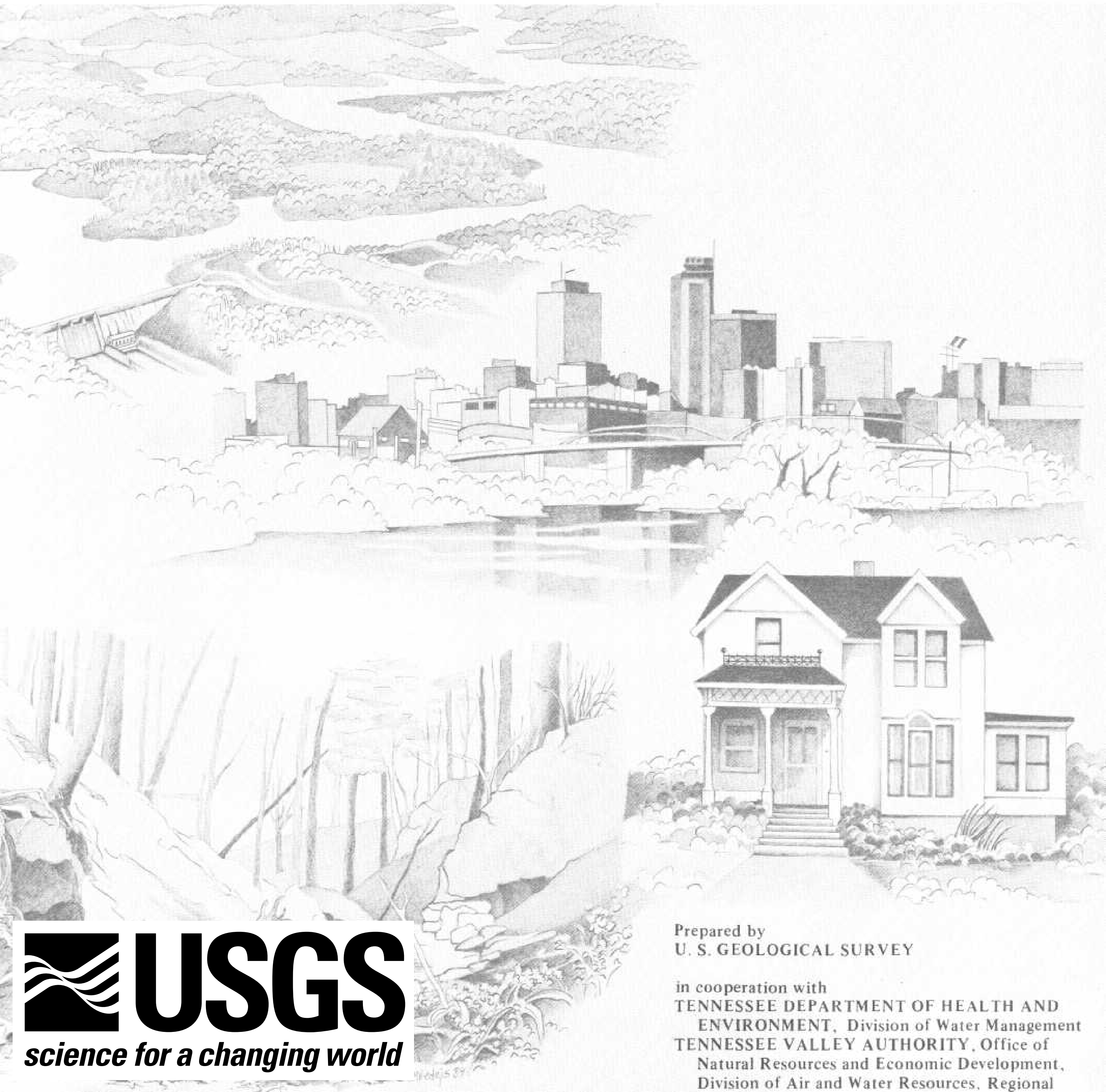
DROUGHT-RELATED IMPACTS ON MUNICIPAL AND MAJOR SELF-SUPPLIED INDUSTRIAL WATER WITHDRAWALS IN TENNESSEE--PART B



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APPENDIX II

BACKGROUND INFORMATION ON OTHER WATER-RELATED PROBLEMS AND ISSUES AFFECTING AVAILABLE WATER SUPPLIES

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INTRODUCTION

Analysis of the data and information compiled through the development of the inventories of community water-supply facilities and large, self-supplied commercial and industrial water users indicates a number of problems which many of these communities and self-supplied water users are already experiencing. Included among these problems are heavy water losses due to deteriorating water mains and distribution lines; inadequate storage facilities; sedimentation and clogging of water intakes; water-supply, quantity-related shortages; and poor water quality. However, there are a number of additional water-related problems and issues such as conflicting or competing water uses, financial constraints, institutional issues, etc., which have been identified recently. These have been identified through various planning and study efforts such as the Second National Water Assessment (U.S. Water Resources Council, 1978) and TVA's Valleywide Assessment of Water Needs (Tennessee Valley Authority, 1974). The current or potential problems may significantly affect the ability of the State's water supplies to meet existing water demands for municipal, commercial, and industrial purposes. More specifically, these types of problems and issues can seriously exacerbate existing or potential water-supply shortages, increase water facilities development costs, and limit community and area attractiveness and capability for economic growth and development.

Other water-related problems and issues which are now or have the potential to impact adversely on community and large, self-supplied water users and (or) delaying the resolution of identified water-supply-related shortages or problems, particularly during severe and (or) extended drought periods, are listed below. To facilitate their presentation and consideration by decisionmakers, these problems and issues have been classified or grouped into two categories: policy and technological issues.

Specific policy and technological issues identified below are not intended to be all inclusive in terms of either the issues themselves or the potential alternatives or solutions to be considered in resolving or alleviating, to the extent possible, identified water-related needs and problems. Basically, they are intended to (1) provide decisionmakers with a general overview of those issues which have been identified as having a significant impact on the ability of an area's water resources to meet existing demands and (2) generate discussion among decisionmakers regarding specific project and program elements (structural and nonstructural) to be considered as they conceptualize, promulgate, and implement viable water-related policies and programs for dealing with short- and long-range water-supply shortages be they drought-related or not. Note, these issues are not listed in order of severity of impact on community and self-supplied water users or priority for resolution.

POLICY ISSUES

Policy issues are those which deal with or concentrate on the consideration of and evaluation for implementability by decisionmakers at all levels of government, particularly the State and Federal level, of new and (or) evolving technologies to resolve or alleviate, to the extent practicable, existing and potential water-related (quantity and quality) needs and problems in a manner which is compatible with established economical, environmental, and social goals and objectives.

Inadequate Integration of Water Quantity and Quality Management

Throughout the history of water resources management, it seems that decisionmakers at all levels of government have tended to approach water management through a variety of water programs, each oriented to achieve a particular goal or objective. This situation has evolved over the years for statutory, institutional, and constituency reasons without the degree of integration and coordination needed to ensure the establishment and implementation of a viable program for effectively managing what is a very valuable, single resource - water. That this situation exists in Tennessee is clearly stated in the following excerpt from the Tennessee part of a document entitled Southeast Water Resources, Legal and Administrative Systems for Water Allocation and Management (North Carolina Water Resources Research Institute, 1978). This document summarizes the proceedings of a conference organized by State Water Resources Research Institutes and State Water Resources Agencies of the southeastern States to discuss the southeast's most important water resources problems.

> State organization for water resources management is fragmented and uncoordinated. State agencies are scattered, and there is no single authoritative spokesman for water resources planning and management. The principal water resources management responsibilities are shared by the Departments of Conservation and Public Health. A Division of Water Resources in the Department of Conservation is responsible for the State water plan, water-related recreation, water problems associated with strip mining permitting and control, licensing of well drillers, and the collection of basic data on water sources and use. The largest share of water resources activity at the State level involves water supply and water pollution control. This is administered by the Department of Public Health.
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> Water resources planning is widely dispersed. The Tennessee State Planning Office is at the top with the overall State planning mission. In practice, it is largely limited to special projects and clearinghouse functions. The Department of Economic and Community Development works in the area of industrial development. State Civil Defense enters the picture in cases of flooding and spills of hazardous substances.

It should be noted that the principal responsibility for water resources management in Tennessee now belongs to the Tennessee Department of Health and Environment (formerly the Department of Public Health) as a result of the transfer of the Tennessee Division of Water Resources from the Tennessee Department of Conservation to the Tennessee Department of Public Health in February 1983.

Specific concerns arising from the fragmentation of water resources planning and management responsibilities and inadequate coordination can be characterized by the following results:

- Fragmented information and data base.
- Inadequate consensus regarding attainable water uses in specific geographic areas.
- Conflicting management priorities.
- Unilateral regulatory decisionmaking.
- Highly variable accessibility to the public planning and policy process.
- Insufficient linkage between water management and other socioeconomic functions and aspirations.
- Measurement techniques which need refinement to ensure accountability for results.
- Excessive duplication and redundancy in data collection and planning activities.

Hydrologic (Surface and Ground Water) Relationships

Recognizing that, in most cases, there is a definite hydrologic relationship between an area's surface- and ground-water resources, planning for the wise use and management of these resources requires that they be managed conjunctively as a single system to protect both the quantity and quality of the resource. Inadequate recognition and consideration of these interrelationships in water management is a problem which is not unique to any one level of government. Currently, the problem manifests itself in several ways including the management of surface- and ground-water supply systems by separate entities, separate water laws for controlling and (or) allocating the use of these resources, and inadequate information and data regarding the effect of various land and water use practices on the area's surface- and ground-water resources. For example, Tennessee water law separates surface water from ground water and attaches separate rights to each source. Surface-water resources are allocated under the common law riparian doctrine with domestic water uses having the highest priority and no limit on withdrawals regardless of the effect on downstream riparian users. Ground-water rights, on the other hand, are governed by the reasonable use doctrine.

Specific water management concerns relative to this problem or issue include the following:

- Increased potential for serious ground-water pollution via surface-water sources as well as contamination from surface and subsurface waste disposal and storage.
- Lack of adequate case or statutory law needed to protect ground-water sources of public supply and the recharge areas to the supply sources. Wetlands or high ground-water table areas are particularly susceptible to contamination.

Competing and (or) Conflicting Water Uses

Another problem or issue affecting available water supplies and their relative ability to meet current and near-term future water demands, particularly during drought conditions, is that of competing and (or) conflicting water uses. This problem is most severe during drought or low streamflow periods and in those areas located along the rim or headwater area of individual river basins. Water-based recreation, hydropower generation, navigation, industrial, and domestic water uses represent the major competing and (or) conflicting water uses in Tennessee, particularly in the eastern and central parts of the State. Recreational interests, particularly in east Tennessee, would like to use the existing TVA lakes for recreational purposes, but the fluctuating lake levels due to reservoir operation for flood control, navigation, and hydropower purposes limit their recreational value. For example, TVA operation of Fort Patrick Henry Reservoir on the South Fork Holston River has led to a water-use conflict among the recreational interests on Fort Patrick Henry Reservoir who want reservoir levels maintained at a certain level conducive to high-quality water-oriented recreation, power generation interests demand for low cost hydropower, heavy water using industries below the dam who have had to resort to extensive water recycling to meet their demands, and downstream domestic water users (U.S. Water Resources Council, 1978). In the Hiwassee River drainage area, conflicts have arisen over the frequency of water releases from Ocoee Dam for whitewater recreation purposes.

Severe and (or) extended drought conditions resulting in decreased reservoir levels, streamflows, and ground-water levels would significantly heighten the competition between these uses and the degree of conflict regarding the allocation of the available resources among the various uses. Of course, in an emergency situation, water use for domestic purposes would take priority over all other uses; but beyond that, Tennessee water law provides no priority system for allocation of available water resources.

Instream Flow Requirements

The increasing public interest in clean water coupled with its decreasing availability due to increased water use, water-quality pollution, and periodic drought conditions has seriously aggravated the conflicts to be resolved by water resources planners and decisionmakers. Determining the proper balance between "consumptive" and "instream" water use of the available water resources is a difficult task in view of the pressure from various special interest groups. "Consumptive" water use refers to water withdrawal for municipal, commercial, industrial, and agricultural purposes which is not returned to a surface- or ground-water source. "Instream" uses or values include water use for the maintenance of fish and wildlife habitat areas and populations, water-based recreation, navigation, hydropower generation, and waste assimilation. In general, the amount of water flowing along a natural stream channel which is sufficient to adequately sustain the pertinent instream uses at an acceptable level constitutes a stream's "minimum instream flow" requirement.

To date, little conflict has arisen in the eastern States including Tennessee relative to the maintenance of adequate instream flow requirements because of the relative abundance of water. However, most States now recognize the need to consider "instream flow protection" as a valid consideration and component of their overall water resources planning and management program. In Tennessee, there appears to be no statutory guidance relative to the maintenance of minimum streamflows except for navigation and fishery resources protection.

While instream flows are generally accepted as a beneficial use, it must be recognized that the protection of instream flows is a controversial and politically volatile issue in every State. The primary controversy seems to focus on the question of who should be responsible for protecting instream water uses--the public or private sector. Resolution of this controversy seems to rest on two basic assumptions:

- Water is a resource which should be allocated in the atmosphere of a free market system.
- Flowing water is a public resource and has public values.

Recognizing the many complex issues to be considered and resolved in managing an area's water resources, it is essential that effective and meaningful negotiation be implemented at all levels of water resources planning and management to protect instream flows under various water-supply conditions, particularly during periods of severe or extended drought.

Comprehensive, Coordinated Planning

A cursory review of the inventories of community and industrial water-supply facilties indicates that the basic water-related problems affecting these facilities are quite varied in nature. Problems include water-supply shortages, poor water quality, sedimentation, and flooding. Analysis of these problems and their origin as well as their effect on the State's natural resources and residents indicates that these problems are very complex and interdisciplinary in nature. Water problems in the Cumberland River, Green River, Horn Lake Creek, Mississippi River main stem, Nonconnah Creek, Obion and Forked Deer Rivers and the Wolf and Loosahatchie Rivers drainage areas are discussed in Volume 4 for the Lower Mississippi Region, Ohio Region, and the Tennessee Region of the Second National Assessment (U.S. Water Resources Council, 1978). It is noted these problems are interdisciplinary in nature and of such complexity that intermediate planning involving a wide range of disciplines and interests at all levels of government is needed to (1) clearly define the problems and issues, and (2) guide the development and implementation of needed project and program measures to resolve the identified needs and problems.

Lt. General William F. Cassidy, former Chief of the U.S. Army Corps of Engineers, noted in a presentation to the Fourth American Water Resources Association Conference in 1968 that technology is not the limiting factor in providing adequate water supplies (quantity and quality) to meet present-day community and self-supplied commercial and industrial needs. According to Lt. General Cassidy, the major problem limiting the utilization of our technological capabilities to address and resolve critical water-related needs, problems, and issues is that of "obtaining consensus and decisions on how to apply our technology" because of the political, environmental, and social considerations. Overcoming this inability to gain consensus on how to use our technology can only be accomplished through the establishment and implementation of a comprehensive, coordinated planning process designed to (1) identify and describe critical water-related needs, problems, and issues, and (2) develop and implement politically, economically, environmentally, and socially acceptable project and program alternatives and (or) plans for decisionmakers to consider in managing the State's natural resources to resolve and alleviate, to the extent possible, critical needs and problems. To be effective, this planning process must be:

- Comprehensive in nature, that is, consider all water uses, because all water uses are interrelated and affect each other.
- Dynamic in nature to enable planners and decisionmakers to revise and update or expand existing and (or) ongoing planning efforts to reflect changes in society's goals and objectives, water-related needs and problems, resource availabilities, new technology, and so forth.
- Coordinated with and provide ample opportunity for involvement by all pertinent local, sub-State, State, and Federal agencies with statutory water-related responsibilities or interests as well as a wide range of public organizations and individual citizens.

Public Education and Information

Despite the increasing awareness of both the national and State-local news media and water resources managers of the very real potential for serious and extended drought conditions or periodic water-supply shortages, much of the public remains oblivious to the situation. This is not unusual when one recognizes that people have long been accustomed to plentiful, almost unlimited, supplies of relatively inexpensive water for a wide variety of uses. This is especially true in areas such as Tennessee which have long been characterized as water rich with abundant supplies of good-quality water which, seemingly, are replenished by ample rainfall each year. Nevertheless, Tennessee's Safe Growth Team appointed by Governor Lamar Alexander expressed the need, in Tennessee's Safe Growth Plan dated January 1981, to "examine carefully what the quality and adequacy of Tennessee's water supply will be during the 1980's." The seriousness of this concern was amplified on April 22, 1981, by the passage of House Bill No. 924 by Tennessee's General Assembly which noted that "although Tennessee is richly blessed with water resources; the patterns of use, reliance on English common law riparian rights, and urban growth in the State are placing a severe strain on these resources" and "increasing heavy industrial development in Tennessee and the consequences of drought in the summer of 1980" necessitate the conduct of a thorough examination of Tennessee's existing water resources, use, and law.

State and local government must make a concerted effort to demonstrate to the public that there is a drought and to enlist popular support both for voluntary water conservation and appropriate legislative action needed to deal with drought-related conditions. More specifically, the public including private citizens; local business, civic, and church groups; as well as pertinent sub-State and special interest groups must be provided pertinent information and data regarding the:

- Availability of the State's water resources, relative value of these resources, and water quantity and quality interrelationships.
- Extent, that is, specific water uses being affected, and severity of the drought.
- Economic, environmental, and social impacts and expected ramifications of the drought.
- Possible alternative solutions and measures (structural and nonstructural) which can be utilized to cope with and alleviate, to the extent possible, the effects of the drought.
- Ongoing and proposed programs at all levels of government for dealing with the drought problem.

Note, the public should be actively involved in the formulation and implementation of appropriate short- and long-range programs for dealing with water quantity-related problems in order to ensure the political viability of these programs. To be truly effective, this program must encompass and involve all segments and age groups of society through a wide variety of methods including the news media, school programs and curriculum courses, newsletters and brochures, public meetings, and so forth.

Financial and Institutional Arrangements

A recent article in the Spring 1982 issue of the Water Spectrum entitled "Institutional Barriers to National Water Policy" by David C. Harrison, National Academy of Public Adminstration, identified six major barriers to integrated water resources management which, of course, entails the resolution of water supply, drought-related, shortages. These barriers include:

- Artificially low water prices which discourage conservation and create water shortages.
- Legal obstacles to the transfer of water rights from a low to a higher priority water use.
- Lack of coordination between Federal, State, and local governments which prevents or hinders integrated surface and ground water and water-quantity and quality management.
- Water policy conflicts between Federal and State entities.
- Inconsistent Federal cost-sharing arrangements for water projects.
- Overlapping or conflicting agency missions, laws, and programs.

This article went on to say that the resolution of water-related needs and problems in today's society is hindered more by "institutional barriers" than technology problems.

More specifically, a recent series of conferences on the subject "Water Needs and Problems in Tennessee" conducted jointly by Tennessee's Water Resources Research Center at the University of Tennessee and Tennessee's DWR during the fall of 1978 identified three major or recurring problem areas relative to water resources planning and management.

- First, there is a shortfall of funding. Basically, the conference participants felt that the general nature of the State's water resources problems is known as well as some reasonable alternatives for solving them, but the financial resources to take on these problems are inadequate.

- Second, the problems are institutional in nature. Essentially, the participants noted that currently there is a myriad of uncoordinated Federal and non-Federal programs and agencies with water-related interests and planning and management responsibilities. While each of these individual programs is generally perceived to be sincere and beneficial in nature, they are often overlapping and even conflicting.
- Third, many participants expressed concern over what might be broadly characterized as a breakdown in communications. Generally, this could be expressed best as a collective feeling on the part of many participants that there is an inadequate exchange of opinions and information between the general public, special interest groups, and government at all levels.

Participants in these conferences included city and county officials, consulting engineers, representatives of universities, State and Federal agencies, regional authorities, environmental organizations, industries, and farm and recreation-oriented interest groups.

Essentially, the overall problem involved in meeting community and self-supplied commercial and industrial water demands can be characterized as the need to "make available an assured quantity of water of acceptable quality where and when it is needed." Thus, four basic factors or considerations are involved in providing adequate municipal and industrial water supplies--quantity, quality, place, and time. While current engineering and construction techniques are fully capable of resolving and dealing with these factors relative to the resolution of identified water-supply shortages, problems are often encountered in reaching consensus on the specific technological measures to be utilized due to political, economic, environmental, and social concerns. These concerns are particularly critical at this time because of the (1) limited grant funds available to communities to finance the development of new and (or) improved water-supply facilities, (2) number of communities desiring and in drastic need of technical and financial assistance, (3) excessive costs involved in developing and maintaining water-supply distribution and treatment facilities to meet current environmental and public health standards, and (4) increased requirement for cost sharing of water-supply development by State, sub-State, and local interests.

Resolving these concerns can best be accomplished by establishing and implementing an institutional mechanism with adequate resources--legal authority, technical expertise, manpower, and funding--to plan and provide for the resolution of the State's water and related-land resources needs and problems in a timely and orderly manner. Basic questions which need to be considered in formulating such an institutional mechanism include the following:

- How should the relationship between management agencies and water user constituencies at all levels of government be cast so that the contributions of each can be considered appropriately?
- What procedure and institutional mechanism will ensure that the individual agencies technical competence, power, and institutional resources can be utilized to the fullest extent without encroaching on the public policy process?

- How should the principal participants in the policy process be organized to increase its productivity and the power of all of its components?

Land-Use Changes and Conflicts

Land use has long been recognized as having a major impact on the quantity and quality, particularly the quality, of an area's available water resources. In the past, this impact has normally been viewed from the perspective of increased erosion and sedimentation resulting from the landowners' failure to utilize sound land-use and soil conservation practices (best management practices) on agricultural and logging operations; construction and highway development sites; surface mine areas; and so forth. However, the increase in land-use changes from one use to another during recent years has resulted in considerable concern regarding the loss of valuable ground-water recharge areas which are needed to maintain and replenish the State's high-quality ground- and surface-water resources. Included among these land-use changes are the following:

- Residential and industrial developments in flood plain areas.
- Vacation and second-home developments in upstream scenic areas.
- Wetlands and swamp drainage.
- Urban and commercial development of agricultural and upstream scenic areas.

In addition to changing land uses, there is also considerable conflict between the coal mining and conservation-recreation interests regarding the classification of various reaches of the Buffalo and Obed Rivers and Clear and Daddy's Creeks and related land resources as part of the Nation's national scenic river system.

Resolution of these conflicts and protection of valuable ground-water recharge areas will be important not only from the standpoint of protecting water quality, but also from the viewpoint of preserving these recharge areas in a relatively undeveloped state to ensure their continued availability and efficiency as recharge areas. This is particularly important since the era of large-scale dam building has essentially ended because virtually all of the State's most favorable sites for large-scale dams have been developed or will not be developed because of their intrinsic environmental and recreation values. Consequently, future water-supply programs will need to be much less structurally oriented and directed at the protection and maintenance of the quantity and quality of existing surface- and ground-water resources. This will be particularly important during periods of severe and extended drought.

Atmospheric Changes and Management

Atmospheric changes have a direct impact on and are constantly altering the quantity and quality of an area's available water resources. Some of these changes are very slow; others occur rapidly; and many are just now being realized by scientists and the public. Atmospheric changes result from natural fluctuations in climate and man's influence on the atmosphere.

The quantity and quality of Tennessee's water resources are irrevocably linked to and dependent upon climatic conditions. Precipitation contributes all of the water available to Tennesseans. However, not all of this water falls directly on the State. Some of it is hundreds of years old and was buried in the ground, and some originates elsewhere and flows into the State via the State's three major river systems - Cumberland, Mississippi, and Tennessee Rivers. Another factor affecting the amount of water available to Tennessee water users is the amount of water lost in the form of evaporation and transpiration. Evapotranspiration is dependent on several factors including the humidity, temperature, and winds. The atmosphere's ability to carry and then deposit natural and anthropogenic pollutants represents a major factor affecting the quality of the State's water resources.

It must also be recognized that climatic conditions are not static, but are constantly varying over time scales ranging from a few years to centuries. Not only do climatic conditions vary over time, but they also vary extensively from area to area depending on local or areawide topographic features and weather patterns. Analysis of past climatic trends indicates that climatic conditions relative to temperature and precipitation have been quite variable during recent years. For example, current news reports indicate that while temperatures are increasing in the polar regions, temperatures in our area are declining. Likewise, analysis of TVA's Annual Precipitation Reports for 1970-79 indicates substantial variability in precipitation across the Valley, but with the 10-year average precipitation being generally greater than the long-term (1941-70) average precipitation.

Recognizing the variability of climatic conditions and their influence on an area's available water supplies, proper assessment of current climatic conditions including an evaluation of its trends, yearly variability, and weather extremes should be an integral part of any effort to plan for the wise use and management of an area's water and related land resources. Such knowledge would be very helpful to planners and decisionmakers dealing with serious water supply, quantity-related shortages, particularly during times of severe and (or) extended drought.

TECHNOLOGICAL ISSUES

Technological issues are those which (1) address or deal with specific water-related (quantity and quality) needs and problems which are common to Tennessee, (2) provide a brief overview of their impact on the State's water resources, and (3) delineate briefly, to the extent possible, for decision-makers consideration and evaluation existing and (or) potentially feasible alternatives for resolving or alleviating identified needs and problems in a timely and orderly manner.

Water Conservation

Increasingly, the American public is being warned that the Nation's water shortage will soon not only rival the energy crisis, but in fact surpass it. A recent issue of the Interstate Conference on Water Problems Washington Report (September 13, 1982) noted that recent studies have shown the national demand for freshwater to be doubling every 20 years. Traditionally, this country has used water because of its apparent abundance as though the supply were inexhaustible. However, Americans are beginning to grasp the gravity of the water-supply shortage problem and recognize the tremendous amounts of water required to produce many of the things which we take for granted. For example, about 15,000 gallons of water are required to grow a bushel of wheat; 60,000 gallons to manufacture a ton of steel; and 120 gallons to produce one egg.

While Tennessee is generally characterized as a water rich region with an abundance of freshwater, there are communities and some large, self-supplied industries located along the rim and headwater areas of several river basins in the State which have experienced serious water-supply shortages during times of drought. These shortages are most pronounced in Cumberland, Grundy, Marion, and Morgan Counties. In general, these shortages result not from the total lack of available water, but rather from the lack of adequate quantities of water to meet both instream and offstream water demands. However, there are instances where the streams and rivers are known to go dry during the late summer and fall months because of their small drainage area and limited precipitation and ground-water supplies are unreliable because of the type of aquifer and limited recharge area.

Water conservation, which is often defined as "any beneficial reduction in water use or water loss," offers one of the least-cost methods available to communities and water users (domestic and industrial) to reduce water-supply costs and assure themselves of a stable and high-quality water-supply adequate to meet current as well as future needs. Even in those instances where ample quantities of water are available, communities and water users can benefit greatly through reduced water costs from the implementation of various water conservation measures rather than the development of new and (or) expanded water-supply treatment and distribution facilities to improve existing service or accommodate population and economic growth.

Therefore, in these times of (1) high interest rates and construction costs, (2) limited available funds for the development of new and (or) expanded water-supply facilities, (3) increased demands for water from all sectors of society, and (4) environmental constraints relative to both the development of structural measures such as dams as well as the strict quality standards to be met for domestic water supplies; the use of nonstructural, conservation-type measures should and must receive top consideration and priority wherever feasible for meeting community and industrial water-supply needs. Such conservation measures might include the following:

- Replacement of leaking water mains and distribution lines.
- Utilization of water-saving plumbing fixtures and appliances.
- Improved management of existing reservoirs and water-supply facilities.
- Increased water rates to consumers and a surcharge for excessive use over and above a predetermined level of use.

Deteriorating Water-Supply Systems

A major problem plaguing many community water-supply systems is that of deteriorating public water-supply systems. Numerous communities throughout

Tennessee have identified serious water leaks in their water mains and distribution lines as their major water-supply problem at the present time. It should be noted that this problem is not unique to Tennessee, but is characteristic of water supplies throughout the Nation. Many of these communities are experiencing water losses ranging from 30 to 50 and some as high as 70 percent of their treated or purchased water.

Through January of 1983, TVA had received 139 formal requests for assistance through its leak detection program from community water-supply systems with serious leakage problems. Since this program was initiated in 1979, TVA has assisted approximately 112 water-supply systems to locate and mark their leakage problems so they can be repaired by the community. This has resulted in the recovery of some 100 million gallons of treated water per month, with an average monthly value of about $70,000.

However, many communities continue to experience water losses due to deteriorating water systems and must remedy the situation if they are to avoid serious water-supply shortages in the future, particularly during periods of severe drought.

Water-Quality Degradation

While water quality in Tennessee compares favorably with other areas of the country and is good overall, cyclical water-quality problems do occur as a result of the seasonal distribution of precipitation, proximity to pollution sources, biological productivity, and seasonal reservoir processes. Consequently, a number of water-quality problem areas have been identified during recent years through several Federal/State agencies (Tennessee Valley Authority, 1980; Tennessee Department of Public Health, 1982; and Bowen and others, 1983). Generally, this section discusses stream quality problems, reservoir release water-quality problems, reservoir and eutrophication, and ground-water quality.

Stream Quality Problems

The overall water quality of the Hatchie River and its tributaries has been degraded by sedimentation due to soil erosion. The erosion problem has also impaired surface drainage in the Hatchie River basin. Efforts to remedy the drainage problem have caused further water pollution. Many miles of tributary streams have been dredged and realigned creating extensive sand deltas at the confluence of some straightened lateral drainageways.

The discharge of inadequately treated wastewater or untreated wastewater has continued to degrade stream quality in parts of the streams of the Hatchie River basin. The most critical point source related problems in the basin are municipal and industrial effluents at Covington and Bolivar. In addition, seasonal low flows and relatively flat streambed slopes inhibit the reaeration of many streams.

In the Obion-Forked Deer River basin, most of the problems associated with municipal, domestic, and industrial discharges are either due to inadequate treatment, low reaeration rates in the receiving streams due to the often low-flow conditions that exist, or possibly the combination of both factors.

By far the most serious water-quality problems in the Obion-Forked Deer River basin are caused by nonpoint source pollution. The major source of pollution is from agricultural activities. The primary pollutant from agriculture in the basin is sediment. Cropland and gully land erosion produce an estimated 42.2 million tons of sediment per year. A major part of the sediment is deposited in the basin's streams resulting in some type of channel restoration being required to maintain its hydraulic efficiency. This causes impairment of water quality and usually severe disruption to aquatic and terrestrial habitats. As long as cropland and gully erosion and deposition of sediment in streams continue, channel restoration will be periodically repeated with a recurrence of adverse impacts on water quality and aquatic and terrestrial habitats.

Pesticides, which are used for crop protection from insects and weed growth control to maintain hydraulic efficiency of channels, are also a source of pollution. The pesticides often bind to soil particles and when washed into a stream can become incorporated into the food chain. A good example exists in Reelfoot Lake where fish flesh samples have shown the presence of pesticides.

Within the Memphis Area basin, many water-quality problems have existed in the past. Several fishkills have occurred in the lower Loosahatchie River in the past because of the heavy discharges of treated wastewater by municipalities, industries, and other domestic sources. Most of these discharges have been eliminated.

Big Creek, a major tributary to the Loosahatchie River, receives considerable agricultural runoff. Very little change in land use is projected within the basin; therefore, any reduction of the suspended-sediment load from agricultural and construction related sources would have a positive effect on water quality in the stream.

Several other stream segments in the Memphis Area basin have been designated as water-quality limited and in violation of water-quality standards. Most of these streams are small tributaries that have no substantial minimum flow during summer months. Violations are the result of industrial wastewater discharges.

The most serious problem area in the Lower Cumberland River basin is the Stones River and its tributaries. The Stones River, impounded by J. Percy Priest Dam in 1969, has experienced numerous water-quality problems such as low dissolved oxygen, algal blooms, and fishkills. Two primary causes have been identified. First, high phosphorous concentration due to natural sources provide for abundant algal production. Second, the hydrologic characteristics of the reservoir result in very stable stratification during summer months.

The Cumberland River at Nashville also has significant water-quality problems resulting from a combination of factors. Low dissolved oxygen levels from Old Hickory and Percy Priest Lakes, the combined effect of numerous municipal and industrial discharges and combined sewer bypasses in the Nashville area often result in frequent water-quality violations. Upgrading existing municipal waste treatment facilities should improve the situation.

The Upper Cumberland River basin has virtually no serious point source water-quality problems as a result of municipal, domestic, and industrial wastewater discharges. Water-quality in the basin is, however, severely impacted by nonpoint problems associated with coal mining. Erosion and acid drainage from surface and deep mines affect several hundred stream miles. Debris, silt clogged streams, and low pH conditions have destroyed the aquatic community in many streams. Because current economic conditions are exerting a great deal of pressure to extract more coal, management of nonpoint-source effects of coal mining will probably play an increasingly important role in water-quality management in the basin. Outside of those areas directly impacted by mining, water quality is generally excellent. Water quality in reservoirs is very good.

The overall water quality of the Tennessee River Western Valley basin can be described as stable, even slightly improving in nature. The area is drained by one major tributary throughout, the Tennessee River, which runs from the Kentucky State line to the Alabama-Mississippi State lines. The Tennessee River is the largest navigable waterway within the State providing industry with an economical means of transportation. The major water-quality problems in the basin are a result of nonpoint source runoff from large expanses of farmland, with minor problems associated with industry and municipal wastes originating at the city of New Johnsonville.

The overall quality of the Duck-Buffalo River basin can be considered as stable; however, the quality may possibly be very slowly declining in some areas. The major problems associated with the Duck-Buffalo River basin are due to low flow, nonpoint source runoff from a largely agricultural area, phosphate mining in the basin, and to a lesser extent industry and municipality discharges. Based on data collected by the Tennessee Valley Authority, there are indications that Normandy Reservoir is eutrophying.

Fecal coliform and fecal strep counts, especially in the Duck River, exceed standards occasionally, especially near the more populated areas. Phosphates and residue excesses are the most common violators due to phosphate mining and agricultural nonpoint source runoff. Copper and mercury have also shown a tendency to exceed limits on occasion though there appears to be no one recognizable cause for problems with either element.

The overall water quality of the Elk River basin is good. Ninety percent of the wells and 100 percent of the springs yield water of potable and palatable quality. Both the Elk River and Shoal Creek register moderate to few standards violations and much of the data registers improvement. The only areas of concern occur downstream from Fayetteville due to the reduction in minimum flow by TVA at Tim's Ford Dam reducing the city's assimilative waste capacity, and in Woods Reservoir where preliminary data has shown evidence of past dumping of PCB's.

The overall water quality in the Lower Tennessee River basin is generally stable. The area is drained by two major tributaries, the Hiwassee and the Sequatchie Rivers which both drain into the Tennessee River. The Tennessee River is the largest navigable waterway within the State and transports large amounts of goods for industry in three states. The major water-quality problems in the Lower Tennessee basin are attributable mainly to industrial and municipal wastes with some agricultural nonpoint source runoff in the outlying areas of the basin.

Both the fecal coliform count and the fecal strep count violate standards with regularity. Total solids also remain in high amounts as do phosphates, iron, and manganese, especially in the Sequatchie River. The Sequatchie River is also the recipient of discharges such as highly acidic runoff, large amounts of iron and manganese, and large quantities of eroded soil due to the decades of coal mining in its watershed.

The Hiwassee and Ocoee Rivers are consistently found to be in violation of standards for copper and lead. The high copper concentrations are due to the large deposits of copper found in the Lower Tennessee River basin. The lead appears to be from both the soil and industry in the area.

The overall water quality in the Upper Tennessee River basin is extremely stable and records few standards violations yearly, particularly in the Little Tennessee River and Tellico Reservoir. Occasional standards violations occur in residue, phosphates, and pH. Two of the reservoirs in the basin, Fort Loudoun and Watts Bar, are more likely to have water-quality problems due to Fort Loudoun's proximity to the city of Knoxville. The Upper Tennessee River basin is largely an agricultural area which is sparsely populated except in the northeastern corner of the basin where Knoxville and its suburbs are situated and industry replaces agriculture.

The overall water quality in the Clinch River basin can best be described as improving. The basin is drained by two major tributaries, the Powell and the Emory Rivers which both drain into the Clinch River. The major water-quality problems in the Clinch River basin are attributable to coal mining runoff, agricultural nonpoint source runoff, and periodic, low flow conditions.

Fecal coliform counts and fecal strep counts exceed standards at times, but do not appear to be serious violations. Mercury levels are found to be high in some areas of the basin. Due to runoff and regular discharges from coal mining operations, some of the minor tributaries are highly acidic causing a drop in pH and subsequent violation of standards usually in the Powell and Clinch Rivers.

The overall water quality in the French Broad River basin can be called stable. Though there are many parameter violations in certain areas of the basin, the violations themselves are becoming less severe. There are two major tributaries draining the basin; the Pigeon and Nolichucky Rivers, both of which drain into the French Broad.

The main problem areas are found to be fecal coliform and fecal strep counts, especially in the resort and urban areas of the basin. Total solids are high at times, as are phosphate and copper. Mercury and lead occasionally violate standards. It has been reported that the Great Smoky Mountains, which border eastern areas of the French Broad River basin, have received falls of acid rain. If the report is accurate, severe degradation of water quality could be caused over a relatively short period of time.

Tourism coupled with low flow in some areas of the mountains have been a major cause for concern in the recent past with respect to municipal discharges in the area. Water-quality problems have been associated with the Gatlinburg and Pigeon Forge municipal sewage discharges to the West Prong Little Pigeon River. Industrial discharges from Sevierville and Greeneville have also caused periodic water-quality problems. A major point source problem occurs on the Pigeon River at Canton, North Carolina. Effluent from a pulp and papermill at Canton has caused high temperatures, low dissolved oxygen below the outfall, as well as color problems in Douglas Reservoir.

The overall water quality in the Holston River basin can be considered to be improving in most areas and stable in the remaining areas. There are three major tributaries draining the basin; the Watauga River and the North and South Forks of the Holston River. The major water-quality problems in the basin are the result of past and present industrial discharges and periodic low dissolved oxygen concentrations in reservoir releases.

There are six TVA reservoirs in the basin and five exhibit varying degrees of dissolved oxygen depletion during the summer and fall months. Interspaced within the stairstep arrangement of reservoirs are the major point source discharges. Between Watauga Reservoir and Boone Reservoir, there are the point sources from Elizabethton and Johnson City; between South Holston Reservoir and Boone Reservoir, there are the point sources from Bristol; between Boone and Fort Patrick Henry Reservoirs and Cherokee Reservoir, there are the discharges from Kingsport. The reservoirs occasionally reduce the assimilative capacity of the receiving streams and the chance of water-quality degradation occurs. The point sources at times, in turn, cause problems in downstream reservoir water quality and at times cause dissolved oxygen depletion, which in turn affects the next downstream point sources. The problem, though mutually aggravating, has gotten progressively better in the basin.

In many respects, the recent history of the Holston River basin has been marked by major achievements in water-quality improvement. Industrial and municipal waste dischargers have installed extensive waste treatment facilities. An aggressive program to control mercury pollution has been implemented. An improved water-supply intake for the city of Morristown has been constructed. Studies by TVA and the State of Tennessee have revealed that toxic metals are not currently present in hazardous levels in the fish or the waters of Cherokee Reservoir. In recognition of these factors, the State of Tennessee, in its most recent Water Quality Inventory covering the years 1980 and 1981 (Tennessee Department of Public Health, 1982), has concluded that the general trend of water quality in the Holston basin is definitely toward improvement although water-quality standards violations still occur for dissolved oxygen, pH, bacteria, mercury, phosphorus, and copper. Because of the improvements which have occurred in recent years, the water-quality condition of the Holston and South Fork Holston Rivers above Cherokee is no longer considered critical.

During periods of severe and (or) extended drought, existing water-quality problems could be expected to become considerably more serious and extensive in nature. In addition, water supplies currently not facing any water-quality problems could expect to experience water-quality-related problems due to (1) decreased streamflows and (2) increased water demands for a limited, declining number of good-quality water sources.

While water-quality problems exist in certain areas, the overall trend in water quality is toward improvement. In fact, in a recent review of water quality in Tennessee, the Tennessee Division of Water Management concluded that water quality is good in the State [The Tennessee 305(b) Report Water Quality Inventory April 1, 1982]. It is apparent that the efforts of TDWM, Environmental Protection Agency, and other agencies concerned with cleaning up the State's waters have been successful. That is not to say that there are no water problems in the State, but that large strides have been made on the road to clean water. The water running through Tennessee today is of much better quality, on the whole, than it was a decade ago. Of course, new water-quality problems are turning up periodically; the result of new development and past indiscretions.

The overall water-quality trends in 13 of the State's hydrological basins may be summarized as follows:

Memphis Area - Stable
Hatchie River -Stable
Obion-Forked Deer - Improving
Western Valley Tennessee River - Stable
Duck River - Stable
Elk River - Improving
Lower Tennessee - Stable
Upper Tennessee - Stable
Clinch River - Improving
French Broad River - Improving
Holston River - Stable
Lower Cumberland - stable
Upper Cumberland - Improving

Stream water-quality problems in the Tennessee Valley region have been further subcategorized as "critical," "serious," and "localized" by the Tennessee Valley Authority to describe the relative severity of water-quality problems.

- "Critical" problems require immediate attention and correction because of (1) public health considerations, (2) extent of water-quality degradation, (3) number of stream uses or stream length affected, and (4) frequent violation of water-quality standards. Problems of this nature are caused by (1) contamination by toxic chemicals that decompose slowly in the environment, (2) waste loadings from both point and nonpoint discharges which greatly exceed stream assimilative capacity, and (3) impacts from major land disturbances including erosion, sedimentation, and acid mine drainage. Listed below are those stream reaches in the Tennessee part of the Tennessee River Basin which have been identified as having "critical" water-quality problems.

Stream reach or area	Nature of the problem
North Fork Holston River from Saltville, Virginia, to Kingsport.	Mercury contamination
East Fork Poplar Creek at Oak Ridge	Mercury contamination

Stream reach or area	Nature of the problem
Chattanooga, Citico, and South Chickamauga Creeks near Chattanooga.	Toxic organics, heavy metals, municipal sewage discharges, and combined sewer overflows.
First, Second, Third, and Fourth Creeks in Knoxville.	Urban runoff and coliform bacteria.
Powell River and tributaries from the Virginia State line to Norris Reservoir.	Suspended solids and acid mine drainage.
Ocoee River near Copperhill	Suspended solids, heavy metals, and low pH.
Nolichucky River from the North Carolina State line to Nolichucky Dam.	Suspended solids
Pigeon River from the North Carolina State line to Douglas Reservoir.	Discoloration, dissolved solids, and thermal pollution.
Headwater tributaries of the Emory and Obed Rivers.	Acid mine drainage and suspended solids.

- "Serious" problems are generally less severe than the "critical" problems because (1) fewer stream uses or shorter stream lengths are affected, (2) water-quality standards are seldom violated, and (3) the stream's waste assimilative capacity is almost, but not entirely, depleted. These problems result primarily from municipal sewage and industrial waste discharges, urban runoff, and agricultural runoff including the disposal of animal waste. Listed below are the stream reaches or areas in the Tennessee part of the Tennessee River Basin which have been identified as having "serious" water-quality problems.

Stream reach or area	Nature of the problem
Holston River from Kingsport to Cherokee Dam.[1]	Inadequate dissolved oxygen compounded by industrial and municipal wastewater discharges, aquatic weed infestation, and accidental spills.

[1] In the 1980 TVA report entitled "Is the water getting cleaner?", the Holston River reach below Kingsport was categorized as a "critical" water-quality problem area. However, improved wastewater treatment by municipal and industrial point sources in the Kingsport area has resulted in significant water-quality improvement in the Holston River below Kingsport. Therefore, the problem has been reduced to the "serious" category to reflect the improved status.

Stream reach or area	Nature of the problem
Nickajack Reservoir from Chattanooga to Guild.	Domestic sewage
Big Rock Creek near Lewisburg	Municipal sewage effluent and low stream flow.
Chestuee Creek in McMinn County	Agricultural runoff
Ellejoy Creek in Blount County	Agricultural runoff
Lick Creek in Greene County	Agricultural runoff

- "Localized" problems are limited to short stream reaches and are not considered serious individually. Collectively, however, these problems may cause extensive degradation at least on a short-term, seasonal basis. These problems are caused by domestic sewage and industrial effluent, agricultural and urban runoff, mine-related pollutants, and landfill leachate. The following is a list of "localized" water-quality problems in the Tennessee part of the Valley.

Stream reach or area	Nature of the problem
Boone Reservoir and Beaver Creek near Bristol.	Domestic sewage and combined sewer overflows.
Watauga River near Elizabethton	Domestic sewage and industrial effluents.
Fort Loudoun Reservoir-Little River embayment.	PCB contamination
Arnott Branch near Kingsport	Industrial effluent
Richland Creek near Greeneville	Domestic sewage effluent
Little Limestone Creek near Jonesboro.	Domestic sewage effluent
Coal Creek at Lake City	Domestic sewage
Rock Creek near Tullahoma	Domestic sewage effluent
Shoal Creek near Lawrenceburg	Domestic sewage and industrial effluents.
Rockhouse Creek near Hohenwald	Domestic sewage effluent
Sugar Creek near Mt. Pleasant	Domestic sewage effluent
Wartrace Creek near Wartrace	Domestic sewage effluent

Stream reach or area	Nature of the problem
South Mouse Creek near Cleveland	Domestic sewage and industrial effluents.
Oostanaula Creek near Athens	Domestic sewage effluent
Fort Loudoun Reservoir near Knoxville.	Urban runoff
Piney River near Spring City	Domestic sewage and industrial effluents.
Pistol Creek near Alcoa	Industrial effluent
Gray Creek in Sequatchie County	Mine-related pollutants
Kelley Creek in Bedford County	Mine-related pollutants
Little Sequatchie River in Grundy and Marion Counties.	Mine-related pollutants
Wolftever Creek near Collegedale	Domestic sewage and industrial effluents.
Trace Creek near Waverly	Domestic sewage effluent
Cane and Cypress Creeks near Camden.	Domestic sewage and industrial effluents.
Town and Bailey Fork Creeks near Paris.	Domestic sewage effluent
Bear Creek near Parsons	Domestic sewage effluent
Cane Creek near Tennessee Ridge	Domestic sewage effluent

Reservoir Release Problems

Currently dissolved oxygen concentrations in downstream waters from eight reservoirs fall below the 5 mg/L criterion for fish and aquatic life for 1 to 5 months each year. Stream reaches below five of these reservoirs (Cherokee, Douglas, Norris, South Holston, and Tims Ford) are classified as "critical" problem areas because dissolved oxygen concentrations in releases from these reservoirs fall below 1 mg/L at least one day each year. Dissolved oxygen concentrations in releases from Cherokee, Douglas, and Tims Ford Reservoirs are below 1 mg/L for 1 to 2 months per year. Stream reaches below Fort Loudoun, Watts Bar, and Fort Patrick Henry Reservoirs are classified as "serious" problem areas because dissolved-oxygen concentrations often drop below 5 mg/L, but rarely below 3 mg/L. It should be noted, however, that investigations are currently being conducted at several TVA tributary reservoirs (Boone, Douglas, Norris, South Holston, and Tims Ford) in Tennessee through TVA's Reservoir

Releases Improvements Program to determine the feasibility of turbine venting and compressed air injection as possible methods for effectively and efficiently increasing the dissolved-oxygen concentrations in releases from these reservoirs without adversely impacting the reservoir's operation for hydropower generation. For example, during the past 3 years TVA has evaluated both turbine venting and compressed air injection at Norris Dam with results, to date, indicating an increase in dissolved-oxygen concentration of about 3 mg/L in releases from Norris Dam with no more than 1 percent loss in power generation efficiency. The technique used at Norris Dam consisted of baffles mounted on the hub of the turbine which creates a vacuum pulling more air through the existing aeration system over the full range of operation. This technique has not worked well on other units. Tests indicate that air blowers which force air into the water as it passes through the turbine would likely be more effective on turbines at some of the projects.

Reservoir development on the Tennessee River and its tributaries has had both beneficial and adverse effects on water quality. Beneficial effects include the stabilization of short-term fluctuations in streamflow and pollutant loads and creation of settling basins that reduce contamination, suspended solids, and turbidity. The designation of a reservoir as having a water-quality problem does not necessarily mean that beneficial uses are being impaired or that applicable standards are not being met. Usually, it simply means that at least one important water-quality indicator suggests that some problems are present and more serious problems may develop. The two most significant problems associated with reservoirs in the Tennessee River Basin are (1) low dissolved oxygen concentrations in reservoir releases and (2) nutrient enrichment leading to accelerated lake eutrophication. Summarized below by category - reservoir releases and reservoir water quality - is a brief overview of those reservoirs in the Tennessee part of the Tennessee River Basin which have been identified as having water-quality problems.

- Problems associated with reservoir releases include reduced levels of dissolved oxygen, increased levels of iron and manganese, and rapidly fluctuating water temperatures. Each of these conditions has the potential to affect water uses below reservoirs, particularly during severe or extended drought periods.

  Water-quality problems associated with increased concentrations of iron and manganese in reservoir releases are very limited in nature with only the South Holston River below South Holston Dam and the Duck River below Normandy Dam occasionally experiencing any problems. In general, no problems are experienced during normal reservoir operation; however, periodic maintenance activities at South Holston Dam require that water be sluiced which contains high concentrations of iron and manganese, primarily manganese. While these releases have adversely affected downstream water treatment plant operations, these sluicing operations are infrequent and closely coordinated with downstream water users to minimize adverse impacts.

  Generally speaking, altered thermal regimes in river reaches below Tennessee River mainstem and tributary dams due to reservoir releases are not viewed as problems, but rather as opportunities to improve recreational benefits by establishing managed, year-round, cold-water (trout) fisheries in the affected stream reaches. However, water releases from Cherokee, Douglas, and

Melton Hill Reservoirs have temperatures that are marginal for developing either a cold- or warm-water fishery, that is, too warm for cold-water species and too cold for warm-water species.

Reservoir Eutrophication

The principal reservoir water-quality problem is that of "cultural eutrophication." Eutrophication is a natural aging process by which lakes become more biologically productive until aquatic plants eventually cover the entire surface and the basin fills in with detritus and sediment. Although rivers and reservoirs are characterized by relatively constant water movement and thus do not age in the same way as natural lakes do, added nutrients may increase the productivity of rivers and reservoirs above desirable levels. Principal sources of nutrients, which accelerate the natural aging process, include municipal and industrial effluents and urban and agricultural runoff. Specific problems resulting from excessive eutrophication include (1) large daily fluctuations in dissolved-oxygen concentrations, (2) taste and odor in municipal water supplies, (3) increased water treatment costs due to clogged filters, (4) an unpleasant taste in food fish, (5) increased populations of rough fish with a gradual decline in the game fish population, (6) interference with normal water-oriented recreation activities, and (7) degradation of the general aesthetics of the water.

TVA recently completed an evaluation of the trophic status of several TVA reservoirs in Tennessee based on tropic potential and trophic response variables. The relative ranking for reservoirs located on the mainstem of the Tennessee River from least eutrophic to most eutrophic was: Pickwick, Kentucky, Chickamauga, Nickajack, Fork Loudoun, and Watts Bar. The rank of tributary reservoirs from least eutrophic to most eutrophic was: Norris, Watauga, South Holston, Tims Ford, Cherokee, Douglas, and Boone Reservoirs.

TVA plans to develop in cooperation with the State of Tennessee water-quality management plans for many of the TVA reservoirs in the State. These plans will assess existing water-quality conditions, identify allowable waste loads where necessary and recommend management strategies of correcting existing problems and for protecting the beneficial water uses of the reservoir. Plans for Cherokee, Tellico, and Fort Loudoun Reservoirs are nearing completion.

Ground-Water Quality

In addition to surface-water quality problems, the potential for serious ground-water pollution has also received considerable attention in recent years. Many of the Tennessee Valley's ground-water resources, particularly in east and east-central Tennessee, are vulnerable to contamination from a wide variety of sources including the direct infiltration of surface water transported pollutants through sinkholes. Common sources of ground-water pollution include (1) leachate from municipal and industrial waste disposal facilities, (2) agricultural runoff from fertilizer, pesticides and herbicides, and livestock wastes, and (3) runoff from surface mine lands and limestone quarries.

Well Construction and Development

There is a general lack of public awareness of the problems that may be involved with the development of ground-water resources. Often the proper information is not sought or is not properly analyzed before a ground-water-related development is started. Summarized below are some of the problems related to the development of ground-water resources in Tennessee. Note, these are not listed in order of frequency of occurrence or overall severity.

- Drilling below the base of fresh ground water
- Finishing a well above the most suitable aquifer
- Locating a well too close to other pumping wells
- Locating a well too close to a source of contamination
- Improper well construction and incomplete well development
- Pumpage-induced land subsidence
- Pumpage-induced transport of contaminants

Drilling below the base of fresh ground water is generally a waste of time and money and will increase the chances of well contamination as the hydrostatic head is reduced by pumping. Deep test holes commonly pass through both fresh ground water and aquifers which contain undesirable water. If the undesirable water zones are not properly plugged, the well becomes a conduit for undesirable water to leak into freshwater zones that have lower hydrostatic heads. This problem has occurred in the Western Valley, Central Basin, Highland Rim, and Valley and Ridge areas in Tennessee.

A well driller may stop drilling a well above the most suitable water-bearing zone when he does not have an adequate knowledge of the geohydrologic characteristics of the area where he is drilling. This problem has occurred throughout Tennessee. A driller's experience, training, and consultation with persons knowledgeable in the area's ground-water occurrence are essential to developing dependable, good-quality ground-water supplies.

Locating a well too close to other pumping wells often results in interference between the wells when they produce water from the same aquifer. The cones of depression in the water table created by continued withdrawals may coalesce. This condition will significantly reduce the amount of water that the aquifer will yield to individual wells and can significantly increase pumping lifts and cost. Proper spacing between wells should be determined during the initial test pumping of the well. This problem has occurred throughout Tennessee.

Location of a well too close to a source of contamination generally results in the well yielding contaminated water. Some of the potential sources of ground-water contamination in Tennessee include leaky sewers, septic tanks, landfills, mining of minerals which contain contaminants, petroleum exploration and development, feedlots, herbicides, and pesticides. Identifying the potential recharge area to a ground-water source and identifying the potential sources of contamination within the recharge area are essential in proper well siting. Determining a suitable distance between wells and contamination sources requires a knowledge of the ground-water gradient, flow pathways, and the capacity of the material to attenuate the contaminants. Again, this problem has also occurred throughout Tennessee.

Incomplete well construction and development usually result in wells which yield turbid or muddy water. A sufficient length of casing adequately seated in consolidated material, sufficient backfill material around the casing annulus, and a well seal on top of the casing will prevent surface contaminants from entering the well. The process of flushing the well with water and air pressure removes well cuttings remaining in the well from the drilling and ensures that the well screen in unconsolidated material or the water-bearing opening in consolidated material is not clogged. This problem has occurred throughout Tennessee.

Deficiencies in public-supply well design, construction, and development often cause wells to yield water which is deficient in both quantity and quality. Most of the small public water systems in Tennessee which utilize well sources did not include adequate well design or supervised well construction and development procedures. These situations often result in wells which yield turbid water or low quantities of water. Also, some of the problems with public water supply wells in Tennessee which have been attributed to deficient ground-water quantities may actually be attributable to deficient well construction methods. To ensure that public supply wells are adequately connected to the aquifer, they should be properly designed, supervised during construction to ensure compliance with design specifications, and properly developed to ensure safe, dependable ground-water yields.

Well pumpage can induce land subsidence in local areas underlain by shallow solution cavities in carbonate bedrock. As the water table is lowered by pumpage, the support provided by the water between the grains of the material overlying the rock is removed. This process initiates the potential for settlement of the surface soils and if there is an excessive removal of silt by pumpage, the land support above shallow cavities is removed, causing a surface collapse of the material into the subsurface cavities. This problem has occurred in some local carbonate areas of Tennessee.

Pumpage can also induce transport of contaminants when wells are installed near contamination sources. Ground-water movement in the vicinity of pumping wells is radial towards the well or point of withdrawal. As pumping increases, a cone of depression in the water table around the well is formed. If there are potential contaminants within the area affected by the pumpage, the well will yield contaminated water. This problem has occurred in some local areas of Tennessee.