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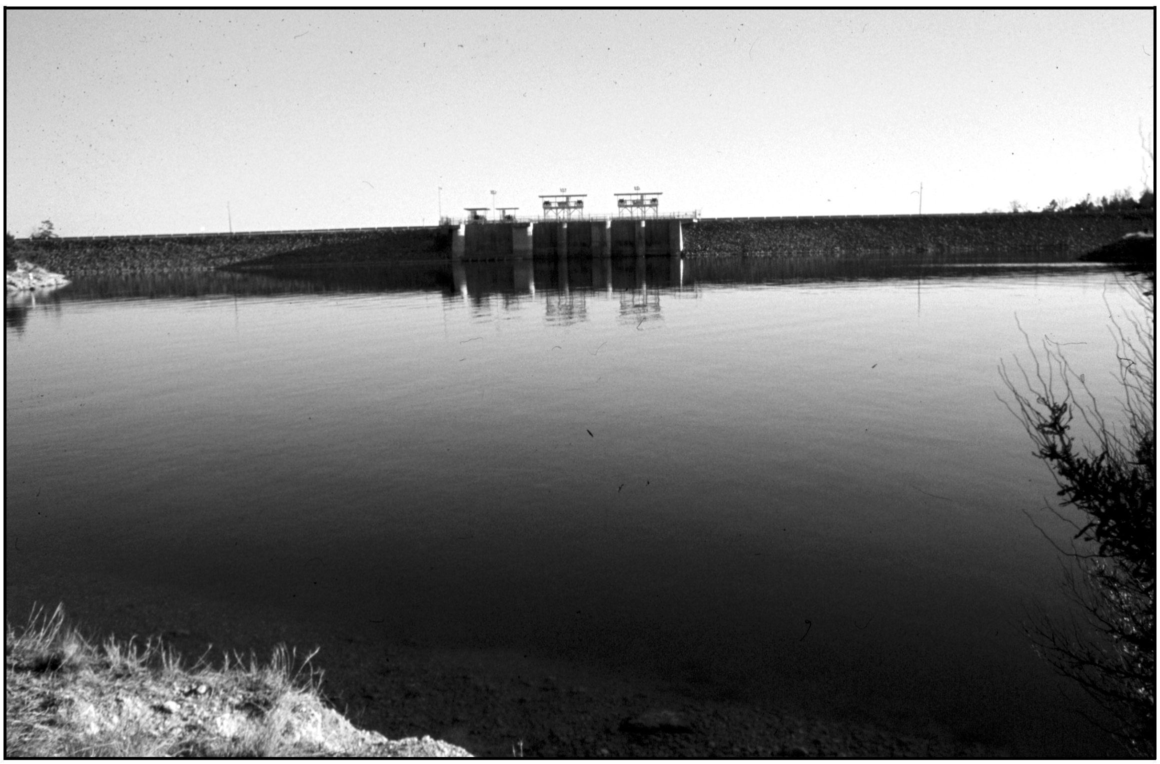
Reservoir and Lake Use Support Assessment



Spillway at Sam Rayburn Reservoir

Reservoir and Lake Use Support Assessment

For the 2000 report, 119 reservoirs and lakes (99 classified and 20 unclassified) encompassing 1,571,233 acres were surveyed and at least one designated beneficial use was assessed in each water body. The surveyed acres represent 93 percent of area covered (1,690,140 acres) by major reservoirs (>500 ac-ft) in the State and 79 percent of the area covered (1,954,600 acres) by all perennial reservoirs (> 10 acres)(Figure 15). Twenty more reservoirs and lakes covering approximately 34,294 acres were surveyed in 2000 than in 1996, the year of the last full statewide assessment conducted by the TNRCC. The increase in surveyed acres is due to additional monitoring of small unclassified reservoirs and lakes.

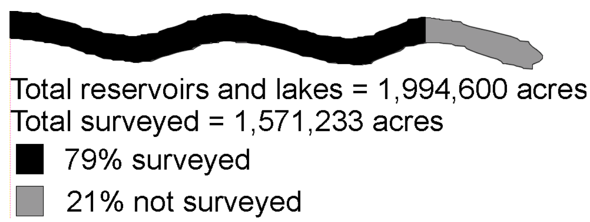


Figure 15. Reservoir and Lake Acres Surveyed

About 62 percent of the 1,547,955 assessed acres fully support all their designated beneficial uses (Figure 16). Of these waters, 55.5 percent fully support designated uses and 6.3 percent have good water quality that fully supports all uses, but is threatened for one use (public water supply). These threatened waters may deteriorate if potential sources of pollution are not properly managed. Some form of pollution impairs the remaining 38.2 percent of assessed reservoir and lake acres. The framework, indicators, and criteria used to assess designated uses in reservoirs is discussed in the "Surface Water Assessment Methodology" section and shown in Tables 18-28.

Figure 17 indicates the causes and sources of pollutants that impair (i.e., prevent from fully supporting designated uses) reservoir and lake acres. Causes that contribute most to overall impairment of designated uses in reservoirs and lakes include mercury (fish consumption use), elevated average dissolved minerals (general uses), depressed dissolved oxygen concentrations (aquatic life uses), and low and high pH values (general uses).

The sources of pollution for most reservoirs and lakes are presently unknown (Figure 17). Atmospheric deposition of mercury accounts for the largest category of known pollution sources, contributing to about 50 percent of impaired assessed acres. Nonpoint source runoff from irrigated crops (14%), sources outside the state (14%), and urban areas (7%) are also identified as significant known sources of pollution that contribute to impairment of uses in reservoirs and lakes.

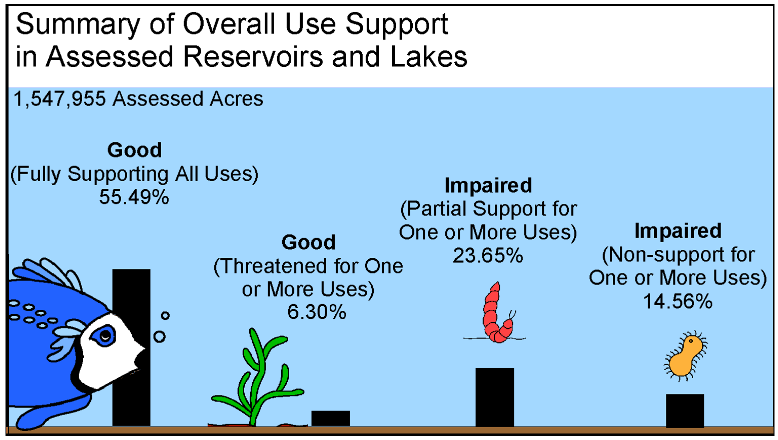
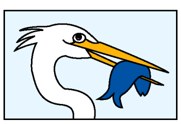


Figure 16. Summary of Overall Use Support in Assessed Reservoirs and Lakes



Aquatic Life Use Support

Individual use support information provides additional detail about water quality problems in reservoirs and lakes. Approximately 1,571,233 acres were surveyed to determine support of the aquatic life use. Sufficient data were available to provide assessment of 694,642 acres (44.2% of surveyed acres) (Table 44). Of these assessed acres, about 84 percent fully supported the aquatic life use, 12 percent partially supported the use, and four percent failed to support the use. Depressed instantaneous (grab sample) dissolved oxygen concentrations was the most common indicator used to assess support of the aquatic life use (Table 45). Of the 651,196 acres assessed (41.4% of surveyed acres) by instantaneous dissolved oxygen, approximately 83 percent supported aquatic life uses, 13 percent partially supported the use, and four percent failed to support the use. The aquatic life use in reservoirs and lakes was assessed in 209,334 acres (13.3% of surveyed acres) by evaluation of metals in water data (acute and chronic exposure to aquatic life) and 98 percent supported the use. For the remaining six indicators (24-hour dissolved oxygen measurements, organic substances in water, water and sediment toxicity testing, and macrobenthos and fish community analyses) data were so insufficient that less than one percent of reservoir and lake acres were assessed by each indicator.

The most common cause of impaired aquatic life uses in reservoirs is depressed dissolved oxygen concentrations. Generally, reservoir areas impacted by low dissolved oxygen concentrations are localized in headwater regions near tributary inflows that transport point and nonpoint pollutant sources. The headwater areas may be marshy and shallow in depth. Reduced velocity and little physical turbulence (low re-aeration) in these headwater areas are natural factors that contribute equally to lower dissolved oxygen concentrations. Assimilation of organic materials, nutrients and sediment oxygen demand act to lower dissolved oxygen in these areas. In some cases, heavy point and nonpoint source nutrient loading overloads reservoir and lake systems and accelerates eutrophication. Algal blooms, depressed dissolved oxygen concentrations, and abundance of aquatic weeds are symptoms of excessive nutrient loading in some reservoirs and lakes.

The aquatic life use in Palo Duro Reservoir (Segment 0199A) is partially supported due to depressed dissolved oxygen concentrations. The aquatic life use in the upper portions of Lake Wright Patman (Segment 0302) is not supported due to depressed dissolved oxygen concentrations. In other areas of the reservoir, depressed dissolved oxygen concentrations cause partial support of the aquatic life use. Sluggish flow through extensive shallow areas coupled with nutrient and suspended sediment loading from point and nonpoint sources likely contribute to the problem. Depressed dissolved oxygen concentrations contribute to partial support of the aquatic life use in the lower portions of Cooper Lake (Segment 0307). In the upper portion of Caddo Lake (Segment 0401), the aquatic life use is not supported, while in the lower portions the use is partially supported due to low dissolved oxygen concentrations. Depressed dissolved oxygen concentrations also impair the aquatic life use in the upper portions of Lake O' the Pines (Segment 0403; partial support), in the Tenaha Creek Arm of Toledo Bend Reservoir (Segment 0504; nonsupport), and in the lower portion of Lake Tawakoni (Segment 0507; nonsupport).

The aquatic life use in the upper Angelina River Arm of Sam Rayburn Reservoir (Segment 0610) is not supported due to depressed dissolved oxygen concentrations. Farther downstream in the Angelina Arm dissolved oxygen concentrations improve, but are low enough to cause partial support of the aquatic life use. Low dissolved oxygen concentrations also cause partial support of the aquatic life use in the upper Ayish and Attoyac Arms of Sam Rayburn Reservoir. Biological data indicate that an intermediate aquatic life use is supported in the upper Angelina River Arm of Sam Rayburn Reservoir. The high aquatic life use in the current TSWQS is not met.

Depressed dissolved oxygen concentrations in six localized areas in Lake Livingston (Segment 0803) cause partial support of aquatic life uses. Nutrients appear to affect dissolved oxygen in Lake Mexia (Segment 1210), where the aquatic life use is not supported in the reservoir. Low dissolved oxygen concentrations in the headwater regions of Lake Proctor (Segment 1222), Aquilla Reservoir (Segment 1254) and Lake Texana (Segment 1604) contribute to partial support of the aquatic life use. In the upper portion of Lake Austin (Segment 1403) depressed dissolved oxygen concentrations, due to anoxic bottom water releases from Lake Travis, cause partial support of the aquatic life use.

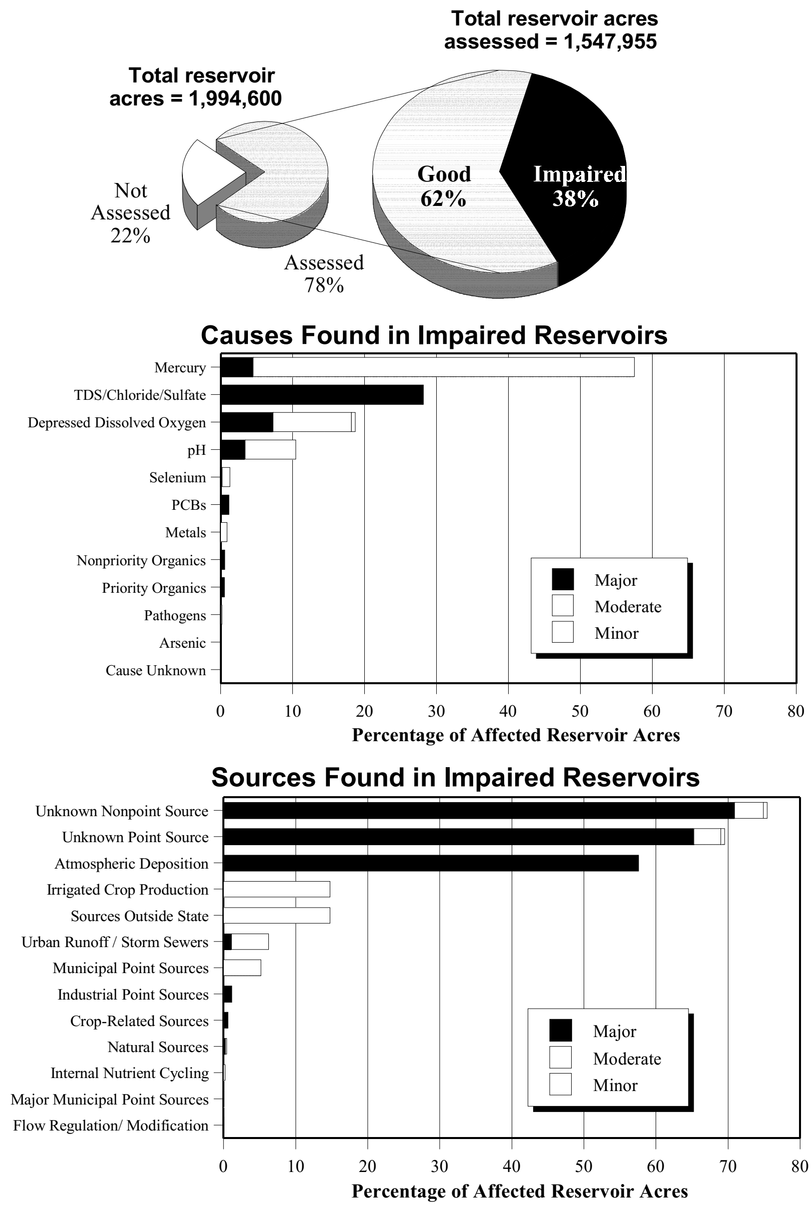
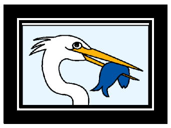
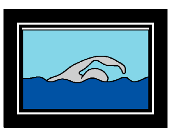
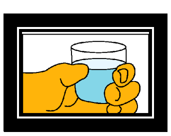
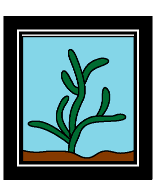


Figure 17. Causes and Sources of Pollution in Reservoirs and Lakes

Table 44. Individual Use Support Indicators for Reservoirs and Lakes

Designated Use	Acres Surveyed	Acres Assessed	Percent of Acres Assessed	Percent of Assessed Acres: Good (Fully Supporting)	Good (Threatened)	Fair (Partially Supporting)	Poor (Not Supporting)
 Aquatic Life Support	1,571,233	694,642	44.21	84	0	12	4
 Fish Consumption	1,571,233	616,532	39.24	43	0	55	2
 Contact Recreation	1,570,709	480,467	30.59	100	0	X*	< 1
 Noncontact Recreation	524	524	100.00	0	0	X*	100
 Public Water Supply	1,516,932	1,516,932	100.00	92	8	0	< 1
 General Uses	1,546,917	1,036,970	67.03	78	0	4	18

X* - Category not applicable

Table 45. Individual Use Support Indicators for Aquatic Life, Fish Consumption, and General Uses

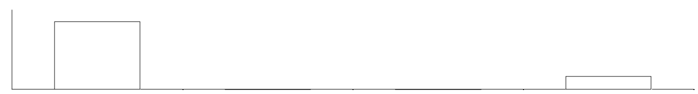
Designated Use	Acres Surveyed	Acres Assessed	Percent of Acres Assessed	Percent of Assessed Acres			
				Good (Fully Supporting)	Good (Threatened)	Fair (Partially Supporting)	Poor (Not Supporting)
Aquatic Life Support							
Instantaneous Dissolved Oxygen	1,571,233	651,196	41.44	83	0	13	4
24-hour Dissolved Oxygen	1,571,233	0	0.00	0	0	0	0
Metals in Water	1,571,233	209,334	13.32	98	0	2	0
Organics Substances in Water	1,571,233	10,710	0.68	100	0	0	0
Water Toxicity	1,571,233	18	< 0.01	100	0	0	0
Sediment Toxicity	1,571,233	43	< 0.01	0	0	0	100
Macrobenthos Community	1,571,233	0	0.00	0	0	0	0
Fish Community	1,571,233	3	<0.01	0	0	0	0

Table 45. Individual Use Support Indicators for Aquatic Life, Fish Consumption, and General Uses (Continued)

Designated Use	Acres Surveyed	Acres Assessed	Percent of Acres Assessed	Percent of Assessed Acres: Good (Fully Supporting)	Good (Threatened)	Fair (Partially Supporting)	Poor (Not Supporting)
Fish Consumption							
Advisories / Closures	1,571,233	604,929	38.50	41	0	56	2
Human Health Criteria	1,571,233	81,297	5.17	99	0	0	< 1
General Uses							
Water Temperature	1,546,917	685,440	44.31	100	0	0	0
pH	1,546,917	680,623	44.00	91	0	6	3
Chloride	1,546,917	1,036,970	67.03	92	0	X*	8
Sulfate	1,546,917	1,036,970	67.03	95	0	X	5

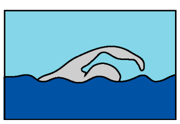
Table 45. Individual Use Support Indicators for Aquatic Life, Fish Consumption, and General Uses (Continued)

Designated Use	Acres Surveyed	Acres Assessed	Percent of Acres Assessed	Percent of Assessed Acres: Good (Fully Supporting)	Good (Threatened)	Fair (Partially Supporting)	Poor (Not Supporting)
Total Dissolved Solids	1,546,917	971,692	62.81	85	0	X	16



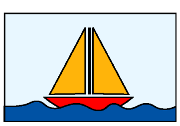
X* - Category not applicable

The aquatic life use is not supported in three reservoirs due to elevated toxic substances in water. In Finfeather Lake and Bryan Municipal Lake (both in Segment 1209), two reservoirs in the Bryan area, the aquatic life use is not supported due to significant effects in sediment toxicity test results. The sediment in both reservoirs contain elevated concentrations of arsenic which originate from historical discharges from an agricultural chemical manufacturing plant. In the middle portion of the Angelina River Arm of Sam Rayburn Reservoir dissolved aluminum concentrations in water exceed the criterion to protect aquatic life from acute exposure.



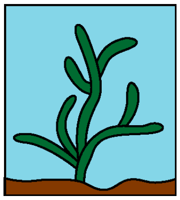
Contact Recreation Use Support

Contact recreation use is assigned to most reservoirs and lakes. Elevated fecal coliform densities (pathogens) play only a very minor contributing role in overall use impairment of reservoirs and lakes. Fecal coliform data were sufficient to provide assessment of contact recreation in 480,467 of 1,570,709 acres surveyed (30.6%) (Table 44). Of the 480,467 acres assessed, 99.9 percent fully supported the contact recreation use. Lake Austin (Segment 1403) is the only reservoir in which the contact recreation use is not supported due to elevated fecal coliform densities. The source of the localized bacterial contamination in Lake Austin near Bull Creek is unknown.



Noncontact Recreation Use Support

Rita Blanca Lake (Segment 0105) is the only reservoir designated for noncontact recreation. Due to elevated fecal coliform densities, the noncontact recreation use was not supported throughout the entire reservoir (524 acres) (Table 44). The source of the bacterial contamination is presently unknown.



General Use Support

Field measurements of pH and water temperature and laboratory analysis of dissolved minerals (chloride, sulfate, and TDS) are used to determine support of the general water quality uses. Together these constituents comprise the second major cause of nonsupport of overall uses in reservoirs and lakes (Figure 17). Most of the classified reservoirs and lakes are assigned water body specific dissolved mineral criteria to safeguard general water quality, rather than for protection of specific uses. Water temperature, pH, and dissolved mineral criteria are not assigned to unclassified reservoirs and lakes, so their acreage was not assessed for general use attainment. Together, water temperature, pH, and dissolved mineral data were sufficient to provide assessment of general uses in 1,036,970 of 1,546,917 acres surveyed (67%) (Table 44).

Chloride and sulfate were monitored slightly more frequently than TDS, but more than 60 percent of reservoir and lake acres were assessed by all three indicators (Table 45). Water temperature and pH measurements were made less frequently providing assessment of about 680,000 acres (44% of surveyed acres). All water temperature measurements supported general uses in assessed reservoir and lake acres and more than 90 percent of assessed acres were fully supported by pH, chloride, and sulfate data. General uses were supported in 85 percent of assessed acres by TDS data, while 16 percent failed to support the use.

Low and high pH values and elevated dissolved mineral concentrations are the cause of most general use impairments, affecting nine reservoirs and lakes (Table 46). Low pH (acidic water) values are common in East Texas water bodies due the low prevalence of acid-neutralizing materials in the sandy soils. The upper portion of Caddo Lake (Segment 0401) is the only reservoir with nonsupported general uses due to low pH values. High pH values may result from photosynthesis by aquatic plants which removes carbon dioxide from the water and increases the pH during daylight hours. Portions of Cooper Lake (Segment 0307) and Wright Patman Reservoir (Segment 0302) have high pH values which cause partial support of general uses in one portion of the impoundments and nonsupport in other areas. High pH values in Lake Tawakoni (Segment 0507) cause nonsupport of general uses.

Dissolved minerals occur naturally in water, as a result of leaching from common minerals in the watershed. In some cases, dissolved minerals may be increased by industrial and domestic wastewater effluents. Elevated average chloride concentrations in surface water cause nonsupport of general uses in two reservoirs; sulfate concentrations cause nonsupport of the use in three reservoirs, and TDS concentrations cause nonsupport of

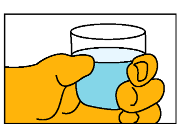
Table 46. Reservoirs and Lakes with Partially Supported or Nonsupported General Uses

Segment Number	Reservoir Name	General Use Support Indicator				
		Low pH	High pH	Chloride	Sulfate	TDS
0105	Rita Blanca Lake		P*	N**		N
0228	Mackenzie					N
0302	Wright Patman		P/N			
0307	Cooper Lake		P/N			
0401	Caddo Lake	P/N				N**
0504	Toledo Bend	P	P			
0512	Lake Fork				N**	N
0507	Lake Tawakoni		N			
0610	Sam Rayburn	P	P			
0613	Lake Tyler/Lake Tyler East	N				
0803	Lake Livingston		P			
0838	Joe Pool				N	N
1233	Hubbard Creek				N	
2303	Falcon			N		N
	Totals	**4**	**7**	**2**	**3**	**6**

* P = Partially Supported Use; N = Nonsupported Use; In some reservoirs, different areas may have differing levels of use support (P/N)

** Water bodies are deferred from placement on 2000 303(d) List, since application of 2000 TSWQS will change the criteria and negate the justifications for listing.

the use in five reservoirs (Table 46). General use impairments for Rita Blanca Lake (Segment 0105; chloride), Caddo Lake (Segment 0401; TDS), and Lake Fork (Segment 0512; sulfate) due to elevated average dissolved mineral concentrations were deferred from placement on the 2000 303(d) List, pending approval of the 2000 TSWQS. General water quality uses are not impaired by water temperature in any reservoirs (Table 45).



Public Water Supply Use Support

Public water supply is a use that is not assigned to all reservoirs and lakes, so slightly less total acres were surveyed (1,516,932 acres)(Table 44). Support of the use is determined by exceedances of organic chemical criteria in finished drinking water (after treatment at the point of entry into the distribution system). Data were sufficient to provide assessment of all 1,516,932 acres surveyed. Of the assessed acres, 92 percent fully supported the public water supply use, the use was threatened in eight percent of the acres, and less than one percent failed to support the use.

Agricultural use of pesticides and herbicides sometimes results in their occurrence in streams and reservoirs located in agricultural areas. The organic contaminants are transported from fields to streams and reservoirs through nonpoint source runoff. Aquilla Reservoir (Segment 1254) is the only reservoir in which the public water supply use is not supported. Impairment of the use is caused by an elevated average concentration of the herbicide, atrazine, in finished drinking water which exceeds the maximum contaminant level. The atrazine originates in the reservoir (source) water and is not removed by conventional treatment. Elevated alachlor concentrations in finished drinking water from Aquilla Reservoir also indicate contamination of the source water and represents a threat to future use. Alachlor is another agricultural herbicide which enters the watershed of the reservoir through nonpoint source runoff.

In eight additional reservoirs [Big Creek Lake (in Segment 0303A), Lake Tawakoni (Segment 0507), Bardwell (Segment 0815), Lake Waxahachie (Segment 0816), Navarro Mills (Segment 0817), Lake Lavon (Segment 0821), Richland-Chambers (Segment 0836), and Joe Pool Lake (Segment 0838)] all water quality measurements currently support use as a public supply. However, atrazine concentrations in finished drinking water exceed 50 percent of the MCL, indicating that the use is threatened. Potential sources of pollution in these water bodies are being managed by the TNRCC and local cooperators through BMPs.

Fish Consumption Use Support

Approximately 1,571,233 acres were surveyed to determine support of the fish consumption use. Sufficient data were available to provide assessment of 616,532 acres (39% of surveyed acres) (Table 44). Of the assessed acres, about 43 percent fully supported the fish consumption use, 55 percent partially supported the use, and two percent failed to support the use. Issuance of fish consumption advisories and aquatic life closures by the TDH was the most common indicator used to assess support of the fish consumption use in reservoirs and lakes (Table 45). Of the 604,929 acres assessed (38.5% of surveyed acres) by issuance of advisories and closures, approximately 41 percent fully supported the fish consumption use, 56 percent partially supported the use, and two percent failed to support the use. Human health criteria in water were also evaluated to determine support of the fish consumption use. Human health criteria are back-calculated from concentrations in fish tissue. Exceedance of the criteria by average toxic substances concentrations in water suggest that concentrations in fish tissue could also be elevated. Only 81,297 acres (5.2% of surveyed acres) were assessed with human health criteria due to insufficient data. Nearly all of the assessed acres (99%) fully supported the fish consumption use based on evaluation of human health criteria in water.

The fish consumption use is partially supported for one lake and four reservoirs located in East Texas due to issuance by the TDH of restricted-consumption advisories for mercury. Caddo Lake (Segment 0401), Toledo Bend Reservoir (Segment 0504), B. A. Steinhagen Reservoir (Segment 0603), Lake Kimball (Segment 0608G), and Sam Rayburn Reservoir (Segment 0610) are affected by the advisories. Mercury is a naturally occurring element that can be toxic if consumed in contaminated fish by humans and animals. Sources of mercury include weathering of the earth's crust, the burning of fossil fuels and garbage, and factories that use mercury. The specific source of mercury in fish from East Texas is atmospheric deposition. Bioaccumulation of mercury in east Texas fishes occurs primarily because of natural processes in streams and reservoirs related to low pH, elevated organic carbon, and low dissolved oxygen concentrations (Twidwell, 2000).

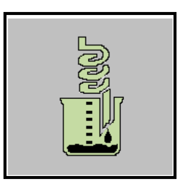
Welsh Reservoir (Segment 0404D), Brandy Branch Reservoir (Segment 0505E), and Martin Creek Reservoir (Segment 0505F) are used by power companies for cooling of steam electric condensers. Coal is burned at the plants to provide heat to run the steam-electric generators. Selenium in the coal is liberated during the burning process, ending up in the bottom ash and fly ash. Runoff from fly ash disposal areas is the suspected source of selenium contamination in the reservoirs. The fish consumption use for these three reservoirs is not supported due to issuance in May 1992 by the TDH of a no-consumption advisory for a sensitive subpopulation (children and women of child bearing age) due to elevated selenium concentrations in fish tissue. All fish species are covered by the advisory.

Aquatic life closures for Como (Segment 0829A) and Fosdic Lakes (Segment 0806A), issued in April 1985 by the TDH, cause nonsupport of the fish consumption use due to elevated toxic organic substances (chlordane, PCBs, DDE, and dieldrin) in edible tissue. A similar aquatic life closure was issued in April 1996 for Mountain Creek Lake (Segment 0810), but in addition includes tissue contaminants DDD, DDT, and heptachlor epoxide. All three lakes are small, urban reservoirs located in the Fort Worth area. Aquatic life closures issued in December 1995 by the TDH for Echo Lake (Segment 0806B) and the Donna Reservoir System (Segment 2202A) in February 1994 and a no-consumption advisory for Lake Worth (Segment 0807) in April 2000, due to elevated PCBs in edible fish tissue, cause nonsupport of the fish consumption use in the three reservoirs. Lake Worth was not placed on the 2000 303(d) List, because the advisory was issued after the assessment period. The organic chemicals found in the tissue of fish from these reservoirs are used for various pest control and industrial purposes and were probably carried into the reservoirs from urban runoff. The source of PCBs in the Donna Reservoir System is unknown. The aquatic life closures prohibit possession of any fish from the reservoirs.

Human health criteria have been developed by the TNRCC in the TSWQS to protect consumers from bioaccumulation of toxic substances in fish tissue. Metals and organic substances in water data are compared to the human health criteria as an additional indicator to determine attainment of the fish consumption use. The average arsenic concentrations in waters from Finfeather (Segment 1209B) and Bryan Municipal (Segment 1209A) lakes exceed the human health criterion causing nonsupport of the fish consumption use.

Reservoir and Lakes Concerns Assessment

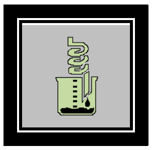
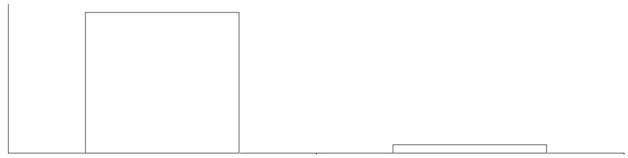
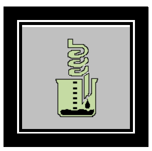
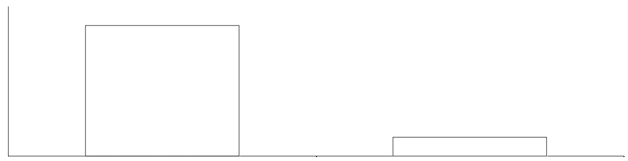
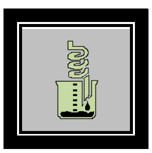
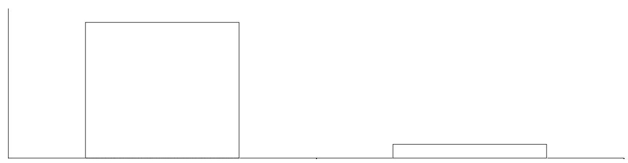
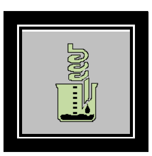
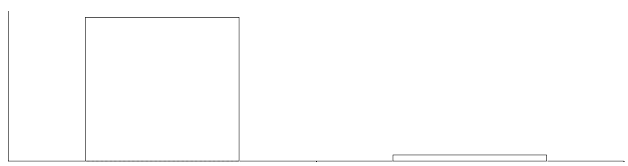
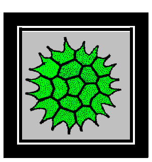
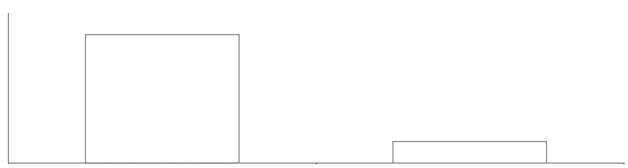
The TNRCC and the CRP has developed screening levels to identify water bodies with elevated nutrient and chlorophyll *a* concentrations in water, elevated toxic substances in sediment, and elevated toxic substances in fish tissue. Water quality criteria have not been developed by the TNRCC in the TSWQS for these constituents. Water quality concerns are identified when greater than 25 per cent of samples exceed screening levels. Public water supply concerns are identified for water bodies when average dissolved mineral concentrations in finished drinking water samples exceed the secondary drinking water criteria. Public water supply concerns are also identified for surface water when average dissolved mineral concentrations exceed secondary finished drinking water criteria. Water bodies that provide supply to systems which experience increased costs for demineralization due to high dissolved solids are also identified with concerns. The framework, indicators, and criteria for evaluation of water quality concerns are discussed in the "Surface Water Assessment Methodology" section and are shown in Tables 29-33. Reservoirs and lakes with identified concerns are targeted by the TNRCC and CRP for increased fixed station monitoring or special studies to identify possible causes and sources.



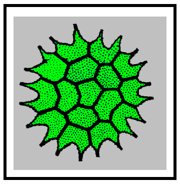
Nutrient Concerns

Approximately 1,571,233 reservoir and lake acres were surveyed to identify areas of concern caused by elevated concentrations of ammonia nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, and total phosphorus (Table 47). Sufficient data were available to provide assessment of about 500,000 acres (about 30% of surveyed acres) for each nutrient indicator. Of the acres assessed in reservoirs and lakes, water quality concerns were identified in only six percent for ammonia nitrogen, 13 percent for nitrite plus nitrate nitrogen, nine percent for orthophosphorus, and four percent for total phosphorus. Four reservoirs and lakes were

Table 47. Individual Indicators for Nutrient and Chlorophyll *a* Concerns

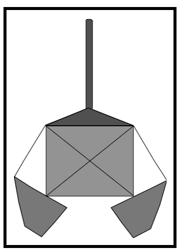
Concern Parameter	**Acres Surveyed**	**Acres Assessed**	**Percent of Acres Assessed**	**Percent of Assessed Acres**		
					No Concern	**Concern**
 Ammonia	1,571,233	504,997	32.14		94	6
 Nitrate + Nitrite	1,571,233	513,051	32.65		87	13
 Orthophosphorus	1,571,233	593,497	37.77		91	9
 Total Phosphorus	1,571,233	469,904	29.91		96	4
 Chlorophyll a	1,571,233	430,737	27.41		86	14

identified with concerns for ammonia nitrogen, 11 for nitrite plus nitrate nitrogen, and five each for orthophosphorus and total phosphorus (Table 48).



Chlorophyll a Concerns

Approximately 1,571,233 reservoir and lake acres were surveyed to identify areas of concern caused by elevated chlorophyll *a* concentrations (Table 47). Sufficient data were available to provide assessment of 430,737 acres (27.4% of surveyed acres). Of the assessed acres, 14 percent were identified with elevated chlorophyll *a* concentrations. The nine reservoirs and lakes with elevated chlorophyll *a* concentrations are located in several different areas of the state (Table 48). Half of the reservoirs with elevated chlorophyll *a* concentrations also were identified with concerns for one or more of the nutrient indicators, suggesting that nutrient loading may be responsible for stimulation of algal growth in the impoundments.



Sediment Concerns

Due to high cost associated with analytical laboratory determinations of metals and organic substances, sediment sampling is not widespread in reservoirs and lakes. Most of the sampling is targeted to reservoirs and lakes likely to be contaminated by point and nonpoint sources. Of the 1,571,233 reservoir and lake acres surveyed for elevated sediment contaminants, sufficient data were available to provide assessment in only 88,463 acres (5.6% of surveyed acres) (Table 49). Of the 88,463 acres assessed, 94 percent were identified with concerns for one or more sediment contaminants.

Elevated concentrations of at least one toxic substance were identified in nine reservoirs and lakes (Table 50). Sediment in the Harrison Bayou Arm of Caddo Lake (Segment 0401) has elevated concentrations of arsenic, mercury, nickel, selenium, zinc, and oil and grease. Ellison Creek Reservoir (in Segment 0404) is located adjacent to a secondary steel manufacturing plant. Sediment from the reservoir has elevated concentrations of barium, copper, manganese, selenium, and silver which may be related to the adjacent location of the steel manufacturing facility. Despite the elevated sediment metals concentrations, historical sediment toxicity testing by the TNRCC and EPA Region 6 has revealed only one significant effect (TNRCC, 2000). Analysis of simultaneously extracted metals (SEM) and acid-volatile sulfide (AVS) has been conducted on some sediment samples from Ellison Creek Reservoir. These analyses (SEM:AVS < 1) suggests that the divalent metals are bound in metal-sulfide complexes making them biologically unavailable. Several localized areas in Sam Rayburn Reservoir (Segment 0610) have elevated

Table 48. Reservoirs and Lakes with Nutrient and Chlorophyll *a* Concerns

Segment Number	Reservoir Name	Nutrient				Chlorophyll *a*
		NH_3-N	$NO_2 + NO_3$-N	OPhos	T-Phos	
0105	Rita Blanca Lake	✓			✓	✓
0229A	Lake Tanglewood		✓	✓	✓	✓
0401	Caddo Lake	✓				
0403	Lake O' the Pines	✓	✓		✓	
0504	Toledo Bend					✓
0507	Lake Tawakoni		✓			✓
0512	Lake Fork		✓			✓
0605	Lake Palestine		✓			
0610	Sam Rayburn	✓		✓		
0803	Lake Livingston			✓		
0821	Lake Lavon		✓			
1002	Lake Houston		✓	✓	✓	
1012	Lake Conroe					✓
1210	Lake Mexia		✓			
1222	Proctor Lake					✓
1225	Lake Waco		✓			✓
1247	Granger Lake		✓			
1254	Aquilla Reservoir		✓			
1429	Town Lake		✓			
1604	Lake Texana			✓		
2303	Falcon					✓
2454A	Cox Lake				✓	
	Totals	**4**	**12**	**5**	**5**	**9**

Table 49. Overall Concern Indicators in Reservoirs and Lakes

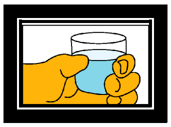
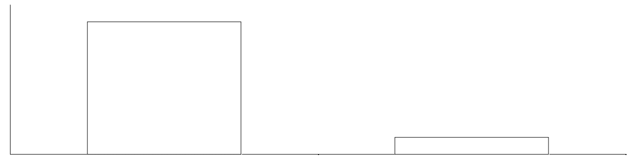
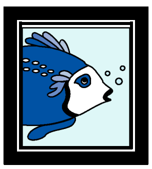
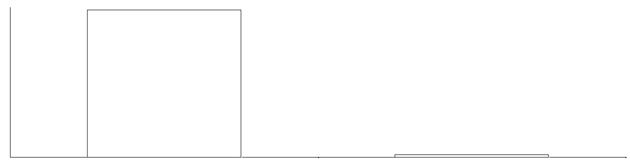
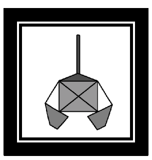
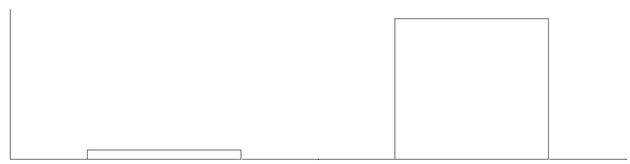
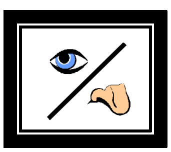
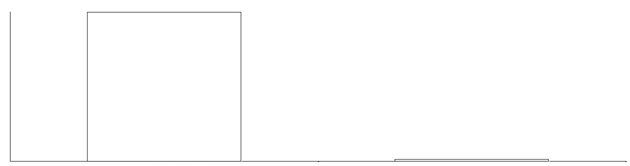
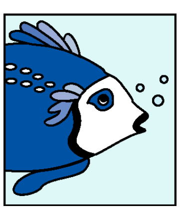
Concern Parameter	Acres Surveyed	Acres Assessed	Percent of Acres Assessed	Percent of Assessed Acres: No Concern	Percent of Assessed Acres: Concern
 Public Water Supply	1,516,932	1,516,932	100.00	 89	11
 Fish Tissue Contaminant	1,571,233	28,448	1.81	 98	2
 Sediment Contaminant	1,571,233	88,463	5.63	 6	94
 Narrative Criteria	1,571,233	1,571,233	100.00	 99	< 1

Table 50. Reservoirs and Lakes with Sediment Concerns

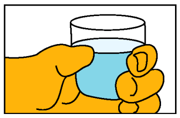
Segment Number	Water Body	Pollutant
0401	Caddo Lake	Arsenic, mercury, nickel, selenium, zinc, and oil and grease
0404A	Ellison Creek Reservoir	Barium, copper, manganese, selenium, and silver
0610	Sam Rayburn Reservoir	Arsenic, manganese, nickel, and oil and grease
0613	Lake Tyler/Lake Tyler East	Arsenic, barium, manganese, nickel, and oil and grease
0838	Joe Pool Lake	Cadmium, chromium, and nickel
1209A	Bryan Municipal Lake	Arsenic, barium, chromium, copper, lead, mercury, and zinc
1209B	Finfeather Lake	Arsenic, barium, chromium, copper, lead, mercury, nickel, selenium, and zinc
1429	Town Lake	Copper, lead, DDD, DDE, DDT, endosulfan sulfate, gamma hexachlorocyclohexane, heptachlor, heptachlor epoxide, and methoxychlor
2312	Red Bluff Reservoir	Barium, chromium, nickel, and selenium
Screening Levels for Toxic substances in Sediment are shown Tables 30 and 31		

sediment concentrations of arsenic, manganese, nickel, and oil and grease. Sediment in Lake Tyler/Lake Tyler East (Segment 0613) has elevated concentrations of arsenic, barium, manganese, nickel, and oil and grease. Elevated cadmium, and nickel sediment concentrations occur in Joe Pool Lake (Segment 0838), principally in the Mountain Creek Arm. Sediment from Finfeather Lake (in Segment 1209) are contaminated by arsenic, barium, chromium, copper, lead, mercury, nickel, selenium, and zinc. Bryan Municipal Lake, located a few miles downstream from Finfeather Lake in Segment 1209, has sediment with elevated concentrations for the same metals, with the exceptions of nickel and selenium. Sediment in Town Lake (Segment 1429) has elevated concentrations of metals (copper and lead) and organic substances (DDD, DDE, DDT, endosulfan sulfate, lindane, heptachlor, heptachlor epoxide, and methoxychlor). Red Bluff Reservoir (Segment 2312) has sediment with elevated barium, chromium, nickel, and selenium concentrations.



Fish Tissue Concerns

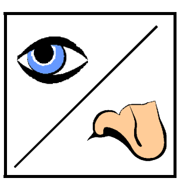
Of the 1,571,233 acres surveyed for elevated contaminants in fish tissue, only 28,448 acres (1.8% of surveyed acres) were assessed (Table 49). The high cost of associated with tissue preparation and analytical laboratory determinations of metals and organic substances limits the amount of statewide fish tissue sampling. Of the 28,448 acres assessed, only about 2 percent were identified with fish tissue concerns. Austin's Town Lake (Segment 1429) is only reservoir with concerns due to elevated toxic substances in fish tissue. Fish from the reservoir have tissue levels that exceeded screening levels for hexachlorobenzene.



Public Water Supply Concerns

Concerns are identified in finished drinking water (after treatment at the point of entry to the distribution system) and surface samples from reservoirs and lakes designated for public water supply if average concentrations exceed secondary standards for chloride (300 mg/L), sulfate (300 mg/L) and TDS (1,000 mg/L). Public water supply systems that experience increased costs for demineralization are also identified as concerns. The public water supply use is not assigned to all reservoirs and lakes. Data were available to provide assessment of all 1,516,932 acres surveyed and 11 percent were identified with public water supply concerns (Table 49).

Surface water concentrations of dissolved minerals cause public water supply concerns for five reservoirs (Table 51). Five reservoirs and lakes are also identified with concerns due to elevated dissolved mineral concentrations in finished drinking water. Advanced waste treatment for removal of dissolved minerals is required for five reservoirs that provide water for domestic supply. These reservoirs are identified as having public water supply concerns due to the increased cost associated with demineralization treatment. Most of the reservoirs identified with public water supply concerns are located in the Canadian and upper regions of the Red, Colorado, and Brazos River basins. In these areas, natural conditions (brine seepage, groundwater seepage, and rainfall runoff from salt bearing strata) or inadequate disposal of brine water produced by oil and gas operations influence dissolved mineral concentrations in surface waters.



Narrative Criteria Concerns

Examples of narrative criteria include such categories as floating debris and oil sheens, suspended solids and excessive foam, odor producing substances, dramatic changes in turbidity or color, and excessive algal blooms. All 1,571,233 reservoir and lake acres were assessed for narrative criteria concerns, and less than one percent was identified with concerns. The extreme headwater region of Sam Rayburn Reservoir is the only impoundment identified with a narrative criteria concern. The color and odor of water in the upper end of the reservoir is influenced by effluent from a paper mill.

Table 51. Reservoirs and Lakes with Public Water Supply Concerns

Segment Number	Reservoir Name	Finished Drinking Water			Surface Water			Increased Costs for Demineralization
		Cl	SO_4	TDS	Cl	SO_4	TDS	
0102	Lake Meredith	✓		✓	✓		✓	
0203	Lake Texoma		✓	✓				✓
1205	Lake Granbury				✓		✓	✓
1207	Possum Kingdom				✓	✓	✓	✓
1224	Lake Olden							✓
1411	E.V. Spence	✓	✓	✓				✓
1412	Lake Colorado City	✓	✓	✓	✓	✓	✓	
1426	Oak Creek Reservoir		✓					
1433	O.H. Ivie				✓		✓	
2202A	Donna Reservoir		✓					
	Totals	**3**	**5**	**4**	**5**	**2**	**5**	**5**

Trophic Classification of Reservoirs and Lakes

Eutrophication is a natural aging process in reservoirs and lakes. Even without human influences, most reservoirs and lakes are likely to gradually become eutrophic. Eutrophication of reservoirs and lakes in southern states is enhanced due to warm, fertile climates. Human activities can accelerate the process by increasing the rate at which nutrients and organic substances enter the impoundments and their surrounding watersheds. Sewage discharges, agricultural and urban runoff, leaking septic tanks, and erosion of stream banks can increase the flow of nutrients and organic substances into reservoirs and lakes. These substances often times overstimulate the growth of algae and aquatic plants, creating conditions that interfere with contact recreation (swimming), boating (noncontact recreation), and the health and diversity of native fish, plant, and animal populations. Over production of bacteria, fungi, and algae may also impart foul odors and tastes to the water.

Section 314 of the CWA of 1987 requires all states to classify lakes and reservoirs according to trophic state. The trophic state of a reservoir refers to its nutritional status. Various classification schemes or indices have been developed that group reservoirs into discrete quality (trophic) states along a continuum from oligotrophic (poorly nourished) to hypereutrophic (over nourished) (Table 52). The basis for the trophic state index concept is that, in many reservoirs, the degree of eutrophication may be related to increased nutrient concentrations. Typically, phosphorus is the nutrient of concern, and an increase in its concentration may trigger a responding increase in the amount of algae (estimated by chlorophyll *a*) in the reservoir. Due to increased algal biomass, water transparency, as measured by a Secchi disk or submarine photometer, would be expected to decrease.

Table 52. Types of Trophic States in Reservoirs and Lakes

Trophic State	Water Quality Characteristics
Oligotrohic	Clear waters with extreme clarity, low nutrient concentrations, little organic matter or sediment, and minimal biological activity.
Mesotrophic	Waters with moderate nutrient concentrations and, therefore , more biological productivity. Waters may be lightly clouded by organic matter, sediment, suspended solids or algae.
Eutrophic	Waters extremely rich in nutrient concentrations, with high biological productivity. Waters clouded by organic matter, sediment, suspended solids and algae. Some species may be eliminated.
Hypereutrophic	Very murky, highly productive waters due to excessive nutrient loading. Many clearwater species cannot survive.

Major Texas reservoirs have been evaluated and ranked by the TNRCC using Carlson's Trophic State Index (TSI). Carlson's Index was developed to compare among reservoirs Secchi disk depths, chlorophyll *a* concentrations, and total phosphorus concentrations obtained by in-reservoir sampling (Carlson, 1977). These three variables are highly correlated and are considered estimators of algal biomass. By using regression analysis, Carlson related Secchi disk depth to total phosphorus concentration and to chlorophyll *a* concentration. The TSI is determined from any of the three computational equations:

$$\text{TSI (Secchi Disk)} = 10\left(6 - \frac{\ln SD}{\ln 2}\right)$$

$$\text{TSI (Chlorophyll } a\text{)} = 10\left(6 - \frac{2.04 - 0.68 \ln Chl}{\ln 2}\right)$$

$$\text{TSI (Total Phosphorus)} = 10\left(6 - \frac{\ln \frac{48}{TP}}{\ln 2}\right)$$

Although chlorophyll *a* is the most direct measure of algal biomass, Carlson used Secchi disk depth as the primary indicator. The index was scaled, so that TSI = 0 represents the largest measured Secchi disk depth

(64 m) among reservoirs. Each halving of transparency represents an increase of 10 TSI units (Table 1). The relationships between Secchi disk and chlorophyll *a* was nonlinear, so a 10-unit TSI (Chl *a*) change does not correspond to a factor-of-two change for chlorophyll *a*. Instead, chlorophyll *a* approximately doubles for each 7-unit increase in TSI (chl *a*) (Table 53).

Table 53. Carlson's Trophic State Index and Associated Parameters

Trophic State Index	Secchi Disk (m)	Total Phosphorus (mg/m^3)	Chlorophyll *a* (mg/m^3)
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.34
30	8	6	0.94
40	4	12	26
50	2	24	6.4
60	1	48	20.0
70	0.5	96	56
80	0.25	192	154
90	0.12	384	427
100	0.062	768	1,183

Carlson's Index provides a useful tool for assessing a reservoir's current condition and monitoring for change over time. For instance, the index would provide a quantitative estimate of the degree of improvement for a reservoir in which the TSI (Chl *a*) decreased from 60 to 40 units following implementation of rehabilitation measures. The index provides useful information in cases where the values are different, e.g., if TSI (TP) > TSI (Chl *a*), phosphorus is probably not the limiting nutrient; TSI (SD) > TSI (Chl *a*) indicates the presence of nonalgal turbidity. Carlson's Index has the advantage of presenting trophic state on a continuous numeric scale and can approximate the oligotrophic-hypereutrophic nomenclature required by the EPA. Secchi disk depths and total phosphorus and chlorophyll *a* concentrations are routinely determined at TNRCC and CRP fixed monitoring stations on reservoirs and lakes, so input data are readily available for computation of Carlson’s Index. The index does not perform well for certain water quality conditions: (1) where transparency is affected by suspended erosional materials rather than phytoplankton, (2) where primary production is controlled by attached algae or aquatic macrophytes rather than phytoplankton, and (3) when phosphorus is not the nutrient limiting phytoplankton growth.

Although the index can be used to classify and rank Texas reservoirs as to trophic state, priority ranking for restoration is difficult. Carlson's Index is not the same as a water quality index. Assessment of reservoir water quality depends to a large degree on the assignment of beneficial uses and

Table 54. Trophic Classification of Major Texas Reservoirs Using Carlson's Trophic State Index (TSI)

Segment Number	SWQM Station ID	Reservoir Name	Chlorophyll *a*					Total Phosphorus				Secchi Disk			
			Rank *	No. Meas.	Mean mg/m^3 **	TSI Chl *a* **	Trend ***	Rank	No. Meas.	Mean mg/m^3	TSI TP	Rank	No. Meas.	Mean m	TSI SD
1216	11894	Stillhouse Hollow	1	9	0.84	32.08	-0.53	6	9	18.0	45.21	6	10	2.51	47.23
2305	13211	Amistad	2	9	1.63	33.52	-1.80	73	43	423.41	61.13	3	57	3.18	44.72
1240	12027	White River Lake	3	7	1.29	33.74	-2.17	29	7	25.86	50.70	73	8	1.03	63.45
1904	12826	Medina Lake	4	5	1.26	33.95	-0.57	1	5	12.40	41.64	5	3	2.58	46.37
0228	10188	Lake Mackenzie	5	20	1.75	34.76	-0.43	13	20	19.70	46.46	25	20	1.67	53.38
0207	10079	Lake Theo	6	4	1.70	35.24	NC	47	4	42.75	56.14	57	4	1.38	60.33
0610	14906	Sam Rayburn	7	7	1.65	35.37	-11.57	4	7	15.71	43.92	9	6	2.25	48.54
0102	10036	Lake Meredith	8	24	2.40	36.07	-0.28	24	23	35.22	49.31	13	23	2.24	49.92
1220	11921	Belton	9	12	2.24	36.12	-1.42	21	12	25.25	48.06	17	24	1.88	52.16
0838	11073	Joe Pool Lake	10	16	2.17	36.21	NC	30	17	194.71	51.14	35	16	1.40	55.82
0614	10639	Lake Jacksonville	11	6	2.33	36.29	-0.72	8	6	14.17	45.70	11	7	2.19	48.77
1805	12598	Canyon Lake	12	36	2.08	36.30	+2.60	55	113	54.86	57.40	2	4	3.45	42.19
0223	10173	Greenbelt	13	19	2.43	36.32	-1.45	11	19	18.84	46.30	15	19	2.02	50.53
1429	12476	Austin Town Lake	14	17	2.03	36.36	-0.26	25	17	29.12	49.90	10	13	2.31	48.65
1249	12111	Lake Georgetown	15	12	2.08	37.06	-1.34	3	12	20.75	43.88	8	11	2.41	47.73
1230	11977	Lake Palo Pinto	16	6	2.15	37.10	-0.46	71	5	62.66	60.66	75	6	0.82	64.10
0215	10157	Diversion Lake	17	7	2.70	37.36	-4.72	28	7	24.29	50.47	72	3	0.79	63.35
1233	12002	Hubbard Creek	18	8	2.97	37.92	-0.41	46	8	57.50	55.91	19	5	1.74	52.79
1404	12302	Lake Travis	19	11	2.46	38.21	+0.18	17	11	43.91	47.35	1	10	4.24	40.09

Table 54. Trophic Classification of Major Texas Reservoirs (Continued)

Segment Number	SWQM Station ID	Reservoir Name	Chlorophyll *a*					Total Phosphorus				Secchi Disk			
			Rank *	No. Meas.	Mean mg/m^3 **	TSI Chl *a* **	Trend ***	Rank	No. Meas.	Mean mg/m^3	TSI TP	Rank	No. Meas.	Mean m	TSI SD
0834	11063	Lake Amon Carter	20	8	3.17	38.26	-0.83	42	8	41.87	55.03	28	3	1.61	54.04
1403	12294	Lake Austin	21	6	2.93	38.36	-0.43	18	6	22.00	47.37	14	5	2.16	50.22
1406	12324	Lake LBJ	22	9	2.67	38.81	+0.36	7	9	22.11	45.49	34	8	1.62	55.52
0210	10139	Farmers Creek	23	11	3.01	39.01	-3.39	35	11	45.00	52.74	71	3	0.85	63.01
0217	10159	Lake Kemp	24	13	3.47	39.02	-2.99	27	13	29.46	50.21	43	6	1.14	57.32
1234	12005	Lake Cisco	25	6	2.87	39.04	-3.13	9	6	21.67	45.99	30	2	1.60	54.31
1231	11979	Lake Graham	26	8	2.85	39.17	-4.68	63	8	63.88	59.29	102	5	0.36	75.31
1224	11939	Leon	27	9	4.11	39.23	-2.56	31	10	30.60	51.20	53	5	1.08	59.47
0613	10637	Lake Tyler	28	7	3.43	39.47	-4.77	19	7	20.71	47.61	36	8	1.38	55.83
0813	10973	Houston County	29	5	3.17	39.68	-2.16	16	5	22.00	47.18	39	4	1.29	56.56
1203	11851	Lake Whitney	30	10	3.73	39.96	-0.29	32	10	26.60	51.39	16	12	1.91	51.31
1418	12395	Lake Brownwood	31	12	3.20	40.22	+0.74	12	12	58.08	46.39	29	4	1.50	54.20
0821	11020	Lake Lavon	32	14	4.09	40.50	-2.20	58	14	44.14	58.23	70	15	0.88	62.93
1419	12398	Lake Coleman	33	9	4.00	41.07	-3.26	5	10	16.80	44.26	33	5	1.39	55.51
1247	12095	Granger Lake	34	15	4.56	41.31	-0.82	44	15	40.53	55.61	95	14	0.47	71.58
1426	12180	Oak Creek	35	6	3.85	41.51	+1.56	22	6	24.50	48.46	48	6	1.17	58.39
0404	14473	Ellison Creek	36	7	3.56	41.72	+1.29	15	7	20.71	46.78	37	7	1.33	56.13
1254	12127	Aquilla	37	10	4.72	41.96	-3.91	74	10	65.90	61.73	84	14	0.73	66.05
1207	11865	Possum Kingdom	38	6	5.43	42.19	-0.28	52	5	44.20	56.58	7	7	2.38	47.64
0816	10980	Lake Waxahachie	39	7	4.13	42.24	-0.90	43	7	50.29	55.19	56	6	1.11	60.22

Table 54. Trophic Classification of Major Texas Reservoirs (Continued)

Segment Number	SWQM Station ID	Reservoir Name	Chlorophyll *a*					Total Phosphorus				Secchi Disk			
			Rank *	No. Meas.	Mean mg/m^3 **	TSI Chl *a* **	Trend ***	Rank	No. Meas.	Mean mg/m^3	TSI TP	Rank	No. Meas.	Mean m	TSI SD
1236	12010	Lake Fort Phantom Hill	40	13	5.96	42.50	-1.94	75	13	63.08	62.42	82	9	0.69	65.14
1433	12511	O.H. Ivie	41	7	5.05	42.53	-6.13	38	7	116.43	54.10	21	5	1.73	52.88
1408	12344	Lake Buchanan	42	8	4.11	42.57	+0.7	2	8	14.50	42.54	4	8	2.81	45.96
0510	10445	Lake Cherokee	43	4	4.15	42.60	-1.17	92	4	115.00	68.29	52	4	1.27	59.38
1205	11860	Lake Granbury	44	6	4.92	42.79	-4.25	34	6	33.50	51.76	60	7	1.17	60.84
0212	10142	Lake Arrowhead	45	10	5.41	43.07	-2.92	102	11	166.36	77.75	108	3	0.20	85.11
1225	11942	Lake Waco	46	14	6.24	43.27	-0.65	40	14	37.00	54.40	66	12	0.93	62.37
1002	11204	Lake Houston	47	33	6.05	43.66	-0.40	103	32	181.06	78.35	101	40	0.39	75.08
0213	10143	Lake Kickapoo	48	7	5.19	43.85	-0.68	57	7	47.14	58.07	106	3	0.25	80.03
1418	12178	Hords Creek	49	5	5.16	43.92	-----	33	6	28.33	51.52	42	3	1.24	57.19
1604	12529	Lake Texana	50	10	6.44	44.02	+1.26	101	9	169.33	76.31	107	9	0.32	80.72
0203	10128	Lake Texoma	51	7	5.85	44.05	-2.05	70	7	258.43	60.28	18	8	1.73	52.23
1235	12006	Lake Stamford	52	14	5.10	44.14	-3.19	85	14	71.57	63.52	86	9	0.62	66.68
0408	10329	Lake Bob Sandlin	53	8	5.80	44.75	-5.26	49	8	70.62	56.49	31	8	1.45	54.84
0613	10638	Lake Tyler East	54	15	5.76	45.05	-6.11	10	15	20.00	45.99	41	16	1.27	57.12
0403	10296	Lake O' Pines	55	25	6.68	45.35	+1.08	83	25	265.40	63.23	44	28	1.27	57.58
1423	12422	Twin Buttes	56	7	5.35	45.60	+0.75	23	7	28.14	49.23	23	7	1.70	53.05
0401	10283	Caddo Lake	57	25	10.21	45.69	+0.76	72	25	68.88	60.86	76	30	0.80	64.11
1405	12319	Lake Marbles Falls	58	11	6.38	46.00	-0.44	26	11	26.00	50.19	27	12	1.56	53.91
0820	10997	Lake Ray Hubbard	59	7	7.84	46.32	-4.88	86	6	68.17	63.96	49	7	1.10	58.68

Table 54. Trophic Classification of Major Texas Reservoirs (Continued)

Segment Number	SWQM Station ID	Reservoir Name	Chlorophyll *a*					Total Phosphorus				Secchi Disk			
			Rank *	No. Meas.	Mean mg/m^3 **	TSI Chl *a* **	Trend ***	Rank	No. Meas.	Mean mg/m^3	TSI TP	Rank	No. Meas.	Mean m	TSI SD
1422	12418	Lake Nasworthy	60	7	7.55	46.50	-0.72	68	7	58.71	59.94	83	6	0.75	65.16
0811	10970	Lake Bridgeport	61	4	7.28	46.61	-1.85	36	4	39.25	53.17	50	4	1.53	58.74
1407	12336	Inks Lake	62	8	6.01	46.68	-0.04	20	8	22.62	47.97	19	8	1.67	52.69
2454	12514	Cox Lake	63	14	10.74	47.22	NC	106	13	390.00	87.61	109	14	0.17	86.20
1237	12021	Lake Sweetwater	64	8	7.86	47.44	-2.02	81	8	144.00	63.00	61	4	0.95	60.90
2116	13019	Choke Canyon	65	14	7.26	47.52	-0.34	56	15	54.93	57.86	58	15	1.02	60.63
1411	12359	E.V. Spence	66	6	6.50	47.97	+1.26	14	6	19.00	46.60	22	7	1.81	52.88
0512	10458	Lake Fork	67	76	8.24	48.04	+0.23	53	71	41.78	57.10	24	117	1.65	53.30
0504	10402	Toledo Bend	68	72	7.46	48.15	+0.80	59	72	45.50	58.25	26	113	1.61	53.86
0199	10005	Palo Duro	69	14	10.31	48.26	-3.52	97	14	188.57	73.64	103	14	0.33	77.62
1425	12429	O.C. Fisher	70	7	9.12	48.84	+1.48	64	7	46.29	59.41	46	5	1.38	58.22
0405	10312	Lake Cypress Springs	71	8	7.40	48.95	-4.03	51	8	73.13	57.00	38	8	1.30	56.24
0209	10138	Pat Mayse	72	9	8.26	49.09	-1.18	62	9	72.22	59.16	40	8	1.31	56.76
1413	12368	Lake J.B. Thomas	73	5	9.58	49.17	-2.48	78	5	60.80	62.71	85	4	1.23	66.56
0208	10137	Lake Crook	74	4	6.82	49.32	+2.39	105	4	337.50	84.58	104	3	0.30	78.10
1209	11792	Bryan Municipal Lake	75	14	15.88	49.46	NC	109	14	811.86	99.64	94	13	0.51	70.76
0823	11025	Lake Lewisville	76	7	8.13	49.48	+0.13	77	7	70.29	62.56	51	7	1.12	59.34
1252	12123	Lake Limestone	77	10	12.40	49.56	-0.96	66	10	68.00	59.78	87	13	0.83	66.87
0828	11040	Lake Arlington	78	6	8.02	49.66	-1.42	54	6	42.50	57.25	62	6	0.94	61.19
2103	12967	Lake Corpus Christi	79	15	13.63	49.77	-1.21	99	15	154.13	75.97	99	15	0.41	73.30

Table 54. Trophic Classification of Major Texas Reservoirs (Continued)

Segment Number	SWQM Station ID	Reservoir Name	Chlorophyll *a*					Total Phosphorus				Secchi Disk			
			Rank *	No. Meas.	Mean mg/m^3 **	TSI Chl *a* **	Trend ***	Rank	No. Meas.	Mean mg/m^3	TSI TP	Rank	No. Meas.	Mean m	TSI SD
0603	10582	B.A. Steinhagen	80	5	7.64	50.02	+2.69	96	4	127.00	72.58	93	5	0.48	70.72
0302	10213	Wright Patman	81	11	13.85	50.17	-6.88	91	11	92.73	68.12	74	11	0.87	63.89
2312	13267	Red Bluff	82	16	11.93	50.83	+0.43	41	16	38.12	54.89	65	19	0.86	62.23
0605	10593	Lake Palestine	83	14	12.59	51.01	-6.46	65	14	76.07	59.61	64	16	0.89	62.13
0817	10981	Navarro Mills	84	6	9.82	51.05	+0.64	79	6	77.83	62.83	90	6	0.59	69.04
1212	11881	Sommerville	85	9	16.19	51.37	-3.08	84	9	64.11	63.46	78	11	0.77	64.17
0826	11035	Grapevine	86	4	8.70	51.46	+0.11	48	4	46.00	56.24	32	4	1.38	55.45
0836	11065	Richland-Chambers	87	4	9.50	51.64	NC	37	4	33.00	53.35	12	4	2.06	49.61
1210	14238	Lake Mexia	88	8	15.08	51.94	-3.56	104	7	192.86	79.69	105	9	0.28	78.85
1222	11935	Proctor Lake	89	16	13.25	52.23	-1.78	88	16	71.87	64.15	92	14	0.52	70.54
0815	10979	Bardwell	90	8	11.75	52.30	-2.92	82	8	70.00	63.12	77	8	0.78	64.14
1209	11798	Finfeather Lake	91	15	19.48	52.40	NC	108	14	700.36	97.17	45	11	1.31	57.98
0832	11061	Lake Weatherford	92	5	10.58	52.40	-1.42	52	5	43.20	57.09	63	5	0.93	61.77
1208	11679	Millers Creek	93	7	12.34	52.45	-1.52	76	7	97.43	62.43	88	5	0.58	67.07
0818	10982	Cedar Creek	94	8	12.89	52.86	-2.72	89	8	77.00	65.50	80	9	0.79	64.88
0230	10192	Lake Tanglewood	95	15	20.48	52.88	-9.69	107	15	794.27	93.96	97	14	0.49	72.06
1012	11342	Lake Conroe	96	17	15.89	53.48	+1.70	45	18	36.94	55.79	67	17	0.90	62.48
0809	10945	Eagle Mountain	97	4	11.05	53.56	+0.14	61	4	54.00	58.74	68	4	0.96	62.53
0507	10434	Lake Tawakoni	98	74	16.97	54.25	+0.40	69	69	49.52	60.14	54	110	1.08	59.55
1416	12179	Brady Creek	99	5	12.36	54.36	+2.06	39	5	34.00	54.35	59	5	0.99	60.72

Table 54. Trophic Classification of Major Texas Reservoirs (Continued)

Segment Number	SWQM Station ID	Reservoir Name	Chlorophyll *a*					Total Phosphorus				Secchi Disk			
			Rank *	No. Meas.	Mean mg/m^3 **	TSI Chl *a* **	Trend ***	Rank	No. Meas.	Mean mg/m^3	TSI TP	Rank	No. Meas.	Mean m	TSI SD
1412	12167	Lake Colorado City	100	7	12.39	54.62	+0.63	60	7	50.71	58.49	55	5	1.00	60.22
2303	13189	Falcon	101	12	13.58	54.86	+0.29	90	13	108.08	66.14	47	11	1.15	58.25
0807	10942	Lake Worth	102	4	15.15	55.82	-0.20	67	4	54.75	59.86	79	4	0.80	64.60
0803	10899	Livingston	103	60	17.40	55.95	-0.24	100	97	163.89	76.10	81	87	0.79	65.02
1228	11974	Pat Cleburne	104	6	27.12	58.86	+0.81	94	6	231.67	70.38	96	6	0.47	71.76
0840	11078	Lake Ray Roberts	105	5	21.20	59.49	NC	95	5	116.40	71.20	98	4	0.47	72.57
0827	11038	White Rock Lake	106	4	25.60	60.69	NC	93	4	90.50	69.05	89	3	0.63	67.15
0219	10163	Lake Wichita	107	4	25.77	61.57	-3.29	98	4	155.00	75.39	100	3	0.35	75.03
0509	10444	Lake Murvaul	108	7	37.06	64.81	-0.48	80	7	62.86	62.86	69	7	0.83	62.92
1241	11529	Buffalo Springs Lake	109	8	39.26	65.94	-1.02	87	8	77.88	64.09	91	9	0.49	69.71
0105	10060	Rita Blanca Lake	110	13	195.87	68.39	-5.49	110	14	3250.71	119.19	110	13	0.08	91.91

* Reservoirs are ranked in priority by TSI (Chl)

** The equations for Carlson's TSI (Chl), (TP), and (SD) involve converting each parameter value to its respective natural log (ln). The Carlson's TSI (Chl), (TP), and (SD) were computed for each reservoir by calculating the arithmetic average for the TSI values from each sample date. The effect of these computations is that the ranking of Carlson's TSI (Chl), (TP), and (SD) values may vary slightly from a ranking based on the arithmetic average of chlorophyll *a*, total phosphorus, and Secchi disk values.

*** A minus(-) preceding a value in the trend column indicates decreased algal content between the 1998 and 2000 reporting cycles; a plus (+) indicates increased algal content; NC indicates no change in values; a dotted line (-----) indicates absence of comparable data.

determinations to evaluate if the uses are being maintained and/or impaired. For this reason, the 305(b) assessment and 303(d) list provide a ranking of priorities for protection and restoration for all water bodies including reservoirs.

Texas reservoirs are ranked in Table 54 according to Carlson's TSI for chlorophyll *a* as an average calculated from 10 years of SWQM data (September 1989-August 1999). In order to maximize comparability among reservoirs, data from the station nearest the dam in the main pool of each reservoir were utilized if available. For many reservoirs, these are the only sites monitored by the TNRCC and the CRP. Chlorophyll *a* was given priority as the primary trophic state indicator, because it is best for estimating algal biomass in most reservoirs. A minimum of four chlorophyll *a* measurements and at least one total phosphorus and Secchi disk measurement were required for a reservoir to be included in the ranking. Based on this assessment, 5 reservoirs are considered oligotrophic, and 105 reservoirs show signs of eutrophication (Table 55). Rankings are also provided for total phosphorus (TP) and Secchi disk transparency (SD). This presentation permits comparison of individual TSI indicators for each reservoir, provides indications of the clearest reservoirs (low TSI SD), and identifies reservoirs with low and high total phosphorus concentrations.

Table 55. Number of Texas Reservoirs Assessed in Each Trophic Class

Trophic Class	TSI (Chl *a*) Index Range	Number of Reservoirs
Oligotrophic	0 - 35	5
Mesotrophic	> 35-45	48
Eutrophic	> 45-55	48
Hypereutrophic	> 55	9

Reservoirs with the clearest water (highest Secchi disk transparency) occur primarily in the central portion of the state and are listed in descending order are: Lake Travis (Segment 1404), Canyon Lake (Segment 1805), Amistad Reservoir (Segment 2305), Lake Buchanan (Segment 1408), and Medina Lake (Segment 1904). Reservoirs with the poorest light transparency (lowest Secchi disk transparency) listed in descending order are: Rita Blanca Lake (Segment 0105), Cox Lake (in Segment 2454), Lake Arrowhead (Segment 0212), Lake Texana (Segment 1604), and Lake Kickapoo (Segment 0213).

Reservoirs with the lowest total phosphorus concentrations listed in descending order are: Medina Lake (Segment 1904), Lake Buchanan

(Segment 1408), Lake Georgetown (Segment 1249), Sam Rayburn Reservoir (Segment 0610), and Lake Coleman (Segment 1419). Reservoirs enriched with the highest total phosphorus concentrations listed in descending order are: Rita Blanca Lake (Segment 0105), Bryan Municipal Lake (in Segment 1209), Finfeather Lake (in Segment 1209), Lake Tanglewood (Segment 0230), and Cox Lake (in Segment 2454).

Water Quality Trends in Reservoirs

Carlson's TSI Chl *a* values for 109 reservoirs from the 1998 and 2000 reporting cycles were compared to indicate temporal trends (Table 54). Insufficient data for one of the reporting periods were available for only one reservoir (Hords Creek) to allow computation of trends. The period of record for the 1998 reporting cycle was September 1987-August 1997; for 2000, the period of record was September 1989-August 1999. Overall, TSI Chl *a* values, which estimate the amount of algal biomass, indicate improvement (decrease in values) in 73 of 109 (67%) reservoirs. Increases in algal biomass (increase in TSI Chl *a* values) are indicated in 28 of 109 (26%) reservoirs. TSI Chl *a* values remained unchanged in 8 of 109 (7%) reservoirs. The TSI Chl *a* values were remarkably stable among the 109 reservoirs between the two reporting cycles, with 50 of 109 (46%) changing by 1 unit or less. In only 23 of 109 (21%) reservoirs, the TSI Chl *a* values changed by 3 units or more.

Reservoirs that improved the most, as shown by decreasing TSI Chl *a* values, are Sam Rayburn (Segment 0610), Lake Tanglewood (Segment 0230), Wright Patman (Segment 0302), Lake Palestine (Segment 0605), and O.H. Ivie (Segment 1433)(Table 53). Reservoirs with the largest trends for increasing algal content (larger positive TSI Chl *a* values) are B.A. Steinhagen (Segment 0603), Canyon Lake (Segment 1805), Lake Crook (Segment 0208), Brady Creek (in Segment 1416), and Lake Conroe (Segment 1012). These changes are for a two-year period and may not represent longer term trends.

Reservoir Control Programs

Texas employs several reservoir pollution control procedures to ensure high-quality water for recreational, domestic, and industrial uses. Surface water quality standards have been adopted for significant reservoirs throughout the state. The standards establish designated uses for classified segments and presumed uses for unclassified segments and include numerical criteria to protect those uses. Designated uses are determined by taking into account the reservoir's physical and biological characteristics, natural water quality, and existing uses. Criteria, depending on parameter, are based on background levels or accepted levels for protection of human health and aquatic life. TMDLs are conducted to determine the assimilative capacity of the segment and to determine discharge treatment levels and nonpoint source loads necessary to meet the criteria. These treatment levels are then required when issuing wastewater permits to dischargers. In some cases, TMDLs may recommend no discharge of wastewater. Compliance with wastewater permits is monitored through on-site inspections by TNRCC personnel and through self-reporting procedures. When noncompliance with permits is found, enforcement actions may be required to attain compliance. The uses, criteria, TMDLs, and permits are periodically reviewed and, if necessary, revised. Each major reservoir is routinely monitored to assess the overall condition of the water body and determine short- or long-term water quality trends. The Carlson's Trophic State Index is used to score reservoirs according to trophic conditions based on Secchi disk transparency, total phosphorus levels, and chlorophyll *a* levels. Reservoirs with nonsupported uses are placed on the State of Texas 303(d) List.

The TNRCC has several specific rules that prescribe permit limitations for discharges of domestic wastewater into reservoirs. Chapter 309 of the effluent standards portion of the TNRCC rules requires discharges located within five river miles upstream of certain reservoirs to achieve a minimum effluent quality of 10 mg/L BOD_5 and 15 mg/L TSS as a 30-day average. This rule applies to reservoirs that are subject to private sewage facilities regulation or that may be used as a source for a public drinking water supply. Currently, 92 Texas reservoirs are designated for the public water supply use. Additional rules under Chapter 311, Watershed Protection, have been promulgated that protect specific reservoirs:

Subchapter D: §§311.31-311.36.

This rule requires all domestic and industrial permittees in the entire Lake Houston watershed to meet effluent limitations equal to or commensurate with 10 mg/L BOD_5, 15 mg/L TSS, and 3 mg/L NH_3-N as a 30-day average. All wastewater effluents disposed of on land shall meet an effluent quality of 20 mg/L BOD_5 and 20 mg/L TSS. Domestic facilities must submit a solids management plan. Additionally, all domestic and industrial facilities with gaseous chlorination disinfection systems must have dual-feed chlorination systems and must meet a minimum chlorine residual of 1 mg/L and a maximum chlorine residual of 4.0 mg/L.

Subchapter A, B and F: §§311.1-.5, 311.11-.15 and 311.51-.55.

These rules apply to a series of reservoirs on the Colorado River, which are commonly referred to as the Highland Lakes, including Lake Austin (Segment 1403), Lake Travis (Segment 1404), Lake Marble Falls (Segment 1405), Lake LBJ, (Segment 1406), Inks Lake (Segment 1407), and Lake Buchanan (Segment 1408). Water quality areas, those portions of the watersheds within 10 river miles of the reservoirs, were established for each reservoir. New wastewater facilities constructed in these areas will be issued no-discharge permits, which means that treated wastewater will not be discharged to surface waters. Any existing facility that requires a permit amendment for expansion or is not meeting permit requirements because of sewage overloading will be issued a no-discharge permit. Proposed new or expanded treatment facilities in the watersheds of these reservoirs will be issued no-discharge permits unless the applicant can establish that any alternative proposed wastewater disposal will protect and maintain the existing quality of the reservoirs.

Subchapter G: §§311.61.-311.66.

This rule applies to Lakes Worth, Eagle Mountain, Bridgeport, Cedar Creek, Arlington, Benbrook, and Richland-Chambers. With the exception of oxidation pond systems, domestic discharges within the water quality areas of the watersheds of these reservoirs are required to meet advanced treatment limits of 10 mg/L BOD_5, and filtration is required to supplement suspended solids removal by January 1, 1993.

In addition to water quality monitoring and creation of rules to regulate the permitting of wastewater discharges to reservoirs, the TNRCC maintains an extensive inspection program of wastewater treatment facilities. When permit limitations are not being met, the appropriate enforcement action is pursued.

Reservoir and Lake Restoration Efforts

Section 314 of the Clean Water Act makes federal grant funds available to states under the Clean Lakes Program. The TNRCC is currently not administering any grant funding under this program.