



OHIO

STREAM MANAGEMENT GUIDE

Natural Stream Processes

Guide No. 03

Streams in their natural state are dynamic ecosystems that perform many beneficial functions. Natural streams and their flood plains convey water and sediment, temporarily store excess flood water, filter and entrap sediment and pollutants in overbank areas, recharge and discharge groundwater, naturally purify instream flows, and provide supportive habitat for diverse plant and animal species. The stream corridors wherein these beneficial functions occur give definition to the land and offer "riverscapes" with aesthetic qualities that are attractive to people.

Human activities that impact stream ecosystems can and often do cause problems by impairing stream functions and beneficial uses of the resource. Solving stream management problems requires knowledge and understanding of the stream's natural processes, and since many problems originate beyond the banks, a watershed approach.

This Ohio Stream Management Guide provides an overview of the stream's natural processes and of the human impacts on stream ecosystems. The information provided here can be used by land managers, watershed groups, river conservationists, public

agency officials, and others to start a thoughtful inquiry into the true source of local stream management problems. The material contained in this guide makes evident that the source of many stream problems is in the watershed, far from the main stream channel. Landowners, local officials, and others concerned with streams need to work together across property lines and jurisdictional boundaries to find suitable solutions to stream problems and to implement practices to protect, restore and maintain healthy stream ecosystems.

STREAMS ARE DYNAMIC ECOSYSTEMS

Streams in their natural condition typically exist in a state of dynamic equilibrium. When a stream is in dynamic equilibrium, the amount of sediment delivered to the channel from the watershed is in long-term balance with the capacity of the stream to transport and discharge the sediment. A balance also exists between communities of aquatic organisms inhabiting a stream and the biochemical processes that

recycle nutrients from natural pollution sources, such as leaf fall, to purifying the water. The natural stream tends to maintain itself through the flushing flows of annual floods that clear the channel of accumulated sediments, debris, and encroaching vegetation. Extreme floods may severely disrupt the stream on occasion, but the natural balance of the stream ecosystem is restored rapidly when it is in a state of dynamic equilibrium.

CHANNEL FORMING AND RECONDITIONING PROCESSES

Flowing water contributes significantly to erosion and the shaping of most land masses. During the evolution of a landscape, stream characteristics develop including: drainage density, stream order, and longitudinal profile (Figure 1). Erosion in watersheds unaffected by human disturbances takes place at geologic rates. During any given year, the majority of waterborne sediment is redeposited within the watershed as colluvium at the base

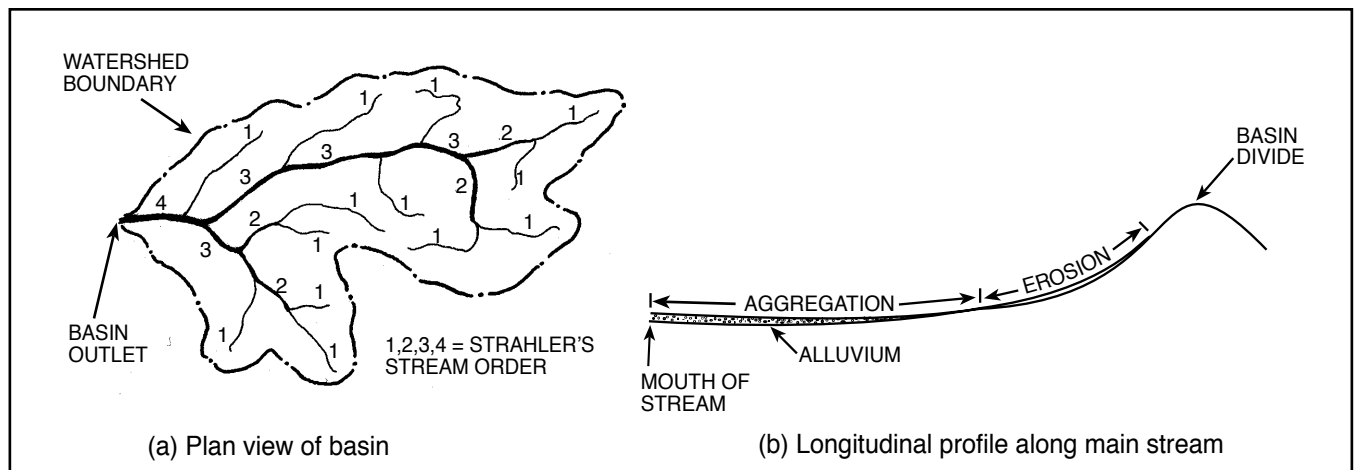


Figure 1. Drainage Basin and Longitudinal Profile Along Stream

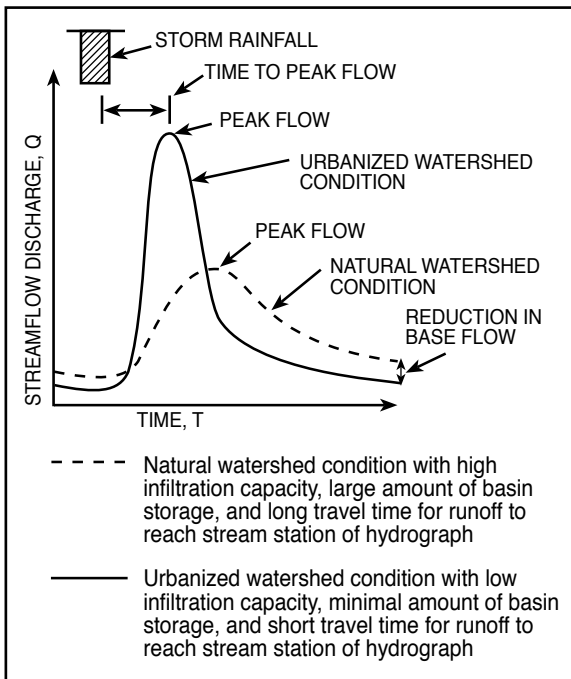


Figure 2. Hydrographs of Streamflow Discharge Before and After Urbanization

of slopes or as alluvium and sediment bars along streams. The amount of sediment discharged from the basin generally represents a small percentage of the gross erosion occurring in the watershed. Longitudinal profiles of channel bottom elevation from stream mouth to headwater divide typically exhibit upward concavity with steepest gradients in headwater areas and flattest gradients toward the mouth. This concave shape is the end result of erosion and deposition as the stream matures.

Down cutting or incising of a stream by erosion is ultimately controlled by its base level, that is, the elevation of a grade control such as resilient bedrock or the confluence with a larger, stable stream of the channel network. A stream that has adjusted its longitudinal profile to a local base level, sediment load and flow regime, and is no longer degrading (down cutting) or aggrading (rising due to sediment deposition) is referred to as a poised or graded stream. Under these conditions, the amount of sediment delivered to the stream is in balance with the capacity of the stream to discharge it. During periods of medium and low flow, tributaries may deliver sediment to the main channel where it is deposited as bars at the confluence until a flood occurs giving the main stream sufficient energy to dislodge and transport the sediment downstream.

Basins with high infiltration capacity and a long time of travel, tend to generate peak flood flows of lesser magnitude than those in similarly sized drainage areas with lower infiltration capacities and shorter time of travel.

CHANNEL TYPES AND PATTERNS

General features of natural streams are the result of physical, chemical and biological processes reflecting a

Bankfull flows play a primary role in forming and reconditioning channels. Bankfull flows in natural watersheds of humid areas, like Ohio, occur about every 1.5 years on average. The full range of rising and falling discharges associated with these runoff events is involved in the channel forming and reconditioning processes. The frequency of bankfull flows may increase significantly with changes in land use, disrupting stream stability. Flood flows along streams in response to precipitation are a function of many factors including: basin area, infiltration capacity, and time of travel of flows (figure 2). Basins

long-term regime of climate, landform, geology (including soils) and resultant vegetation. Each channel reach has its own unique history of flow conditions and regime factors giving rise to its general features. A river system may contain many different channel types each transitioning from one to another.

Natural channels can be broadly grouped into alluvial channels and hard-bed or rock-bed channels. The bed and banks of alluvial channels consist of riverine deposits that allow for relatively rapid adjustment of channel geometry in response to changes in flow conditions and sediment load. Hard-bed or rock-bed channels are relatively resistant to down cutting but may have alluvial banks that allow for rapid lateral adjustments. Sediment deposits may cover portions of a hard-bed or rock-bed channel giving it the appearance of an alluvial channel. Alluvial channels in a given drainage basin tend to share similarity in their hydraulic geometry, that is, the mean depth, top width and velocity relationships for typical cross sections. Coarse materials characterize alluvial channel beds in headwater areas; fine materials dominate the lower channel reaches.

Natural channels in plan view can be considered to be either straight, meandering or braided. The distinction between straight and meandering channels depends on the degree of sinuosity, that is, the ratio of channel length to valley length. Channels with

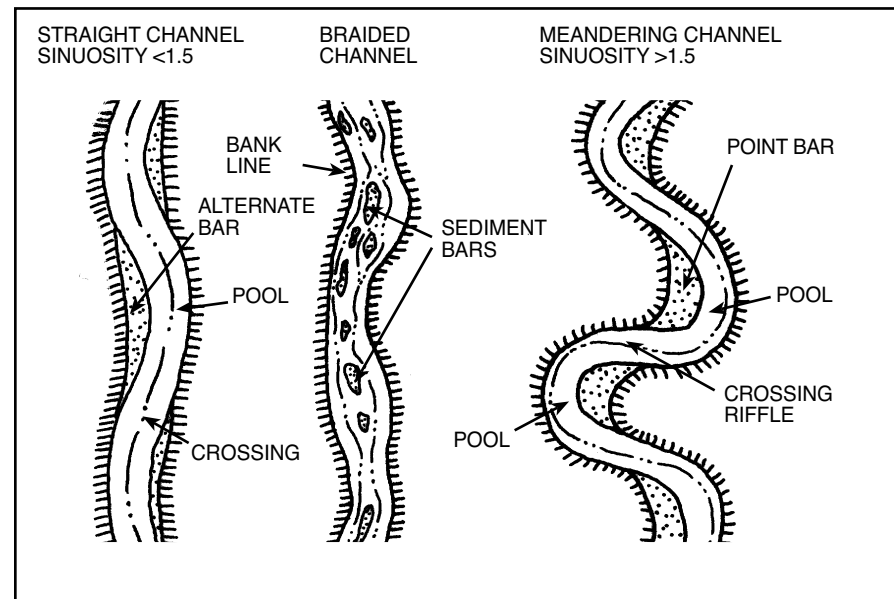


Figure 3. Plan View of Straight, Braided and Meandering Channel Forms.

sinuosity greater than 1.5 are generally considered to be meandering. Braided channels contain sediment bars that cause multiple channels to form during low-flow conditions. Straight, meandering or braided channels may change from one form to another over time such that a continuum exists between the three channel patterns (Figure 3).

Meander forms of alluvial streams tend to exhibit sine wave patterns of predictable geometry, but non-uniformities in the alluvial deposits along streams and flood plains generally disrupts the regular pattern. Nonuniformities consisting of erosion resistant materials can slow the progression of bank erosion at meander bends causing cutoffs and oxbow channels to form making the stream develop an irregular winding pattern. All of the various positions that a meandering stream occupies over time defines a meander belt with outer boundaries at the extreme meander positions (Figure 4). The meandering pattern typical of many alluvial streams is an adjustment of the stream to its most stable form. Meanders lengthen a stream's course and decrease its gradient thereby effecting a balance between stream energy and sediment load.

It is possible to make qualitative predictions of stream response to changes in discharge, sediment load, base level and stream bank condition. For example, a sudden increase in sediment load to a stream typically causes an alluvial channel to widen, and with sufficient loading the stream may become braided. Lowering of the base level of an alluvial stream is typically followed by channel down cutting upstream along the main stem and its tributaries. Removal of streamside vegetation from a meandering alluvial channel generally accelerates the meandering process.

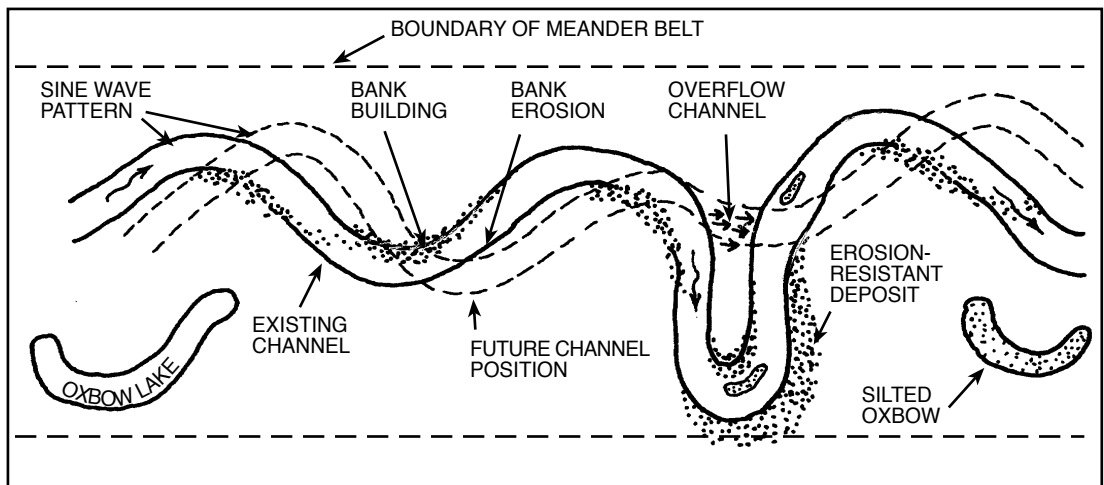


Figure 4. Meandering Stream in an Alluvial Floodplain

STREAM FLOW DYNAMICS

Flow in natural channels normally occurs as turbulent, gradually-varied flow. Under conditions of gradually-varied flow, the stream's velocity, cross-section, bed slope, and roughness vary from section to section, but the changes occur gradually enough that formulae for steady-uniform flow can be applied in analysis. Steady-uniform flow occurs when conditions at any given point in the channel remain the same over time and velocity of flow along any streamline (line of flow) remains constant in both magnitude and direction. Basic formulae used to analyze flow in natural channels, as discussed below, include:

the continuity equation, the energy equation, and Manning's equation.

The continuity equation expresses one of the fundamental principles of stream flow dynamics. It states that the discharge passing a channel cross section is equal to the cross-sectional area multiplied by the average velocity of flow. Average velocity is used in the equation because velocity is not uniformly distributed in a channel cross sections due to boundary shear resistance and other factors. Velocity distribution at channel bends is significantly affected by deflection of faster moving water to the outside of the bend due to centrifugal force (Figure 5). This redistribution of velocity and energy is an essential part of meander formation.

Stream flow involves expenditure of energy wherein potential energy of

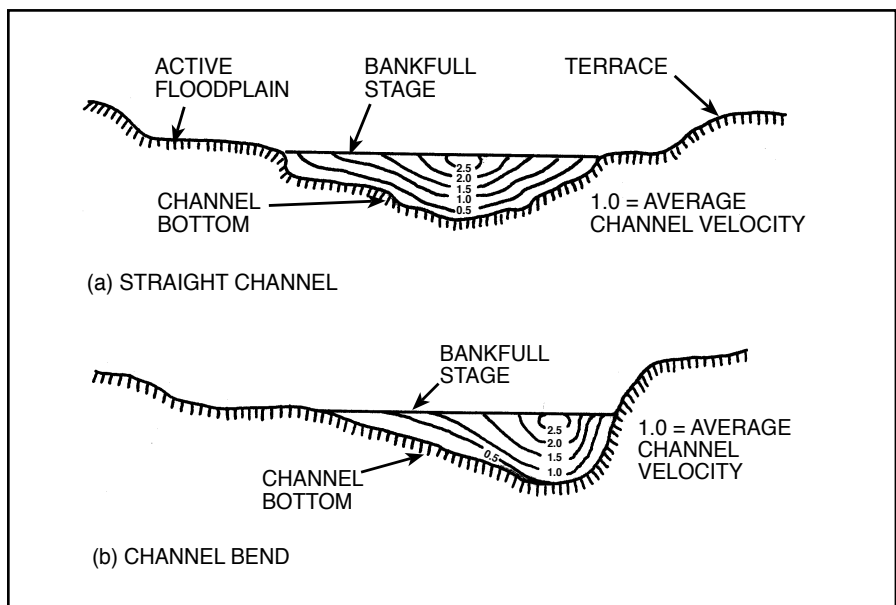


Figure 5. Cross Sections of Natural Channels Showing Velocity Distributions

the water due to position and force of gravity is converted to kinetic energy of motion. The energy equation expresses the relationship between the elevation head, velocity head and energy dissipation required to move water and sediment. Energy losses include those due to friction and expansion or contraction of flow. Friction losses are determined by applying the Manning equation. Simultaneous solution of the continuity equation, energy equation and Manning equation allows for calculation of water surface profiles and average velocities of flow (Figure 6).

Flow disturbances caused by channel obstructions, sinuosity, and channel roughness, create different forms of large-scale turbulence that are important because of their connection to channel erosion and sediment transport processes. All forms of turbulence originate with boundary roughness, the most important being sinuosity and alternation of pools and bars. The strength of turbulence varies with stream stage, increasing with each rising stage to a peak when streams develop maximum energy. Forms of large-scale turbulence include: rhythmic surges, bottom rollers, bank eddies, vortex action, transverse oscillation, helicoidal flow, standing waves, sand ripple waves, and antidunes.

Boils are a form of large-scale turbulence that play a significant role in the bank caving process. Boils develop when stream flow encounters obstructions or irregularities along the stream bed causing water to surge vertically to the surface. Stream bed material adjacent to banks may be moved upward into the current by boils causing deepening of the channel bed

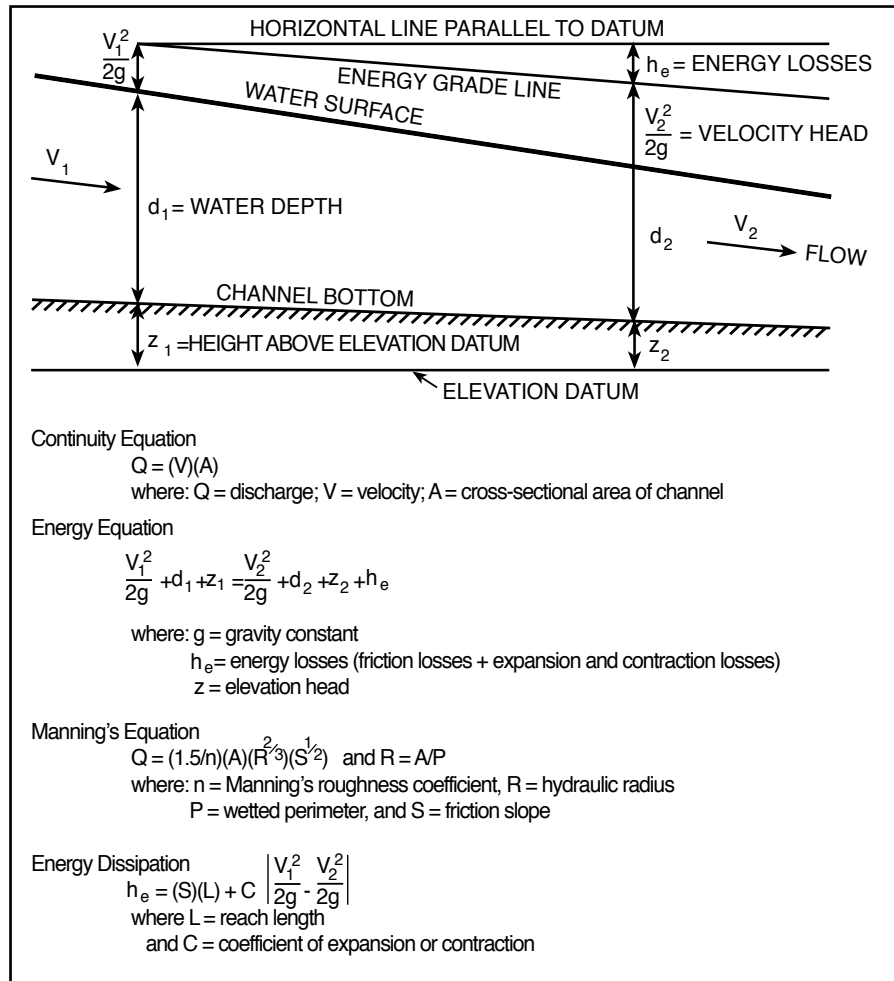


Figure 6. Stream Channel Profile: Slope Relationships for Gradually Varied Flow

and increasing bank height. This leads to instability and slumping of banks when flow recedes, thus removing hydrostatic support from the bank (Figure 7). Scouring of stream banks by fast moving water can cause “pop-outs” and slab-type failures of material from near vertical banks as well as undercutting and toppling of streamside trees. Dense root masses of streamside trees

tends to armor banks and create flow retarding roughness that protects banks from scour.

SEDIMENT LOAD IN STREAMS

Sediment production in watersheds is generated by sheet, rill and gully erosion including mass wasting at gully headcuts. Mass movement of

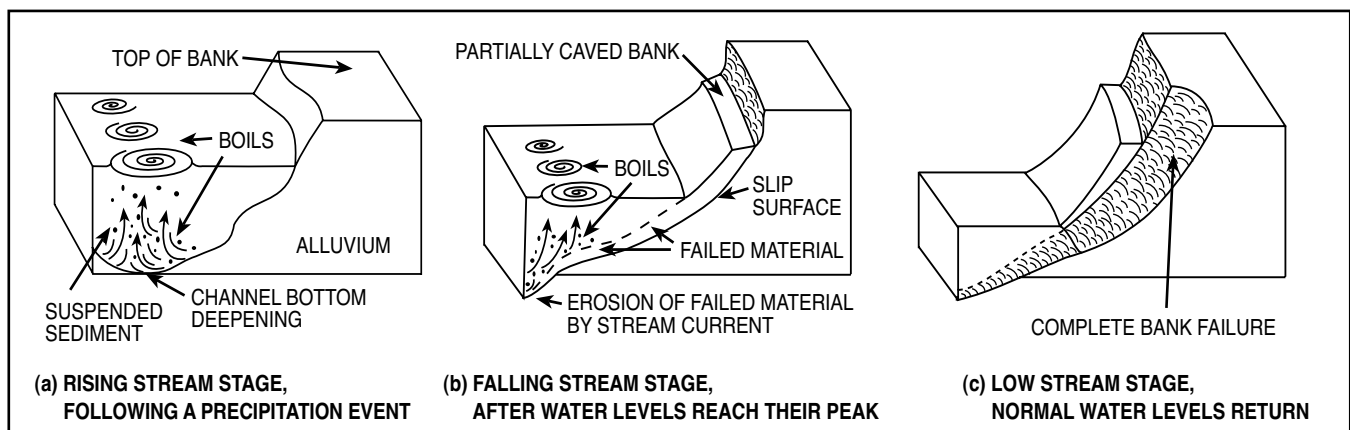


Figure 7. Stream Boil Turbulence Resulting in Bank Failure

material by slow, down slope creep and landslides may also contribute to sediment production. Eroded material that reaches streams combines with material eroded from channel bed and banks to create the sediment load—boulders, cobbles, gravels, sand, silt, and clay particles. The sediment load, dissolved minerals, and organic matter in streams constitutes the total solids load.

Dissolved minerals and suspended sediment (material kept in suspension by fluid turbulence) are important factors affecting the water quality of a stream and often comprise a disproportionately large amount of the total solids load, but it is the bed load sediment that is of primary significance for channel stability. Bed load consists of material that is moved by sliding, rolling or bouncing along the bed. Tractive force developed by the stream acts in the direction of flow on the channel bed and banks, dislodging and moving material downstream. Calculations can be made to determine allowable tractive forces and permissible velocities for stable channels.

Stream power is the energy expended by the stream in discharging water and sediment. The more energy the stream has, the more sediment it can carry. During floods, when a stream has higher energy levels, it may erode the bed and banks of the channel to balance the energy and sediment load. Straightening a meandering channel generally increases stream energy and the potential for erosion. Over a long period of time, the majority of sediment transported by a stream is carried by the bankfull flows. Stream competence refers to the sediment load a stream can carry at bankfull flow.

When flood flows recede, stream energy is dissipated and sediment is deposited. The deposits are of predictable form and location such as the point

bars and crossing bars of meandering alluvial streams. These depositional features may undergo considerable disturbance during the passage of floods as sediment is eroded, transported, and redeposited. In a stable sinuous channel, straightening of the axis of flow occurs during floods so that material on crossing bars and point bars may be eroded, transported and redeposited downstream leaving depositional features with new material but largely unchanged in form, size, and location (Figure 8).

BASE-FLOW CHARACTERISTICS OF STREAMS

During dry weather periods, flow in natural streams is sustained primarily by ground water discharging from quifers (water bearing formations) intercepted by the channels. These dry weather flows, or base flows, typically exhibit the chemical properties of the groundwater. Streams flowing on bedrock generally have relatively low sustained base flows, whereas streams formed in glacial outwash material consisting of sands and gravel have relatively high base flows. Streams flowing across glacial till and along end moraines may receive moderate contributions of ground water to sustain base flows from sand and gravel lenses in the glacial deposits. The natural base-flow regime of many streams is significantly altered by regulation caused by reservoirs, stream intakes, well fields, wastewater treatment plants and other facilities.

The amount of ground water contributing to stream flow varies along the channel and according to the hydraulic gradient in the contributing aquifer. When stream level is below the bordering ground water table, a

positive gradient exists and ground water flows into the stream. If the bordering water table declines below stream level, seepage may flow from the stream into the aquifer. Water that seeps into stream banks

during passage of floods is referred to as bank storage and returns relatively quickly to the stream after high flows recede.

Alluvial flood plains and riparian wetlands are significant ground water source areas that are effective in sustaining stream flows during dry weather periods. Good sustained base flow is highly beneficial to many forms of aquatic life. It lessens the impact of water quality problems caused by concentration of pollutants and depletion of dissolved oxygen during dry weather periods. In addition, a stream with good base-flow characteristics that ceases flowing during drought may continue to discharge water along its course through porous bed material. This subsurface flow is important for survival of many aquatic animals that normally inhabit the stream bed or burrow into it during drought.

STREAM ECOLOGY AND NATURAL PURIFICATION PROCESSES

Natural streams are dynamic systems that convey, store, and transform water, sediment, and organic matter. The transformations involve: physical processes—aeration, dispersion currents, sedimentation; chemical processes—photosynthesis, metabolism; and biological processes—biological flocculation and precipitation that act in concert to naturally purify the water. Aerobic purification processes require free oxygen and are dominant in natural streams, although important anaerobic processes occur as well where free oxygen is absent.

Organic matter and nutrients in streams are decomposed and resynthesized through chemical reactions in association with aquatic organisms. The material is transformed by the cycles of nitrogen, phosphorus, carbon and sulfur in aerobic decomposition. These processes create biochemical oxygen demand that depletes dissolved oxygen in the water. Reoxygenation is effected through aeration, absorption and photosynthesis. Riffles and other natural turbulence in streams enhance aeration and oxygen absorption. Aquatic plants add oxygen to the water through transpiration. Oxygen production from

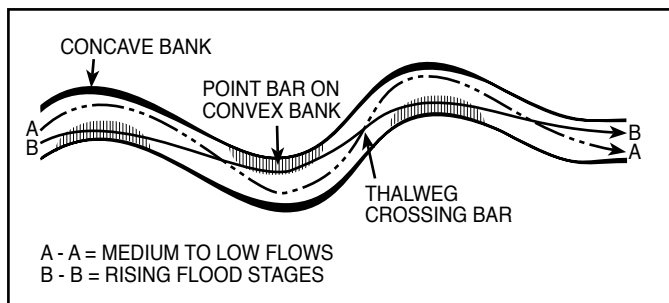


Figure 8. Axis of Main Current Along a Sinuous Channel

photosynthesis of aquatic plants, primarily blue-green algae, slows down or ceases at night creating a diurnal or daily fluctuation in dissolved oxygen levels in streams. The amount of dissolved oxygen a stream can retain increases as water temperatures cool and concentration of dissolved solids diminish.

Fish and other aquatic organisms that utilize the dissolved oxygen in water for respiration may suffocate if oxygen levels are severely depleted. Excessive loading of streams with organic matter and nutrients from point and nonpoint-source discharges can create significant biochemical oxygen demand and reduce dissolved oxygen to critical levels. Nutrient enrichment of streams may cause algae to rapidly multiply, bloom, die and decompose during low-flow periods resulting in severe oxygen depletion and fish kills.

Aquatic organisms that inhabit natural streams may be grouped (from Fair, Geyer, and Okun, 1968) as follows:

AQUATIC PLANTS

- **seed bearing plants**
 - plants attached to stream bed or banks
 - free floating plants (duckweed)
- **mosses and liverworts**
- **ferns and horsetails**
- **primitive plants (algae)**

AQUATIC ANIMALS

- **vertebrates**
 - fish
 - amphibians
- **invertebrates**
 - mollusks (mussels, snails, slugs)
 - arthropods (crustaceans, insects, spiders, mites)
 - worms
 - protozoa

AQUATIC MOLDS, BACTERIA, VIRUSES

- **true fungi** (phycomycetes, fungi imperfecti)
- **bacteria** (streptococcus, escherichia coli, nitrosomonas, nitrobacter, beeggiatoa)

• **viruses** (poliomyelitis)

Streams in their natural state tend to maintain a dynamic balance between populations of aquatic organisms and available food. The population dynamics of the communities of aquatic organisms in stream ecosystems involve: substrate utilization, the food web, nutrient spiraling, and the growth curve.

Waste organic substances in streams form the substrate on which microorganisms grow and become part of the food web. Growth of microorganisms follows sequent portions of the growth curve including: nutriently unrestricted exponential growth, nutriently restricted growth, and stationary or declining growth due to environmental conditions. Population growth of the microorganisms is a metabolic response to food under specific stream conditions.

Nutrients circulate from surface to substrate as they flow downstream and are continuously available to bacteria, algae, fungi, invertebrates, fish and other aquatic organisms. The circulation, capture, release and recapture of nutrients is termed nutrient spiraling. The ability of a stream to assimilate nutrients and store them in the living tissue of plants and animals is termed its assimilative capacity. Streams that are physically complex and healthy have a relatively high nutrient assimilative capacity, which is needed to maintain good water quality.

The quality of water in a stream is manifest by its physical and chemical properties, and by the composition and health of the aquatic organisms that live in the stream. The presence of larvae of stoneflies, caddisflies, and dragonflies, for example, generally indicates good quality water; whereas, large populations of rat tail maggot, blood worm, and sewage fungus indicate polluted water. Ecological interpretations can be made based on what associations of organisms should be in the stream, and recognition of abnormal numbers, associations, and conditions of living things. In other words, the condition or health of a stream ecosystem is reflected by

its biological integrity. Biological integrity has been defined as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitats of the region." (Karr and Dudley, 1981)

Survival of the many species of organisms found in natural streams depends on the integrity of the water resource. Five principal factors and some of their important chemical, physical and biological components that influence and determine the integrity of surface water resources (from Yoder and Rankin, 1995) are as follows:

FLOW REGIME

precipitation and runoff, high- or low-flow extremes, velocity of flow, ground water component, land use.

HABITAT STRUCTURE

channel morphology, pool-riffle sequence, bed material, gradient, in-stream cover, canopy, substrate, current, sinuosity, siltation, riparian vegetation, channel width/depth ratio, bank stability.

ENERGY SOURCE

sunlight, organic matter inputs, nutrients, seasonal cycles, primary and secondary production.

CHEMICAL VARIABLES

dissolved oxygen, temperature, pH, alkalinity, solubilities, adsorption, nutrients, organics, hardness, turbidity.

BIOTIC FACTORS

reproduction, disease, parasitism, feeding, predation, competition.

The status of factors determining the integrity of the stream resource depend in large measure on the condition of riparian zones, flood plains, valleys and watersheds. Vegetated riparian zones filter overland runoff, trap sediment, and utilize phosphorus adhering to sediment particles. Ground water near the surface in riparian areas creates conditions that support cyclical transformations of nitrogen, phosphorus, carbon and sulfur. Denitrification of nitrates is one of these

important transformations. Vegetated riparian zones, vital to the health of streams, may nevertheless be overwhelmed by accelerated runoff, sediment, and pollution from mismanaged watersheds. The health of stream ecosystems and the condition of riparian zones, flood plains, valleys, and watersheds are interdependent.

HUMAN IMPACTS ON STREAM SYSTEMS

Planned and unplanned changes in one or more features of a stream ecosystem by human activity generally triggers additional changes in other stream features that can disrupt the stream's natural processes, impair natural functions and result in loss of beneficial uses. These negative consequences are often unanticipated by people in the watershed community.

Stream systems are impacted by human activities that make use of stream resources, and by human occupancy and use of flood plains and uplands. Impacts can result from direct disturbance of natural streams through such things as channelization and point discharge of pollutants to receiving waters. Impacts may also arise more indirectly through damaging land management practices and nonpoint-source pollution in watersheds. In many situations, streams are responding in a complex manner to multiple disturbances and sources of pollution that have occurred over a long period of time.

The most damaging impacts result from changes in the basic structure and functioning of the stream ecosystem. (Doppelt, et al., 1993) These impacts include the following:

- changes in water quantity and flow regime by diversions, drainage projects and land use changes (see Figure 2);
- modification of channel and riparian ecosystem morphology by channelization, damming, and removal of streamside vegetation;
- degradation of chemical water quality by addition of contaminants;

- excessive nonpoint-source pollution including siltation and nutrient enrichment;
- deterioration of stream substrate quality and stability;

- destabilization of stream banks and channel bottom directly by such things as livestock grazing and instream mining or indirectly by land use changes and damaging land management practices;

- separation of streams from their normal ground water table and elimination of riparian wetlands by dredging and induced down cutting of streams;

- modification of normal water temperature regime by removal of tree canopy or alteration of base flow regime;

- introduction of exotic species that disrupt the dynamic balance of the riverine ecosystem.

The cumulative results of damaging human impacts on stream systems include the following:

- degradation of the physical, chemical and biological integrity of the water resource;
- reduction of life-supporting complexity and diversity of the riverine ecosystem, that is, ecosystem simplification;
- impairment of beneficial functions and natural stream processes;
- loss of beneficial uses of stream resources, that is, water supply, recreation, fish consumption and aquatic life uses.

STREAM MANAGEMENT OBJECTIVES

The overall objective of stream management coincides with the principal objective of the Clean Water Act—to restore and maintain the physical, chemical and biological integrity of the water resource and achieve full attainment for designated uses. Achieving

this overall objective will require that attention be given to all of the principal factors influencing and determining the integrity of the water resource, that is, flow regime, habitat structure, energy source, chemical variables and biotic factors. An important first step in the stream management process is defining specific management objectives. Stream management objectives that will apply in most situations include the following:

- to increase public awareness of the value of natural stream corridors and their beneficial functions;
- to promote acceptance of streams as dynamic systems that inherently flood and meander;
- to effect wide-spread adoption of best management practices in watersheds in order to minimize human impacts on stream ecosystems;
- to protect existing stream resources from unnecessary degradation and restore stream resources where appropriate and feasible;
- to work with the stream in an environmentally sensitive manner consistent with the stream's natural processes;
- to have active citizen involvement in stream monitoring, protection, and restoration efforts.

WATERSHED APPROACH TO STREAM MANAGEMENT

When trying to understand the stream's natural processes and how stream management problems might be addressed, it is generally useful to take a watershed perspective and look at the stream as a system, both spatially and in time. Stream restoration measures are more likely to succeed if formulated with a good knowledge of the past history of the stream, and an accurate assessment of its current status and likely future tendencies. Factors affecting stream processes that can be changed, such as land management practices, must be distinguished

from factors that generally cannot be changed—geology and climate. In most cases, it is more practical and advisable to work with the stream, rather than against it.

Management of stream resources requires multi-disciplinary knowledge of: (1) the climatic environment; (2) geologic factors, including soil conditions; (3) surface water and ground water hydrology; (4) stream channel hydraulics; (5) sedimentation; (6) fluvial geomorphology; (7) stream ecology; (8) watershed management; and (9) social, cultural, economic and political constraints. A team of knowledgeable individuals is generally needed to accurately assess the factors contributing to stream problems and to find suitable solutions. Stream management depends upon bringing together people with a great diversity of interests, knowledge, and background of experience.

There are many stream management techniques and remedial action measures for addressing specific problem areas. Management initiatives, however, must do more than simply treat symptoms of problems; they must address the root causes of the problems to be of lasting effect. Success in stream management requires a strategy for protecting existing stream resources from further degradation by addressing the causes of problems while selectively restoring impaired channel reaches to the extent feasible and appropriate. Implementation of such basin-wide strategies may best be accomplished through community-based, watershed-ecosystem approaches. Above all, to be effective, stream management activities and supportive public policies and programs must be connected to how streams actually function.

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This Guide is one of a series of Ohio Stream Management Guides covering a variety of watershed and stream management issues and methods of addressing stream related problems. The overview Guides listed below, are intended to give the reader an understanding of the functions and values of streams. For more information about stream management programs, issues and methodologies, see Guide 05 Index of Titles or call the ODNR Division of Soil and Water Resources at 614/265-6739. All Guides are available from the Ohio Department of Natural



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