the beneficial uses of the stream identified by the community, and where these uses are being threatened (Behar and Dates 1995, 5). Be aware that to properly narrow this focus will require viewing problems within the context of the entire watershed. Once these areas have been identified, the specific focus

may shift slightly, depending upon the nature and extent of the water quality problem, the existing administrative boundaries, national watershed delineations (such as those mapped by the USGS and NRCS), and "ecoregion" boundaries. "Ecoregions" are "units reflecting homogeneous ecological systems" determined according to "topography, land use, potential natural vegetation, and soils" (Omernik 1986, *cited in* EPA 1995, 841-R-95-03, 2-3, 2-4).

In determining a specific reach, try to mark off a length of at least 500 feet. A common definition of a stream reach is that it is "at least 20 times the bankfull width of the channel" (Harrelson, Rawlins, and Potyondy 1994, 7). Either way, it should at a minimum cover an entire meander, defined as two bends. The *Streamkeeper's Field Guide* further recommends extending the survey area 250 feet from either side of the stream, giving a total of a 500 x 500 square foot area (Murdoch, Cheo, and O'Laughlin 1996, 57). This provides a survey area encompassing at least part of the riparian corridor.

When determining a specific water sampling site within a stream reach, the main concern is accessibility. Keep in mind that the exact same spot will need to be located and accessed over and over again, in all sorts of weather conditions. It is also important that one can safely sample parameters within the stream channel at the chosen location.

As a final note on selecting stream reaches for surveying purposes, it is of the utmost importance that the rights of neighbors are respected. If access to the selected site is on private property, traverses private property, or in any way could possibly impact a landowner, it is essential to establish a working relationship with this person. Do not assume that a landowner will permit trespassing simply because you are a volunteer trying to benefit the community. Always take the approach that you are asking a favor,

and would greatly appreciate any assistance by the landowner to enable you to carry out your study.

For more information on delineating a stream reach and surveying the area, consult: Harrelson, Cherly C., C.L. Rawlins, and John P. Potyondy, *Stream channel reference sites: An illustrated guide to field technique*, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-245, Fort Collins, Colorado, April, 1994. Another useful text is: Murdoch, Tom and Martha Cheo, with Kate O'Laughlin, *Streamkeeper's field guide: Watershed inventory and stream monitoring methods*, The Adopt-A-Stream Foundation, Everett, Washington, 1996.

## IDENTIFY SPECIFIC ISSUES

Deciding which specific water quality issues available resources should be put toward depends upon the same identified beneficial uses and values that were used to select the study area. Of course, it is sometimes necessary to select the issue to be studied before selecting a study area. What is important is to be specific about both.

Unfortunately, all aspects of a stream cannot be addressed at once. It is therefore necessary to decide which aspects are most important to the community, and which issues can be adequately addressed with the available resources. To do this properly may require short-term monitoring (see *Monitoring* section). The data accumulated from monitoring will probably make it evident where the problems lie. Sometimes, more useful information can be obtained simply by asking people around the community. The property owners, the "old-timers," the elected officials, and other concerned citizens will probably all have an idea of what they feel is of most concern regarding the degradation

of the local stream. Conversations with these people can quickly lead to an understanding of what uses and values the community feels are being threatened. It is also always beneficial to consult local ecologists or natural resource professionals for their input.

#### FIND SOURCE OF EACH ISSUE

Aristotle once said “a good doctor treats the patient, not the disease.” However, This can be very difficult and time-consuming. The patient, in this case, is the entire watershed, and the disease is the problem found within the stream. As an example, it is common in this country to attempt to solve the problem of declining fish populations by raising fish in hatcheries and using them to stock the depleted streams. This is a case of treating the symptoms instead of curing the problem.

The *Streamkeeper's Field Guide* puts it this way: “When fish runs disappear...rather than protecting habitat that indigenous species of fish require, we humans often try to introduce exotic species that can adapt to the changing environment” (Murdoch, Cheo, and O’Laughlin 1996, 250). This, in fact, only completes the alteration of the natural environment, and gives the public a false idea that the system is being improved. As Elmore and Beschta point out (1989, 118), “in the rush to install expensive and often counterproductive fisheries enhancement structures, we have ignored what should be the primary management focus--restoring streamside vegetation.”

What is being alluded to here is the importance of understanding the causes within the watershed which are leading to the effects seen in the stream channel. “Since a disturbed channel is an effect of watershed conditions, it is important not to attempt (a



rehabilitation project) until the watershed condition which caused the disturbance is corrected” (Jackson and Van Haveren 1984, 702). Otherwise the project into which much time, effort, and money has been invested will only have short-term success.

Another difficulty lies in determining if the apparent “degradation” is a result of natural causes, or of human interference. For example, streambank erosion may be the result of a river’s natural tendency to meander, or it may be a result of increased stormwater runoff, or disturbance to the riparian vegetation (Czaplinski 1997, 6). One must be careful not to “rehabilitate” a healthy stream.

Determining the true source of a problem, however, can be extremely difficult. Because of the complexities of the human cultural system, and the dynamics of the natural hydrological system, matching effects to causes can require a vast amount of research. For example, one might assume an increase in algae production to be the result of an increase in nutrient loading into the stream. Upon further research, however, it may be found to be the result of a decrease in flow or a decrease in the population of macroinvertebrate grazers. In this case, attempts to lower algae production would fail because they are already at natural levels (Watson 1997). This emphasizes the importance of performing a detailed study in order to understand the nature of the problems and possible solutions.

Cumulative watershed effects pose a difficulty in identifying causes of problems (EPA 1994, 910/B-94-05, iii). Although the effect may be severe degradation to water quality, the cause may be a product of many minor contributors. This hampers the effort of determining the ultimate cause of the problem in question. This again emphasizes the importance of the background investigation, coupled with a stream walk, to aid in

understanding what is impacting the stream, and where these impacts are located. Unfortunately, the problem is usually not as easily identifiable as locating a pipe and following it to its source. This is part of the reason why the EPA addressed point source pollution before making an issue of NPS.

Again, the best tool to determine the true source of any existing or potential impact to a stream is to talk with the local citizen. Friendly conversations with landowners and business proprietors, coupled with the background investigation and visual assessment, will result in a better understanding of how and why any pollution is reaching the stream channel. When discussing these issues with landowners, remember that these "polluters" are also members of the watershed community, and likely recognize the same beneficial uses and values as the rest of the community. They are more often than not willing to make changes to lessen their impacts to the stream, as long as they understand how they are impacting the stream and what their alternatives are. It is important to make an effort to work collaboratively with neighbors, and not to alienate them by working against them.

#### **DETERMINE IF ISSUES SHOULD BE ADDRESSED**

Now that a focus area and specific issues have been identified, it is necessary to examine each identified issue to decide if it warrants a more detailed study. This involves prioritizing issues according to the beneficial uses and values identified by the community, and understanding the costs and benefits associated with each possible project.

Again, this may require short-term monitoring (see *Monitoring* section). Without the data gathered from monitoring, it can be difficult to determine the severity of an issue, or the likelihood that anything will be able to be done about it. Sometimes, however, monitoring data can take years to collect if it is to be considered useable. One may be able to use the background information to serve similar purposes, however, if the information is detailed enough. If not, there are tools available which may provide the necessary information without spending many years collecting data.

These tools include watershed inventories, stream walks, and other field work. A watershed inventory is essentially a checklist of different physical, chemical, and biological parameters to determine if a stream reach is healthy. (See *Appendix A* for examples of watershed inventories.) A stream walk, this time examining areas in more detail than on the first (reconnaissance) stream walk, can help lead to an understanding of what is contributing to problems to the stream, as well as determining the severity of each. This second and more detailed stream walk involves mapping problem areas, noting specific phenomena, and using one's senses to better understand what is happening within the stream and the watershed as a whole. Other field work may include taking measurements, testing samples, and surveying the upland areas of the watershed. Combined, these three tools should help answer many questions regarding the types and sources of pollution reaching the stream in question.

While contemplating what can be done to protect or rehabilitate a stream, do not omit the option of allowing it to recover on its own. This was "perhaps...(the) most important conclusion" of a watershed study performed during the 1960s (White and Brynildson 1967, *cited in* Beschta et al. 1995). Of course, the concept of allowing the

stream to recover on its own presupposes that additional problems are not being perpetually created. This idea of leaving the system alone is often difficult for managers who usually feel they need to practice hands-on management. When one understands the dynamics of a stream system, however, and its ability to take care of itself given the chance, it often becomes clear that the best solution is to leave the stream alone. This issue mostly arises when one is considering rehabilitation projects, but it can be useful to those thinking about whether their limited resources should go toward further analyzing any particular problem.

Ultimately, however, whether a specific threat is addressed depends upon the priority placed upon the particular use and/or value threatened, and the resources available. In other words, one must have the time, money, and expertise to gather data adequately, assess the situation, possibly rehabilitate the site, and educate professionals and the public about what was determined and what procedures were performed.

## DECIDE ON PROPER ACTION TO TAKE

When the time to take action arrives, the **stakeholders** (those directly involved with the process) and the community must decide among a few alternatives. These alternatives include deciding to do nothing at all; determining that the situation still needs further study; postponing the project; initiating only part of the project; or going ahead and working to accomplish the entire project (Terene Institute 1993, 19).

In terms of attempting a rehabilitation project, there are many possible solutions to any given identified impact, too many to attempt to describe in this document. Oftentimes, however, the options are between natural and artificial restoration

techniques. The feasibility and cost-effectiveness of each may vary considerably, but as a rule of thumb “artificial stream restoration must never substitute for a vigorous, responsible stewardship of riparian systems and their surrounding watershed” (Beschta et al. 1995). Artificial systems are usually more permanent, but they are also often more expensive, and typically only address a single issue. Riprap, for example, stabilizes a streambank effectively, but provides little or no fish habitat or canopy cover to the stream. Vegetative restoration methods, on the other hand, usually provide more benefits to the overall system, although certain methods are more expensive and labor-intensive to implement. Either way, the general rules to follow when deciding upon a rehabilitation technique are to have realistic objectives, evaluate a range of alternatives, and seek the input of professionals (Montana Department of Environmental Quality 1995, 15).

The most important action to take before embarking upon a project may be to consult the stakeholders. These may include landowners, businesses, government agencies, conservation groups or other organizations, and other concerned citizens. The more input that one has, the greater the possibility that the decision will be “the right one.” After discussions with the stakeholders, and examination of all of the alternatives, the most cost-effective solution addressing the issue of highest priority to the community should be chosen. This method is believed to be more successful than “targeting groups to get them to listen to what the information planners alone may believe relevant” (O’Keefe n.d., 3-4).

Oftentimes, the first instinct of a concerned citizen upon finding a pollution source is to contact an authority on the issue, such as a government agency. It is important, however, to realize the alternative options. A bit of advice is to keep the issue

a local one for as long as possible. If necessary, the option of contacting the authorities, or even the media, to bring a suspected illegal polluter into compliance will always be available. It has been shown, however, that more often than not, if the landowner is made aware of the problem, and understands the impacts being caused, he will work to remedy the situation (O'Keefe n.d., 3; Friends of the Mad River 1995, 108; The Freshwater Foundation 1985, 14). Again, consider that the landowner is also a member of the community who has a stake in the quality of the river, and may simply be unaware of the consequences of his actions. After all, it is "the individual property owner who ultimately decides whether or not to follow the rules" (Murdoch, Cheo, and O'Laughlin 1996, 229).

#### ESTABLISH MONITORING PROGRAM

Monitoring is often required before, during, and after any project is implemented. Before a project is begun, monitoring is often necessary to fully understand the problem and the dynamics of the system, so that an accurate decision in choosing the most effective rehabilitative solution can be made. During implementation of a project, monitoring is often necessary to keep abreast of changes because "watershed conditions continue to degrade during the time of the investigation" (EPA 1994, 910/B-94-05, 42). After a project has been completed, monitoring is necessary to ensure that short-term and long-term objectives have been met, that the desired water quality levels are being maintained, and to determine if another rehabilitation project is needed.

It is also beneficial to monitor streams in all conditions. "Undisturbed watersheds need monitoring to provide baselines for regional environmental quality; disturbed

watersheds need monitoring to evaluate the condition and the success of recovery strategies” (EPA 1994, *910/B94-05*, 36). As long as the purpose for gathering data is understood, and there is a plan for how to use it, then the information collected on any given stream can be useful to many different local, regional, and national organizations.

There are seven basic types of monitoring (Brooks et al. 1991, 203; Dates 1995):

- \*Trend Monitoring: Establishes a trend to determine if designated uses are being protected.
- \*Baseline Monitoring: Determines **natural background levels** by examining a “pristine” stream.
- \*Implementation Monitoring: Determines how BMPs, and which ones, should be implemented.
- \*Effectiveness Monitoring: Determines if BMPs are effective in accomplishing objectives.
- \*Project Monitoring: Determines the positive and negative effects of a project.
- \*Validation Monitoring: Determines if a hydrological model being used is valid.
- \*Compliance Monitoring: Determines if water quality standards are being met.

These monitoring methods can be divided into three categories (Dates 1995, 1-2): observation, field measurements, and sampling and analysis. All three of these can be used for physical, chemical, and biological parameters, but the usefulness of the data varies.

Monitoring by observation uses subjective judgments about the appearance or odor of the stream. This qualitative assessment is essentially a watershed inventory--that which was performed on the stream walk, for example. This information is simple and inexpensive to collect, and can be useful in understanding the general health of a stream. It is not effective, however, if it is necessary to present the data to the public.

Monitoring by field measurements uses tools, such as a thermometer, pH kit, or tape measure, to make measurements in the field. These data are also relatively simple

and inexpensive to collect, and are more useful than data gathered by observation because they are quantifiable.

Monitoring by sampling and analysis is the most time-consuming and expensive, because it involves taking samples from the field and bringing them to a lab for analysis with technological equipment. Because of its scientific credibility, however, this data proves most effective when it is necessary to present results to a group, such as a planning committee or a government agency. Regardless of the system selected, there is a common set of questions to ask before beginning. These questions are (Murdoch, Cheo, and O'Laughlin 1996, 44; Dates 1995):

\*Why are you monitoring? "Before monitoring begins, the purpose for gathering the information must be defined" (Campbell and Wildberger 1992, 11). This purpose will be clear if the community has clearly determined which beneficial uses and values are of highest priority, and what specific pollution sources may be threatening these uses and values. Once this is clear, the most suitable monitoring method should become evident. Answering this question, therefore, helps answer many of the following questions.

\*What parameters will you monitor? This question was most likely answered in the previous question. The parameters one needs to measure obviously depend upon what one is trying to discover. However, they may also depend upon the available resources, meaning the time, equipment, and expertise required may be limiting factors.

\*Where will you monitor? Where one monitors can depend upon many factors. The main criterion is usually accessibility. Getting to the sampling site must be both safe and legal. But it will also depend upon what is being monitored. For instance, for



effectiveness monitoring, a sample site may need to be established just downstream from a suspected polluter. Another example may require a sample site to be located in a riffle in order to get a representative sample of macroinvertebrates. Also, some parameters such as temperature may require multiple sampling sites throughout a stream reach.

**\*When will you monitor?** When one monitors refers to the time of day and the time of year at which samples are collected. This will depend not only upon weather conditions and time availability, but also upon what parameters are being studied and what the objectives are. As mentioned earlier, for example, macroinvertebrates should be sampled in the spring and in the fall, or if one is doing compliance monitoring for pH or DO, sampling may need to be done in the early morning. The *Streamkeeper's Field Guide* recommends stream reach surveys be conducted four times a year, once in each season, in order to detect seasonal changes that occur in the stream (Murdoch, Cheo, and O'Laughlin 1996, 68).

**\*Who will monitor?** It is important that a qualified individual is selected. This is related to when monitoring is done, so that this individual (or group of individuals) is available at the determined times. It may be necessary to train multiple individuals or groups to assure that the data will be collected in a timely manner.

**\*What are your quality assurance / quality control measures?** "The ability to accurately make and replicate stream channel measurements over a period of years and through changes in personnel is vital" (Harrelson, Rawlins, and Potyondy 1994, 1). Quality assurance / quality control (QA/QC) measures are steps taken so that anyone interested in reviewing the data can be assured they are valid. These measures include steps that assure consistency in how and when the data are collected, stored, transported,

and measured. A QA/QC is essentially a written sampling and testing process that will be followed precisely every time a sample is collected. A good way to test the credibility of a QA/QC process is to perform an experiment in which someone unfamiliar with the study, on his or her own, is able to go out to the precise location selected; take a measurement or collect a sample in the exact same way; use the same equipment; perform an evaluation or a test using the same methods and guidelines; and obtain essentially the same results.

\*How will you use your data? This may be the most important step, and one which is much too often ignored. As the EPA says, "do not simply collect data" (1997, 841-R-97-006, 36). A common mistake made by many watershed managers is to monitor for the sake of monitoring. Oftentimes, when a threat to a stream is perceived, people go out and start collecting data. If they do not explicitly understand how this data is to be used, however, they may end up collecting a lot of irrelevant data. "Remember that no data is better than wrong data," since wrong data is a waste of time, and only serves to confuse the issue (San Francisco Estuary Institute 1996, 29).

\*An example of a successful citizen monitoring program: A citizen monitoring program in central Vermont, called Mad River Watch, has been operating successfully since the summer of 1988. This program employs volunteers who sample on a regular basis throughout the summer for bacteria. The samples are tested in a laboratory at the local high school. The purpose is to alert the public to possible dangers at popular swimming holes. The group's president, Jack Byrne, attributes the success of the project to three factors: 1) It has focused upon an issue of importance to the public; 2) It has reported data "persistently and consistently"; and 3) It has used many forums to spread

the knowledge--such as annual reports, newspaper columns, newsletters, and community meetings (Byrne 1994).

For more information on determining why, what, where, how, and when to monitor, consult: Dates, Geoff, *Study design: The foundation of credibility*, reprinted from "The Volunteer Monitor," Vol.4, No.2, Fall 1992, River Watch Network, Montpelier, Vermont.

## CHAPTER FOUR

### CASE STUDY

#### BRIEF DISCUSSION OF FREEMAN BROOK

The Mad River flows for twenty-six miles, originating in the Granville Gulf of central Vermont, and flowing northward until its confluence with the Winooski River in the town of Middlesex. The Winooski River flows northwestward into Lake Champlain, which eventually reaches the Atlantic Ocean by way of the St. Lawrence River. One of the tributaries of the Mad River is called Freeman Brook, a.k.a. Kids' Brook. This perennial stream flows entirely within the boundaries of the town of Warren, Vermont. The headwaters of Freeman Brook are in the forested slopes of the Northfield Range of the Green Mountains in East Warren, Vermont.

As it descends this hillside, Freeman Brook enters a minor agricultural area, essentially consisting of one dairy farm and a few corn fields. It passes by a couple of homes before crossing underneath a paved road (Plunkton Road), after which it parallels Brook Road, also paved, down to Warren Village. Once it enters the village, its banks are almost entirely ripped as it meanders among homes and underneath roads. It borders a couple of commercial sites as it passes just behind the Pitcher Inn, and finally reaches the Mad River just beyond the Warren Store.

#### CHOOSING FREEMAN BROOK AS THE STUDY AREA

The first step of this case study was to decide upon a study area. The Mad River watershed was decided upon because the author is most familiar with that area. The original plan was to cover the twenty-six miles of the main-stem, but it was quickly

realized that this would require much more time and resources than was available. The twenty-six miles of river length could be feasible if one were to simply walk the channel and observe conditions along the way, but the task was daunting when the many more miles of tributary streams, and the 143 square miles of watershed area, were taken into consideration (Friends of the Mad River 1995, 18). If such a large study area was chosen, with the limited resources (mainly time) available, the result would inevitably be a mass of data generalized to the point that they would be only marginally useful to those who might benefit from such a study.

The criteria for narrowing the focus were to find an area near home, an area that was relatively small, and an area on which some previous research had already been conducted. Satisfaction of these criteria would facilitate field work, and alleviate problems associated with the limited resources. Another important criterion was to locate an area of concern to the stakeholders within the community. Freeman Brook was chosen based on these criteria.

## GATHERING BACKGROUND INFORMATION ON FREEMAN BROOK

Freeman Brook is a very small tributary to a small river in a rural part of the country. Largely for these reasons, few studies have been conducted on this particular stream. There are no USGS flow meters along its length (although there is one on the Mad River downstream from the confluence with Freeman Brook), and no long-term monitoring data for any specific parameter of the brook exists. What exists, as is the case in all parts of the United States, are maps.

A lot of information, including what is and is not available concerning Freeman Brook, has been personally gained from the author spending approximately twenty years in this particular area. There are always, however, aspects or bits of knowledge which, even after twenty years of living in an area, are not known to the local resident. For this reason, it was necessary to consult maps and members of the community to find out what was not already known.

After reviewing a USGS topographic map of the area, as well as some aerial photographs, it was time to ask community members what specific impacts were of local concern. This led to conversations with Kinny Connell and Richard Czaplinski, President of and environmental consultant to FMR, respectively.

Friends of the Mad River is a non-profit organization located in nearby Waitsfield, Vermont. It was founded with the purpose of protecting and improving the ecological, scenic, and recreational values of the Mad River and its tributaries. In so doing, FMR also works to educate and involve the public of the Mad River Valley, a settlement area made up by the towns of Warren, Waitsfield, Fayston, and Moretown.

These conversations with Kinny and Richard, as well as those with other community members, shed light on some of the impacts facing Freeman Brook. From land use to road traffic, from the construction of an inn in the village to logging, the concerns the community had regarding the degradation of the brook were realized. With this general knowledge the author set out to walk the channel from mouth to headwaters.

## IDENTIFY SPECIFIC ISSUES FACING FREEMAN BROOK

The primary concern in determining which specific issue facing Freeman Brook would be examined was what most concerned the community. The primary issue concerning Freeman Brook, according to Kinny and other FMR board members, was that after a rainstorm a substantial amount of sediment washed downstream, with the subsequent muddy appearance sometimes lasting for several days. Sedimentation, as previously mentioned, is an issue throughout the United States, including the state of Vermont, where sedimentation from soil erosion is “the greatest cause of pollution to streams and lakes” (Warren 1997). Susan Warren (1997), an aquatic biologist for the state of Vermont, also states that an indication that erosion is occurring is muddy streams during rainstorms.

It is common knowledge throughout the Mad River Valley that this particular brook flows through agricultural land, and that in this area streambanks are visibly eroding, apparently owing to cattle trodding in the riparian zone. A little hiking also revealed evidence of slope failures in the uplands. There are, of course, other impediments to the water quality of Freeman Brook, including extreme low flows, slight channelization, and an influx of organic pollution. As mentioned earlier, however, the goal was to focus upon a single impact, and sedimentation seemed to be of special concern to the citizens of the Mad River Valley.

A camera and a notepad, along with some light hiking boots, were the tools used for the stream walk. Along the way, sources of sediment reaching the water column were sought. It was a sunny day in September, and it hadn't rained for several days, so the actual deposition of sediment to the stream was minimal. Nevertheless, it was still plain

to see where sediment had washed down slopes, and at what points it was entering the channel. Photographs were taken of these specific areas.

It is important to realize that sedimentation is a natural phenomenon that is only considered polluting if it occurs at excessive rates. Many of the sedimentation sources found along Freeman Brook were caused by minor streambank erosion. Some of this seemed to be occurring naturally, but much of it was a result of humans clearing the riparian zone to extend lawns to the river's edge. Cumulatively, these sources can have a relatively severe impact on water quality but, for the purposes of this case study, it was felt the greatest benefit could be accomplished with the limited resources by focusing on the more major sources of sediment. This led to a selection of three particular sites.

#### FIND SOURCE OF EACH ISSUE

The first site was along a fill slope of Brook Road. There had recently been a construction project (completed in August, 1997) carried out to install a guardrail along several hundred yards of the road. The last step of the project was to dump dirt on the bank (a slope about forty feet long with a gradient of approximately forty degrees, sloping directly down to the stream channel) and cover it with grass seed. There were no precautions taken, however, to prevent this soil from being carried by runoff down the slope and into the stream. To prevent this surface runoff from eroding the bank, a channel was formed along the edge of the road, with periodic exits to force the water to flow down this slope in predetermined locations. At some locations, pipes were installed under the road surface to carry moisture from underneath the road to prevent frost heaves. These pipes, of course, also have precise outlets at which the water exits the pipe, falls to



the slope, and travels down toward the brook. The routes for this water were inadequately protected, however. Rocks had been placed where the pipes and channels deposited the water to lessen the impact caused by the falling water, but channels were not created all the way down to the stream to prevent the erosion that would inevitably occur from this cascading water.

The second site was that of a slumping slope. The slope, consisting mainly of sand and clay soils, is very steep, almost vertical. The brook lies immediately at the base of this slope, which rises perhaps forty feet above the channel. The causes of this slump, however, are difficult to determine.

The slumping slope is on the left bank (determined as one faces downstream) of Freeman Brook, whereas the road is located on the right bank. However, after discussions with Wayne Kathan, Town of Warren Road Commissioner, and from looking at aerial photographs, it appeared that the stream had been moved to accommodate the road. This relocation may have led to the erosion of the toe of this slope, ultimately causing the entire slope to lose equilibrium and begin to slump. On the other hand, of course, it is possible that this slope is slumping as a result of natural causes. Even so, this would not preclude the possibility of attempting to rehabilitate the area to lessen sedimentation to Freeman Brook.

The third site was a case of severe streambank erosion within a dairy operation on an unnamed tributary of Freeman Brook. For about seventy-five yards, the channel has become incised, apparently due to removal of riparian vegetation and trampling by cattle. On the north edge of this field lies Airport Road, with a culvert running underneath it. On the north side of Airport Road the stream appears healthy, with diverse riparian

vegetation and a narrow channel. On the south side of this road, beginning exactly where the culvert empties, which is also where the fence to contain the cattle is located, the stream explodes. The channel becomes very deep (bank heights during low flow are approximately ten inches north of the road and six feet south of the road ), and the stream occupies roughly five percent of the channel. The erosion which has already occurred is evident, and the erosion which will continue to occur, unless management steps are taken, and/or until the stream has completed its process of establishing equilibrium (see *Width-to-Depth Ratio* section in Chapter Two), is equally evident.

#### DETERMINE IF ISSUES SHOULD BE ADDRESSED

The conclusion from the first site (the fill slope) was clearly that the issue should be addressed for three reasons. First, it is clearly a man-made impact, resulting from a construction project and the building of a road. Second, it can be easily improved with limited expertise and little equipment. Third, the benefits will certainly outweigh the costs, as the costs will be very low. The only resources required will most likely be a half-day of labor, and perhaps some rocks and/or concrete.

A decision was more difficult to come by on the second site (the slumping slope) because, with the limited time available, it was difficult to determine the costs that would be associated with the project. The benefits, of course, are obvious. During a rainstorm soils will clearly become loose as a result of raindrop impact, and will subsequently be drawn by gravity down to the stream channel. Furthermore, this site seems to be a particularly significant source of sediment to Freeman Brook. The costs of rehabilitation, however, could be high. See the *Decide On Proper Action To Take* section for further

descriptions on the costs associated with the various possible rehabilitation techniques for this particular site.

The conclusion for the third site (the eroding streambank) was to begin a rehabilitation project, mainly because it is clearly a result of careless riparian management, and because the costs should outweigh the benefits (see the *Decide On Proper Action To Take* section for a description of the selected method of rehabilitation). The term "careless" is used because cattle are allowed to graze right up to the edge of the stream, and even walk down the banks to drink out of it. Because of this, the only riparian vegetation is herbaceous. This vegetation has a weak root system, and the problem is further complicated by the trampling of the cattle along the banks. (See *Riparian Vegetation* section in Chapter Two for a more detailed analysis of this type of stream degradation.)

## DECIDE ON PROPER ACTION TO TAKE

There are many ways to rehabilitate a site, depending upon a myriad of factors. The first question to answer is whether rehabilitation is necessary. In all three of these instances, it seems that the stream is out of equilibrium and would benefit by some intervention. The second site (the slumping slope) still causes some confusion, since it may be a natural occurrence, but that will be examined soon. If rehabilitation is deemed necessary, the proper technique must be chosen. This technique will have to fit whatever resources are available. To make the proper selection, an expert in the field should always be consulted.

For the purposes of this case study, it was clear there would not be enough time to carry out any rehabilitation projects. The goals were to assess the sites and come up with possible solutions that FMR could then implement if they so chose. The following is a possible solution for each site, determined in conversation and site visits with Kinny Connell and Richard Czaplinski.

The first site would be fairly simple to rehabilitate, since the problem was not severe. Some care had been taken to install pipes and a drainage ditch to facilitate the removal of water from the road surface, and to govern its route down the slope toward the stream. The only concern was the erosion this water would produce as it fell from the pipes onto the slope, and as it flowed down the hill. It was therefore decided to contact the Road Commissioner for assistance, and discuss the problem with him so that a similar error would not be repeated. To rehabilitate this site, it was felt that proper placement of rocks would deflect the erosive power of the water tumbling out of the pipes, and that the construction of rock channels down to the stream channel would eliminate any erosion which would potentially be incurred by the flowing water.

Whether to rehabilitate the second site is still currently undecided. There was insufficient evidence as to the cause of the slump by the time this document went to press. The feeling was that if the slope was slumping as a result of natural causes, then the system should be left alone to reshape the landscape as it saw fit. If, on the other hand, the slope was slumping because the river had been moved up against it to make room for the road, the feeling was that action should be taken.

If action were taken on this site, there would be a few options available, albeit expensive options. For instance, the slope could be reinforced with riprap, **revetments**,

or a combination of the two; or the slope could be sloped back (which may require the use of heavy machinery) to reach an angle of repose, and then vegetation could be planted, also possibly with the help of a revetment. Whichever method is chosen, assuming the site should be "fixed" in the first place, the procedure would probably require considerable resources, including time, expenses, equipment, and professional guidance.

For the third site, a site visit was made with two members of the Vermont State government. The view of the stream downcutting through the agricultural field quickly convinced them that action should be taken. The agreed upon plan of action was to contact the farmer and work with him to reclaim the site. It would be a joint effort between FMR (providing labor and materials), the state (pressuring the farmer to allow this work to be done so as to avoid state penalties resulting from improper land management), and the farmer (allowing some of his grazing land to be taken out of productivity).

The solution decided upon was to put up a fence around the eroding streambank to keep the cattle out. This first step would give the streambanks a chance to hold together as step two was enacted. The fencing would only eliminate a small percentage of the grazing land since it would not divide the field, thereby allowing the cattle access to the grazing area behind the fence. To further lessen the impact to the riparian zone, it would be suggested to the farmer that he provide water to the cattle far away from the stream to encourage them not to walk into the channel to drink. Once the fence was erected (with sufficient distance from the streambank to prohibit the cattle from reaching through and eating the riparian vegetation, and to allow for any further erosion expected

from the stream), step two would be to plant willow posts along the banks. To do this, some of the steeper banks would need to be sloped back to a forty-five degree angle. In other places, the willow posts could simply be stuck into the bank as it is. The stream here usually has a very low flow, so it may not even be necessary to protect the banks with deflectors.

The benefits of this project would be a healthy riparian zone for any aquatic life in the stream, less sediment flowing down the channel to be deposited into Freeman Brook, and, most importantly, a saving of land for the farmer by discontinuing the rapid slumping of his farmland into the brook ("most importantly" because it is enormously beneficial to be able to confront the "polluter" from the standpoint of someone looking to help, rather than as someone trying to stir up trouble), as well as protection for the farmer from any state sanctions which would surely befall him. A winning solution for all parties involved.

#### ESTABLISH MONITORING PROGRAM FOR FREEMAN BROOK

As mentioned earlier, monitoring can be an important part of any watershed assessment and/or stream rehabilitation project. Unfortunately, it requires time which was in limited supply for this case study.

To circumvent the part of monitoring before the onset of any project, information was obtained from a stream walk and discussions with members of FMR, who have made it their commitment to visually monitor, and analytically monitor in the case of *e. coli* bacteria, the Mad River and its tributaries.

During a project, again, it is important to monitor to keep abreast of any changes taking place within the stream system throughout the sometimes lengthy process of installing any rehabilitation structures. This part of monitoring is rendered irrelevant to the purposes of this case study, since no projects were actually begun.

Monitoring after completion of a project, as previously stated, is necessary to ensure that declared goals have been met, and to determine if any future projects may be necessary. To circumvent this monitoring step, it was resolved not to carry out any projects. Again, time constraints limited how much could actually be accomplished, and how effective any projects would have been. For this reason, it was decided to accomplish the desired goals by examining the sites, and proposing possible solutions that could then be followed up at a later date.

## APPENDIX A

### WATERSHED INVENTORIES

**Introduction:** There are many different ways to measure river “cleanliness” and, thus, to survey a watershed (Byrne 1995, 1). How a watershed inventory is conducted, and what information it includes, largely depends upon the resources available and the objectives of the data collection. Included here is a list of many qualitative and quantitative watershed inventories. Some of them are long, and many are quite similar to one another, so instead of writing out the inventories themselves, only origins are given so that the reader can find them if he so chooses. Where possible, a short description of the inventory is also included to help the reader better determine which one (or combination of a few) will be most suitable.

**Stream Walk:** “Some indicators of how we human beings may be abusing the land can be readily observed just by walking along a stream and looking carefully at the streambanks and stream bottom” (Czaplinski 1997, 6). This type of watershed inventory is called a stream walk. It is a qualitative inventory and, therefore, relatively simple to conduct by any volunteer. A stream walk consists of going into the field, walking the length (or maybe just a reach) of the stream, and making notes and/or drawing a map of what is seen, heard, and smelled. What is included within each of these will vary. Two examples of stream walk inventories are:

\**A guide to streamwalking*, written by Ferne B. Winborne and published by the North Carolina Department of Natural Resources, Water Division, in 1989. This publication has a short, general description of organizing a stream walk. It includes some helpful hints for gathering background information, describes what to look for while on a



stream walk, and also contains some information for taking biological measurements. It does not, however, have any information for taking physical or chemical measurements. This guide also contains a macroinvertebrate taxonomic key, what to look for to specifically diagnose a stream (for example, if one is looking for mining effects he may want to look for discolored water), a stream survey data sheet (which does not include the significance of each component), and a water quality assessment that describes to the reader how to determine if the stream reach is "Dead, Poor, Fair or Good."

*\*Watershed owner's streamwalk guide*, published by the Texas Natural Resource Conservation Commission (TNRCC). This group is located in Austin, Texas, and the publication is number GI-218, and it is dated May, 1996. This pamphlet tells the reader what to look for, but does not describe how the observations are rated, or what a specific measurement may indicate. It also does not have any information for taking technical measurements. It is simply a guide to get the reader out onto the stream and understand what to observe and write down.

**Adopt-A-Stream Foundation:** The Adopt-A-Stream Foundation of Everett, Washington, printed, in 1996, *Streamkeeper's field guide: Watershed inventory and stream monitoring methods*. The principal authors are Tom Murdoch, Martha Cheo, and Kate O'Laughlin. This is probably the most complete and most easily understood watershed inventory guide available to the volunteer monitor. This book of approximately 250 pages includes an introduction to the importance of water, and continues to describe many of the ways in which humans degrade surface waters. The authors lead a potential volunteer monitor through the steps of gathering information, from beginning to end, to complete a watershed inventory. This process starts with

obtaining a map of the watershed, and goes on to describe the processes necessary to gather physical, biological, historical, and political information for the entire watershed. This watershed inventory directs the reader to gather information on fish; wildlife; vegetation; gradient; sinuosity; streambanks; in-stream habitat; substrate; flow; velocity; benthic macroinvertebrates (for which they include a taxonomic key); pH; DO; temperature; alkalinity; BOD; nutrients; bacteria; conductivity; turbidity; and total solids. For each of these parameters, they explain how they are often affected and, to a lesser extent, why these parameters are important to the biotic habitat. The *Streamkeeper's Field Guide* also describes some of the equipment required, and directs the reader as to how to monitor all of the above parameters. The monitoring section does an excellent job of helping people understand their goals before monitoring begins, and to realize how they intend to use the data they collect. The main drawback of the *Streamkeeper's Field Guide* is that it does a poor job of explaining why monitoring each parameter is important in assessing the overall health of the stream system.

**Pfankuch Procedure:** This method was published under the title *Stream reach inventory and channel stability evaluation* by the USDA Forest Service, Northern Region, in April of 1975. The publication is numbered R1-75-002. The principal author is Dale Pfankuch, and so today it is commonly referred to as the Pfankuch Procedure. This procedure was designed to assess channel stability, and "has been the most popular method for assessing peak flow-related channel damage to date" (Jones & Stokes Associates 1992, 1). Riparian expert Paul Hansen states that it is ideal "to determine...the resistance of streams to sediment production" (Hansen et al. 1995).

Pfankuch designed this procedure to be used on mountain streams in western Montana, but it can be, and is, widely used in areas of similar geography (Hansen et al. 1995).

This procedure directs the user to break a stream system down into three general parts: upper channel banks, lower channel banks, and the channel bottom. The section on upper channel banks includes observations on landform, mass wasting hazard, debris jam potential, and vegetative bank protection. The section on lower channel banks includes channel capacity, bank rock content, obstructions and flow deflectors, cutting, and deposition. The section on the channel bottom includes angularity, brightness, consolidation, bottom size distribution, scouring, and aquatic vegetation. Each of these parameters is issued a rating of excellent, good, fair, or poor and, based on the overall results, a numerical value is determined to assess the overall health of the particular stream reach.

**Rosgen:** Dave Rosgen is a prominent hydrologist working out of the state of Colorado. He developed a classification system by which streams sharing similar characteristics can be grouped together to present a common understanding of different stream types. This is not a stream inventory per se, but the measurements he recommends taking can be used to classify a stream to help determine whether it is in a state of equilibrium. This method, developed in 1985 and focused only on physical parameters, requires measurements of stream gradient, sinuosity, width-to-depth ratio, channel materials, entrenchment, confinement, and soil/landform features.

**Equivalent Roaded Area:** The Equivalent Roaded Area (ERA) is a watershed inventory method developed by Haskins in 1983 for the United States Forest Service. Also called Equivalent Clearcut Acres, it is another inventory based upon physical

parameters. Its original design was to aid in the management of forest lands, but it can be used to help determine the relative stability of a watershed. It works by measuring the amount of cleared area (such as clearcut forest, paved roads, gravel roads, and suburban developments), and comparing this figure to a predetermined threshold of concern (TOC). Depending upon the ratio, an estimate of the stability of the watershed can be determined. The method includes equations to estimate the percentage of cleared area, and to rate each according to the supposed severity. For example, a paved road is considered to have more severe detrimental effects than a vacant lot.

**Riparian And Wetland Research Program:** The Riparian and Wetland Research Program (RWRP) was designed by Paul Hansen *et al.* in 1995 to assess the riparian and wetland areas of Montana. It can, however, be used in other geographical locations as well.

This evaluation form attempts to determine riparian and wetland health by determining how effectively the area is performing its functions. The inventory is broken down into three categories: vegetation (consisting of tree regeneration; amount of dead and decadent woody species; density of trees and shrubs; possibility of shrub regeneration; total canopy cover of woody species; combined canopy cover of all vegetation; total area occupied by noxious weed species; and total area occupied by undesirable herbaceous species); soils/geology (consisting of the amount of fine material present to hold water and act as a rooting medium; and the percentage of the area exhibiting human-caused soil-surface exposure); and hydrology/streambank (consisting of stream channel incisement; and the percentages of streambank with: active lateral cutting; vegetation altered by human-caused disturbances; and a deep, binding root mass.

**Gap Analysis:** Gap Analysis is a geographical information systems (GIS) based method to assess the quality of habitat within an area. By overlaying coverages of selected parameters (such as vegetation, roads, developments, and waterways), one can gain an understanding of the quality of habitat within a given area. This method is sometimes employed to assess the stability of a watershed.

**Other Watershed Inventory Methods:**

\*The FWS measures physical habitat conditions using the Habitat Evaluation Procedure and the Instream Flow Incremental Methodology (Terrell et al. 1982; Stalnaker 1982; *cited in* Karr et al. 1986, 4).

\*The Index of Biotic Integrity (IBI) focuses on fish species. It uses the presence and abundance of indicator species to determine the health of a biotic system and, thus, overall ecosystem health (Karr 1986).

**Other Watershed Inventories:**

\*Oregon Department of Fish and Wildlife, *The stream scene: Watersheds, wildlife, and people*, 1992, has appendices indicating how to make watershed assessment tools out of household products, and suggests methods to improve salmon habitat. It also has a watershed inventory which includes a general survey; a wildlife inventory; a photo record; a fish survey; a water quality survey (including temperature, DO, pH, flow, and velocity); an invertebrate survey; and methods of stream mapping. This document is geared toward the citizen as opposed to an experienced professional.

\*Platts, William S. et al., *Methods for evaluating riparian habitats with applications to management*, 1987, instructs the reader on how to collect such data as historical information on riparian areas; vegetation measurements; riparian community

classification; riparian soils analysis; streambank analysis; mapping of organic debris; macroinvertebrate community assessment to evaluate riparian areas; and some water column measurements. This pamphlet also includes information on some restorative measures, such as the planting of various species, to stabilize an area. It does not, however, inform the reader of what the measurements taken indicate.

\*San Francisco Estuary Institute, *Volunteer monitoring protocols: A reference guide for monitoring California's rivers, streams and watersheds*, 1996, has what they call the SFEI-Habitat assessment. This assessment includes ratings for in-stream cover; epifaunal substrate; embeddedness; channel alteration; sediment deposition; frequency of riffles; channel flow status; bank vegetative protection; bank stability; and riparian vegetative zone width. Furthermore, their Coyote Creek Riparian Station has produced a fisheries habitat protocol for volunteers.

\*Terrell, Charles R. and Patricia Bytnar Perfetti, *Water quality indicators guide: Surface waters*, 1989, in conjunction with the *Water quality field guide*, provides descriptions, methods, and watershed assessment inventories for sediment; nutrients; pesticides; animal wastes; and salts. These publications, combined, also have a good identification guide, as well as how to interpret the existence or nonexistence of certain species of benthic macroinvertebrates, fish, and algae.

\*United States Department of Agriculture, *A federal agency guide for pilot watershed analysis*, 1994, is geared toward experts in that it assumes a lot of prior knowledge. However, it does have an extensive breakdown of what is entailed in a watershed analysis, and it devotes a lot of space to helping the reader understand what a watershed analysis is and why it is important. This inventory includes: vegetation

(existing vegetation, potential vegetation, landscape patterns, and plant species of concern); disturbance (historic disturbance, human settlement and management, blowdown, roads, erosion, and sedimentation (sheet and rill erosion, landslides, debris flows, bank erosion, gully erosion, and sediment yield)); runoff (streamflow characteristics, peak flow, base flow, and overland flow); channel condition; biological components (aquatic biology and wildlife biology); water quality (water temperature); and human use (domestic water supply).

\*United States Department of the Interior, *Riparian area management: Process for assessing proper functioning condition*, 1993, provides a very short and simple riparian-wetland checklist (strictly qualitative) to determine if a riparian-wetland area is functional, functional--at risk, non-functional, or unknown. It examines hydrological, vegetative, and erosion deposition factors; and differentiates between an area's potential and actual capability. It also includes detailed information on statistics, and different sampling procedures.

\*United States Department of the Interior, *Riparian area management: Inventory and monitoring of riparian areas*, 1987, provides much more detail on assessing a riparian zone than the previous literature source. It has about twenty-five variables, and describes how to measure each and, in contrast to the previous publication, describes the significance of each. There is also an inventory chart in the back for one to follow and mark up. This inventory includes many watershed-wide characteristics (such as drainage area, orientation, landform, and stream order), as well as channel and bank characteristics. The specific focus is upon soils.

\*United States Environmental Protection Agency, *A watershed assessment primer*, 1994, is a good tool to understand how to carry out a watershed inventory from beginning to end. It has sections on problem identification; scoping; inventory; analysis; prediction; and monitoring; and also mentions many other sources for specific inventories, such as a sediment budget and biotic stream sampling.

\*Washington Forest Practices Board, *Board manual: Standard methodology for conducting watershed analysis*, 1997, is an extensive watershed analysis manual. It is geared toward professional managers in Washington State, and is mostly concerned with the cumulative effects of streams on salmonid habitat. It has measurement techniques (not the significance of findings), and causes and effects for the following parameters: mass wasting (sediment deposition); surface erosion (sediment deposition); hydrology (channel morphology); riparian (LWD recruitment potential and canopy closure/stream temperature); stream channel (substrate, width, depth, and discharge); fish habitat (pools and riffles, shading); water quality (temperature, nutrients (nitrogen and phosphorous), acidity, alkalinity, and DO); water supply/public works (effects of man-made structures); and routing (transportation of upland sediments to the stream). This document is full of charts and worksheets to help carry out an analysis, but it does not have much information on the interpretation of results.

**Additional Sources:** (adapted from USDO I 1993, 1737-9, 5; and EPA 1994, 910/B-94-05)

**Riparian inventory sources:**

\*Batson et al., *The use of aerial photography to inventory and monitor riparian areas*, 1987.



\*Leonard et al., *Procedure for ecological site inventory--with special reference to riparian-wetland sites*, 1992.

\*Myers, *Inventory and monitoring of riparian areas*, 1989.

\*United States Department of Agriculture, *Integrated riparian evaluation guide*, 1992.

#### Biological inventory sources:

\*British Columbia Department of Fisheries and Oceans, *The streamkeepers handbook*, 1995.

\*Hankin and Reeves, *(title unknown)*, 1988.

\*Mulvey, M., L. Caton, and R. Hafele, *Oregon nonpoint source monitoring protocols stream bioassessment field manual for macroinvertebrates and habitat assessment*, 1992.

\*Pacific Rivers Council, *(title unknown)*, 1992.

\*United States Environmental Protection Agency, *Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish*, 1989.

#### General inventory sources:

\*Bain, M.B. et al., *Quantifying stream substrate for habitat analysis studies*, North American Journal of Fisheries, 1985, 5:499-500.

\*Benda, Lee and Lynne Rodgers Miller, *Geomorphological watershed analysis: A conceptual framework and review of techniques*, TFW-SH10-91-001, 1991.

\*Dickett, Thomas G. and Andrea E. Tuttle, *Cumulative impact assessment in environmental planning: A coastal wetland watershed example*, Environmental Impact Assessment Review, 1985, 5:37-64.

\*Frissell, C.A. et al., *A hierarchical framework for stream habitat classification: Viewing streams in a watershed context*, Environmental Management, 1986, 10:199-214.

\*Haskins, Donald M., *A management model for evaluating cumulative watershed effects*, 1986.

\*Kaufmann, P. and E.G. Robinson, *A quantitative habitat assessment protocol for field evaluation of physical habitat in small wadable streams*, 1993.

\*Livingston, Eric H., *Water quality problem identification in urban watersheds*, date unknown.

\*Platts, W.S. et al., *Methods for evaluating stream, riparian, and biotic conditions*, 1983.

\*Schloss, Alan J., *Watershed condition index, appendix 3-e: Analytical methods*, 1991.

\*United States Forest Service, Region 5, *Cumulative off-site watershed effects analysis*, 1988.

\*Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson, *AGNPS: A non-point source pollution model for evaluating agricultural watersheds*, *Journal of Soil and Water Conservation*, 1989, 44:168-173.

## APPENDIX B

### SUCCESS STORIES

There are hundreds and hundreds of examples from across the United States and throughout the entire world where concerned citizens have come together and succeeded in restoring or preserving a portion of their local watershed. Some examples from the U.S. are:

\*The Mattole Watershed Salmon Support Group (MWSSG), consisting of about a dozen people residing in the Mattole watershed of California. This group has initiated projects in erosion control, reforestation, fishery habitat repair, and habitat enhancement.

\*The Merrimack River Initiative (MRI), which was created in 1988. By the end of World War II, this river, which originates in the White Mountains of New Hampshire, and empties into the Atlantic Ocean north of Boston, Massachusetts, was recognized as one of the ten most polluted rivers in the Nation because of its use by humans as a waste stream. Today, the MRI, which is a collaboration of agencies, businesses, nonprofit organizations, and citizen groups from within the watershed, is successfully addressing the issues of river life and water quality (Dates 1994, 2).

\*The Watershed Management Committee, which contains representatives from the Tulalip and Stillaguamish Tribes of Washington State, county and city governments, environmental and business interest groups, and homeowners and citizens' organizations. This group completed the Stillaguamish Watershed Action Plan in 1989, which has led to success regarding recommendations including developing farm conservation plans, reducing improper disposal of human waste, preventing urban runoff, and sampling on a regular basis to track water quality trends (EPA 1991, 503/9-92/002, 4).

In many cases, these “citizen groups and organizations...play a crucial role in monitoring water quality and making other observations of the river when state environmental agencies are unable to do so” (Friends of the Mad River 1995, 103). In other cases, they have pooled their resources to construct structures to aid a stream in the rehabilitation process. And in still others, they have successfully voiced opposition to proposed projects that would have degraded the stream ecosystem. What follows are a few examples of citizens making a difference in the health of their nearby stream.

**\*The Fish Migration Barrier:** In Washington State, teachers and students from the Sunnyside Elementary School and Marysville High School discovered a culvert that was acting as a barrier to salmon migration on an unnamed tributary of the Snohomish River. Questions posed to the local fish and wildlife habitat manager determined that the state was trying to eliminate barriers to salmon migration. Questions then posed to the county public works director determined that funds were not available to construct a fish ladder.

The response of these teachers and students was to offer their labor in return for materials. The county agreed, and in four weeks a fish ladder was constructed with no out-of-pocket expenses. That fall the entire county was able to witness salmon upstream from the culvert that had once blocked their migration. (*Adapted from Murdoch, Cheo, and O’Laughlin 1996, 235-236*).

**\*The 1824 House Inn Streambank Stabilization Project:** After receiving some grant money from the State of Vermont, FMR set out to decide how it could best be spent. Some careful research led them to the 1824 House Inn site. This particular bend in the Mad River was eroding rapidly, cutting into a farmer’s cornfield and depositing

large amounts of sediment into the stream channel. Some consultations with professionals helped them realize they could rehabilitate this site.

By putting the word out to the community, they quickly had numerous volunteers willing and eager to pitch in to the project. These included FMR board members, other members of the community who wished to help the river, local high school teachers who incorporated it into their classroom curriculum, the farmer who was losing his land to the river, and people who were just passing by and asked questions and wanted to help.

The money was spent buying materials, and paying a professional, who accepted a minimum amount. Then, on a cold and rainy autumn day, this group got together with their willing labor and stack of materials, and set out to stabilize the streambank. The process required using heavy machinery to slope the bank back so that planted vegetation would have a chance to take hold. Then revetments, in the form of trees and shrub bundles, were cabled to the bottom of the bank. After that, some willow posts were planted and erosion blankets laid down.

In the spring, this group returned to the site to survey the damage done by ice scour and high flows. The project was deemed a success, as the vast majority of willow posts survived and appeared vigorous. Today, the streambank stabilization project is complete and “the vegetated bank is showing signs of being home to birds, mice, woodchucks and otter” (Connell 1997, 1). This is just another example of “property owners, government agencies, professionals, and lots of caring volunteers...all (working) together to improve the Mad River’s health” (Friends of the Mad River 1996-97, 2).

\*Land Use in the Riparian Corridor: The Picnic Point Creek Protection Association (PPCPA) of Mukilteo, Washington, has worked to organize stream clean-ups

in the community, posted volunteers to nab illegal dumpers of garbage along the stream corridor, and collected information on the trout and wildlife populations of the stream and watershed. In addition to this, they have successfully fought developers to help conserve the riparian corridor.

Being faced with increasing population pressures, and an associated sharp rise in the rate of development, the landscape of the Picnic Point Creek watershed has been altered greatly since 1985. The PPCPA, to express the community's concern at the proposal of still more development, presented the county council with an aerial photograph of the watershed in 1985. Using overlays of the projected new developments, together with their data on trout and other wildlife, they convinced the council that the effects of all of these minor developments were having a profound cumulative effect on Picnic Point Creek.

Because of the PPCPA's efforts, the council decreed preservation of the riparian corridor. This decree led to a redesigning of all lots adjacent to the creek, the designation of a "native growth protection area," and removal of proposed roads that would have infringed upon the corridor. (*Adapted from* Murdoch, Cheo, and O'Laughlin 1996, 238-239).

## APPENDIX C

### PEOPLE AND ORGANIZATIONS TO CONTACT FOR FURTHER INFORMATION

(It should be noted that most materials obtained through this directory, such as topographic maps and aerial photographs, require a fee.)

#### **To Obtain Topographic Maps:**

\*The Earth Science Information Center (ESIC) of the USGS can provide a catalog of available USGS topographic maps, a brochure on how to use topographic maps, and general information on ESIC services. They can also refer you to commercial map distributors across the United States (Texas Natural Resource Conservation Commission 1997, 15). Their address is: USGS Earth Science Information Center, 507 National Center, 12201 Sunrise Valley Drive, Reston, Virginia, 22092. The phone number is 1-800-USA-MAPS.

\*If the coordinates of the map are already known, it can be ordered directly from: USGS, Map Distribution, Box 25286, Denver, Colorado, 80225.

\*Further information regarding state maps and how to order them is available from (USDOT 1982, 19): Branch of Distribution, USGS, 1200 South Eads St., Arlington, Virginia, 22202.

\*The USGS has also designed and mapped a national system of hydrological units for cataloging, sometimes called HUCs, that provide a common national framework for delineating watersheds and their boundaries at a number of different geographical scales. Sometimes these are available from state government agencies (EPA 1995, 841-R-95-004, 2-1).

**To Obtain Aerial Photographs:** Federal sources of aerial photographs include (Texas Natural Resource Conservation Commission 1997, 18):

\*USDA Agricultural Stabilization and Conservation Service, Aerial Photography Field Office, 222 West 2300 South, P.O. Box 30010, Salt Lake City, Utah, 84103-0010. The phone number is 801-524-5856.

\*Cartographic and Architectural Branch, National Archives and Records Administration, 8601 Adelphi Road, College Park, Maryland, 20740-6001.

\*National Cartographic Information Center (NCIC), 507 National Center, Reston, Virginia, 22092. The phone number is 703-860-6045.

\*Other places to contact for historic and current aerial photographs are local and state governments, and private firms. Examples include planning offices, highway departments, soil and water conservation districts, state departments of transportation, and universities.

**Other Sources of Information Regarding Land Use:** Aside from topographic maps and aerial photographs, other sources of land use information are local planning offices, conservation district offices, the Agriculture Extension Service, and the NRCS.

**For Information on Best Management Practices:** To obtain information on current Pollution Control Methods, or BMPs, for the following activities (Terene Institute 1993), contact the agencies listed below.

\*Agriculture--NRCS and Agricultural Stabilization and Conservation Service, EPA, County Extension Service, Agricultural Research Stations, state soil and water conservation commissions, state departments of agriculture, state water quality agencies.



\*Urban--EPA, Council of Governments, state water quality agencies, city planners, private engineers.

\*Mining--U.S. Office of Surface Mining, BLM, USFS, U.S. Minerals Management Service, EPA, Tennessee Valley Authority (TVA), state departments of mining and minerals, state water quality agencies.

\*Roads--DOT, EPA, NRCS, USFS, BLM, state highway departments, state water quality agencies, private engineers, county commissioners, county extension services. (In addition, the DOT and local transportation agencies should also have records on when highways and bridges were built (Texas Natural Resource Conservation Commission 1997, 19).)

\*Forestry--FWS, USFS, state departments of forestry, private consultants, timber companies.

**For Further Information on the Watershed Protection Approach:** For more information on the Watershed Protection Approach (EPA 1991, 503/9-92/002), contact: Policy and Communications Staff, Office of Wetlands, Oceans, and Watersheds, U.S. Environmental Protection Agency, 401 M Street, SW, Washington, D.C., 20460. The phone number is 202-260-7166.

**Sources for Specific Types of Data:** To obtain information on the following measures, contact the agencies listed below.

\*Water Quality Data--USGS, EPA, COE, FWS, state water quality agencies, state fish and game departments, state departments of health, tribal environmental offices.

\*Land Use Data--NRCS and Agricultural Stabilization and Conservation Service, USFS, Bureau of Indian Affairs (BIA), Bureau of Reclamation, BLM, state cooperative

extension services, state land office, tribal environmental or agricultural offices, city planners, county commissioners.

\*Economic Data--county extension service, councils of government, Economic Research Service, chambers of commerce, state department of commerce, tribal councils, real estate agents, private consultants, city and county budgets, tax offices, census reports, state departments of human resources.

\*Demographic Data--Council of Governments, census reports, chambers of commerce, state statistics bureaus, almanacs.

**Legislation Pertaining to Watershed Protection:** The following federal legislation pertains to watershed protection. For more information on any of them, contact your local library.

- \*National Environmental Policy Act (NEPA), 1969
- \*Clean Water Act (CWA), 1972
- \*Clean Water Act of 1977
- \*1987 Clean Water Act Amendments
- \*Coastal Zone Management Act (CZMA)
- \*Wild and Scenic Rivers Act
- \*Water Pollution Control Act of 1966
- \*Federal Water Pollution Control Act Amendments of 1972

Furthermore, "citizens can obtain information about environmental laws and regulations from many sources such as: state and federal agencies; environmental and social advocacy groups (The Natural Resources Defense Council (NRDC), the Sierra Club, the Conservation Foundation, the National Wildlife Federation, etc.) often have departments that specialize in environmental litigation; county judge; district attorney's office; justice of the peace; city planner's office; zoning board; chamber of commerce; law firms; private lawyers; (and) consultants who specialize in environmental law" (Terene Institute 1993, 51). Other examples are the Environmental Law Foundation, the

Conservation Law Foundation, Trout Unlimited, and watershed associations (Dates 1990, 19).

**Point Source Pollution:** Any industry or wastewater treatment plant that discharges into the stream should be on record at the city or county environmental offices (Texas Natural Resource Conservation Commission 1997, 19).

**Soils Information:** The NRCS has local offices throughout the country. They are a good source from which to obtain soils maps. Some offices also have aerial photographs and information on vegetation, geological features, water resources, and land uses. On a more local scale, many counties have a published book of soils maps called a Soil Survey (USDA Soil Conservation Service 1991, 11).

**Climate Data:** The National Weather Service can provide useful climate information.

**Local Governments (Regional, County, City, Township):** Most people are aware of the information kept by the Federal Government. Often overlooked, however, are the state branches of the same agencies. Some of these offices include: state department of fish and wildlife; state department of environmental quality; state department of natural resources and conservation; and the state office of the COE. Any of these offices may be able to provide more local information, and it may be easier to obtain.

**Water Quality Testing Agencies:** The following companies sell equipment to be used for testing water samples (EPA 1991, 440/4-91-002, 121):

\*HACH Company, P.O. Box 389, Loveland, Colorado, 80539, 800-525-5940.

\*LaMotte Chemical Products, P.O. Box 329, Chestertown, Maryland, 21620, 800-344-3100.

\*Fisher Scientific, 711 Forbes Ave., Pittsburgh, Pennsylvania, 15219-4785, 800-766-7000.

\*Thomas Scientific, 99 High Hill Rd. at I-295, P.O. Box 99, Swedesboro, New Jersey, 08085-0099, 609-467-2000.

\*VWR Scientific, P.O. Box 2643, Irving, Texas, 75061, 800-527-1576.

\*Wildlife Supply Company, 301 Cass St., Saginaw, Michigan, 48602, 517-799-8100.

\*YSI Incorporated, 1725 Brannum Lane, Yellow Springs, Ohio, 45387, 513-767-7241.

\*Millipore Corporation, 397 Williams St., Marlborough, Massachusetts, 01752, 800-225-1380.

\*Hydrolab Corporation, P.O. Box 50116, Austin, Texas, 78763, 512-255-8841.

One can also contact National Testing Laboratories at 800-458-3330. They will do a complete chemical analysis of a water sample for a fee.

#### **Water Quality Testing Literature:**

\*United States Environmental Protection Agency, *Methods for chemical analysis of water and wastes*, 1983, is a helpful source when testing water samples.

\*American Public Health Association, *Standard methods for the examination of water and wastewater*, 1985, contains "methods for analyzing most any water quality indicator you can think of" (Dates 1992, 9).

\*Protocols for analyzing water samples are also available from the USGS, and from state water quality agencies.

#### **Other Helpful Literature Citations:**

\*United States Environmental Protection Agency, *Watershed protection: Catalog of federal programs*, 1993, provides information on which federal agencies can be contacted for watershed protection.

\*Harrelson, Cheryl C., C.L. Rawlins, and John P. Potyondy, *Stream channel reference sites: An illustrated guide to field technique*, 1994, is incomparable as a source to use when measuring a cross-section, selecting a site for long-term monitoring,

determining floodplain and bankfull indicators, measuring discharge, or characterizing bed and bank material.

\*Merritt *et al.* (1984) give an excellent introduction to biotic stream sampling techniques, including equipment and sampling problems (*cited in EPA 1994, 910/B-94-05, 58*).

\*United States Forest Service, *Riparian forest buffers: Function and design for enhancement in water resources*, 1992, helps explain the role riparian functions can play in stream quality.

\*United States Environmental Protection Agency, *Directory of citizen, river and watershed organizations in Virginia, Maryland and the District of Columbia*, 1996, lists hundreds of organizations within this region which can be of assistance. There may be similar sources for other regions of the United States as well.

**Additional Sources of Interest:**

\*North Carolina State University, *Evaluation of the experimental rural clean water program--project report*, date unknown. This publication can be obtained by calling 919-515-3723.

\*Puget Sound Water Quality Authority, *Managing nonpoint pollution: An action plan for Puget Sound watersheds*, date unknown. This publication can be obtained by calling 206-464-7320.

\*North Carolina Cooperative Extension Service, *Public perception and communication of risk*, date unknown. This publication can be obtained by calling 919-515-1676.

\*United States Environmental Protection Agency, *Guidelines specifying management measures for sources of nonpoint pollution in coastal waters*, 1992.

\*United States Environmental Protection Agency, *Volunteer water monitoring: A guide for state managers*, 1990, discusses implementing a volunteer monitoring program for all types of waters and water quality parameters. This publication contains the following subjects: volunteers in water monitoring; planning a volunteer monitoring program; implementing a volunteer monitoring program; providing credible information; and costs and funding. It also lists the following organizations and contacts for further assistance.

\*Illinois' Volunteer Lake Monitoring Program, Amy Burns, Lakes Program, Division of Water and Pollution Control, Illinois EPA, 2200 Churchill Road, Springfield, Illinois, 62706. The phone number is 217-782-3362.

\*Kentucky's Water Watch Volunteer Stream Sampling Project, Ken Cooke, Kentucky Water Watch, Division of Water, Kentucky Natural Resources and Environmental Protection Cabinet, 18 Reilly Road, Frankfort, Kentucky, 40601. The phone number is 502-564-3410.

\*New York Citizen Statewide Lake Assessment Program, Scott Kishbaugh, New York Department of Environmental Conservation, Bureau of Technical Services and Research, Room 301, 50 Wolf Road, Albany, New York, 12233-3502. The phone number is 518-457-7470.

\*Ohio's Scenic River Volunteer Monitoring Program, John Kopec, Ohio Department of Natural Resources, Scenic Rivers Section, Fountain Square, Columbus, Ohio, 43224. The phone number is 614-265-6458.

\*Chesapeake Bay Citizen Monitoring Program, Kathleen Ellett, Citizen Monitoring Director, and Gayla Campbell, Maryland Citizen Monitoring Coordinator, ACB, 410 Severn Avenue, Suite 110, Annapolis, Maryland, 21403. The phone number is 301-266-6873. Also, Billy Mills, Virginia Citizen Monitoring Coordinator, ACB, P.O. Box 1981, Richmond, Virginia, 23216. The phone number is 804-775-0951.

**Valuable Watershed Assessment Information:** There are four sources similar to this document which can be invaluable to the beginning watershed assessor. They are:

\*The Adopt-A-Stream Foundation, *Streamkeeper's field guide: Watershed inventory and stream monitoring methods*, 1996. The primary authors are Tom Murdoch, Martha Cheo, and Kate O'Laughlin. The organization is located in Everett, Washington, and has other helpful publications as well. This field guide is geared toward the volunteer who does not have previous experience with such matters, and is an excellent tool to use with children.

\*Terene Institute, *Clean water in your watershed: A citizens guide to watershed protection*, 1993, is similar to The Adopt-A-Stream's field guide, but is less comprehensive. The Terene Institute also has several additional publications from which to choose. This particular guide provides an extensive list of agencies to contact to obtain funds and support in beginning a watershed assessment project. The Terene Institute is located at: Terene Institute, 1717 K Street, NW, Suite 801, Washington, D.C., 20006. The phone number is 202-833-8317.

\*United States Environmental Protection Agency, *A watershed assessment primer*, 1994, is a bit more technical, yet complete in helping the monitor carry out a watershed assessment. This publication is most helpful to volunteers wishing to establish

a long-term monitoring program from which results will be used by state officials. It has sections on problem identification; scoping; inventory; analysis; prediction; and monitoring. It also mentions many other sources to contact for additional watershed inventories.

\*La Motte Company, *The monitor's handbook*, 1992, is helpful for the volunteer monitor measuring mostly chemical parameters. The primary authors are Gayla Campbell and Steve Wildberger.

### **Helpful Internet Sites:**

- \*United States Geological Survey at <http://www.usgs.gov>.
- \*United States Environmental Protection Agency at <http://www.epa.gov>.
- \*EPA's Surf Your Watershed page at <http://www.epa.gov/surf>.
- \*EPA's Office of Water at <http://www.epa.gov/OW>.
- \*EPA's Office of Water, Oceans, and Wetlands at <http://www.epa.gov/OWOW>.
- \*United States Fish & Wildlife Service at <http://www.fws.gov>.
- \*United States Forest Service at <http://www.fs.fed.us/Homepage.html>.
- \*River Network at <http://www.rivernetwork.org>.
- \*Izaak Walton League of America at <http://iwla.org>.
- \*River Watch Network at [http://www.riverwatch.org/index\\_noframe.html](http://www.riverwatch.org/index_noframe.html).
- \*Universities Water Information Network at <http://www.uwin.siu.edu>.
- \*Environmental Working Group at <http://www.ewg.org>.
- \*List of water links from Texas A & M University at <http://twri.tamu.edu/wrlinks>.



## LIST OF ABBREVIATIONS

AGU--American Geophysical Union  
BIA--Bureau of Indian Affairs  
BLM--Bureau of Land Management  
BMP--Best Management Practice  
BOD--Biochemical Oxygen Demand  
CFS--Cubic Feet per Second  
CMS--Cubic Meters per Second  
COE--United States Army Corps of Engineers  
CWA--Clean Water Act  
CWD--Coarse Woody Debris  
CWE--Cumulative Watershed Effects  
CZMA--Coastal Zone Management Act  
DO--Dissolved Oxygen  
EPA--Environmental Protection Agency  
ERA--Equivalent Roaded Area  
ESIC--Earth Science Information Center  
FMR--Friends of the Mad River  
FWS--United States Fish and Wildlife Service  
GIS--Geographical Information Systems  
HUC--Hydrological Units for Cataloging  
IBI--Index of Biotic Integrity  
JTU--Jackson Turbidity Unit  
LOD--Large Organic Debris  
LWD--Large Woody Debris  
MG/L--Milligrams per Liter  
MRI--Merrimack River Initiative  
MWSSG--Mattole Watershed Salmon Support Group  
NCIC--National Cartographic Information Center  
NEPA--National Environmental Policy Act  
NPDES--National Pollutant Discharge Elimination System  
NPS--Non-point Source Pollution  
NRCS--Natural Resource Conservation Service  
NRDC--Natural Resources Defense Council  
NTU--Nephelometric Turbidity Unit  
PPCPA--Picnic Point Creek Protection Association  
PPM--Parts Per Million  
QA/QC--Quality Assurance/Quality Control  
RWN--River Watch Network  
RWRP--Riparian and Wetland Research Program  
SCS--Soil Conservation Service  
SFEI--San Francisco Estuary Institute  
SI--Sinuosity Index  
TNRCC--Texas Natural Resource Conservation Commission  
TOC--Threshold of Concern

**TSS--Total Suspended Sediment**  
**TVA--Tennessee Valley Authority**  
**USDA--United States Department of Agriculture**  
**USDOI--United States Department of the Interior**  
**USDOT--United States Department of Transportation**  
**USFS--United States Forest Service**  
**USGS--United States Geological Survey**  
**WPCL--Water Pollution Control Laboratory (of California)**

## GLOSSARY

**Aggradation.** The accumulation of bed materials.

**Algae.** Photosynthetic plants that contain chlorophyll and have a simple reproductive structure, but do not have tissues that differentiate into true roots, stems, or leaves.

**Algal Bloom.** An unusual or excessive abundance of algae.

**Aquifer.** Water-bearing porous soil or rock strata that yield significant amounts of water to wells.

**Bankfull Stage.** The stream level when stream water just begins to overflow into the active floodplain.

**Bars.** Sediment accumulations along waterways deposited by moving water. Examples include point bars, side bars, mid-channel bars, and delta bars.

**Base Flow.** The lowest annual flow.

**Base Level.** The lowest elevation attained by a stream.

**Bedload.** The material which generally remains in contact with the streambed when it moves by rolling, sliding or hopping.

**Beneficial Uses.** The uses of a waterbody that are protected by state laws called water quality standards. Some waters are used for habitat; others for aquatic life, or for recreational fishing, boating or swimming.

**Benthic.** Dwelling on or near the bottom. In watershed assessment terms, commonly used with macroinvertebrate to define an animal making its home on the bottom of the stream.

**Best Management Practices (BMPs).** Pollution controls for nonpoint source pollution. BMPs consist of structural, vegetative, or management systems that human beings can perform or install to prevent water pollution originating from human activity.

**Biochemical Oxygen Demand (BOD).** The amount of oxygen consumed by bacteria in the decomposition of organic material.

**Braided Channel.** A channel which has divided into several multiple intertwining channels due to excessive sediment accumulation.

**Buffer Strip.** Riparian lands maintained immediately adjacent to streams or lakes to protect water quality, fish habitat, and other resources.

**Canopy Cover.** The percentage of ground covered by the gross outline of an individual plant's foliage, or collectively covered by all individuals within a stand.

**Carrying Capacity.** The maximum amount of sediment able to be moved by a stream.

**Channel.** The area between two high water marks in which water and sediment are transported.

**Channel Maintenance Flow.** Periodic high flow with a recurrence interval of approximately 1.5 years, which dominates the creation of the physical channel. Often described by some dominant discharge such as "bankfull."

**Channelization.** The altering of the channel to force a stream to flow in a straight path.

**Check Dam.** A barrier placed in an actively eroding gully, the purpose of which is to trap sediment that is carried down the gully during periodic flow events.

**Competence.** The largest size particle able to be moved by the stream.

**Cross-Section.** A site selected for purposes of study or observation at which width and depth measurements are made.

**Cumulative Watershed Effects (CWE).** The accumulation of many smaller impacts creating a greater impact on the overall watershed.

**Degradation.** The downcutting of a stream into its bed materials.

**Downcutting.** *See Incisement.*

**Dynamic Equilibrium.** This concept does not imply absolute equilibrium conditions, but that the stream can adjust to a new hydraulic situation within a relatively short time, perhaps within a few years. Dynamic equilibrium cannot be well defined.

**Embeddedness.** The extent to which cobbles are surrounded or covered by fine sediment.

**Entrainment.** The event of bedload being lifted by the current and becoming suspended sediment.

- Ephemeral Stream.** A stream or stretch of a stream that flows only in direct response to precipitation. It receives no water from springs, and no continued supply from melting snow or other surface source. Its stream channel is at all times above the water table. These streams do not normally flow for thirty consecutive days.
- Evapotranspiration.** Evaporation from soils, plant surfaces, and water bodies, together with water losses through plant leaves.
- Falling Limb.** The section of the hydrograph where the flow is decreasing.
- Fish Kill.** The event of a sudden die-off of many fish due to exposure to a pollutant.
- Flashiness.** The relation between the amount of precipitation within the watershed and the time it takes for this precipitation to reach the stream channel.
- Flood.** An unusually large overflow of water onto land.
- Flood Stage.** A water level attained by a particular flood frequency.
- Floodplain.** A flat area adjacent to the channel constructed by the river and overflowed by the river at a recurrence interval of about two years or less.
- Flushing Flow.** A flow maintained for forty-eight hours to flush fines from gravels.
- Gabions.** A streambank stabilization method employing wire mesh or bags of rocks placed in the channel, along the bank.
- Glide.** Relatively slow moving area, but still faster than a pool.
- Gully Erosion.** The detachment and movement of material, either individual soil particles or large aggregates, in a well-defined channel.
- Headward Erosion.** The progression of the erosional process in the upstream direction. Commonly occurs where water drops off of a ledge, gradually eroding back the ledge.
- Hydric Soils.** Soils that are saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part of the soil profile.
- Hydrograph.** A graph of water discharge or depth against time.
- Hydrophytic Vegetation.** Plant life growing in water or on a substrate that is at least potentially deficient in oxygen as a result of excessive water content.
- Imbrication.** The event of particles being stacked against each other, nose-down into the oncoming current.

**Incisement.** The downcutting of a stream channel. A stream is incised when downcutting has lowered the channel bed so that the average two year flood cannot come out of the banks.

**Indicator Species.** Species which, by their existence or absence and their abundance, indicate the presence or absence of pollution.

**Infiltration.** The process by which water enters the soil.

**Intermittent Stream.** A stream or reach of stream which flows only at certain times of the year, when it receives water from springs or from some surface source, such as melting snow. These streams generally flow continuously during periods of at least one month or more during the year.

**Large Woody Debris (LWD).** Pieces or parts of dead trees that have collected in the stream channel. Also termed Coarse Woody Debris (CWD) or Large Organic Debris (LOD).

**Larvae.** An immature stage of development in offspring of many kinds of animals.

**Longitudinal Profile.** A profile of the length of the stream illustrating the way the stream's elevation changes over distance.

**Macroinvertebrates.** Animals which do not have backbones and are visible to the naked eye.

**Main-Stem.** The highest order stream within a watershed, or the one into which all other tributaries flow.

**Mixing Zone.** A length of stream in which pollutants are able to be diluted before needing to meet water quality standards.

**Natural Background Level.** An estimate of levels and characteristics exhibited before the onset of European settlement.

**Non-Point Source Pollution (NPS).** Precipitation-driven stormwater runoff, generated by land-based activities, such as agriculture, construction, mining, and silviculture.

**Oxbow Lake.** A meander channel of a stream or river that is formed by breaching of a meander loop during flood stage. The ends of the cut-off meander are blocked by bank sediments.

**Peak Flow.** The highest annual flow.

- Perennial Stream.** A stream or reach of a stream that flows continuously. They are generally fed in part by springs. Surface water elevations are commonly lower than water table elevations in adjacent soils.
- Point Source Pollution.** Water pollutants originating from a known point.
- Pool.** A region of deeper, slower-moving water with fine bed materials.
- Reach.** A selected segment of a stream with similar characteristics selected for study or observation. Usually defined as 500 feet, or twenty times the bankfull width.
- Recurrence Interval.** The average length of time between two floods of a given size or larger. Also called return period.
- Revetment.** A facing or retaining wall for protecting earthworks, river banks, etc.
- Riffle.** A region of shallow, faster-moving water with coarse bed materials. Often associated with whitewater.
- Riparian.** Of, on, or relating to the banks of a natural course of water.
- Riparian Zone.** The area of vegetation adjacent to the stream.
- Riprap.** A retaining wall, commonly built by laying stones with the purpose of stopping the lateral erosion of a stream.
- Rising Limb.** The section of the hydrograph where the flow is increasing.
- Run.** Relatively fast moving area, but not shallow enough that the substrate creates whitewater riffles.
- Saturation.** The maximum level of dissolved oxygen that would be present in the water at a specific temperature, in the absence of other influences.
- Sediment.** Fine materials that settle to the bottom of, or are carried by, a liquid.
- Sedimentation.** The accumulation of sediments within the stream channel.
- Siltation.** *See Sedimentation.*
- Stakeholder.** Anyone with a personal, vested interest in the matter at hand.
- Streambed.** The bottom portion of a stream channel.
- Substrate.** The particles on the streambed, both organic and inorganic.
- Subwatershed.** The watershed of a tributary. Also called a sub-basin.

- Surface Runoff.** Water that flows over the soil surface and occurs from areas that are impervious, locally saturated, or areas where the rainfall rate exceeds the infiltration capacity of the soil. Also called overland flow.
- Suspended Sediment.** The material which generally remains in suspension within the water column as it is transported downstream. Also called washload.
- Thalweg.** The path of maximum depth of the stream. Commonly the path of maximum velocity, as well.
- Total Suspended Sediment (TSS).** The total amount of sediment suspended within the water column.
- Tributary.** A smaller feeder stream or river which empties into a larger main-stem river.
- Turbidity.** Clarity of water. An indicator of the property of water that causes light to become scattered or absorbed. Caused by suspended clays, silts, organic matter, plankton, and other inorganic and organic particles.
- Upland Zone.** Any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils, and/or hydrologic characteristics associated with wetlands.
- Water Column.** A vertical area within a stream channel from which a water sample can be taken.
- Watershed.** A geographic area in which water, sediments, and dissolved materials drain into a common outlet. Also called a (drainage) basin or catchment area.
- Wetland.** An area that under normal circumstances has hydrophytic vegetation, hydric soils, and wetland hydrology. They include landscape units such as bogs, fens, carrs, marshes, and lowlands covered with shallow, and sometimes ephemeral or intermittent, waters. Wetlands are also potholes, sloughs, wet meadows, riparian zones, overflow areas, and shallow lakes and ponds having submerged and emergent vegetation. Permanent waters of streams and water deeper than ten feet in lakes and reservoirs are not considered wetlands.
- Wetland Hydrology.** Permanent or periodic inundation or prolonged soil saturation sufficient to create anaerobic conditions in the soil.
- Wetted Perimeter.** That part of the channel cross section submerged under the water of a given flow.



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