

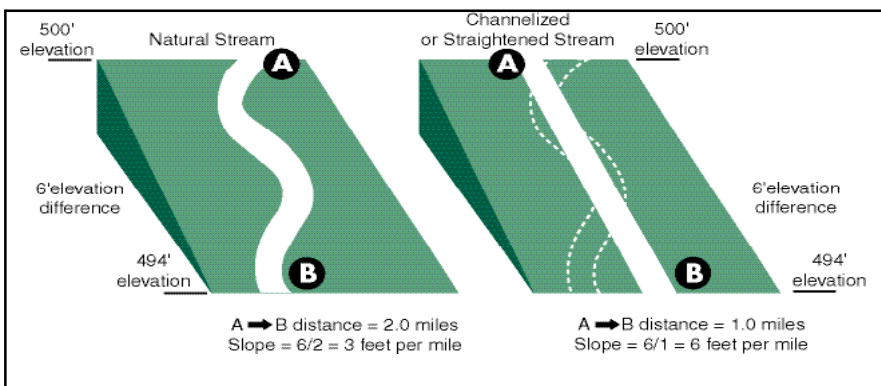
# Chapter 1. Stream Ecology and Channel and Bank Stability

## Physical Processes

Streams are broadly classified according to their bed materials and temperature. Whether a stream is a bedrock or alluvial stream depends on the geology of the basin through which the stream flows. Coldwater streams can support trout and salmon year-round. Warmwater streams, such as ours in Mississippi, cannot support trout and salmon. Classic mountain trout streams that have large boulders, and flow over rocky beds usually fit the bedrock type. The trout streams of the upper south, northeast and west are bedrock streams. Alluvial streams like ours in Mississippi flow through deposits of sand, gravel, silt, and clay and move this material called alluvium downstream and are in a constant process of shaping and reshaping their beds, banks, and floodplains. They deposit some of this material in their beds, and when they overflow their banks, the alluvium gets deposited in their floodplains. The Mississippi River is a big alluvial stream that, over history, has built natural banks and deltas. Over thousands of years it has moved its channel laterally (east to west) hundreds of miles.

All streams, whether alluvial or bedrock, have four basic characters that define them: Slope, discharge, sediment load, and particle size. Slope describes the vertical drop of a stream from its headwaters to its mouth, or to the sea. Slope is the proportion of fall to run. For example: a 1-foot drop in 100 feet of length gives a 1/100 or 1 % slope.

Discharge is the volume of water carried by the stream. It is measured as a rate and given in cubic feet per unit of time, often by cubic feet per second (cfs) or in some other time increment such as thousands or



**Figure 1.** Change in stream slope due to channelization

stream with a given slope and discharge, can carry a certain amount of material of a certain type. Another way to put this is that a channel will remain in equilibrium if changes in sediment load and particle size are balanced by changes in water discharge and slope.

When this stability is changed, a channel will respond by one of two processes: degradation (picking up sediment or system-wide bed-scour), or aggradation (system-wide deposition of sediment).

millions of cubic feet per day or year.

Sediment load and particle size describe the silt, sand, gravel, rocks, and other substances picked up and moved by flowing water. Slope, discharge, sediment load, and particle size work in equilibrium.

For example, a stable

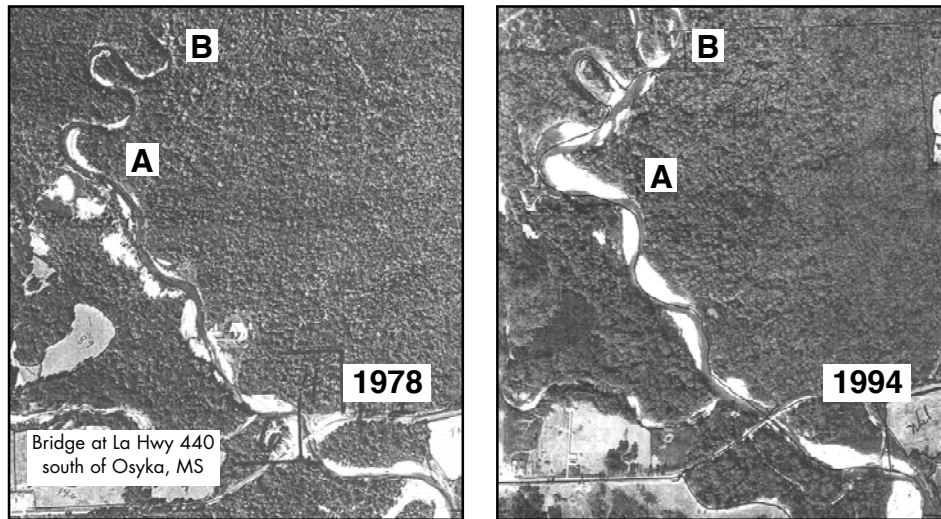
A degrading channel cuts into its bed when increased flow energy picks up bed materials and moves them. An aggrading channel has its bed built up as flow energy decreases and drops sediment. For instance, one such variation would be to decrease the discharge of a stream by diverting some of its water, perhaps for irrigation or industrial

use. The stream would have less volume, move more slowly, and deposit more of its load of sediment and suspended materials on its bed. Channelizing a stream by straightening (cutting across bends) and deepening a section of it will change its equilibrium in a different way.

In a channelized stream section, slope is altered. Water will now fall from the upper elevation to the lower elevation over a shorter distance. If a mile of bends are bypassed through channelizing and straightening, a stream that used to drop 6 feet in 2 miles now drops that same 6 feet in 1 mile (Fig. 1). The water will be moving faster, with increased energy, and can carry more material. This stream will begin cutting a deeper channel where the water runs faster. To reach the equilibrium point, sediment will begin to move or slough from above the deepened, or straightened section. This system wide sloughing is called “accelerated erosion.” It is also called “headcutting” because of the tendency for the sloughing to work its way upstream or toward the head-waters of a stream (Fig. 2).

Other activities beside channelization can cause headcutting including natural occurrences such as increased runoff after fires in the watershed. Scooping sand or gravel from a stream bed and trenching across a stream bed to bury a pipe can initiate headcuts. When a hole or trench is dug in the bed of the river, it can create a knickpoint. The increased energy and turbulence caused by the knickpoint results in the upstream migration of the knickpoint. The current will cut away at the upstream lip of the knickpoint, removing these bed materials and carrying them downstream.

As the knickpoint migrates, it can cause the banks along the channel to become unstable and slough down so that the next flood will wash them away. A local term for headcutting is “blowout”. The banks above a headcut which once were forested will become unstable as the soil and sand wash out and the trees topple into the stream.

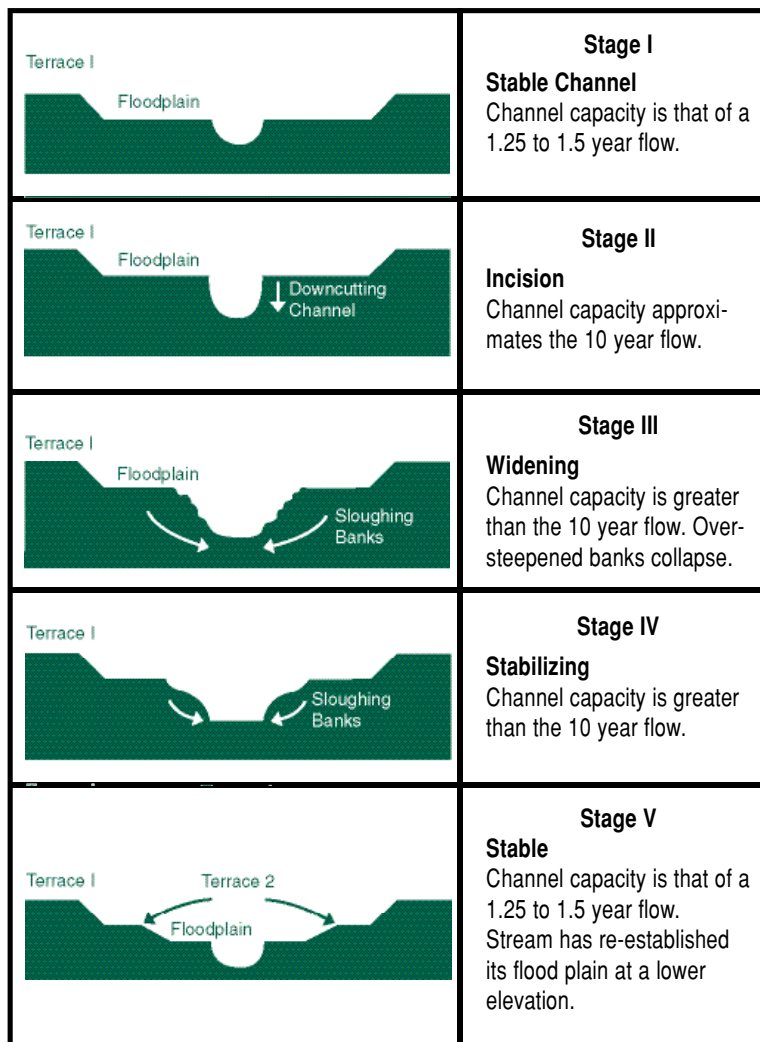


**Figure 2.** Headcutting on Tangipahoa River between 1978 and 1994. Note “A” widening of sandbars, and “B” loss of forest canopy as headcut migrates upstream leaving new sandbars where the forest once grew.

Headcutting is the same process as the formation of gullies on land. Gullies stop migrating upslope in a field when the rainfall stops. Headcuts have a constant source of erosive energy as long as the stream flows.

In Mississippi, Bayou Pierre is sometimes called the “mother of all headcuts”. Beginning at its mouth at the Mississippi River, this stream has blown out its banks and those of most of its upstream tributaries across four counties. This headcut began marching upstream in the 1930s and is still active. Some erosion is natural, but this accelerated process is set in motion by man-induced stream-bed disturbance. Headcuts are extreme and destructive example of streams tending to work back to an equilibrium after disturbance of slope, which along with discharge, sediment load, and particle size define the physical nature of flowing water.

This general pattern of headcutting and channel response was described in the channel evolution model (Schumm, 1977)<sup>2</sup>. The model breaks the process down into five stages: Stage I: stable channel, Stage II: incision, Stage III: widening, Stage IV: Stabilizing, Stage V: Stable. The stream, over time, cuts down in its bed in response to some change or insult to its equilibrium. Starting with a stable stage I channel, there may be a knickpoint or channelization or increased runoff in the watershed. In stage II the stream excavates a deeper, larger volume channel that can accommodate the increased flows. Stage III brings on a widening of the channel, with bank collapse due to vertical instability. The bed and bank erosion which accompanies a stage III channel means that much sediment is transported and deposited periodically in point bars and then moved during high flows. Stage IV channels show some stabilizing trends as vegetation becomes established on the sediment, and banks are held in place first by grasses, then by shrubs and trees.



**Figure 3.** The Channel Evolution Model breaks headcutting into five stages; after Schumm 1977

In stage V the stream regains the stability it had as a stage I channel, but the overall elevation of the streambed is lower, and the former floodplain is now a terrace.<sup>3</sup> (Fig. 3)

### **Historical Stream Disturbance in Mississippi**

In the southeastern United States in general, and in Mississippi in particular, human activity has touched almost every stream, and certainly part of every drainage basin. The land use changes that have taken place in the last two-and-a-half centuries are due to land clearing for agricultural activities, settlement patterns, timber harvest, road and railroad building, and the spread of towns and cities (urbanization and sprawl).

Settlement and development of land by Europeans first followed rivers and Native American trade routes. With the arrival of railroads in Mississippi in the 1830's, settlement followed along their routes. Forests were cut at a much faster pace than in pre-railroad times.

In the seventy years from the end of the Civil War to the Great Depression, a majority of old growth pine and hardwood forests were cut and taken to mill and market by rail. Mississippi's pine and other southern-grown lumber helped build Chicago and countless other 19th century American cities. It was also used to help re-build Europe after both world wars.<sup>4</sup>

The landscape of much of the South changed after these old forests were cleared. The cotton economy was already in place in the rich river bottom-lands before the railroads boomed. After the railroads spread and the forests were cut, much of the former forest lands, whether hilly or flat could be farmed. Most of these lands were planted in cotton. They were farmed intensely in these seventy years (1860-1930), so much so, that natural nutrients were depleted on marginal land, and erosion removed vast amounts of topsoil.



**Figure 4.**  
Virgin Pines in Southern Mississippi.

Due to its nutrient requirements, cotton is very hard on even the best soils, and during these years it was planted almost everywhere regardless of the suitability of the soil. The middle South had an upland cotton economy until the land gave out, about the same time of the Great Depression. In some areas of Mississippi, this economy based on growing cotton on unsuitable soil lasted past the depression years, but even these remnants of this system had ground to a halt by about 1960.<sup>5,6</sup>

When the landscape changed from forest to small farms, the rivers and streams draining these areas showed the effects of land use changes. Over the years, streams that ran clear became muddy as sediment and topsoil from fields and hillsides were washed into them. As farms were abandoned, the forests

reclaimed the poor or marginal land, and the streams became clear again, but some streams still retain massive amounts of sediment from this time that are shifted around as the streams seek an equilibrium in an altered physical state. In portions of Mississippi that receive drainage from poor, hilly land that was farmed in the 19th century, the streams are still affected by these accumulated loads of sediment.

The Loess Hills and the North-Central Hills of Mississippi are the two physiographic regions where streams most notably show the effects of land uses of 100 years ago. Basically, these are the places where the kudzu is the thickest today. This imported exotic vine was planted to fight the enormous forces of erosion, and it remains a telltale sign of this period of agricultural history and land use. Streams in the southern part of the state do not seem to suffer as much from the disruptive farming practices of the upland cotton days. The landscape is a bit flatter, suffered less from erosion, and, generally was less affected by problems rooted in historical land use.

Even our best remaining natural streams have a long history of alteration. There are some streams that hardly show these effects, and these are the streams that people find most attractive and will work hard to conserve.

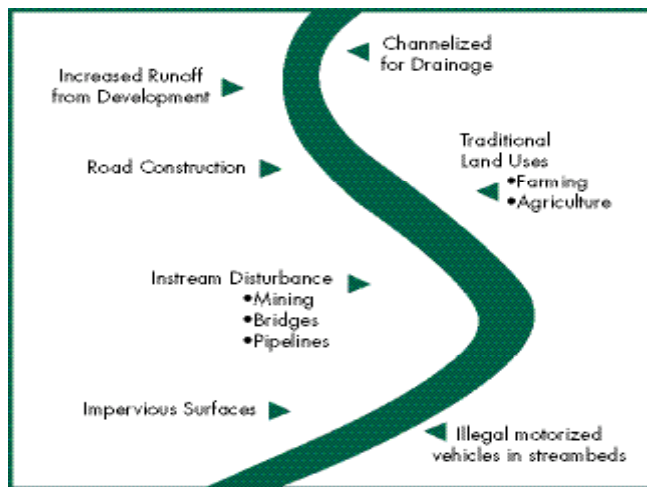
### Modern Era Stream Disturbance

Streams drain the changing landscape of Mississippi and they face the traditional land uses of farming and forestry activities. But they are being stressed by the spread of cities and towns and the construction of roads, streets and parking lots coinciding with development. In a sense, streams and rivers are being sandwiched between traditional land uses and the new pressures development puts on natural drainage systems.

Farming and silviculture have cycles of temporary land use changes. Crops or trees are planted on prepared sites; they grow and are harvested.

Farming has an annual cycle from planting to harvest, while the cycle of forestry activities is longer, from 15 to 40 years or more. The land recovers, or at least stabilizes, within these cycles and there is some soil loss in rainwater runoff. Most importantly, the soil still allows water to percolate down and seep into the earth (groundwater infiltration). The soil of a pasture, field, or forest remains permeable and eventually recovers from disturbance.

Development poses a much more difficult problem for ground water infiltration and surface drainage.



**Figure 5.**  
Physical stresses on streams

Hardened surfaces don't allow water to percolate into the soil. Developed land is permanently changed in its use, and the way the land drains is forever altered. Rainwater quickly runs off roofs, streets, roads, and parking lots. Underground drainage directs stormwater from roads and concrete surfaces to ditches that take the water directly to a stream, creek, or river. On undeveloped land, precipitation ordinarily takes days to percolate down into the shallow ground water and then seep into a stream where it contributes to the stream's base flow. With development, less water seeps into the soil and more rainfall is transmitted as surface runoff which is quickly delivered to the stream. Development is permanent, and there is no cycle over which the land can regain its ability to absorb water through percolation or seepage.

What development does to a natural stream or river is disrupt its equilibrium. Stream discharge is increased as runoff water finds its way to the main channel more quickly. The stream rises much faster than when it drained fields, and forests. Flash floods occur now when they did not prior to development, and the stream channel will adjust to handle the greater, faster, and higher storm water flows. Over time, the stream must carry a greater volume of water and sediment and will adjust its slope by cutting into its bed if its bed materials are soft enough. When water reaches hard clay formations or sandstone and can no longer cut down, it will top the banks and spread out into the floodplain (if the stream channel is not too deeply incised). The stream may also undercut its banks and cause them to fail.

In urbanizing basins, where small streams must carry increased storm water runoff, streams change their character physically and biologically. Fishes and aquatic life that cannot tolerate the radical changes in the altered stream environment simply disappear because their habitat requirements are no longer met. A stream that supported a dozen or more species of fish prior to urbanization, will support two or three species afterward. This is the death of a natural stream and marks its transformation to an urban ditch. There are streams bearing the evidence of this sad course of events at the sprawling edges of Mississippi cities and increasingly on the developing fringes of smaller towns that incorporate adjacent rural communities.

Rural streams safe from urbanization face various impairments to their health from road construction projects, pipeline crossings, and excessive sediment and polluted runoff from farming and forestry activities. All of this is collectively called non-point source pollution. For road construction, agriculture, and forestry, there exist soil conservation measures and water quality improvement practices formulated to reduce the impacts of non-point source pollution on streams. These Best Management Practices (BMPs) are designed to maintain good water quality in streams that may be affected by construction sites, farming and forestry activities.

Any stream impacted by channel or bank disturbance, coupled with increased nonpoint source runoff eventually can show the effects of accelerated erosion. In the earlier discussion of channel stability, accelerated erosion (headcutting) was introduced. BMPs reduce adverse impacts to a stream's water quality, and their use will help fight the effects of accelerated erosion.

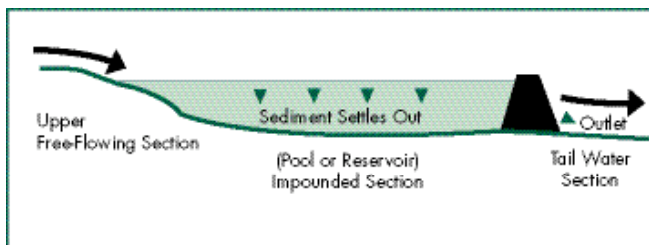
## Changes to Stream Ecology by Dams and Impoundments

When a dam is constructed on a stream to create a lake or reservoir, there are many changes that take place affecting the physical and biological features of the stream. The stream environment is defined to a great degree by flowing water and is sometimes called a lotic environment by biologists. Lotic comes from the word *lotus* which in Latin means bathing or washing. It signifies moving waters.

Lakes are lentic environments, from the Latin *lentus* meaning slow, calm, or sluggish. A reservoir is a combination of the lentic and lotic environments because some water is constantly coming in from the river, moving through the reservoir and out the dam or spillway. The character of the river is changed to a very slow, almost still condition in which the flow is hardly noticeable. For all practical purposes, the river is changed to a lake.

The biological and physical features of free-flowing rivers and dammed impoundments are very different. Several things stop happening when a river is dammed. Fish reproduction, transport of sediment, and elements of the aquatic food chain are disrupted or re-arranged. Many species adapted to life in flowing water depend on seasonal cues for reproduction, like temperature and water level. Streams are at low flow in the summer and early fall and at peak flows during late winter and spring. Many species of fish follow flood waters out of the banks into the floodplain where they feed. Additionally, some fish spawn as river waters move out onto the floodplain where their young can take advantage of abundant food. The seasonal cues are not as strong in reservoirs as they are in streams.

River-dependent fish species must migrate up and down rivers during their life cycles. American eels live as adults in rivers and migrate to the sea to spawn, while the breeding Gulf sturgeon lays eggs in river-bottom gravel beds and then returns to the waters of brackish bays and estuaries of the Mississippi Sound. The blockage caused by a dam means these basic conditions are not met. These fish will not reproduce and over time will disappear from the river reaches above the dam. In the northeast, and northwest U.S., runs of migrating salmon and shad are stopped by dams. In our southeastern U. S. streams that drain to the Gulf of Mexico, migration and spawning of eels, sturgeon, herring, striped bass, paddlefish, and some species of shad are stopped by dams.

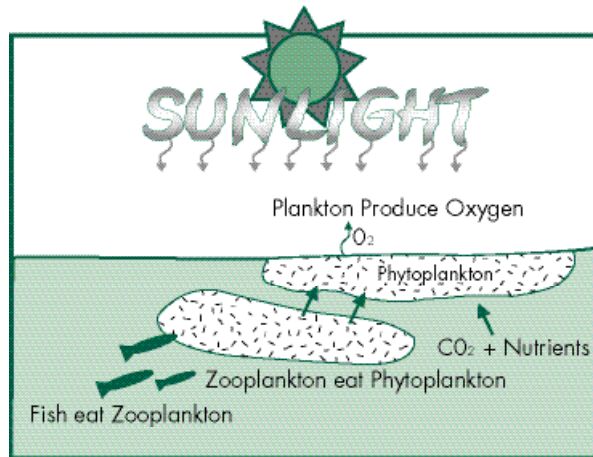


**Figure 6.** The free-flowing, impounded, and tailwater reaches of a river that has been dammed

When the flowing water of a river slows down in a reservoir it cannot carry its suspended load, so sediment drops out of suspension and goes to the bottom. Reservoirs begin filling with sediment as soon as the dam is closed. They have finite life spans unless dredging keeps the sediment from collecting. If a reservoir is built to control floods or store drinking water, this accumulation of sediment robs its capacity to store water.

As the bottom builds up from sedimentation, the reservoir becomes filled with soil, sand, and silt and will hold less water. A glass half full of sand will not hold as much water as when it is empty. This analogy holds true for reservoirs as well.

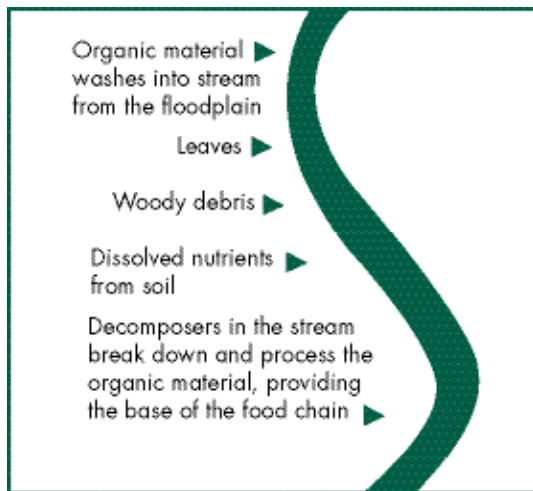
Some things start happening in the reservoir environment that did not happen in the river. The slower water of the reservoir means that populations of free-floating, tiny, green plants or phytoplankton will establish residence in the water column. Rivers have a moderate amount of plankton, but because the water is always moving, large populations usually don't get established. Phytoplankton manufacture their own food from sunlight through photosynthesis. The plankton-based food chain of a reservoir functions like other plankton-based food chains in lakes and in the oceans (Fig. 7). This is fundamentally different from the food chain of the river



**Figure 7.** Autochthonous Food Chain of a reservoir. Phytoplankton produce their own food through photosynthesis. Zooplankton feed on Phytoplankton and provide food for fish.

which depends on washed-in organic material supporting aquatic insects and other invertebrates such as crayfish. A river's source of nutrients is based on the things that wash into it or that are covered by flood

waters and are processed by invertebrates. In one respect, rivers and streams are like long, wet, moving compost piles with populations of invertebrate decomposers, shredders, filter feeders and predators forming the base of the food chain for fish. These small organisms are in turn eaten by fish. Leaves and woody debris from stream-side floodplain forests are a very important source of organic or carbon-based nutrients that drive an *allochthonous* system. This Greek word means "other earth" and signifies that the nutrients driving the food chain in a river are washed in from the flood plain of the stream.<sup>7</sup>



**Figure 8.** Allochthonous Food Chain of a stream or river. The river receives nutrients from organic material that washes in from the floodplain.

When a population of plankton gets established in a reservoir, the allochthonous system shifts to an *autochthonous* system, another Greek word meaning "own earth". It describes a food chain that to some degree can produce its own food. This refers to the tiny green plants or phytoplankton that use photosynthesis to convert the sun's energy to biological material.

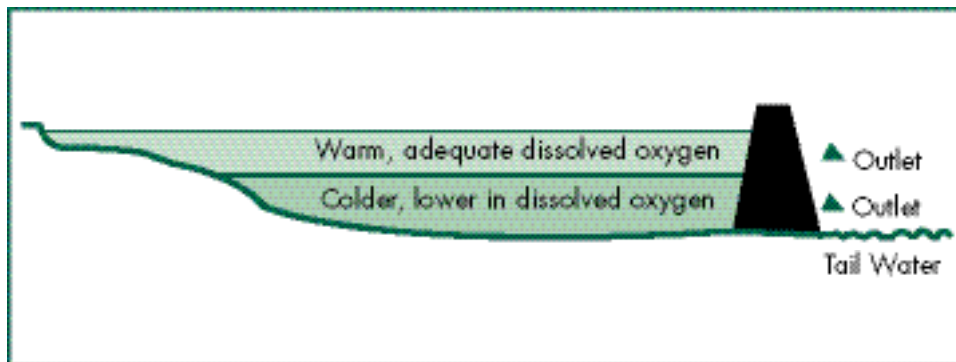
Phytoplankton form the base of a reservoir food chain and are eaten by zooplankton (tiny free floating animals). Zooplankton populations in a reservoir are composed of rotifers and other protozoans, also tiny crustaceans and the drifting larvae of certain insects and fish.

Juvenile crappie and bluegill and some adult fish like shad and paddlefish can filter plankton out of the water using the filaments on their gill arches. Large plankton populations can support enormous populations of filter feeding shad. In turn, the shad feed adult predators such as black bass, crappie, catfish, and others. Sometimes shad become so numerous that no amount of predators can control them. Environmental factors can also cause the plankton population to collapse which can in turn cause a decrease in the filter feeder populations. This can set in motion a cycle of decline in numbers of predator fish.

On the other hand, river food chains are more dependent on the annual cycles of flooding and the annual introductions of organic material, especially leaves, and the organisms that process them. Reservoir food chains are also influenced by seasons, but depend more heavily on the population cycles of the plankton. The stream environment is always richer and more biologically diverse than the reservoir environment that is created by damming the stream. Impounded reaches of rivers and streams decline in biodiversity compared to the free-flowing reaches because the lentic environment is more homogeneous and has fewer habitat types. River dependent species cease to breed, become rare, and eventually are lost from reservoirs.

The tailwater is the section of a river below a dam. The tailwater environment can be similar to, or very different from the natural reach of the river above the dam. This depends upon whether water leaves the dam from the bottom of the reservoir or from the top. Some hydroelectric dams draw water from deep in the reservoir to run through penstocks and turn turbines. During most of the year, water at the bottom or in the middle depths of the reservoir is much cooler than surface water. This stratification effect is common to lakes and reservoirs

in the temperate zones. Mississippi's subtropical climate causes its lakes and reservoirs to only partially stratify. Nevertheless, our reservoirs have warmer water at the surface and the coldest water at the bot-



**Figure 9.** The character of the tailwater environment depends on whether tailwater is withdrawn from upper or lower levels of reservoir at dam.

tom. Even in summer, deep parts of a reservoir are cold, hovering around 50 degrees Fahrenheit.

If cold water is withdrawn and released into the tailwaters, it changes the environment so radically that warmwater fishes are displaced. In this instance, the tailwater temperature profile is essentially changed into that of a trout stream for some distance downstream, until the river warms enough to be considered

a warmwater stream. Indeed, rainbow trout are stocked into these cold tailwaters in many Tennessee Valley Authority (TVA) lakes and deep hydroelectric reservoirs in Arkansas, Tennessee, and elsewhere in the Mid-South. The dominant fish species of a warmwater stream are bass, sunfish, catfish, various suckers, and minnows. These warmwater adapted species are unable to reproduce and sustain their populations in cold tailwaters.

When the water leaving a dam is withdrawn from the warm upper layers of a reservoir, the temperature of this released water is close to what would be considered seasonally normal for the river, and a warmwater stream environment will exist in the tailwater. Reservoir tailwaters usually support abundant fisheries since the water drawn from the upper layers of a reservoir is rich with plankton and small forage fish like shad. Also adult fish such as crappie are continually washed out of the reservoir into the tailwaters, particularly during large discharges. All Mississippi reservoirs have warmwater environments in their tailwaters.

A dam has effects on a natural river that are far reaching. In some parts of the U.S., dams are being removed from rivers when it is economically justifiable. These rivers are returning to a natural condition after a century or more. Fish that could not make spawning migrations because of dams are reinvading their former spawning sites and reproducing. Anglers are seeing these fish again after a long absence. In New England, migratory shad and sea-run trout have returned to their former habitats when dams have been removed. These homecomings are being celebrated as landmark events for the rivers, the towns, and people along them.