5.4 Water Quality

5.4.1 Introduction

This section represents a summary analysis of the impacts of the policy alternatives on water quality. The primary evaluation tool was a numerical water quality model. A number of reservoir and riverine water quality metrics derived from the model formed the basis of this analysis. Effects of changes in water quality on aquatic resources, threatened and endangered species, water supply, and power (among other resources that are associated with water quality) are discussed in other sections of the EIS.

The representation of existing conditions used to quantify the impacts of the policy alternatives on water quality is called the Base Case. The Base Case is an integration of current conditions and currently scheduled changes to the system. In effect, the Base Case moves the current condition to a point in the future when all reasonably foreseeable, currently scheduled changes in the system have been implemented.

The alternatives under consideration generally vary in the timing and amount of water flow through the system. Changes in this timing may alter the retention times of the reservoirs, the degree and extent of thermal stratification, the temperatures of reservoirs and tailwaters, and DO concentrations in reservoirs and tailwaters. These characteristics and the metrics that describe them represent the majority of anticipated water quality changes associated with the alternatives considered and are the main focus of the water quality analysis. Many of the tailwaters have target DO concentrations set by the Lake Improvement Plan. These targets were incorporated into all of the alternatives because the Lake Improvement Plan targets will be maintained regardless of the policy alternative selected. Release targets and a list of projects included in the Lake Improvement Plan are presented in Appendix A, Table A-05.

Other water quality parameters that could be affected by reservoir operations (as described in Section 4.4) are closely related to residence time, temperature, and DO. Parameters in this category include manganese, sulfides, and ammonia, which are formed or move from reservoir sediments when DO concentrations are low. Analysis of very low DO concentrations (termed anoxia in this analysis) in the reservoirs captures these parameters. Phosphorus is released from sediments when DO concentrations are low—although the majority of the phosphorus in the system comes from sources in the watershed that would be unaffected by any of the policy alternatives under consideration. The relative contribution of sediment-released phosphorus to the total amount present throughout the TVA reservoir system would increase under any alternative that results in lower reservoir DO concentrations.

System-wide turbidity and sediment deposition attributable to reservoir operations are not expected to change substantially under any alternative. Localized erosion related to reservoir operations is discussed in Section 5.16, Shoreline Erosion. Likewise, the fate and transport of contaminants in the sediments throughout the TVA reservoir system are not anticipated to be influenced substantially by a change in reservoir operations, except for those compounds and contaminants mentioned above that are mobilized when DO concentrations are low. The occurrence of bacteria and pathogens in the system would not be substantially affected by any policy alternative.

5.4.2 Impact Assessment Methods and Data Summarization

TVA water quality monitoring has been conducted under various weather and reservoir flow conditions that have resulted in a wide range of water quality conditions. Understanding of the historical variability in water quality throughout the TVA reservoir system has fostered the development of models of water flow and quality. When combined with water quality data, these models are useful as tools to identify differences in water quality between the Base Case and alternative reservoir operations policies. Experience gained from TVA's monitoring program has substantiated the intuitive relationship between reservoir flows and water quality. Although quantifying the extent of these changes under various operating regimes is a job best suited for models, the real-world experience based on TVA's Reservoir Vital Signs Monitoring Program is essential for appropriate interpretation of modeling results. The following evaluation of various policy alternatives is based on this two-pronged approach. The water quality models are used to evaluate flows, temperature, and DO concentrations as they relate to the policy alternatives. The relationship of algae (measured by chlorophyll-a) to water retention time in the reservoirs was evaluated using data from TVA's Vital Signs Monitoring Program.

Water Quality Modeling

TVA developed water quality models of 32 reservoirs and 12 tailwaters using computer programs TVARMS (Hauser et al. 1995), BETTER (Bender et al. 1990), and CE-QUAL-W2 (Cole and Buchak 1995) (Appendix C). The models simulate hydrodynamic and water quality conditions, such as water movement, temperature, thermal stratification, and DO concentrations.

The modeling approach used in this evaluation was to link models of individual reservoirs and tailwaters to simulate nearly the entire TVA river system—using the water quality model SysTempO. The models simulate the physical, chemical, and biological processes in sections of the system. TVARMS is used for the riverine sections, and CE-QUAL-W2 and BETTER are used for the reservoirs. SysTempO links the river and reservoir models. The methodology uses water quality data outputs from upstream waterbodies as input for the next tailwater or reservoir downstream. Existing water quality improvements were not included in models of reservoirs where in some cases aeration equipment injects compressed air or liquid oxygen immediately upstream of the dam. When SysTempO sets upstream inflow water quality for the next downstream dam, the Lake Improvement Plan DO targets are used. Release targets and a list of projects included in the Lake Improvement Plan are presented in Appendix A, Table A-05.

The individual elements in SysTempO were pre-calibrated for at least 1 year of data before being linked. After linking models together in SysTempO, 8 years (1987 to 1994) of modeled temperature and DO were compared to measured data. Calibrations were adjusted to closely approximate observed conditions. Generally, modeled temperatures were within 1 °F of those measured, and modeled DO was within 1 mg/L for most locations. The model was then used to simulate conditions under the Base Case and policy alternatives in order to examine the effects of changes in the existing reservoir operations policy.

The result was a set of tools that enabled the simultaneous evaluation of the policy alternatives on reservoir and tailwater water quality throughout the TVA reservoir system. To help focus evaluation on important water quality impacts associated with operational modifications linked to different alternatives, model results over a broad range of hydrometeorologic conditions represented in the 1987–1994 period were used to generate estimates of the water quality metrics described in Table 5.4-01 for all policy alternatives under consideration. A broad variety of hydrologic and weather conditions were experienced during this period. For example, certain years within this time period could be considered representative of normal conditions (1990), hot and dry conditions (1993), and cool and wet conditions (1994).

Table 5.4-01 Water Quality Metrics Used to Evaluate Policy Alternatives

Parameter	Metric	Target Use Potentially Affected
Reservoirs		
Hydrodynamics	Summer residence time from 6/1 to 9/30 (days)	General water quality
	Days that forebay surface-bottom temperature is ≥4 °C (# days)	General water quality
	Maximum forebay surface-bottom temperature difference (°C)	General water quality
	Sum of daily total reservoir volume (million m^3-days)	General water quality
Dissolved oxygen	Sum of daily volume DO ≤5 mg/L (million m^3-days)	General water quality
	Minimum reservoir volume DO ≥5 mg/L (million m^3-days) on worst-case day	Assimilative capacity
	Sum of daily volume DO ≤2 mg/L (million m^3-days) from 7/1 to 10/31	Tolerant aquatic life support
	Sum of daily volume DO ≤1 mg/L (million m^3-days)	Potential anoxia
Temperature	Sum of daily volume temperature >26 °C (million m^3-days)	Assimilative capacity
	Sum of daily volume temperature ≤10 °C (million m^3-days)	Cold water in storage
Algal activity	Chlorophyll-a concentration (micrograms/L)	Trophic status
Dam Releases		
Dissolved oxygen	Average annual minimum DO (mg/L)	General water quality
	Average number days/year DO <5 mg/L	General water quality
Temperature	Average annual maximum temperature (°C)	General water quality
	Average number of days/year temperature >10 °C	General water quality

Notes:

All results were derived from the water quality model, except for algal activity, which were assessed using Vital Signs Monitoring Program data.

DO = Dissolved oxygen.

This approach was used successfully and consistently for most alternatives. The Summer Hydropower Alternative resulted in flow and elevation conditions that prevented completion of successful model runs during certain dry years; therefore, water quality model results for the Summer Hydropower Alternative were based on 1990 to 1994 rather than the full 8-year period referenced above for the other alternatives. This situation did not allow full evaluation of effects on water quality of operations under the Summer Hydropower Alternative under all flow conditions. Consequently, evaluations of effects under this alternative must be viewed cautiously with this limitation in mind. Also, it is inappropriate to directly compare water quality effects of the Summer Hydropower Alternative to effects resulting from operations under the remaining policy alternatives because of the more limited set of weather and flow conditions used for the Summer Hydropower Alternative.

Use of Vital Signs Monitoring Results

The relationship of algae (measured by chlorophyll-a) to water retention time in the reservoirs was evaluated using Vital Signs Monitoring Program data and linear regression because the water quality model was not calibrated specifically for algal growth. A comparison of long-term average chlorophyll-*a* concentrations to 2002 data (a low-flow year similar to many of the alternatives) supplemented the evaluation, allowing an assessment of the impact of lower flow rates associated with many of the policy alternatives on algal growth.

Selection of Representative Reservoirs/Dam Releases

The integrated SysTempO model was run for 32 reservoirs and 12 tailwaters. Detailed water quality analyses and evaluations were compiled from a subset of reservoirs and dam releases that represent a variety of reservoir types and geographic regions. Specific water quality issues within certain reservoirs may not be reflected in this set of reservoirs; however, the overriding water quality issues appropriate for a programmatic evaluation are represented.

Representative reservoirs for three reservoir categories defined specifically for water quality analyses include:

- **Storage Tributary Reservoirs.** These reservoirs generally have long retention times and substantial winter drawdown for flood control. A total of 13 storage tributary reservoirs could be affected by policy alternatives. South Holston and Douglas Reservoirs initially were selected to represent tributary storage reservoirs. Hiwassee Reservoir was added to this group as a representative reservoir in response to comments received during review of the DEIS that suggested inclusion of a reservoir representative of the high-elevation reservoirs in the nutrient-poor Blue Ridge physiographic region.

- **Transitional Tributary Reservoirs.** This group of reservoirs did not fit with the other tributary reservoirs because the reservoirs have a relatively short retention, have nominal winter drawdown, or are much smaller. Five transitional reservoirs could be affected by policy alternatives. Boone and Melton Hill Reservoirs were selected to represent transitional tributary reservoirs.

- **Mainstem Reservoirs.** These reservoirs are typified by short retention times and nominal winter drawdown. Kentucky is the most downstream reservoir and represents the water quality that leaves the TVA reservoir system. Nine mainstem reservoirs would be potentially affected by policy alternatives. Three reservoirs were initially selected to represent mainstem reservoirs: Guntersville, Pickwick, and Kentucky. Watts Bar Reservoir was added as a representative mainstem reservoir following completion of the DEIS because one of the operational changes considered under the Preferred Alternative is delayed spring fill of three mainstem reservoirs (Fort Loudoun, Watts Bar, and Chickamauga), none of which had been included the initial set of representative reservoirs.

Summarization of Results

Appendix D1 provides detailed results from the water quality model for the Base Case and each policy alternative. In Appendix D1, Table D1-02 presents a compilation of metric results from the water quality model for reservoirs under the Base Case and all policy alternatives except the Summer Hydropower Alternative; Table D1-03 presents this information for the Summer Hydropower Alternative. Tables D1-04 and D1-05 present comparable information for dam releases.

Tables 5.4-02 and 5.4-03 summarize the detailed results from Tables D1-02–05 by using categories to describe the magnitude of relative change in water quality metrics between the Base Case and each policy alternative. Four categories were selected to quantify changes from the Base Case. These include; 0 to10 percent; 11 to 25 percent; 26 to 50 percent; and >50 percent.

In the following text, Section 5.4.3 summarizes Base Case conditions. Sections 5.4.4 through 5.4.11 use the quantitative changes in Tables 5.4-02 and 5.4-03 as the basis for discussion of relative changes for each policy alternative. Section 5.4.12 examines effects of policy alternatives on water quality under low-flow conditions. Flow conditions for 1993 were used in this analysis. The analysis in Section 5.4.12 is parallel to that in Sections 5.4.4 through 5.4.11 in that it provides a quantitative comparison of changes as they relate to the Base Case. A more thorough evaluation of impacts on assimilative capacity and the potential for formation of anoxic products is provided in Sections 5.4.15 and 5.4.16.

Table 5.4-03 reflects the effect and importance of TVA's commitment to maintain tailwater DO concentrations at or above targets set by the Lake Improvement Plan. Although Table 5.4-02 shows that larger volumes of low DO water would occur in some reservoirs (e.g., Hiwassee) under some policy alternatives, this would not be reflected in downstream tailwater releases. TVA would improve the lower DO levels by a corresponding increase in aeration methods. This explains why, in Table 5.4-03, reservoirs with downstream aeration facilities are listed as "LIP target."

Categories of change in Tables 5.4-02 and 5.4-03 were subjectively defined as follows:

- Not different from the Base Case = +/-10% of base (shown in these tables as “**o**”).
- Increase compared to the Base Case = 11 to 25% change from conditions under the Base Case (shown in these tables as“↑“).
- Decrease compared to the Base Case = 11 to 25% change from conditions under the Base Case (shown in these tables as“↓“).
- An “*” is used in Tables 5.4-02 and 5.4-03 if changes from the Base Case were from 26 to 50%, and a double “**” is used if changes were >50% change from the Base Case.
- <u>Note</u> - The symbol “∞” is used in these tables to identify occurrences when both Base Case data and alternative data are infinitely small, causing nominal changes from the Base Case to appear quite large proportionally. Caution is needed in interpreting results in this situation, and the reader is urged to refer to tables in Appendix D1, where actual results for each water quality metric under the Base Case and each action alternative are provided.)

This approach facilitates a relative evaluation of each alternative compared to conditions under the Base Case. The up or down direction of arrows should not be construed to indicate improvement or degradation of water quality. The arrows only indicate change from conditions under the Base Case.

It should be noted that 13 tributaries, five transitional, and nine mainstem reservoirs were considered in this analysis. Mainstem and tributary reservoirs are more numerous in the system than transition reservoirs and collectively impound a much greater volume of water. Consequently, impacts on mainstem and tributary reservoirs should carry more weight than impacts on transitional reservoirs.

Table 5.4-02 Summation of Responses for Water Quality Characteristics in Representative Reservoirs by Policy Alternative

Alternative	Reservoir	Change in Reservoir Volume with Dissolved Oxygen Concentrations Compared to Base Case				Change in Reservoir Volume with Water Temperature Compared to Base Case	
		≤5 mg/L	≤2 mg/L	≤1 mg/L	≥5 mg/L	>26 ºC	≤10 ºC
Reservoir Recreation A	South Holston	o	o	o	↑	↑	o
	Douglas	o	↑	↑	↑*	o	↑
	Hiwassee	o	↑	↑**	o	o	↑
	Boone	↑*	↑∞	↑∞	↓	↑	o
	Melton Hill	↑**	↑∞	↑∞	o	↑*	o
	Watts Bar	o	↑*	↑**	o	o	o
	Guntersville	↑	↑**	↑*	o	o	o
	Pickwick	↑	↑*	↑*	o	o	o
	Kentucky	↑	↑	o	o	o	o
Reservoir Recreation B	South Holston	↑	o	o	↑	↑	↑
	Douglas	↑	↑*	↑	↑*	↑	↑*
	Hiwassee	↑	↑*	↑*	o	o	↑
	Boone	↑	↑**	↑∞	o	↑	o
	Melton Hill	↑**	↑∞	↑∞	o	↑**	↑
	Watts Bar	o	↑*	↑**	o	↑	o
	Guntersville	↑*	↑**	↑**	o	o	o
	Pickwick	↑	↑**	↑**	o	o	o
	Kentucky	↑*	↑**	↑**	o	o	↑
Summer Hydropower	South Holston	o	o	↑	↓	o	o
	Douglas	↓	↓*	↓	↑*	o	↑*
	Hiwassee	↓*	↓	↓	↓	↓*	o
	Boone	↓*	↑∞	↑∞	↓*	↓*	o
	Melton Hill	o	↑∞	↑∞	o	↓	↑
	Watts Bar	o	↓	↓*	↓*	o	o
	Guntersville	↓*	↓**	↓**	o	o	o
	Pickwick	↓*	↓**	↓**	o	o	o
	Kentucky	↓*	↓**	↓**	o	o	o

Table 5.4-02 Summation of Responses for Water Quality Characteristics in Representative Reservoirs by Policy Alternative (continued)

Alternative	Reservoir	Change in Reservoir Volume with Dissolved Oxygen Concentrations Compared to Base Case				Change in Reservoir Volume with Water Temperature Compared to Base Case	
		≤5 mg/L	≤2 mg/L	≤1 mg/L	≥5 mg/L	>26 ºC	≤10 ºC
Equalized Summer/ Winter Flood Risk	South Holston	o	o	o	o	o	o
	Douglas	↓*	↓*	↓*	o	o	o
	Hiwassee	o	o	↑	↓	o	o
	Boone	↑	↑∞	↑∞	↓	↓*	↑
	Melton Hill	↑**	↑∞	↑∞	↓	↑**	↑
	Watts Bar	o	↑*	↑**	o	↑*	o
	Guntersville	↑	↑*	↑	o	o	o
	Pickwick	↑	↑*	↑*	o	o	o
	Kentucky	↑	↑**	↑**	o	o	o
Commercial Navigation	South Holston	o	o	o	o	o	o
	Douglas	o	o	o	o	o	o
	Hiwassee	o	o	o	o	o	o
	Boone	o	↑∞	↑∞	o	o	o
	Melton Hill	o	o	o	o	o	o
	Watts Bar	o	o	o	o	o	o
	Guntersville	o	o	↓	o	o	o
	Pickwick	o	o	o	o	o	o
	Kentucky	o	↓*	↓*	o	o	↑
Tailwater Recreation	South Holston	↑	o	o	↑	↑	↑
	Douglas	↑	↑	↑	↑*	↑	↑*
	Hiwassee	↑	↑**	↑**	↓	o	o
	Boone	↑	↑∞	↑∞	o	↑	o
	Melton Hill	↑**	o	↓∞	o	↑*	↑
	Watts Bar	o	↑*	↑**	o	↑	o
	Guntersville	↑*	↑**	↑*	o	o	o
	Pickwick	↑	↑**	↑**	o	o	o
	Kentucky	↑	↑**	↑**	o	o	↑

Table 5.4-02 Summation of Responses for Water Quality Characteristics in Representative Reservoirs by Policy Alternative (continued)

Alternative	Reservoir	Change in Reservoir Volume with Dissolved Oxygen Concentrations Compared to Base Case				Change in Reservoir Volume with Water Temperature Compared to Base Case	
		≤5 mg/L	≤2 mg/L	≤1 mg/L	≥5 mg/L	>26 ºC	≤10 ºC
Tailwater Habitat	South Holston	↑	o	o	↑	↑	o
	Douglas	↑*	↑*	↑*	↑**	↑	↑*
	Hiwassee	↑*	↑**	↑**	↓	↓	↑
	Boone	↑	↑∞	↑∞	o	↑	o
	Melton Hill	↑**	↑∞	↑∞	↓	↑**	o
	Watts Bar	o	↑	↑*	o	↑*	o
	Guntersville	↑*	↑**	↑*	o	o	o
	Pickwick	↑	↑**	↑*	o	o	o
	Kentucky	↑**	↑**	↑**	o	o	o
Preferred	South Holston	o	o	o	o	o	o
	Douglas	o	o	o	↑*	o	↑
	Hiwassee	o	o	o	o	o	↑*
	Boone	↑	↑∞	↑∞	o	↑	o
	Melton Hill	↑**	↓∞	↓∞	o	o	o
	Watts Bar	↑	↑**	↑**	↓	o	o
	Guntersville	o	↓	o	o	o	o
	Pickwick	o	↑*	↑	o	o	o
	Kentucky	↑	↑	o	o	o	o

Notes:

Responses are relative to conditions under the Base Case.

Model results for each water quality metric under the Base Case and each policy alternative are provided in Table D1-02 for all alternatives other than the Summer Hydropower and are based on hydrometeorologic conditions that existed from 1987 to 1994. Table D1-03 provides water quality characteristics for the Base Case and the Summer Hydropower Alternative based on hydrometeorologic conditions that existed from 1990 to 1994.

o = No appreciable change from conditions under the Base Case (+/- 10%).
↑ or ↓ = Used to identify changes (+/-) from conditions under the Base Case from 11 to 25%.
* = Used to identified changes (+/-) from conditions under the Base Case from 26 to 50%.
* * = Used to identify changes (+/-) from conditions under the Base Case >50%.
∞ = Used to identify occurrences when both Base Case data and policy alternative data are infinitely small, causing nominal changes from base to appear quite large proportionally.

Table 5.4-03 Summation of Responses for Water Quality Characteristics in Representative Dam Releases by Policy Alternative

Alternative	Reservoir	Dissolved Oxygen		Temperature	
		Annual Average Minimum DO	Average Number Days/Year DO <5 mg/L	Average Days/Year Temperature >10 °C	Annual Average Maximum Temperature
Reservoir Recreation A	South Holston	LIP target	LIP target	↑	o
	Douglas	LIP target	LIP target	o	o
	Hiwassee	LIP target	LIP target	o	o
	Boone	LIP target	LIP target	o	o
	Melton Hill	↓	↑**	o	o
	Watts Bar	LIP target	LIP target	o	o
	Guntersville	o	↑	o	o
	Pickwick	o	↑*	o	o
	Kentucky	↓	↑	o	o
Reservoir Recreation B	South Holston	LIP target	LIP target	↑*	o
	Douglas	LIP target	LIP target	o	o
	Hiwassee	LIP target	LIP target	o	o
	Boone	LIP target	LIP target	o	o
	Melton Hill	↓	↑**	o	o
	Watts Bar	LIP target	LIP target	o	o
	Guntersville	o	↑*	o	o
	Pickwick	o	↑*	o	o
	Kentucky	↓	↑	o	o
Summer Hydropower	South Holston	LIP target	LIP target	o	o
	Douglas	LIP target	LIP target	o	o
	Hiwassee	LIP target	LIP target	o	o
	Boone	LIP target	LIP target	o	↑
	Melton Hill	o	o	o	o
	Watts Bar	LIP target	LIP target	o	o
	Guntersville	↑	↓**	o	o
	Pickwick	↑	↓**	o	o
	Kentucky	↑	↓**	o	o
Equalized Summer/ Winter Flood Risk	South Holston	LIP target	LIP target	↑	o
	Douglas	LIP target	LIP target	o	o
	Hiwassee	LIP target	LIP target	o	o
	Boone	LIP target	LIP target	o	o
	Melton Hill	↓	↑**	o	o
	Watts Bar	LIP target	LIP target	o	o
	Guntersville	o	↑	o	o
	Pickwick	o	↑*	o	o
	Kentucky	↓	↑*	o	o

Table 5.4-03 Summation of Responses for Water Quality Characteristics in Representative Dam Releases by Policy Alternative (continued)

Alternative	Reservoir	Dissolved Oxygen		Temperature	
		Annual Average Minimum DO	Average Number Days/Year DO <5 mg/L	Average Days/Year Temperature >10 °C	Annual Average Maximum Temperature
Commercial Navigation	South Holston	LIP target	LIP target	o	o
	Douglas	LIP target	LIP target	o	o
	Hiwassee	LIP target	LIP target	o	o
	Boone	LIP target	LIP target	o	o
	Melton Hill	o	o	o	o
	Watts Bar	LIP target	LIP target	o	o
	Guntersville	o	o	o	o
	Pickwick	o	o	o	o
	Kentucky	↑	↓	o	o
Tailwater Recreation	South Holston	LIP target	LIP target	↑*	↓
	Douglas	LIP target	LIP target	o	o
	Hiwassee	LIP target	LIP target	o	o
	Boone	LIP target	LIP target	o	o
	Melton Hill	↓	↑**	o	o
	Watts Bar	LIP target	LIP target	o	o
	Guntersville	o	↑*	o	o
	Pickwick	o	↑*	o	o
	Kentucky	↓	↑	o	o
Tailwater Habitat	South Holston	LIP target	LIP target	↑*	o
	Douglas	LIP target	LIP target	o	o
	Hiwassee	LIP target	LIP target	o	o
	Boone	LIP target	LIP target	o	o
	Melton Hill	↓*	↑**	o	o
	Watts Bar	LIP target	LIP target	o	o
	Guntersville	o	↑**	o	o
	Pickwick	↓	↑**	o	o
	Kentucky	↓*	↑*	o	o

Table 5.4-03 Summation of Responses for Water Quality Characteristics in Representative Dam Releases by Policy Alternative (continued)

Alternative	Reservoir	Dissolved Oxygen		Temperature	
		Annual Average Minimum DO	Average Number Days/Year DO <5 mg/L	Average Days/Year Temperature >10 °C	Annual Average Maximum Temperature
Preferred	South Holston	LIP target	LIP target	**o**	**o**
	Douglas	LIP target	LIP target	**o**	**o**
	Hiwassee	LIP target	LIP target	**o**	**o**
	Boone	LIP target	LIP target	**o**	**o**
	Melton Hill	**o**	↑**	**o**	**o**
	Watts Bar	LIP target	LIP target	**o**	**o**
	Guntersville	**o**	↓*	**o**	**o**
	Pickwick	**o**	↑	**o**	**o**
	Kentucky	**o**	↑	**o**	**o**

Notes:

Responses are relative to conditions under the Base Case.

Model results for each water quality metric under the Base Case and policy alternatives are provided in Table D1-04 for all alternatives other than the Summer Hydropower Alternative and are based on hydrometeorologic conditions that existed from 1987 to 1994. Table D1-05 provides metric results for the Base Case and the Summer Hydropower Alternative based on hydrometeorologic conditions that existed from 1990 to 1994.

LIP = Lake Improvement Plan (TVA 1990).
o = No appreciable change from conditions under the Base Case (+/- 10%) .
↑ or ↓ = Used to identify changes (+/-) from conditions under the Base Case from 11 to 25%.
* = Changes (+/-) from conditions under the Base Case from 26 to 50%.
** = Changes (+/-) from conditions under the Base Case >50%.

5.4.3 Base Case

The Base Case represents a continuation of existing reservoir operations throughout the system. The water quality represented by the Base Case is described in detail in Section 4.4, Water Quality.

Under the Base Case, water temperature in the TVA reservoirs would continue to vary depending on the season, the weather, the amount of rainfall and the amount and temperature of water entering each reservoir. Most tributary reservoirs would stratify in summer and surface water temperatures would approach or exceed 30 °C in late summer. Those reservoirs that stratify would mix in early to late fall in response to cooling weather and release of cooler water from deep levels in the reservoirs through the dams. Tailwater temperatures downstream from tributary reservoirs would fluctuate during the summer stratification period as turbines are cycled on and off, periodically releasing cold reservoir water that is subsequently warmed as it moves downstream. During dry years, stratification would be somewhat stronger and possibly persist longer into fall. During wet years, stratification would be weaker and break down earlier in the season. The mainstem reservoirs would not stratify thermally to the extent of the tributary reservoirs due to the mixing created by shallower depths, higher flows, and shorter residence times. Slight vertical temperature differences and weak thermal stratification would occur, particularly during dry years when the upstream water is held back to fill the tributary reservoirs. The stratification that does occur would typically be broken up when flows are increased progressively in June, July, and August.

The deeper strata of the tributary reservoirs would continue to have little or no DO during thermal stratification in summer and late fall. Dissolved oxygen concentrations in the mainstem reservoirs would remain generally higher than in the tributary reservoirs due to shorter residence times in the mainstem reservoirs. Nevertheless, reduced DO concentrations would occur in some mainstem reservoirs during hot, dry periods. The release of water from the lower depths of many reservoirs would result in low concentrations of DO in the releases and downstream in tailwaters without DO mitigation and associated DO targets (Appendix A, Table A-05).

Tributary reservoirs would continue to experience periodic increases in algal growth in response to nutrient inputs from runoff from heavy rainstorms. Mainstem reservoirs would continue to experience increases in algal growth during hot, dry years when flow through the reservoirs is diminished.

5.4.4 Reservoir Recreation Alternative A

Under Reservoir Recreation Alternative A, the mainstem reservoirs would experience an increase in volumes of water with low DO concentrations and essentially no change in the volumes of water with the temperatures examined in the analysis.

The transitional tributary reservoirs would exhibit an increase in the volumes of water with low DO concentrations and an increase in the volume of warm water. Presence of large proportional increases in the volume of water with particularly low DO concentrations ($\leq$2 and $\leq$1 mg/L) must be interpreted cautiously because these volumes would be quite small under both the Base Case and Reservoir Recreation Alternative A.

The storage tributary reservoirs would tend to react differently to operating conditions under Reservoir Recreation Alternative A. For instance, Douglas and Hiwassee Reservoirs would tend to have an increase in the volume of cool water and little change in the volume of warm water, whereas South Holston would have an increase in the volume of warm water and little change in the volume of cool water. Douglas and South Holston Reservoirs would have an increase in the minimum volume of water available for assimilative capacity (i.e., an increase in the minimum volume of water with DO $\geq$5 mg/L), whereas Douglas and Hiwassee Reservoirs would have an increase in the volume of water with particularly low DO concentrations (i.e., $\leq$2 and $\leq$1 mg/L). The increase in volumes of cool/cold water would result both from higher pool levels in winter and summer, and the increase in volumes with low DO concentrations would result from higher pool levels and decreases in dam releases in late summer.

The operating conditions established under Reservoir Recreation Alternative A would increase the number of days each year in which discharges from the dams would have DO concentrations <5 mg/L for those representative reservoirs without aeration devices (i.e., Melton Hill, Guntersville, Pickwick, and Kentucky). The annual average minimum DO (i.e., the average of the lowest DO concentration that occurred each year in model runs) would be lower under Reservoir Recreation Alternative A than under Base Case conditions at Melton Hill and Kentucky Reservoirs but would be similar to the Base Case on Guntersville and Pickwick Reservoirs.

Generally, effects of Reservoir Recreation Alternative A on release temperature would be similar to those under the Base Case. However, releases at South Holston Reservoir would have fewer days each year when temperatures would exceed 10 °C (Table 5.4-03).

5.4.5 Reservoir Recreation Alternative B

The mainstem reservoirs would experience an increase in volumes of water with low DO concentrations under Reservoir Recreation Alternative B relative to the Base Case, particularly the volume with very low DO concentrations ($\leq$2 and $\leq$1 mg/L). Changes in volumes of warm water and cool water would be minor on the mainstem reservoirs under Reservoir Recreation Alternative B.

The transitional tributary reservoirs would exhibit an increase in the volumes of water with low DO concentrations as well as an increase in the volume of warm water. As described before, presence of large proportional increases in the volume of water with particularly low DO concentrations ($\leq$2 and $\leq$1 mg/L) must be interpreted cautiously because these volumes would be quite small in both Base Case and under Reservoir Recreation Alternative B.

The storage tributary reservoirs would exhibit more consistency in response to operational changes under Reservoir Recreation Alternative B than described above for Reservoir Recreation Alternative A. All three representative storage tributary reservoirs would experience an increase in the volume of water with low DO concentrations—Douglas and Hiwassee more so than South Holston. Also, these reservoirs would experience increases in not only volume of warm water but also volume of cool water—likely the result of higher pool levels in winter and in summer compared to the Base Case.

Similar to Reservoir Recreation Alternative A, operations under Reservoir Recreation Alternative B would increase the number of days each year in which dam releases would have DO concentrations <5 mg/L in releases from representative reservoirs that do not have aeration devices. It would reduce the annual average minimum DO in releases from Melton Hill and Kentucky Reservoirs but not those from Guntersville and Pickwick Reservoirs. Release temperatures under Reservoir Recreation Alternative B would be similar to those under Reservoir Recreation Alternative A. The annual average maximum temperature and the average number of days each year with release temperatures >10 °C would be similar to the Base Case except for releases from South Holston Reservoir, which would exhibit fewer days per year with releases above that temperature.

5.4.6 Summer Hydropower Alternative

As described in Section 5.4.2, the evaluation of effects of the Summer Hydropower Alternative on water quality is based on the set of hydrological conditions that existed in 1990–1994, whereas the evaluation for the other alternatives is based on a broader set of hydrological conditions that existed in 1987 to 1994.

The mainstem reservoirs would experience a substantial decrease in volumes of water with low DO concentrations under the Summer Hydropower Alternative. Effects on volumes of warm water and cool water at the temperatures examined for this evaluation would be minor on the mainstem reservoirs under the Summer Hydropower Alternative.

The transitional tributary reservoirs would exhibit an increase in the volumes of water with low DO concentrations under the Summer Hydropower Alternative as well as a decrease in the volume of warm water. As described before, presence of large proportional increases or decreases must be interpreted cautiously.

Response of the storage tributary reservoirs to operation under the Summer Hydropower Alternative would vary among reservoirs, although Douglas and Hiwassee would tend to respond similarly for most water quality characteristics. Douglas and Hiwassee Reservoirs would experience greater changes to water quality characteristics under the Summer Hydropower Alternative operation than would South Holston Reservoir. For example, Douglas and Hiwassee Reservoirs would tend to have a decrease in the volume of water with low DO at all concentrations examined, whereas South Holston Reservoir would have an increase in the volume with particularly low DO concentrations and no change in the volumes at the other concentrations. Douglas Reservoir would have an increase in the minimum volume of water available for assimilative capacity (DO ≥5 mg/L), while South Holston and Hiwassee Reservoirs would experience a decrease. Both Douglas and South Holston Reservoirs would have little change in the volume of warm water, but the volume of warm would decrease on Hiwassee

Reservoir. As for the volume of cool/cold water, South Holston and Hiwassee Reservoirs would be relatively unchanged, while Douglas Reservoir would experience a large increase.

The operating regime under the Summer Hydropower Alternative would increase the annual average minimum DO concentrations in releases from the mainstem reservoirs relative to the Base Case. The average number of days with release DO concentration >5 mg/L would be substantially lower in these same releases. DO concentrations in releases from tributary and transitional reservoirs would be similar to those under the Base Case. Release water temperatures under the Summer Hydropower Alternative would be similar to those under the Base Case.

5.4.7 Equalized Summer/Winter Flood Risk Alternative

The mainstem reservoirs would experience an increase in volumes of water with low DO concentrations and essentially no change in the volumes of warm or cool water under the Equalized Summer/Winter Flood Risk Alternative.

The transitional tributary reservoirs would also exhibit an increase in the volumes of water with low DO. As described above, presence of large proportional increases in the volume of water with particularly low DO concentrations (≤2 and ≤1 mg/L) must be interpreted cautiously. The volume of cool water would be larger in these reservoirs under the Equalized Summer/Winter Flood Risk Alternative than under the Base Case; however, the impact on the volume of warm water would differ between the two reservoirs. Boone would have a smaller volume of warm water and Melton Hill a larger volume—most likely due to differing operations of upstream storage tributary reservoirs under the Equalized Summer/Winter Flood Risk Alternative, which is tailored to individual watersheds to equalize flood risk throughout the year.

Water quality characteristics in the storage tributary reservoirs under the Equalized Summer/Winter Flood Risk Alternative would vary depending on watershed-specific flood risks. There would be only nominal differences in water quality characteristics on South Holston Reservoir under this alternative compared to Base Case operations. Hiwassee Reservoir would experience an increase in the volume of anoxic water (as represented by the DO ≤1 mg/L metric) and a decrease in the minimum volume of water available for assimilative capacity. Douglas Reservoir would exhibit a decrease in the volume of water with low DO concentrations—most likely due to a decrease in reservoir volume during summer months (compared to the Base Case), when low DO concentrations occur.

Water quality conditions in dam releases under the Equalized Summer/Winter Flood Risk Alternative would be almost identical to those described above for Reservoir Recreation Alternatives A and B. This is true for both DO and temperature measures.

5.4.8 Commercial Navigation Alternative

Mainstem reservoirs would experience only nominal changes to DO and temperature conditions under the Commercial Navigation Alternative. The uncommon exceptions would be a decrease in the volumes of water with particularly low DO concentrations on Kentucky Reservoir and, to lesser extent, Guntersville Reservoir. The transitional tributary reservoirs would exhibit essentially the same temperature and DO conditions under the Commercial Navigation Alternative as under the Base Case. The storage tributary reservoirs would likewise be unchanged under the Commercial Navigation Alternative.

The operating regime under the Commercial Navigation Alternative would be similar to that under the Base Case with only a few changes. Most of the release water quality characteristics under the Commercial Navigation Alternative would be similar to the Base Case, as indicated in Table 5.4-03. The exception to this observation would be at Kentucky Reservoir, where the annual average minimum DO of releases would be increased and the number of days with DO concentrations <5 mg/L would be reduced under the Commercial Navigation Alternative operations.

5.4.9 Tailwater Recreation Alternative

Changes to DO and temperature conditions in reservoirs under the Tailwater Recreation Alternative are sufficiently similar to those described above for Reservoir Recreation Alternative B to not be repeated here.

The operating regime under the Tailwater Recreation Alternative would be similar to that under Reservoir Recreation Alternative B. Similar changes to DO and temperature would also occur. The number of days each year in which discharges would have DO concentrations <5 mg/L would increase, and the average annual minimum DO would be lower at Melton Hill and Kentucky Reservoirs but similar to the Base Case at Guntersville and Pickwick Reservoirs.

The average number of days per year with release temperature >10 °C as well as the average annual maximum temperature in releases would be similar to the Base Case under the Tailwater Recreation Alternative at all representative dams, except South Holston. Releases at South Holston Reservoir would exceed 10 °C for fewer days each year and have a lower average annual maximum temperature.

5.4.10 Tailwater Habitat Alternative

The mainstem reservoirs would experience an increase in volumes of water with low DO concentrations under the Tailwater Habitat Alternative. The increase in volume of water with low DO concentrations (≤2 and ≤1 mg/L) would be substantial, particularly for Kentucky Reservoir. Impacts on volumes of warm water and cool water would be minor on the mainstem reservoirs under the Tailwater Habitat Alternative.

The transitional tributary reservoirs would also exhibit an increase in the volumes of water with low DO concentrations as well as an increase in the volume of warm water. As described before, the presence of large proportional increases must be interpreted cautiously.

All three representative storage tributary reservoirs would experience increases in the volume of water with low DO concentrations under the Tailwater Habitat Alternative. South Holston

Reservoir would be affected the least and Hiwassee Reservoir the most. Douglas and South Holston Reservoirs would tend to have an increase in the minimum volume of water available for assimilative capacity, whereas Hiwassee Reservoir would experience a decrease. Likewise, Douglas and South Holston Reservoirs would have an increase in volume of warm water and Hiwassee a decrease. Douglas and Hiwassee Reservoirs would tend to have an increase in the volume of cool water.

The operating regime under the Tailwater Habitat Alternative would reduce the annual average minimum DO concentrations in releases from Melton Hill, Pickwick, and Kentucky Reservoirs relative to the Base Case. The average number of days each with release DO concentration <5 mg/L would be substantially greater in these same releases and those at Guntersville Reservoir. Temperature impacts would be minor except for South Holston Reservoir, which would experience fewer days, when release temperatures exceed 10 °C.

5.4.11 Preferred Alternative

Section 4.4 describes the relationships between the reservoir operations policy and water quality in reservoirs and in dam releases, particularly as operations affect reservoir flows and residence times. A common concern related to most of the policy alternatives described above is increased residence times resulting from reduced flows during summer months compared to the Base Case, particularly for mainstem reservoirs. The Preferred Alternative would reduce the residence time concern by including higher system minimum flows through Chickamauga Reservoir in June, July, and August compared to Reservoir Recreation Alternatives A and B and the Tailwater Recreation Alternative. These higher summer minimum flows would occur as long as the system minimum operations guide curves are met or exceeded. Table 5.4-04 lists the preferred minimum flows at Chickamauga Dam each week during summer and the frequencies those flows would be expected to be met or exceeded under the Base Case and the Preferred Alternative. Chickamauga Dam was used in this comparison because Chickamauga is the location chosen to measure weekly system-wide minimum flows (see Chapter 3).

Potential water quality effects of these lower-than-preferred flows were evaluated in two ways. First, several of the 8 years included in the analysis (1987–1994) had modeled flows at or below the preferred minimums. These years are identified in Table 5.4-05. Second, one of these years (1993) had low flows representative of near worst-case conditions and was evaluated separately in Section 5.4.12.

The increased summer minimum flows under the Preferred Alternative would provide summer residence times more similar to the Base Case than most of the other policy alternatives. Results for the full 8-year model period indicate that largest increases in average summer residence time under the Preferred Alternative would occur on storage tributary reservoirs, which already have extended residence times under the Base Case. South Holston would experience the greatest increase in summer residence time, with a calculated hydraulic residence time of 483 days under the Preferred Alternative compared to 436 days under the Base Case.

Table 5.4-04 Frequency of Meeting Preferred Minimum Flows at Chickamauga during Summer under the Base Case and the Preferred Alternative

Week	Approximate Date	Preferred Minimum Flow for Preferred Alternative (cfs)	Percentage of Years Flows Would Be Met or Exceeded under Base Case (%)	Percentage of Years Flows Would Be Met or Exceeded under Preferred Alternative (%)
23	1st Week of June	14,000	83	86
24	2nd Week of June	15,000	82	86
25	3rd Week of June	16,000	76	82
26	4th Week of June	17,000	79	77
27	1st Week of July	19,000	76	60
28	2nd Week of July	21,000	77	52
29	3rd Week of July	23,000	76	40
30	4th Week of July	25,000	77	48
31-35	August	29,000	74	50

Table 5.4-05 Water Quality Model Years with Modeled Flows at or below Preferred Minimum Flows under the Preferred Alternative

Week	Preferred Minimum Flow (cfs)	1987	1988	1989	1990	1991	1992	1993	1994
23	14,000		X					X	
25	16,000	X	X					X	
27	19,000	X	X		X			X	
29	23,000	X	X		X	X	X	X	
30	25,000	X	X		X	X	X	X	
31	29,000	X	X		X	X	X	X	
33	29,000	X	X	X	X	X	X	X	

Residence time for representative transitional tributary reservoirs would be increased by 4 days or less under the Preferred Alternative. Average summer residence time on representative mainstem reservoirs would be increased by only 1 or 2 days under Preferred Alternative operations. A noteworthy point about residence time is that, as shown in Table 5.4-05, the occurrence of reservoir flows above the preferred minimum is higher than the Base Case in early summer and lower in late summer. Hence, residence time under the Preferred Alternative is expected to be longer in late summer than under the Base Case.

Operational changes under the Preferred Alternative would result in only minor changes in volumes of either warm or cool water in mainstem reservoirs. However, compared to the Base Case, three of the four representative mainstem reservoirs would experience an increase in the volume of water with low DO concentrations under the Preferred Alternative. Of these three, Watts Bar would experience the greatest increases. There would be more water in Watts Bar Reservoir with DO $\leq$5, $\leq$2, and $\leq$1 mg/L. Additionally, there would be a decrease in the minimum volume of water available for assimilative capacity (i.e., minimum volume with DO $\geq$5 mg/L on a "worst-case" day). Guntersville Reservoir would differ from the other three representative mainstem reservoirs—with an apparent reduction in the volume of water with particularly low DO concentrations (i.e., $\leq$2 mg/L and $\leq$1 mg/L) under the Preferred Alternative and only nominal changes in the volume available for assimilative capacity. Modeling results indicate that low DO concentrations in Guntersville Reservoir occur primarily during low-flow (drought) conditions, such as those that occurred during 1988. Reservoir flows do not have to be that low for low DO concentrations to occur on the other mainstem reservoirs. For most years, the Preferred Alternative would have slightly lower reservoir flows during summer than under the Base Case. However, flows during particularly dry years like 1988 would be greater under the Preferred Alternative than under the Base Case—if the reservoir system is operated as specified during extreme drought conditions such as those that occurred in 1988.

The transitional tributary reservoirs would also vary in response to operations under the Preferred Alternative. Under the Base Case, Boone Reservoir has a fairly large volume of water with DO $\leq$5 mg/L yet quite small volumes of water with particularly low DO concentrations (i.e., $\leq$2 and $\leq$1 mg/L). Although volumes of all three of these concentrations would increase on Boone Reservoir under the Preferred Alternative, the volume of water with particularly low DO concentrations would still be relatively small. Operation under the Preferred Alternative would tend to increase the volume of warm water in Boone but would result in little change in the volume of cool/cold water. Melton Hill Reservoir also has only a small volume of low DO water under the Base Case. Model results indicate that the volume with very low DO concentrations (i.e., $\leq$2 and $\leq$1 mg/L) might be even less under the Preferred Alternative. The volume of water with DO $\leq$5 mg/l would increase under the Preferred Alternative, but the actual volume would still be small in comparison to total reservoir volume. Temperature characteristics of Melton Hill Reservoir, as well as the minimum volume of water available for assimilative capacity, would be essentially unaffected by Preferred Alternative operations.

Operation under the Preferred Alternative would produce few changes in DO and temperature characteristics for the three storage tributary reservoirs examined. Water quality metrics (both DO and temperature) for South Holston Reservoir under the Preferred Alternative would be similar to those that would exist under the Base Case. For Hiwassee Reservoir, DO metrics under the Preferred Alternative would be similar to those under the Base Case, but the volume of cool/cold water would increase—probably due to higher elevation (and volume) in winter. For Douglas Reservoir, the volume of water available for assimilative capacity would increase, with no measurable changes in volumes of water with low DO concentrations. There would be essentially no change in the volume of warm water, but the volume of cold water would increase—similar to the situation on Hiwassee Reservoir.

The average annual minimum DO concentrations in releases from representative reservoirs that do not have aeration devices (i.e., Melton Hill, Guntersville, Pickwick, and Kentucky) would be similar under the Preferred Alternative to those that would occur under the Base Case. The other DO metric (average number of days/year with DO <5 mg/L) would be increased by the Preferred Alternative for Melton Hill, Pickwick, and Kentucky Reservoir releases, yet decreased for Guntersville releases. The reason that Guntersville Reservoir differs is the dramatic effects of very low-flow conditions due to drought, as described above for 1988. The Preferred Alternative would have no appreciable effect on either of the water temperature metrics (average number of days/year with temperature >10 °C and average annual maximum temperature).

5.4.12 Impacts of Policy Alternatives on DO under Low-Flow Conditions

In evaluating the potential effects of reservoir operations policy alternatives on water quality, it is important to consider a broad range of weather and reservoir conditions. In particular, it is important to consider a situation approximating a scenario that would be expected to occur periodically under hot, low-flow conditions. For the 8 years modeled, the system inflows above Chickamauga Dam for 1988 were the lowest in the last 100 years. Instead of focusing on such a severe drought year, TVA chose to examine a less extreme event. System inflows above Chickamauga Dam for another modeled year (1993) were the seventh-lowest of the last 100 years. This situation can be expected to occur more frequently than the 1988 drought; consequently, modeled flows and water quality conditions for 1993 were used to examine potential effects of the various alternatives under low-flow conditions.

This analysis focuses on effects of low flows on DO because DO is the water quality parameter expected to be most affected under these conditions and because DO is critical to maintaining acceptable water quality conditions in reservoirs. The volume of water with a DO concentration ≤1 mg/l, the metric representing potential anoxic conditions, was selected as the basis of comparison. Table 5.4-06 provides predicted volumes of water with low DO concentrations under each policy alternative, including the Base Case, for 1993 flow conditions. It also expresses those volumes as a percentage of the total reservoir volume during the periods when water quality modeling results predicted this condition would occur.

These results are summarized for each category of TVA reservoir, comparing the effects of operation under the various policy alternatives to the Base Case. Any substantial increase in volume of water with low DO concentration is undesirable.

Table 5.4-06 Predicted Water Volumes and Percentage of Total Reservoir Volume with Low DO Concentration by Policy Alternative (1993 Flows)

Reservoir	Sum of Daily Volumes of Water with DO ≤1 mg/L (million m3-days) and Percent of Total Reservoir Volume with DO ≤1 mg/L (1993 Conditions)								
	Base Case	Reservoir Recreation A	Reservoir Recreation B	Summer Hydropower	Equalized Summer/Winter Flood Risk	Commercial Navigation	Tailwater Recreation	Tailwater Habitat	Preferred
South Holston									
Volume	4,257	4,282	4,216	4,294	4,195	4,066	3,969	4,324	4,131
Percent of total volume	3.6%	3.6%	3.6%	4.1%	3.4%	3.5%	3.4%	3.7%	3.5%
Douglas									
Volume	33,948	33,084	39,551	14,259	19,942	33,983	39,275	45,089	33,032
Percent of total volume	19.8%	19.3%	20.7%	12.3%	17.0%	19.7%	20.6%	21.9%	19.4%
Hiwassee									
Volume	975	990	1,489	616	1,133	944	1,699	2,374	1,141
Percent of total volume	2.7%	2.7%	3.7%	2.7%	3.4%	2.6%	4.2%	5.9%	3.0%
Boone									
Volume	0	0	0	0	0	0	7	0	0
Percent of total volume	0%	0%	0%	0%	0%	0%	0.4%	0%	0%
Melton Hill									
Volume	10	141	61	0	79	11	4	261	28
Percent of total volume	0.6%	2.3%	0.9%	0%	1.1%	0.6%	0.1%	3.0%	0.5%
Watts Bar									
Volume	13,996	15,818	23,759	2,443	20,439	13,810	22,940	13,776	23,371
Percent of total volume	11.1%	12.2%	16.3%	2.7%	17.5%	11.1%	15.8%	11.2%	16.9%
Guntersville									
Volume	2,737	5,098	5,608	252	4,979	2,752	5,620	5,133	3,243
Percent of total volume	2.7%	4.9%	5.3%	0.3%	5.0%	2.7%	5.3%	4.7%	3.0%
Pickwick									
Volume	7,374	9,787	12,227	1,121	10,850	6,975	12,091	10,374	9,241
Percent of total volume	7.3%	9.3%	11.5%	1.3%	10.1%	6.9%	11. 4%	9.9%	8.8%
Kentucky									
Volume	863	2,702	3,341	237	3,118	319	3,332	9,890	1,648
Percent of total volume	0.3%	0.9%	1.1%	0.1%	1.0%	0.1%	1.1%	2.4%	0.4%

Storage Tributary Reservoirs

- Increase in low DO volume compared to the Base Case: Reservoir Recreation B, Tailwater Recreation Alternative, and Tailwater Habitat Alternative.
- Low DO volume similar to the Base Case: Reservoir Recreation Alternative A, Commercial Navigation Alternative, and Preferred Alternative.
- Decreased low DO volume compared to the Base Case: Summer Hydropower Alternative.
- Inconsistent response among reservoirs compared to the Base Case: Equalized Summer/Winter Flood Risk Alternative.

Transitional Tributary Reservoirs

- Model results indicate that volumes of water with low DO concentrations would be quite small relative to total reservoir volume under the Base Case and all the action alternatives.
- The largest increase in volume of low DO water would occur under the Tailwater Habitat Alternative, and a decrease would occur under the Summer Hydropower Alternative.

Mainstem Reservoirs

- The predicted volume of water with DO <1 mg/L and percentage of total reservoir volume would vary considerably among the representative mainstem reservoirs. Watts Bar Reservoir would have the largest low DO volume as well as the greatest proportion of total reservoir volume with DO <1 mg/L, and Kentucky would have the smallest volume and portion. Kentucky is the largest among all TVA reservoirs, with a total reservoir volume much greater than any of the other reservoirs.
- Increase in low DO volume compared to the Base Case: Reservoir Recreation Alternative A, Reservoir Recreation Alternative B, Equalized Summer/Winter Flood Risk Alternative, Tailwater Recreation Alternative, Tailwater Habitat Alternative, and the Preferred Alternative.
- Low DO volume similar to the Base Case: Commercial Navigation Alternative.
- Decrease in low DO volume compared to the Base Case: Summer Hydropower Alternative.

In summary, operation under the different policy alternatives under 1993 flow conditions would have varying effects on the volumes of low DO water, depending on alternative and reservoir.

Under the Commercial Navigation Alternative, the volume of low DO water in most reservoirs would be similar to those under the Base Case, and decreases would occur in most reservoirs under the Summer Hydropower Alternative. Under the other policy alternatives, low DO volumes appear to increase for most reservoirs—particularly the mainstem Tennessee River reservoirs.

Another important consideration is how alternatives affect summer hydraulic residence times, especially on mainstem reservoirs during low-flow years such as 1993. Table 5.4-07 shows the changes in summer residence times (days) for the representative mainstem reservoirs under each policy alternative.

Table 5.4-07 Summer Residence Time Changes for Representative Mainstem Reservoirs (1993 Flows)

Reservoir	Base Case (days)	Residence Time Changes Relative to Base Case (days)							
		Reservoir Recreation A	Reservoir Recreation B	Summer Hydropower	Equalized Summer/Winter Flood Risk	Commercial Navigation	Tailwater Recreation	Tailwater Habitat	Preferred
Watts Bar	24.8	+3.9	+10.4	-7.9	+13.6	+0.1	+9.7	+17.0	+3.3
Guntersville	21.3	+2.8	+7.9	-6.0	+9.9	0	+7.8	+11.6	+3.0
Pickwick	19.8	+3.3	+8.2	-6.5	+11.6	-0.2	+8.1	+11.7	+3.7
Kentucky	46.5	+7.2	+17.7	-10.2	+12.6	-0.8	+17.5	+16.9	+3.2

Notes:

Summer represents June 1 through September 30.

+ = Indicates an increase in residence time relative to the Base Case.

5.4.13 Impacts of Policy Alternatives on Algae

Impacts of alternative operations policies on algal activity are not included in Table 5.4-02 or the discussion of each alternative. Absence of an appropriate, alternative-specific predictive tool prevents such a presentation of potential effects. The water quality models used in this evaluation were not specifically calibrated for algal activity. As a result, the evaluation of potential effects of various alternatives was based on an examination of Vital Signs Monitoring Program results. A regression analysis for chlorophyll-a (a measure of the amount of algae) concentrations predicted generally small increases in chlorophyll-a among the alternatives, with a maximum increase less than 10 percent. Based on past monitoring experience, a larger increase was expected in reservoirs with relatively short residence times because operation under most alternatives would result in increased residence time, which should be sufficient to result in increased chlorophyll-a concentrations. Further analysis compared chlorophyll-a concentrations in each representative reservoir in 2002 to their respective long-term averages. The basis of this comparison was that low flows, because of drought conditions in 2002, were generally similar to those that would occur under several alternatives. In effect, the long-term average represents the Base Case, and 2002 represents alternatives that result in decreased summer flows (Reservoir Recreation Alternative A, Reservoir Recreation Alternative B, the Equalized Summer/Winter Flood Risk Alternative, the Tailwater Recreation Alternative, the Tailwater Habitat Alternative and, to a lesser extent, the Preferred Alternative). That comparison showed higher concentrations in all representative reservoirs in 2002 than the long-term average, with greatest increases in reservoirs with short retention times and least increases in reservoirs with long retention times. These results indicate that increased retention times due to lower flows associated with several alternatives could result in higher chlorophyll-a concentrations in several reservoirs, especially mainstem reservoirs. Based on 2002 results, some of the increases could be substantial.

5.4.14 General Water Quality Impacts

The water quality metrics described above provide a quantitative comparison among policy alternatives and are useful in determining the relative difference between the Base Case and the action alternatives. The focus of the analysis was on hydrodynamics, DO, and temperature. Of primary interest among these metrics are those that describe changes in DO concentrations. The presence, absence, and concentrations of DO in a reservoir both control and are controlled by many physical, chemical, and biological processes. Clearly, adequate DO concentrations are essential for many water uses such as support for a healthy and robust aquatic community and for assimilating oxygen demanding wastes.

The quantitative evaluation provided above for each policy alternative indicated that several of the operations policies would increase the volume of water with low DO concentrations. Potential implications of these increases could include loss of habitat for aquatic life, increased water treatment costs, loss in assimilative capacity, and increase in anoxic products. These changes would be expected to be of greater concern in reservoirs and tailwaters that never or rarely experience low DO concentrations than in those that experience such conditions routinely. Impacts of changes in water quality on aquatic resources are discussed in Section 5.7 (Aquatic Resources), impacts on threatened and endangered species are discussed in Section 5.13 (Threatened and Endangered Species), and impacts on water supply are discussed in Section 5.5 (Water Supply). Impacts of increases in volumes of water with low DO concentrations on assimilative capacity and the potential for anoxic products are described in Section 5.4.15.

5.4.15 Assimilative Capacity and Anoxic Products

The evaluation summarized in Table 5.4-08 uses the following criteria to describe relative impacts of alternatives on assimilative capacity and the extent of anoxia compared to the Base Case. These categories are similar in magnitude to those used previously, but include a judgment of whether the change would result in a beneficial or adverse impact on water quality. In addition to these quantitative changes, the evaluation considers other factors such as existence of low DO conditions under the Base Case, availability of an ample supply of water with adequate DO concentrations, and existence of aeration systems.

- Not different from the Base Case – +/-10% of Base Case (shown as No Change).

- Slightly Beneficial – 11 to 25% increase in the volume of water with DO ≥5 mg/L for assimilative capacity and 11 to 25% decrease in the volume of water DO ≤1 mg/L for evaluation of anoxia.

- Beneficial – 26 to 50% increase in the volume of water with DO ≥5 mg/L for assimilative capacity and 26 to 50% decrease in the volume of water DO ≤1 mg/L for evaluation of anoxia.

- Substantially Beneficial – >50% increase in the volume of water with DO ≥5 mg/L for assimilative capacity and >50% decrease in the volume of water DO ≤1 mg/L for evaluation of anoxia.

- Slightly Adverse – 11 to 25% decrease in the volume of water with DO ≥5 mg/L for assimilative capacity and 11 to 25% increase in the volume of water DO ≤1 mg/L for evaluation of anoxia.

- Adverse – 26 to 50% decrease in the volume of water with DO ≥5 mg/L for assimilative capacity and 26 to 50% increase in the volume of water DO ≤1 mg/L for evaluation of anoxia.

- Substantially Adverse – >50% decrease in the volume of water with DO ≥5 mg/L for assimilative capacity and >50% increase in the volume of water DO ≤1 mg/L for evaluation of anoxia.

- Note: The volume of water associated with certain metrics under certain alternatives for certain reservoirs could be quite small, causing nominal changes from the Base Case to appear quite large proportionally. Consequently, absolute volumes in Appendix D1 also were considered. Where this occurred, the judgment was labeled as Slightly Beneficial or Slightly Adverse regardless of the actual percentage change.

Assimilative Capacity

The analysis on impacts of reservoir operations on assimilative capacity was accomplished using the metric that measured the minimum volume of reservoir water that exceeded 5 mg/L oxygen on the “worst-case” day for each of the 8 years examined by the water quality model. It was assumed that this condition would provide a constraint on the amount of oxygen consuming waste a reservoir could accept. The analysis used this parameter as an indicator of the system-wide impacts of policy alternatives on the ability of the reservoirs to assimilate oxygen consuming wastes. The analysis did not evaluate specific discharges, it did not evaluate potential discharges to tailwaters or free-flowing sections, nor did it evaluate the ability of the system to assimilate other wastes that do not consume oxygen. A beneficial impact under this category of uses is defined as an increase in assimilative capacity while an adverse impact is defined as a loss in assimilative capacity.

Table 5.4-08 Summary of Impacts on Assimilative Capacity and Anoxia by Policy Alternative

Alternative	Assimilative Capacity	Potential for Anoxic Products
Reservoir Recreation A	This policy alternative would result in a slight increase in the minimum volume of water available to assimilate oxygen consuming wastes on tributary storage reservoirs (Slightly Beneficial). For the transitional tributary reservoirs, there would either be no change or a slight reduction in this volume (No Change – Slightly Adverse). This volume would be relatively unchanged from the Base Case for the mainstem reservoirs (No Change).	The volume of water with oxygen concentrations favoring development of anoxic products would increase somewhat on the storage tributary reservoirs and transitional tributary reservoirs compared to the Base Case (Slightly Adverse). Even greater proportional increases would occur on most representative mainstem reservoirs (Adverse).
Reservoir Recreation B	This policy alternative would result in essentially the same changes in representative reservoirs described for Reservoir Recreation A. The only difference is that the transitional tributary reservoirs would be rated No Change because the minimum volume available would be similar to the Base Case.	This policy alternative would result in essentially the same changes in storage tributary and transitional tributary reservoirs described for Reservoir Recreation A. For the mainstem reservoirs, the increase in volume compared the Base Case would be substantial for all representative reservoirs (Substantially Adverse).
Summer Hydropower	Changes under this alternative in the minimum volume of water available to assimilate oxygen-demanding materials were evaluated only for normal- to high-flow years. Impacts under low flows during dry years could not be evaluated because conditions created insufficient water availability for completion of model runs. For the flow conditions that could be evaluated, most representative reservoirs would have essentially the same volume of water with this characteristic as the Base Case or would have a slight reduction (No Change to Slightly Adverse).	Changes under this alternative in the volume of water with oxygen concentrations favoring development of anoxic products were evaluated only for normal- to high-flow years. Impacts under low flows during dry years could not be evaluated because conditions created insufficient water availability for completion of model runs. For the flow conditions that could be evaluated, volume reductions would occur more often than increases on the storage tributary reservoirs (Slightly Beneficial). Transitional tributary reservoirs would experience increases (Slightly Adverse). High summer flows through the mainstem reservoirs would result in large reductions compared to the Base Case (Substantially Beneficial).
Equalized Summer/ Winter Flood Risk	This policy alternative would result in essentially no change in the minimum water available to assimilate oxygen-demanding wastes in two of the storage tributary reservoirs and a slight reduction in the other (No Change to Slightly Adverse); a slight reduction in both transitional tributary reservoirs (Slightly Adverse); and similar volumes to Base Case operations for all representative mainstem reservoirs (No Change).	Changes under this alternative in the volume of water with oxygen concentrations favoring development of anoxic products would vary among storage tributary reservoirs from a slight increase to a decrease (overall rating Slightly Beneficial). The transitional tributary reservoirs would experience a slight increase under this alternative (Slightly Adverse). This volume would increase on all representative mainstem reservoirs, with proportional increases being substantial on some reservoirs (Adverse – Substantially Adverse).

Table 5.4-08 Summary of Impacts on Assimilative Capacity and Anoxia by Policy Alternative (continued)

Alternative	Assimilative Capacity	Potential for Anoxic Products
Commercial Navigation	The minimum volume of water available to assimilate oxygen-demanding wastes would be relatively unchanged compared to the Base Case for all representative reservoirs (No Change).	This policy alternative would result in about the same volumes of water with oxygen concentrations favoring development of anoxic products as the Base Case on storage tributary reservoirs (No Change). This volume would be slightly increased on some transitional tributary reservoirs and unchanged compared to the Base Case on others (No Change – Slightly Adverse). Mainstem reservoirs would either remain similar to the Base Case or experience a slight decrease in volume (overall rating Slightly Beneficial).
Tailwater Recreation	Effects of this policy alternative would be the same as those described for Reservoir Recreation B.	This policy alternative would result in either similar volumes of water with potential anoxic conditions on storage tributary reservoirs compared to the Base Case or a notable increase (No Change – Adverse). Some transitional tributary reservoirs would experience an increase, while others would experience a decrease (Slightly Adverse – Slightly Beneficial). Most mainstem reservoirs would encounter a large increase in this volume (Substantially Adverse).
Tailwater Habitat	Effects of this policy alternative would vary among the storage tributary reservoirs. There would be a notable increase in the minimum volume of water available to assimilate oxygen consuming wastes on one tributary storage reservoir and a slight decrease on another (overall rating Slightly Beneficial). For the transitional tributary reservoirs, there would either be no change or slight reduction in this volume (No Change – Slightly Adverse). This volume would remain relatively unchanged on the mainstem reservoirs (No Change).	The volume of water with oxygen concentrations favoring development of anoxic products would increase on almost all representative reservoirs. The increase would be sufficiently large as defined in this context to be rated Adverse on the storage tributary reservoirs; No Change to Slightly Adverse on transitional tributary reservoirs; and even larger increases on mainstem reservoirs would be rated Adverse to Substantially Adverse.
Preferred	This policy alternative would result in either an increase in the volume of water available for assimilating oxygen-demanding wastes or volumes similar to the Base Case for the storage tributary reservoirs (Slightly Beneficial). Volumes on the transitional tributary reservoirs would be similar to the Base Case (No Change). Volumes on three of the four mainstem reservoirs would be similar to the Base Case and slightly reduced compared to the Base Case on the other representative mainstem reservoir (overall rating No Change).	This policy alternative would result in about the same volumes of water with oxygen concentrations favoring development of anoxic products as the Base Case on storage tributary reservoirs (No Change). This volume would be slightly increased on some transitional tributary reservoirs and slightly decreased compared to Base Case on others (Slightly Adverse – Slightly Beneficial). Mainstem reservoirs would remain similar to the Base Case, experience a slight decrease in volume, or experience a large increase in volume (overall rating Slightly Adverse).

Anoxic Products

In addition to the direct impacts on aquatic life (discussed in Section 5.7, Aquatic Resources) low concentrations of DO approaching anoxia have the potential to introduce iron, manganese, sulfides, and ammonia into deeper strata of reservoirs. Because this process is so closely tied to DO concentrations, the potential for these compounds to be mobilized or formed was evaluated by looking at the volume of water in the reservoirs having a DO concentration less than 1 mg/L. A decrease in the potential for anoxic product formation or mobilization is designated as a beneficial impact while an increase is designated as an adverse impact.

5.4.16 Summary of Impacts

Table 5.4-04 identified relatively few changes in the minimum volume of water available to assimilate oxygen-demanding wastes compared to Base Case conditions. This metric was selected to be an indicator of system-wide impacts of policy alternatives on assimilative capacity. It was not intended to be a detailed evaluation of policy alternatives on assimilative capacity, nor was it intended to examine site-specific impacts. From this perspective, this analysis indicates that none of the alternative operations policies would result in substantial impacts on assimilative capacity.

Increases in anoxia and potential anoxic products are of particular concern, especially on mainstem reservoirs. Presence of anoxia on storage tributary reservoirs is an expected condition because of long residence times and thermal stratification. However, frequency, duration, and extent of anoxia are much less on most of the mainstem reservoirs than on the storage tributary reservoirs because of shorter residence times and lack of thermal stratification. This analysis shows that most policy alternatives would affect DO more in mainstem reservoirs than in storage tributary reservoirs.

Of the policy alternatives that were evaluated for the complete 8-year model period (i.e., all but the Summer Hydropower Alternative), several policy alternatives would result in a relative increase in the potential for anoxic products on most or all representative mainstem reservoirs and thus be considered an adverse to substantially adverse impact. Only one, the Commercial Navigation Alternative, would result in volumes of potential anoxic water either similar to or slightly less than the Base Case. The Preferred Alternative would affect each mainstem reservoir differently, ranging from a volume of potential anoxic water similar to the Base Case to a volume substantially larger than the Base Case. The increase would occur on Watts Bar Reservoir, which experiences relatively large volumes of low DO water on a more frequent basis than any of the other mainstem reservoirs. Watts Bar Reservoir presently has aeration equipment to maintain its Lake Improvement Plan target for the tailwater.

Analysis of the effects of policy alternatives on water quality under low-flow conditions acknowledged that the volume of water with low DO concentrations was greater on most representative reservoirs during dry years with low reservoir flows under the Base Case operations. Several policy alternatives would increase this volume beyond what would occur under the Base Case, especially on mainstem reservoirs. Flows for 1993 were used to represent low-flow conditions. Water quality model runs were completed for all policy alternatives under 1993 conditions. Results indicate that the Summer Hydropower Alternative would reduce the volume of low DO water on mainstem reservoirs compared to the Base Case; the Commercial Navigation Alternative would result in volumes similar to the Base Case; and all other alternatives would increase the volume of low DO water compared to the Base Case. Among the alternatives that would result in increased volume, the Preferred Alternative would create the smallest increase.

Conditions that exist under low flows are often a good predictor of future conditions under normal flow. This analysis indicates that most policy alternatives would tend to increase volumes of water with low DO concentrations, especially on mainstem reservoirs under low-flow conditions. The results of this analysis indicate that any operations policy that would reduce flows on mainstem reservoirs beyond those under the Preferred Alternative—whether one of the alternatives considered here or a future alternative—could compromise water quality in unacceptable ways.