SECTION 4: WATER RESOURCES

Introduction

The scope of the Energy Vision 2020 water resources study covers the entire Tennessee River basins and portions of the Cumberland, lower Ohio, lower Mississippi, and Green River basins, as shown in the map in *Figure T1-63*. Fresh water abounds in this area and generally supports most beneficial uses, including fish and aquatic life, public water supply, industrial water supply, waste assimilation, agriculture, and water contact recreation such as swimming.

Water quality concerns in the region include the following:

- Point sources of pollution such as wastes from sewage treatment facilities and industrial plants
- Non-point sources of pollution such as agricultural and urban runoff
- Toxic substances found both in sediment and fish in some reservoirs
- Occurrences of low dissolved oxygen levels in tailwaters downstream of certain dams. (A tailwater is the water immediately downstream from a dam, including water released from the dam.)

Principal water quality concerns in TVA reservoirs are shown in the table in *Figure T1-64*. Principal water quality concerns in Tennessee Valley watersheds are shown in the table in *Figure T1-65*.

Water quality and aquatic habitats differ substantially according to the type of aquatic environment. Aquatic environments in the region can be characterized as follows:

- Unregulated streams and stream reaches sufficiently far downstream of dams to have returned to "stream-like" conditions
- Mainstream reservoirs (reservoirs on large rivers such as the Tennessee River)
- Tributary reservoirs and associated tailwaters.

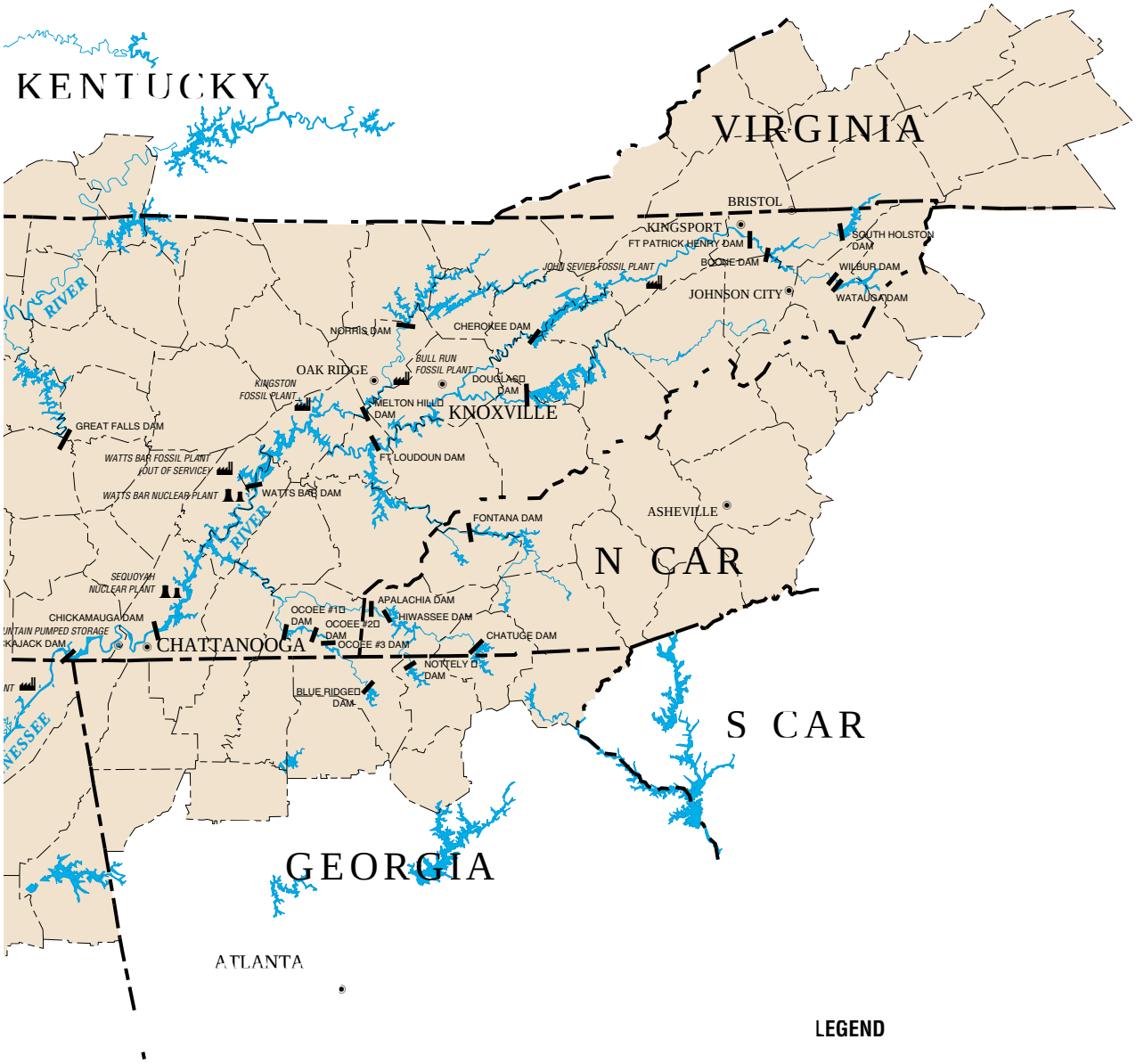
For the most part, smaller streams and some reaches of larger streams in the region are unregulated or free-flowing. Stream habitats vary from cold water mountain streams to lowland warm water creeks and small rivers. The water quality and aquatic life in these streams are affected by the characteristics of the watershed (the area draining into a stream or river), as well as human activities. Many small streams are susceptible to impacts from runoff, waste discharges, and contaminated groundwater seepage. The small streams that form in the Appalachian mountains have a low buffering capacity (ability to absorb acids and bases without altering the stream pH). This makes them particularly vulnerable to the effects of acid mine drainage and acid precipitation. Mining produces coal for many TVA power plants, and emissions from TVA coal-fired power plants contribute to acid precipitation.

Mainstream dams on the Tennessee River are operated primarily for navigation, flood control, and hydroelectric power production. They form relatively shallow, run-of-the-river reservoirs that exhibit characteristics of both lakes and rivers. The upstream portions of the reservoirs are more riverine with a gradual downstream transition to lake-like conditions. The relatively higher flow rates in these mainstream reservoirs aid in maintaining adequate dissolved oxygen levels. Thermal stratification (layering of water with different temperatures—warmer near the surface and colder near the bottom) occurs to some extent in the downstream, lake-like portions of the reservoirs but generally does not occur in the upstream portions.

Tributary reservoirs are operated for flood control, hydroelectric power production, and to a lesser extent, augmentation of downstream water supplies. They are relatively deep, lake-like reservoirs that thermally stratify during the summer and fall. Releases from the lower levels of stratified reservoirs are often low in dissolved oxygen and may have elevated concentrations of metals such as iron and manganese. Also, operation of hydro power units to meet peak power demands often results in low or intermittent downstream water flows. Therefore, the quality of the water released intermittently from the reservoirs during the summer may be characterized by low dissolved oxygen levels and elevated concentrations of some metals.

TVA, through its Lake Improvement Plan, is reaerating reservoir releases and providing minimum continuous water flows downstream of most of its tributary reservoirs. The establishment of minimum flows and aeration of releases will recover over 170 miles of aquatic habitat lost from intermittent drying of the river bed below TVA tributary dams and improve levels of dissolved oxygen in over 300 miles of river where water quality is now impaired in the late summer and fall by releases through TVA dams. Proposed summer lake levels in tributary reservoirs will also improve, as will reservoir fisheries, by increasing survival of young fish.

Figure T1-63. **Water Resources Considered in Energy Vision 2020 Include the Entire Tennessee River Basin and Portions of the Cumberland, Ohio, Mississippi, and Green River Basins**


KENTUCKY
VIRGINIA
BRISTOL
KINGSPORT
FT PATRICK HENRY DAM
SOUTH HOLSTON DAM
BOONE DAM
WILBUR DAM
JOHN SEVIER FOSSIL PLANT
JOHNSON CITY
WATAUGA DAM
RIVER
NORRIS DAM
CHEROKEE DAM
OAK RIDGE
BULL RUN FOSSIL PLANT
KINGSTON FOSSIL PLANT
DOUGLAS DAM
MELTON HILL DAM
KNOXVILLE
GREAT FALLS DAM
WATTS BAR FOSSIL PLANT (OUT OF SERVICE)
FT LOUDOUN DAM
WATTS BAR NUCLEAR PLANT
WATTS BAR DAM
ASHEVILLE
FONTANA DAM
N CAR
SEQUOYAH NUCLEAR PLANT
APALACHIA DAM
HIWASSEE DAM
OCOEE #1 DAM
OCOEE #2 DAM
OCOEE #3 DAM
CHICKAMAUGA DAM
CHATTANOOGA
CHATUGE DAM
NOTTELY DAM
BLUE RIDGE DAM
S CAR
GEORGIA
ATLANTA
LEGEND
State Boundary
County Boundary
Stream, Tributary, Lake
TVA Power Facilities: Fossil, Hydro
Nuclear, Pumped Storage
Major Cities
MAPS PREPARED BY TVA GEOGRAPHIC INFORMATION AND ENGINEERING

Tennessee River

The Tennessee River basin contains all but one of TVA's dams and covers most of the TVA region.

The Tennessee River is formed by the Holston and French Broad Rivers joining at Knoxville, Tennessee, 652 river miles from where it empties into the Ohio River near Paducah, Kentucky. The entire length of the Tennessee River is regulated by a series of nine locks and dams built mostly in the 1930s and 40s that allow navigation to Knoxville. Virtually all the major tributaries have at least one dam, creating 14 multi-purpose storage reservoirs and 7 single-purpose power reservoirs. *Figure T1-63* is a map of the basin, showing dams and reservoirs. This system of dams and their operation is the most significant factor affecting water quality and aquatic habitats in the Tennessee River and its major tributaries.

SURFACE WATER

Major water quality concerns within the Tennessee River drainage basin include point and non-point sources of pollution that degrade water quality at several locations on mainstream reservoirs and tributary rivers and reservoirs. Toxic substances have also been found in sediment and fish in reservoirs that oth-

FIGURE T1-64. **Principal Water Quality Concerns in TVA Reservoirs**

	USES AFFECTED				SOURCE	
Navigation & West Tributary Reservoirs	**Aquatic Life**	**Fish Consumption**	**Recreation**	**Water Supply**	**Point**	**Non-Point**
Kentucky			Aquatic Plants			
Normandy	Low Dissolved Oxygen			Taste, Odor, Iron, Manganese	X	
Pickwick				Algae		X
Wilson	Low Dissolved Oxygen			Taste, Odor		X
Wheeler	Low Dissolved Oxygen	DDT			X	X
Tims Ford	Low Dissolved Oxygen					X
Guntersville			Aquatic Plants			X
Nickajack		PCBs, Chlordane			X	X
Chickamauga	Low Dissolved Oxygen				X	X
Watts Bar	Low Dissolved Oxygen	PCBs			X	X
Melton Hill		PCBs				X
Ft. Loudoun		PCBs	Bacteria		X	X
Tellico	Low Dissolved Oxygen	PCBs				X
East Tributary Reservoirs						
Norris	Low Dissolved Oxygen					X
Cherokee	Low Dissolved Oxygen				X	X
Ft. Patrick Henry						
Boone	Low Dissolved Oxygen	Metals, Toxics			X	X
South Holston	Low Dissolved Oxygen					X
Wilbur						
Watauga						
Douglas	Low Dissolved Oxygen			Color	X	X
Nolichucky	Siltation		Siltation	Siltation		X
Fontana	Low Dissolved Oxygen					X
Ocoee 1-3	Metals, Siltation	PCBs	Siltation		X	X
Blue Ridge						
Appalachia						
Hiwassee	Low Dissolved Oxygen					X
Nottely	Low Dissolved Oxygen				X	X
Chatuge	Low Dissolved Oxygen					X

erwise have good water quality. Other water quality concerns include occurrences of low dissolved oxygen levels downstream of dams, which stresses aquatic life and limits the ability of the water to assimilate wastes.

The principal water quality concerns in TVA reservoirs and watersheds are summarized in *Figures T1-64* and *T1-65*. This information was derived primarily using data and analysis generated through TVA's comprehensive ecological health and use suitability monitoring program as well as other TVA aquatic monitoring and assessment activities. The criteria used in making the determinations were state water quality standards and fish consumption advisories. This summary reflects the current understanding of the causes and effects of point and non-point sources of pollution on water quality.

Point and Non-Point Sources of Pollution

Point and non-point sources of pollution include:

- Heat-release – Utility and industrial plants may release water into streams or lakes that has been heated above the temperature of the body of water.
- Wastewater – Sewage treatment systems, utilities, industry, and others dispose of waste into streams and lakes.
- Runoff from agriculture, urban uses, and mined land.
- Air pollution – Pollutant concentrations in the air can affect surface waters through rain and deposition.

Heat Releases

Power plants use water from streams or lakes for various purposes. The water returned to the streams or lakes is often heated above the temperature of the body of water. When the Clean Water Act was first considered, little was known about the effects of waste heat on freshwater ecosystems. Many possible consequences were postulated, including direct mortality, blockage, or interruption of fish spawning migrations; advanced spawning of fish or hatching of aquatic insects; increased toxicity of certain pollutants; and shift of phytoplankton populations to less desirable species. Because of the uncertainty surrounding this issue, extremely conservative thermal water quality criteria and permit limitations were established based primarily on laboratory studies of these potential effects. To provide relief to dischargers from the unnecessarily stringent limitations that would in many cases likely be imposed , the Act provided for alternative thermal limits where dischargers could demonstrate to regulators that the waste heat limits imposed were more stringent than necessary to protect indigenous aquatic communities. Many of TVA's power plants are now operating under alternative thermal limits granted as a result of such demonstrations.

TVA conducts extensive aquatic monitoring programs to ensure that thermal and other discharges do not cause adverse impacts even at permitted levels. Recently, programs have focused primarily on potential effects on spawning and development of cool-water fish species such as sauger (*Stizostedion canadense*) and walleye (*Stizostedion vitreum*), but have also included attraction of fish to thermal plumes from power plants and possible increases in undesirable aquatic microorganisms, such as blue-green algae. In general, these monitoring programs have failed to detect significant negative effects resulting from release of heated water from TVA facilities.

There are presently 2 operating nuclear plants and 11 operating coal-fired plants in the TVA power system. A third nuclear plant is scheduled to begin operating in 1996. Each of these plants withdraws process cooling water from the river upon which it is located. The heated water is then discharged back into the river at or below the temperature necessary to meet the thermal discharge limitations stated in each plant's discharge permit. Permits normally state a maximum allowable temperature after mixing of the thermal discharge with the receiving stream, as well as a maximum temperature change relative to upstream conditions and a maximum rate of temperature change.

Various measures are used by TVA to ensure compliance with thermal limits. All three nuclear plants and one fossil plant have cooling towers that

FIGURE T1-65. **Principal Water Quality Concerns in Tennessee Valley Watersheds[1]**

Aquatic Watershed	USES AFFECTED [2]			SOURCE	
	Fish Life	Consumption	Recreation	Point	Non-Point
Chickamauga-Nickajack		PCBs	Bacteria		X
Pickwick-Wilson	Toxics				X
Watts Bar-Melton Hill	Siltation	PCBs	Bacteria		X
Duck River	Siltation		Bacteria		X
Guntersville-Sequatchie	Siltation		Bacteria		X
Clinch-Powell	Siltation				X
Wheeler-Elk		DDT, PCBs	Bacteria		X
Holston	Toxics	Mercury	Bacteria	X	X
French Broad	Siltation	Dioxin	Bacteria	X	X
Little Tennessee	Siltation	PCBs		X	X
Hiwassee	Metals, Siltation			X	X

1 As designated by TVA's Clean Water Initiative
2 Uses are affected by the problem noted on at least one stream in the watershed.

may be used as appropriate to dissipate heat to the atmosphere before water is discharged. Depending on conditions and permit requirements, these plants may continually recirculate cooling water through the towers, they may pass the heated water through the towers once before discharging, or they may bypass the towers altogether and discharge the heated water directly to the river. Heated water at nuclear plants is discharged to the river through diffusers that extend well out into the river to produce rapid mixing.

Three coal-fired plants that do not have cooling towers may experience conditions during certain times of some years when they cannot operate at full power and still meet thermal limits. During those times, electricity generation is cut back to reduce the amount of waste heat released to the river. A few plants can discharge once-through cooling water without either cooling towers or operational cut backs because of their location on large water bodies that quickly assimilate waste heat discharges.

Wastewater

Discharges of pollutants from point sources, such as sewage treatment facilities and industrial plants, are regulated by the U.S. Environmental Protection Agency and the states to achieve a certain level of water quality. As a result, impacts from these sources have been greatly reduced.

Nuclear Plant Wastewater

Nuclear power plants have non-complex wastewaters that are subjected to various levels of treatment and usually discharged to surface waters. These releases are controlled through state-issued National Pollutant Discharge Elimination System permits, which are part of Federal Clean Water Act statutes. Wastewater (discharged cooling tower and steam generator recirculation water, turbine building sump, sanitary wastewater, intake screen and strainer backwash, water treatment neutralization wastes, etc.) from various plant systems is normally mixed with heated condenser cooling water before being discharged to surface water. Periodic toxicity testing is performed on this discharge as part of the National Pollutant Discharge Elimination System permit to ensure that plant effluents do not contain chemicals at deleterious levels that could affect aquatic life. In addition, storm water runoff is monitored at regular intervals as part of the National Pollutant Discharge Elimination System.

Radiological wastewater releases to surface waters are controlled by the U.S. Nuclear Regulatory Commission and plant Technical Specifications, as well as the state-issued National Pollutant Discharge Elimination System permit. A radiological monitoring program is also conducted on the body of water receiving the wastewater, fish, intake water, river sediment, and aquatic invertebrates on a routine basis.

Coal-Fired Plant Wastewater

Coal-fired plants have several liquid waste streams that are treated and released to surface waters. These releases are permitted by each state environmental agency under the National Pollutant Discharge Elimination System. Biomonitoring of wastewater is required to ensure that there are no acute toxic effects to aquatic life.

At many plants, fly ash is sluiced to an ash storage pond. The sluicing water, which is drawn from the river or reservoir serving the plant, flows continuously. Metal cleaning waste is a waste stream that may be acidic or basic. After treatment for neutralization, these wastes are also typically discharged to the ash pond for mixing with the pond water and, potentially, additional treatment. On-site treatment of domestic sewage occurs at some plants that are not connected to a local community sewage collection and treatment system. After treatment, the wastewater is typically discharged to the ash storage pond for mixing with the pond water and possible further treatment. Stormwater runoff from the plant site is also typically routed to the ash ponds, where it mixes with the ash pond water.

Rainfall and Runoff Pollutants

Non-point sources of pollution have not been subjected to government regulations or control in most cases. They contribute as much as five times more dissolved oxygen-consuming wastes than point sources. Principal causes of non-point source pollution are agriculture, including runoff from fertilizer and pesticide applications, erosion, and animal wastes; mining, including erosion and acid mine drainage; and urban runoff. Mining is necessary to extract coal and uranium used as fuel by power plants.

Air Pollution

Atmospheric deposition of air pollutants is another source of pollution affecting water quality, particularly in relation to acid rain and fallout of toxic metals, especially mercury. Section 3 in this document (Volume 2, Technical Document 1, Comprehensive Affected Environment) discusses air pollution, its effects, and TVA's contribution in some detail.

Low Dissolved Oxygen Levels

Another major water quality concern in the Tennessee River is low dissolved oxygen levels in streams below TVA dams on tributary rivers. When rivers are dammed, organic material from normal runoff, upstream pollution sources, and fallout from living organisms in the upper water levels tends to accumulate in sediments behind the dams. As this organic material decomposes, it uses up the oxygen in the overlying deep water layer. When turbines in the dam are operated to generate electricity, this low-oxygen water is released downstream, creating poor habitat for

aquatic life. TVA addressed this issue in its 1990 environmental impact statement, "Tennessee River and Reservoir System Operation and Planning Review" (TVA 1990). As a result, TVA has initiated a program to improve dissolved oxygen levels in water discharged from its dams based on this study.

To understand the causes of low dissolved oxygen levels in water released through TVA dams, it is necessary to understand the changes in temperature and dissolved oxygen content that occur in deep tributary reservoirs during a typical year. Tributary reservoirs begin to stratify (layering of the water with warmer water near the surface and cooler water near the bottom) during the spring as a result of surface heating and reduced stream flows. The dissolved oxygen content of the upper 10 to 20 feet usually remains at an acceptable level due to surface reaeration and exposure to the atmosphere and to light. Planktonic algae absorb the light and through photosynthesis produce oxygen in the water. However, oxygen levels in the lower portion decline because there is no photosynthesis in the bottom waters due to a lack of light, and they are isolated from surface reaeration. The existing oxygen is used by decaying algae and other organic matter as it settles in the water column.

Hydroelectric plants at TVA dams were designed to withdraw water from near the reservoir bottom to provide maximum flexibility for operation and maintenance of the turbines. These low level intakes maximize generating potential, and allow the hydroelectric plant turbines to operate during the winter season when reservoir levels are kept low to provide flood storage capacity, or during other times of the year under drought conditions. As a result, the water released through TVA dams in the process of hydroelectric power generation from mid-summer to early fall can contain no or low concentrations of dissolved oxygen.

In some reservoirs, discharge from the deep water layer also contributes to the release of dissolved sulfides, iron, and manganese in the tailwaters below the dams affecting water supplies and aquatic life. The presence of sulfides has been documented in the tailwaters of upper Bear Creek and Douglas Reservoirs. The presence of iron and manganese has been documented at these and other projects.

Temperatures in deep tributary reservoirs follow an annual cycle that begins with large amounts of cold, well-mixed water in storage at the beginning of spring. During the spring, surface water in the reservoir is heated, while deeper water remains at a relatively constant winter temperature. As spring and summer progress, flows enter the reservoir at an intermediate depth. Three layers form:

- The warm, stagnant surface layer
- The spring and summer interflow layer
- The cold winter layer on the bottom.

Turbine operation during the summer gradually draws off the cold water at the bottom of the reservoir. At some point in late summer or early fall, withdrawal of the colder water and gradual reduction in air temperature act in concert to again cause mixing of surface and bottom water. Completely mixed conditions last through the winter while the temperature of the reservoir is gradually lowered. The annual cycle then begins to repeat during the next spring season, when reservoirs are again filled.

GROUNDWATER

Power plants often use fuels such as coal, natural gas, and uranium. Extracting these fuels from the ground can affect the quality of groundwater. Also, ash ponds at coal-fired plants can potentially affect groundwater.

Uses

Groundwater refers to water located beneath the ground in rock formations known as aquifers. Six major aquifer areas exist in the Tennessee Valley region. One of the most important is in the Valley and Ridge Province, which is characterized by its Karst geology. Approximately half the region has limited groundwater availability because of natural geohydrological conditions. Decreasing water table levels indicate that too much water is being pumped from aquifers in the central and western portions of the region.

More than 64 percent of the region's residents rely totally, or in part, on groundwater for potable drinking water. For every public surface water supply system, three public groundwater systems exist; but, in general, the groundwater systems serve fewer people. Over 1.7 million residents (22 percent) in the region maintain individual household groundwater systems, usually a well. All the areas in the Tennessee Valley region can generally supply enough water for at least domestic needs. Groundwater is also used by nearly 3,700 community water systems, businesses, industries, hospitals, churches, campgrounds, and schools.

Supply and Quality

Precipitation is the source of both surface water and groundwater. In an average year, precipitation across the Tennessee Valley region ranges from 40 to 85 inches, with an average of 52 inches. Water entering the groundwater system is stored in the pore spaces in unconsolidated sediments, or in fractures and solution openings in the bedrock. All groundwater in storage moves toward areas where it is discharged, such as springs, streams, and wells. Consequently, the base flow of streams is related to the amount of groundwater available. Stream baseflow is that portion of the stream flow that is sustained by groundwater, rather than rain-

fall runoff. During the dry season, when rainfall is lowest, stream flow is sustained primarily by groundwater discharging into the stream. Groundwater in relatively shallow carbonate aquifers is discharged rapidly during dry periods, causing a decline in water table levels in unconfined aquifers and thus reduced stream flow. Groundwater discharge in a normal year approximately equals the annual baseflow of streams (over half the annual rainfall runoff into streams).

For the most part, groundwater quality is sufficient to support existing water supply uses, though some minimal treatment, such as filtration and chlorination, may be required. However, no agency maintains a network of observation wells to detect groundwater contamination from routine human activities. There have been some instances of groundwater contamination in the region from improper waste disposal, coal mining activities, oil and gas exploration, agricultural activities, septic tanks, industries, coal-fired plant ash ponds, and general urbanization activities. Contamination has required closure of well and spring supplies in some areas. Toxic compounds have been found in the groundwater at some locations. The degree and extent of contamination vary from case to case.

Groundwater is naturally mineralized and exhibits variable characteristics. In some local areas, it can possibly affect health. Fluoride, for example, can exceed Interim Primary Drinking Water Standards in parts of the Highland Rim physiographic province, and hydrogen sulfide can give a "rotten egg" odor to water in other areas.

Some parameters can vary by a factor of 10 to 100 in concentration among the physiographic provinces (e.g., the sulfate concentrations in groundwater of the Blue Ridge province generally are less than 20 milligrams per liter, but in the coastal plain province, concentrations can exceed 1,400 milligrams per liter). See Section 5 in this document (Volume 2, Technical Document 1, Comprehensive Affected Environment) for a description and illustration of the physical geographic (physiographic) provinces in the TVA region.

The quality can change dramatically at a single location depending on the depth of the well, the aquifer used, and how the well is constructed. If several aquifers exist in an area, the water quality depends upon the depth of the well and which aquifer is tapped. Shallow aquifers generally have better quality than deeper aquifers because they are low in dissolved solids, soft, and only slightly acidic. Extremely deep water is generally so high in dissolved solids (brine) that it is considered unsuitable for most uses. Water that comes in contact with sandstone or shale containing pyrite can have high iron or sulfur content. Acidic water (such as rainfall) reacts with limestone and dolomite rocks to release bicarbonates, calcium, and magnesium, which tend to make the water hard and alkaline.

Bacteriological contamination of groundwater can occur in carbonate rock areas where contaminated surface drainage enters the ground through sinkholes or disappearing streams. Springs located in carbonate rock areas are particularly susceptible to contamination during storm periods, but wells can also be affected. Natural groundwater quality is generally believed good.

AQUATIC LIFE

The construction of the TVA dam and reservoir system fundamentally changed the character of the Tennessee River and its tributaries. While dams promote navigation, flood control, power benefits, and reservoir-based recreation by moderating the flow effects of floods and droughts throughout the year, they also disrupt the daily, seasonal, and annual patterns that are characteristic of a river (TVA 1990). Characteristics include water, sediments, nutrients, and organic material that affect the health, number, and diversity of aquatic life. Aquatic life can also be affected by runoff and erosion due to construction of power plants and runoff and acid drainage from mines to extract fuel to use in power plants.

In broad terms, aquatic life in the Tennessee River basin can be considered to exist in the three habitat types previously described, i.e., flowing streams, tributary reservoirs and tailwaters, and mainstream reservoirs. The following descriptions of these three types of environments are to a large extent general and apply to all river basins and reaches included in this study.

Flowing Streams

Small first- and second-order streams in the Tennessee Valley typically provide unstable habitat conditions. These support only those relatively few species able to survive and reproduce under such conditions. The small streams that rise in the Appalachian Mountains and the Cumberland plateau commonly have steep gradients, large rock substrates (stream beds), and cold temperatures. The aquatic community contains relatively few fish and insect species, and other types of aquatic life are rare. Rainbow, brown, and native brook trout (*Salvelinus fontinalis*) occur in these streams. These small streams rising in the Blue Ridge province of the southern Appalachian Mountains contain little carbonate alkalinity. Therefore, they have little capacity to resist pH change from acidic precipitation or other acidic inputs. Data exists to indicate decreased alkalinity through time in many of these streams. However, the actual effect of these acidification processes on the ecological quality of surface waters in the Southeast is virtually unknown. Other types of lower gradient small stream habitats seldom support aquatic life of direct use to people.

A virtual explosion in the diversity of aquatic life accompanies the perennial flow and diversity of habitats in larger creeks and small rivers. These streams flow within well-established chan-

nels with a flood plain that becomes part of the watercourse during high flows. A variety of fish, insects, crustaceans, mollusks, and other aquatic groups colonize each habitat. Over time, complex communities have evolved, including resident species and those which migrate from one habitat to another during the year or over the course of their development. Stream habitats support large sunfish (*Lepomis* spp.) and bass populations sought by sports fishermen all year, as well as other species, such as white bass (*Morone chrysops*), sauger (*Stizostedion canadense*), and suckers (*Catostomus* spp.) that are harvested during seasonal spawning migrations.

A few of the larger tributary rivers in the Tennessee Valley remain unimpounded (undammed), including the Emory, Sequatchie, North Fork Holston, and Buffalo Rivers. Also, extensive stream reaches exist above reservoirs on the Clinch, Powell, and French Broad Rivers, and there are long stretches of flowing streams below headwater reservoirs on both the Duck and Elk Rivers. These large free-flowing rivers, like their smaller tributaries, support extremely diverse aquatic communities.

Tributary Reservoirs and Tailwaters

Reservoirs on tributary rivers of the Tennessee River are typically deep storage reservoirs that retain waters for long periods of time. Little flow and regular periods of thermal stratification result in oxygen depletion in the deeper water. These aquatic habitats are simplified relative to undammed streams, and fewer species are found. However, some species relatively rare in streams (e.g., largemouth bass [*Micropterus salmoides*], gizzard shad [*Dorosoma cepedianum*]) develop large populations in these reservoirs. Other non-native fish species, such as striped bass (*Morone saxatilis*), have been introduced into some reservoirs to fill unexploited niches, producing popular sport fisheries.

Even though TVA attempts to enhance fish spawning by providing stable pool levels for a two-week period during the peak of the spring spawning season, certain aspects of reservoir operations are detrimental to fish populations in tributary reservoirs. The most productive region of a reservoir is the shoreline because of submerged vegetation for cover and organic material and aquatic invertebrates (benthos) for food. Operations that alter this reservoir margin have a variety of negative effects. Water level drawdowns for hydroelectric power production destroy cover and reduce the food supply for young-of-year fish. Drastic changes in levels due to flood control can discourage spawning, strand fish eggs on the shoreline, and leave fish in isolated pools.

Lack of minimum flows in the first few miles below tributary dams may severely limit the habitat needed by native fish. It may restrict their movement, migration, reproduction, and available food supply. On days when turbine use is intermittent, daily temperature variations of 5 to 9 degrees C (41 to 48 degrees F) are common in tributary tailwaters and can stress some fish species. Dissolved oxygen levels of less than 5 or 6 milligrams per liter affect fish growth, and levels of less than 3 or 4 milligrams per liter lead to decreased survival and poor reproduction. TVA has recently implemented a plan to improve dam tailwater conditions by maintaining minimum continuous flows and aerating releases below 16 dams to increase dissolved oxygen. TVA will also delay unrestricted summer drawdown until the first of August on 10 tributary reservoirs to improve recreation and associated economic development.

For the most part, TVA tributary reservoir releases support healthy stocked cold-water fisheries, primarily rainbow and brown trout (*Salmo trutta*). The ability of tailwaters below dams to support these fisheries is one of the positive effects of TVA reservoir system construction. The Chatuge Reservoir tailwater supports a self-sustaining wild trout population. A few tailwaters, such as those below Douglas and Cherokee reservoirs, support cool- and warm-water fisheries.

Benthic invertebrates (benthos), are a vital part of the food chain of aquatic ecosystems. Benthos refers to the wide variety of animals that live on or in the first few inches of the mud, sand, gravel, or other material that makes up the bottom of streams and lakes. Benthic life includes worms, snails, and crayfish, which spend all of their lives in or on the substrate, and aquatic insects, mussels and clams, which live there during all or part of their life cycle. They transform nutrients and organic material into biomass and provide a food base for fish and other vertebrate predators.

Most benthic organisms have specific habitat requirements in terms of physical, chemical, and biological factors. Alterations of these factors cause changes in both the composition and productivity of the benthic community. Many benthic organisms have narrow habitat requirements that are not always met in reservoirs or tailwaters. Benthic organisms generally are extremely limited in the deep portions of tributary reservoirs because of the low water flow and low dissolved oxygen. Shoreline habitat is limited because of water level fluctuations. In the tailwater areas below tributary dams, only those species survive that can tolerate low dissolved oxygen, high turbulence, and cold temperatures. Further downstream, the number of benthic species increases as natural reaeration occurs, dissolved oxygen rises, and temperatures climb.

Because most tributary reservoirs are deep and have long hydraulic retention times, they tend to follow the pattern described above. They have thermal stratification persisting during the warm months and one period of complete mixing that lasts throughout the colder months. During stratification, light and nutrients in the mixed layer combine to produce phyto-

plankton, microscopic plant life, which in turn supports a growing zooplankton microscopic animal life community. The productivity of this layer is usually limited by nutrient inflows from the watershed and varies from reservoir to reservoir.

During the period of complete mixing, nutrients and organic materials that have accumulated in the deeper water and sediments are recycled to the surface, where they promote the growth of phytoplankton. Because most of the inflowing nutrients and organics are retained in the reservoir, less are released downstream, so the tailwaters tend to be less productive than the river before it was dammed.

Mainstream Reservoirs

The nine mainstream reservoirs on the Tennessee River differ from tributary reservoirs primarily in that they are more shallow, have greater flows, and thus have much lower hydraulic retention times. They generally do not become as strongly stratified as tributary reservoirs. Although dissolved oxygen in the deeper regions of the reservoir is often reduced, it is seldom depleted. Winter drawdowns on mainstream reservoirs are much less severe than on tributary reservoirs, so bottom habitats generally remain wet all year. This benefits benthic organisms and promotes the growth of aquatic plants in the extensive shallow overbank areas of some reservoirs. These plants benefit fisheries by providing cover and nursery habitat, but create extensive mosquito breeding areas and have led to conflicts among fishermen, boaters, and shoreline landowners whose access to the water is limited by thick vegetation.

The lack of stratification in mainstream reservoirs creates a habitat where plankton are constantly cycled into and out of the zone with sufficient sunlight for growth. This creates some of the same inhibitions on growth that limit plankton production in large undammed rivers. Ordinarily, however, these factors are sufficiently muted to permit sufficient plankton growth to support healthy aquatic communities. Phytoplankton growth in Tennessee River mainstream reservoirs is more likely to be limited by light than by nutrient availability.

Since oxygen depletion near the bottom is rare, benthic communities occur in the mainstream reservoirs. However, species diversity is low in comparison to the rivers before reservoirs were formed. Benthic communities in mainstream reservoirs tend to be dominated by midge larvae, aquatic worms, mayflies, mussels, and sometimes caddisflies and snails.

The effect of dams on benthic species diversity is most readily apparent in mussels. Because of their long lives, sedentary nature, and tendency to occur clumped in areas of suitable habitat, mussels are highly vulnerable to disruptions of habitat or changes in environmental factors. Prior to the formation of reservoirs, the Tennessee River and its tributaries supported a large and diverse mussel fauna. Damming the rivers reduced the amount of suitable habitat (shallow, flowing water over stable gravel or cobble bottom). Today, there are only about 175 miles of suitable mussel habitat in the Tennessee River. This represents 27 percent of what once existed. Nearly all of this is located in Guntersville, Wheeler, Pickwick, and Kentucky reservoirs, where commercial musseling is still carried on. Pollution, sedimentation, and commercial overharvesting have adversely affected mussel stocks that survived the destruction of habitat due to dams. Recent investigations indicate that mussel stocks in the main river and most tributaries are continuing to decline. Mussel species dominate the list of threatened and endangered species in the Tennessee Valley.

The Asiatic clam *(Corbicula fluminea)* was introduced into the Tennessee river from the West Coast during the 1950s. It is now a major component of the benthic community throughout the Tennessee system and has been implicated as a fouling agent in water intake structures.

A more recent and potentially more troublesome invader is the zebra mussel *(Dreissena polymorpha)*, which recently reached the Tennessee River via barge traffic from the Great Lakes area, where it was introduced from Eurasia in the mid-1980s. Zebra mussels are now present in low numbers throughout the length of the river and are likely to increase in numbers during the next few years. Because of their tendency to attach in large numbers to firm substrates, zebra mussels have enormous potential for biofouling (clogging) power plant water intakes and other systems that use raw water. It is estimated that zebra mussels will cost water users in excess of $5 billion in the Great Lakes area alone by the year 2000. Zebra mussels will be a major factor in future decisions regarding the type and location of any new water-using facilities in the TVA region.

Tennessee River mainstream reservoirs generally support healthy fish communities, ranging from about 50 to 90 species per reservoir. There are good to excellent sport fisheries, primarily for black basses (*Micropterus* spp.), crappie (*Pomoxis* spp.), sauger (*Stizostedion canadense*), white (*Morone obrysops*) and striped basses (*Morone saxatilis*), sunfish (*Lepomi*s spp.), and catfish (*Ictalurus* spp.). The primary commercial species are channel (*Ictalurus punctatus*) and blue catfish (*Ictalurus furcatus*) and buffalo (*Ictiobus* spp.). Fish consumption advisories have been issued for some reservoirs, notably Wheeler for DDT contamination and Nickajack, Watts Bar, and Fort Loudoun for PCB contamination.

Cumberland River

The Cumberland River is formed by the junction of the Poor and Clover Forks in Harlan County, Kentucky, about 693 miles above its confluence with the Ohio River near Smithland, Kentucky *(Figure T1-63)*. The river flows westerly, then southwesterly into Tennessee. At Nashville it turns northwesterly back into Kentucky, emptying into the Ohio River about 58.5 miles upstream of the junction of the Ohio and Mississippi rivers. The drainage area of the Cumberland is 17,598 square miles. A system of locks and dams makes the Cumberland commercially navigable (maintained 9 foot channel) from the Ohio to mile 381.0 at Celina, Tennessee. TVA operates two fossil plants on the Cumberland, Gallatin on Old Hickory Lake and Cumberland on Barkley Lake. The hydroelectric plant at Great Falls Dam on the Caney Fork is also part of the TVA system.

The Nashville District United States Army Corps of Engineers operates nine multi-purpose reservoirs which incorporate hydroelectric production facilities on the Cumberland River and tributaries. Approximately half the power production from eight of these projects is marketed through the Southeastern Power Administration to TVA. The Corps of Engineers does not anticipate any significant changes in these power resources. The Corps of Engineers has, however, completed a hydropower optimization feasibility study at Lake Cumberland which focused on uprating the existing six units at Wolf Creek Powerhouse for peaking operation. On the middle Cumberland River reservoir regulation integrates the need for adequate cooling water at TVA's Gallatin and Cumberland City Fossil Plants on Old Hickory Lake and Lake Barkely, respectively. In addition, the Corps of Engineers has performed a preliminary analysis of pumpback at Laurel Lake on the Upper Cumberland River.

SURFACE WATER

The Cumberland River and its tributaries generally exhibit moderate to high concentrations of calcium and magnesium and a slightly alkaline pH because much of the basin is comprised of limestone and dolomitic bedrock. Total dissolved solids concentrations, a measure of all salts in solution, range from 1.0 to 100 milligrams per liter (mg/L) in the upper Cumberland, upstream of Nashville. These low values contrast with the generally higher concentrations of dissolved solids in the lower Cumberland watershed, in particular the mainstream river downstream of Nashville (U.S. Army Corps of Engineers 1975). There total dissolved solids concentrations range from 100 to 300 milligrams per liter. These increased concentrations are due in part to a change in rock formation in the Nashville area. The area east of Nashville is underlain by Ordovician Age limestones and shales, which is more resistant and less soluble than the Mississippian Age limestones, found in the area west of Nashville. The first is more resistant and less soluble than the latter.

Generally, the mainstream Cumberland River exhibits lower suspended solids concentrations than its tributaries. Suspended solids in the mainstream and in the upper Cumberland watershed tributaries usually range in concentrations from 0 to 300 milligrams per liter. The lower Cumberland watershed tributaries, west of Nashville, are characterized by higher suspended solids concentrations ranging from 300 to 2,000 milligrams per liter. The higher values in the lower Cumberland watershed tributaries are caused in part by differences in soils and rock formation. The Mississippian materials of the lower watershed are generally more erosion prone than the Ordovician materials of the upper watershed. Topography and land usage also influence the erodibility of the lower Cumberland tributary valleys.

Erosion due to runoff in the lower Cumberland watershed is the primary source of the suspended solids described above. Shoreline and stream-bank erosion are also thought to be major contributors of silts and clays. The generally lower suspended solids levels in the mainstream river result from dredging for the navigation channel of the river. This has created areas of reduced velocity and formed deposits of sediment. Sediment deposition also occurs in the upper Cumberland flood control reservoirs, upstream of the study area. Wolf Creek Dam, Dale Hollow Dam, Center Hill Dam, and J. Percy Priest Dam trap large amounts of suspended solids and sediments, and discharge waters with relatively low suspended solids levels into areas downstream.

GROUNDWATER

The formations that comprise the Mississippian carbonate aquifer in the Highland Rim and the Ordovician carbonate aquifer in the Central Basin of the Cumberland River basin are primarily limestone and dolomite, with small amounts of shale. Water in these carbonate aquifers occurs in solution-enlarged openings and resides in confined-to-partly-confined space near the land surface. It can also be confined at depth in aquifers. These aquifers are important sources of drinking water for rural users and some public supplies.

The Mississippian carbonate and Ordovician carbonate aquifers are connected to land surface by caves and sinkholes in many areas and are susceptible to contamination. In general, the water hardness exceeds 200 milligrams per liter as calcium carbonate. In the Highland Rim, iron and sulfate concentrations in water from the Mississippian carbonate aquifer may exceed 0.30 and 500 milligrams per liter, respectively. The odor of sulfide is detectable in water from some wells.

AQUATIC LIFE

The Cumberland River is in most important ways similar to the Tennessee River in both its natural characteristics and the ways in which it has been developed and altered. Aquatic habitats and aquatic life characteristics are also similar, and the previous general discussion of flowing streams and the effects of reservoirs on aquatic communities in the Tennessee River basin is also applicable to the Cumberland River system. In the mainstream Cumberland River area, studies of aquatic life have been generally geared to sport fisheries, stocking programs, and species of commercial importance. Fish studies are more complete than evaluations of aquatic habitats or invertebrate species. Compositional and community studies on the Cumberland River are qualitative at best.

Early studies of the wild river indicated a much varied habitat depending on the area through which the river passed. Mountainous areas in the upper basin were characterized by waterfalls, riffles, and limestone banks. The river was generally shallow except during high flow seasons. As the Cumberland passed through the flatter terrain of the mid and lower watershed region, waterfalls became less impressive in size, but riffle and ravine character continued. Wetlands and broad floodplains generally characterized the Cumberland from Nashville downstream to the mouth.

The formation of reservoirs caused numerous changes in the aquatic life of the Cumberland River. These changes, however, are not well documented in the scientific literature. Community, distribution, and inventory studies after the formation of reservoirs are lacking for the remaining free-flowing portions of the river. Site-specific aquatic biological surveys have been done by TVA at Cumberland and Gallatin fossil-fuel plants and at the site of the canceled Hartsville Nuclear Plant.

The tributary reservoirs of the Cumberland River basin are similar to the tributary reservoirs described for the Tennessee River. Laurel River Lake, Lake Cumberland (Wolf Creek Dam), Dale Hollow Lake, and Center Hill Lake are deep, steep-sided reservoirs with substantial winter drawdowns. J. Percy Priest Lake is somewhat shallower with more sloping shorelines.

Laurel River Lake supports a good trout and walleye (*Stizostedion vitreum*) fishery. Lake Cumberland has a good fishery for black bass (*Micropterus* spp.), striped bass (*Morone saxatilis*), and walleye (*Stizostedion vitreum*). Center Hill lake also supports a good black bass (*Micropterus* spp.) and striped bass (*Morone saxatilis*) fishery. Dale Hollow is world-famous for its smallmouth bass (*Micropterus dolomiou*) fishery. It also maintains a good lake trout (*Salvelinus namaycush*) fishery. J. Percy Priest Lake continues to provide a good fishery for black bass (*Micropterus* spp.), striped bass (*Morone saxatilis*), crappie (*Pomoxis* spp.), and bluegill (*Lepomis macrochirus*) despite very heavy fishing pressure.

The cold tailwaters of Laurel River Lake, Lake Cumberland, Dale Hollow Lake, and Center Hill Lake provide good to excellent rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) fisheries. Striped bass (*Morone saxatilis*) are stocked below J. Percy Priest Dam, providing one of the best-noted and most-fished resources in the region, especially when discharge rates are high.

The Cumberland River mainstream reservoirs are similar to their counterparts on the Tennessee River. Cordell Hull Lake is relatively deep and subject to cold-water inflows that contribute to a spotty sport fishery. The upstream portion of the lake maintains an excellent but not well-known and consequently underutilized trout (*Salvelinus namaycush*) and walleye (*Stizostedion vitreum*) fishery, as well as a good striped bass (*Morone saxatilis*) fishery. The downstream portion of the lake is intermediate in terms of temperature, and thus not ideal for either warm-water or cold-water fish species, although a fair largemouth bass (*Micropterus salmoides*) fishery exists in the embayment areas. Old Hickory and Cheatham Lakes have good fisheries for black bass (*Micropterus* spp.), crappie (*Pomoxis* spp.), and bluegill (*Lepomis macrochirus*). Lake Barkley is similar to Kentucky Lake on the Tennessee River, and the two are connected by a short canal near the two dams. Both lakes are nationally famous for their black bass (*Micropterus* spp.) and crappie (*Pomoxis* spp.) fisheries. Barkley also supports good populations of white bass (*Morone chrysops*), bluegill (*Lepomis macrochirus*), and blue (*Ictalurus furcatus*) and channel (*Ictalurus punctatus*) catfish.

Ohio River

The lower Ohio River receives drainage from an extensive 204,000 square-mile watershed that reaches into 13 states, encompassing much of the east central United States. The upper Ohio Valley is highly industrialized, and the sources of pollution from industrial and municipal sources are many and varied. Non-point source pollution, primarily from agricultural runoff and mining, also contributes to the sediment and pollution load. A series of locks and dams allows commercial navigation along the entire 981-mile length of the river from the Mississippi River to Pittsburgh, Pennsylvania. About 136 million metric tons of freight are transported on the Ohio annually. TVA's Shawnee Fossil Plant is located on the Ohio River just downstream from Paducah, Kentucky.

SURFACE WATER

The Ohio River supplies more than one-half of all surface water withdrawn in the state. It forms the northern boundary of Kentucky for a distance of 664 stream miles. The river system drains an area of 33,300 square miles in Kentucky (about 82 percent of the state). Identifying sources of contamination in such a large basin is difficult. The Ohio River Valley Water Sanitation Commission is responsible for evaluating water quality in the mainstream.

GROUNDWATER

The alluvial aquifer, an aquifer which exists in material deposited by flowing water, along the Ohio River is by far the most intensively used aquifer in Kentucky. Many towns and industries located along the river depend upon large surface supplies from the river and on groundwater supplies from shallow wells in the alluvium. Properly constructed wells near the river can induce infiltration of stream flow, which ensures dependable supplies. The quality of water in the alluvium generally is suitable for most uses but may require treatment for excessive hardness and iron for some uses. Hardness commonly exceeds 300 milligrams per liter as calcium carbonate, and iron commonly exceeds 1 milligram per liter. Contamination of the aquifer by wastes from industrial sites and from landfills and septic tank systems in urban areas poses the most serious water quality-related problem. High groundwater levels are a potential problem in the Louisville area, where water levels are just a few feet below structures in some places.

AQUATIC LIFE

The lower Ohio River is a large river habitat, often turbid or cloudy, with swift currents. Bottom substrates or stream beds are often rocky near shore, with cobble, gravel, and sand in the channel. The benthic community includes a substantial mussel population in certain areas, which is threatened by zebra mussels. Zebra mussels are now found in large numbers throughout the lower Ohio River. A very high percentage of native mussels from Smithland Dam to the Mississippi River have been found to have zebra mussels attached to their shells. Large numbers of attached zebra mussels interfere with the feeding and movement of native mussels. In other areas, they have resulted in the virtual elimination of native mussel populations.

New dams on the lower Ohio (i.e., Newburgh, Uniontown, and Smithland) have created reservoirs on that section of the river. These reservoirs have in turn created additional flooded brush and timber habitat, as well as small embayments in the lower portions of tributary streams. The fishery for black bass (*Micropterus* spp), crappie (*Pomoxis* spp.), and bluegill (*Lepomis macrochirus*) has been greatly enhanced by this additional habitat. The tailwaters of these dams provide outstanding fisheries for striped bass (*Morone saxatilis*) and sauger (*Stizostedion canadense*).

Fish consumption advisories have been placed on paddlefish (*Polyodon spathula*), paddlefish eggs (harvested for caviar), channel catfish (*Ictalurus punctatus*), carp (*Cyprinus carpio*), and white bass (*Morone obrysops*) along the entire length of the Ohio River bordering Kentucky because of chlordane, a pesticide, and PCB contamination. Little Raven Creek, a tributary below Paducah, has a consumption advisory for all fish species due to PCB contamination. Also, the West Kentucky Wildlife Management Area Lakes, which are oxbow and overflow lakes that drain into the Ohio River below Paducah, have a consumption advisory for largemouth bass (*Micropterus salmoides*) because of mercury contamination.

Green River

The Green River Basin is located in south central Kentucky and north central Tennessee. The drainage area is 9,273 square miles, of which 377 are in Tennessee. The Green River rises in Lincoln and Casey Counties in Kentucky and flows generally westward for 330 miles to its confluence with the Ohio River just upstream from Henderson, Kentucky. A system of seven locks and dams enables navigation on the downstream portion of the Green River.

The upper basin is characterized by rugged, hilly terrain. The central part of the basin drains the Karst region, an area that is interlaced with large cave systems. The Karst region includes Mammoth Cave National Park. In the Karst region, surface streams are almost non-existent. Most of the water drainage is subterranean, eventually draining to the Green River via large springs. The lower basin consists primarily of alluvial plains. TVA's Paradise Fossil Plant is located on the Green River about 100 miles from the mouth.

SURFACE WATER

The Green River basin contains about one-fourth of Kentucky's land area and is the largest drainage basin in the state. Reservoirs have been constructed by the U.S. Army Corps of Engineers on the Rough, Nolin, and Barren Rivers, as well as on the mainstream of the Green River in the upper basin. The topography in this section of the Interior Low Plateaus is characterized by gently rolling terrain underlain by limestone in the upper basin and hills and broad flood plains underlain by sandstone, shale, and coal in the lower basin. Land uses in the upper basin include agriculture, urban areas, and mining or drilling. Major sources of stream contamination in the upper basin are agriculture

(sediment, nutrients, and pesticides); mining or drilling (chloride); on-site and municipal wastewater-treatment systems (decomposable organic matter, nutrients, and bacteria); and urban stormwater runoff (toxic metals, nutrients, and sediment).

Concentrations of chloride in the upper basin of the Green River are higher than those recorded at other locations in the basin and have been associated with brines from oil production. However, dissolved solids concentrations in the upper basin were not high relative to those in other Kentucky streams. Concentrations of sulfate, another major component of dissolved solids were low in samples collected during 1987-89. The relatively high median concentrations of nitrite (0.87 milligrams per liter) and suspended sediment (27 milligrams per liter) were among the highest for Kentucky's monitoring locations. The high values possibly were due to agricultural and urban runoff and municipal wastewater discharges.

GROUNDWATER

The Pennsylvanian aquifer system in the Green River basin is in the coal mining regions of eastern and west central Kentucky. Wells tapping these aquifers are used for domestic and livestock supplies.

Concentrations of dissolved solids in water from the shallow groundwater circulation zone of the Pennsylvanian aquifer system in eastern Kentucky generally do not exceed the drinking water standard. The water is moderately hard, with only about 25 percent of the hardness values being larger than 120 milligrams per liter. The water generally contains iron in excess of the secondary drinking water standard. Concentrations of chloride generally are smaller than 110 milligrams per liter, and 90 percent of the nitrate concentrations are smaller than 1.2 milligrams per liter.

Water from the Pennsylvanian aquifer system in west central Kentucky generally contains dissolved solids concentrations larger than 500 milligrams per liter. Water from these aquifers is hard to very hard—the median hardness is 120 milligrams per liter. Concentrations of iron generally are larger than 300 micrograms per liter, and chloride concentrations normally are smaller than 60 milligrams per liter. Concentrations of nitrate are larger in the western Kentucky Pennsylvanian aquifers than in the eastern Kentucky Pennsylvanian aquifers. In the western Kentucky aquifers, 25 percent of the nitrate concentrations are larger than 1.2 milligrams per liter, compared to 10 percent for the eastern Kentucky Pennsylvanian aquifers.

The coal mining regions of eastern and western Kentucky are being mined and extensively explored for oil and gas reserves. Water samples from deep oil-test wells commonly are salty.

AQUATIC LIFE

The four reservoirs in the Green River basin are headwater reservoirs. They generally possess the same characteristics in terms of depth, stratification, water level fluctuations, and impacts on aquatic communities as the tributary reservoirs described in the Tennessee River basin. In addition to these reservoirs, there are also six navigation locks and dams on the Green River and one on the Barren River. These are virtually run-of-the-river dams and appear to stabilize the river substrate or stream beds and protect aquatic life.

Green River contains a varied habitat which supports 146 fish species representing 22 taxonomic families. Additionally, Green River contains a diverse benthic community including a number of mussel species. Some of the upper basin tributary streams and reservoir tailwaters support good sport fisheries for rainbow (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). Additionally, a good muskellunge (*Esax masquinongy*) fishery exists in the central and upper basins in both reservoirs and major streams. The reservoirs and the larger streams in the lower basin provide good warm-water fisheries for largemouth bass (*Micropterus salmoides*), white crappie (*Pomoxis* spp.), blue (*Ictalurus furcatus*) and channel catfish (*Ictalurus punctatus*), and bluegill (*Lepomis macrochirus*).

The major source of pollution in the Green River Basin is mining in the western coal-fields region of the lower basin. The river is very turbid or cloudy due to runoff from these coal fields and extensive barge traffic. Other sources of pollution in the basin include municipal wastewater-treatment plants and agricultural runoff. Two streams in the basin currently have fish consumption advisories in place for PCB contamination: Drakes Creek from the city of Franklin to the Barren River, and Mud River from the city of Russellville to the Green River.

Mississippi River

The lower Mississippi River in the reach that borders west Tennessee is one of the largest rivers in the world. Its drainage basin includes nearly all of the United States between the Rocky Mountains and the Appalachian Mountains. The drainage basin is 1,247,000 square miles and includes the nation's most productive industrial and agricultural regions. Ships can travel the river for more than 1,800 miles from Minneapolis, Minnesota, to the Gulf of Mexico. TVA operates the Allen Fossil Plant on the Mississippi River at Memphis, Tennessee.

SURFACE WATER

The Mississippi River has an average daily discharge of 312,000 million gallons per day at Memphis, Tennessee, and 377,000 million gallons per day at Vicksburg, Mississippi. In general, the quality of water in the Mississippi is suitable for most uses. The median concentrations of alkalinity (106 milligrams per liter), sulfate (55 milligrams per liter), dissolved solids (239 milligrams per liter), and nitrite plus nitrate (1.2 milligrams per liter) were much less than the federal criteria for untreated drinking water supplies. About half of the sulfate in the Mississippi River is due to runoff over weathered rock, and the other half is due to biochemical processes and human activities.

GROUNDWATER

The most extensive and productive aquifer in Tennessee is the Tertiary sand, along the Mississippi River, which supplies about 190 million gallons of water per day to the city of Memphis. Calcium bicarbonate-type water from this confined aquifer has small concentrations of dissolved solids (90 percent of analyses are less than 163 milligrams per liter), and is generally soft (median hardness is 39 milligrams per liter). The only major water quality problem is a large iron concentration, which requires that the water be treated before use. The median iron concentration is 600 micrograms per liter.

There is concern, however, that leakage of contaminated water from the overlying alluvial aquifer may degrade water quality in the Tertiary sand. In addition, several hazardous waste sites are located in recharge areas of this important aquifer.

The chemical characteristics of water in the shallow (less than 200 feet below land surface) Mississippi River alluvial aquifer are fairly uniform throughout the aquifer. A chemical quality change occurs gradually, with depth as the result of ion exchange and other natural geochemical processes. Dissolved solids concentrations and pH values of water at depths of about 100 feet or less in recharge areas may be much smaller than 100 milligrams per liter and 7 standard units, respectively.

AQUATIC LIFE

The lower Mississippi River is turbid and swift, with shifting sand and silt substrates or stream beds that are not conducive to colonization by benthic organisms. Commercial fishing occurs on the Mississippi, primarily for catfish (*Ictalurus* spp.) and buffalo (*Ictiobus* spp.). Zebra mussels now occur throughout the Mississippi River. A significant sport fishery for largemouth bass (*Micropterus salmoides*), crappie (*Pomoxis* spp.), and bluegill (*Lepomis macrochirus*) exists in the numerous cutoffs, oxbows and backwater sloughs found in this section of the river. A fish consumption advisory for chlordane contamination is in effect for all fish species in the Mississippi River adjacent to Shelby County, Tennessee (Memphis), and McKellar Lake, Wolf River, Loosahatchie River and Nonconnah Creek, which are tributaries to the Mississippi River in Shelby County.

Water Quality Indices and Rationale for Weightings

TVA's existing energy resources and many of the energy resource options considered for Energy Vision 2020 can affect water quality. The primary impact categories evaluated for Energy Vision 2020 include: human health by ingestion, water supply and waste assimilation, and fish and aquatic life and biodiversity. A full explanation of the process used to develop measures for environmental evaluation criteria can be found in Volume 2, Technical Document 4, Evaluation Criteria.

Water Quality Indices

Water quality indices were developed to help characterize how TVA power system operations might contribute to each of the impact areas selected. The indices provide measures to evaluate environmental impacts of alternative future energy supply strategies. Measures in the indices are weighted by the relative contribution of TVA power system operations to water quality impacts and issues.

Eight measures of power system operation that affect water quality are used to evaluate the three impact areas. There are two direct measures: water consumption and water use. Six surrogate measures were used: coal burned; heat releases to surface water; power production by coal-fired, nuclear, and hydroelectric plants; and the number of new power plants constructed. A surrogate measure is a substitute measure that varies in the same way as the pollutant it represents. The uses of these eight measures in the index and their weighting factors are given in the table in *Figure T1-66*.

HUMAN HEALTH–INGESTION

The discharge of toxic metals in waste streams from coal-fired power plant sites presents the greatest potential risk to health from ingestion (eating or drinking) and is estimated at 50 percent of TVA's effects. These discharges are made directly to water bodies that supply drinking water for humans and livestock and serve as habitats for aquatic organisms. As a result, toxic metals can become concentrated in fish tissue.

FIGURE T1-66. **Weighting Factors for Water Quality Evaluation Measures Used in Three Impact Area Indices**

Environmental Measure	Health Ingestion	Water Supply and Waste Assimilation	Fish and Aquatic Life and Biodiversity
Heat Releases to Surface Water		0.10	0.05
Water Consumption		0.10	
Water Use			0.03
Coal Burned			0.20
Nuclear Power Production	0.05		0.02
Coal Power Production	0.60		0.05
Hydroelectric Peaking Power Production	0.35	0.80	0.60
New Power Plants Constructed			0.05

For effects on human health, the hazards of atmospheric deposition are considered low and are estimated at 10 percent of total human health-ingestion effects. Mercury in flue gases is the contaminant of main concern. Its concentration in the gas is small, and atmospheric dispersion decreases the concentration further. A secondary consideration is acid rain effects on water bodies resulting in the mobilization of metals in lakes and streams. This is not an important issue in the TVA region, however, because the geology of most of the region, with the exception of some Appalachian Mountain areas, provides ample buffering capacity to resist changes in pH. The surrogate measure for coal-fired power plant effects is millions of kilowatt-hours of coal-fired production. The weighting for the combined effects discussed above is 60 percent or a factor of 0.60.

Hydroelectric power plant discharge of metals released from sediments is second in importance for effects on human health due to ingestion of toxic metals and is estimated at 35 percent of total human-health effects. It is assigned a weighting factor of 0.35. It is second to coal-fired plant releases because it is likely to contain a smaller variety of metals and would only be important at tributary dams during summer months. Biomagnification may be a more important pathway for ingestion in this situation because the entire flow of the river may be contaminated, as opposed to a contaminant plume that organisms could avoid. The surrogate measure for hydroelectric plant effects is millions of kilowatt-hours of peaking hydroelectric production.

Because of the relatively small quantities of metals and the minute quantities of radionuclides present in nuclear plant discharges, the effect on human health by ingestion is estimated at only 5 percent (weighting factor of 0.05) of the total TVA effects. The surrogate measure for nuclear plant effects is millions of kilowatt-hours of nuclear plant production.

WATER SUPPLY AND WASTE ASSIMILATION

The primary effects on water supply and waste assimilation result from operation of hydroelectric plants. Operations alter the flow regime of the river downstream, both reducing flows and dissolved oxygen concentration at certain times. This effect is estimated at 80 percent (weighting factor of 0.80) of total TVA effects on water supply and waste assimilation and is measured by millions of kilowatt-hours of peaking hydroelectric power production. Coal-fired and nuclear power plants consume water and release heat to surface water. Water consumption adversely affects both water supply and waste assimilation, whereas heat releases only affect waste assimilation. These effects are very minor compared to the effects of altering the flow of the river and are each estimated at 10 percent (weighting factor of 0.10) of the total TVA effects. Water consumption (millions of gallons) is a direct measure, and the heat release rate (billions of Btu) is the surrogate measure for thermal effects.

FISH AND AQUATIC LIFE AND BIODIVERSITY

TVA's action in damming the Tennessee River and its tributaries to generate power, control floods, and allow navigation primarily affects aquatic life in surface waters by changing water quality and aquatic habitats. These effects are most pronounced in tributary tailwaters where altered flow patterns from hydroelectric plant releases result in dramatic reductions in numbers and kinds of aquatic life. Because these releases commonly are drawn from near the bottom of the reservoir, they cause tailwaters to be colder, lower in dissolved oxygen, and higher in toxic materials derived from sediments than undammed portions of the stream. This combination of factors is estimated to account for about 60 percent (weighting factor of 0.60) of power generation-related effects on aquatic life. The best surrogate measure would be one proportional to the amount of hydroelectric plant operation on the rivers most vulnerable to these effects. This led to the choice of millions of kilowatt-hours of peaking hydroelectric plant production.

The next most important category of effects on aquatic life is associated with the fuel cycle, specifically habitat destruction from the mining of coal and the effects of runoff from mines. These effects are widespread and difficult to quantify, but are estimated to account for about 20 percent (weighting factor of 0.20) of all TVA power system aquatic life impacts. The best surrogate measure for such effects is tons of coal burned in the pro-

duction of electric power. This should be directly proportional to mining activities.

Coal-fired generated power is estimated to account for about 5 percent of aquatic ecosystem effects. Liquid discharge from coal-fired plants, including those from ash storage and disposal, and effects of materials reaching surface waters through fallout and rainout of air pollutants are the primary factors involved. The best surrogate measure of these effects is millions of kilowatt-hours of coal-fired generated power.

The effects of releases of heated water on aquatic life were once expected to be important, but experience has shown that not generally to be the case. Releases of heated water are judged to contribute 5 percent of the overall aquatic effects by TVA, and to be best measured in gross terms by the total amount of heat released to the river from TVA coal-fired and nuclear power plants.

A related effect is drawing plankton and fish through equipment or injuring or killing them by causing them to collide with intake screens when cooling water is being drawn from the river or lake. This has been shown to cause only minor local effects (about 3 percent of the total TVA effects) on fish and aquatic life and biodiversity and is best measured by the total amount of water used by TVA power plants.

Localized effects of power-related construction activities, such as new or modified plants or transmission facilities, are considered to be minor, perhaps 5 percent, measured by the number of new plants built. Non-thermal discharges of radionuclides and miscellaneous chemicals from nuclear power plants are also relatively minor, with a 2 percent estimated weighting factor, measured by millions of kilowatt-hours of nuclear power generated.