Trophic Classification of Texas Reservoirs

2020 Texas Integrated Report for Clean Water Act Sections 305(b) and 303(d)

The primary productivity of reservoirs, as indicated by the amount of nutrients (phosphorus and nitrogen) and the extent of algae (suspended, floating, and attached) and rooted aquatic plants, can have a significant effect on water quality. Up to a point, nutrients promote ecosystem production and healthy growth of algae, larger plants, and fish and other aquatic organisms. However, excess nutrients and algae in reservoirs can have a deleterious effect on water quality, and algae can reach nuisance levels that potentially (1) create nuisance aesthetic conditions, (2) cause taste and odor in drinking water sources, (3) contribute to reduced dissolved oxygen as algae decay, and (4) and ultimately reduce the ability of a water body to support healthy, diverse aquatic communities.

Eutrophication refers to an overall condition characterized by an accumulation of nutrients that support relatively elevated growth of algae and other organisms. Eutrophication is primarily influenced by the physical and hydrological characteristics of the water body and can be affected by natural processes and human activities in the surrounding watershed. Human activities can accelerate the eutrophication process by increasing the rate at which nutrients and organic substances enter impoundments and surrounding watersheds. Discharges of treated sewage, agricultural and urban runoff, leaking septic tanks, and erosion of stream banks can increase the flow of nutrients and organic substances into reservoirs. In comparison to natural lakes in northern states, the eutrophication process in southern reservoirs is often enhanced by (1) warm climates with long growing seasons, (2) soils and geologic substrates that create high concentrations of sediment and nutrients in rainfall runoff, and (3) relatively high river inflows on main stem impoundments. As a result, some reservoirs in Texas can be relatively eutrophic even where nutrient loadings due to human activities are not relatively large.

The trophic state of a reservoir refers to its nutritional status that is indicated by measurements of nutrients and algae. Section 314 of the U.S. Clean Water Act (CWA) requires all states to classify lakes and reservoirs according to trophic state. Assessing water body condition based on algae is accomplished by evaluating indicators that reflect nutrient dynamics that drive primary production. Various classification schemes (Table 1-1) or indices have been developed that group reservoirs into discrete quality (trophic) states along a continuum from oligotrophic (poorly nourished) to hypereutrophic (over nourished). 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 changes in its concentration may trigger a response that influences the amount of algae, as estimated by chlorophyll *a* (Chl *a*) in the reservoir. For example, increases in phosphorus can result in higher algal biomass, which in turn decreases water transparency (as measured by a Secchi disk or submarine photometer).

Table 1 - 1. Types of Trophic States in Reservoirs and Lakes

Trophic State	Water Quality Characteristics
Oligotrophic	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 relatively rich in nutrient concentrations, with high biological productivity. Waters more clouded by organic matter, sediment, suspended solids, and algae.
Hypereutrophic	Murkier, highly productive waters. Dense algae, very high nutrient concentrations.

(Adapted from a variety of descriptions of trophic state characteristics)

Major Texas reservoirs have been evaluated and ranked every two years by the TCEQ using Carlson's Trophic State Index (TSI). Carlson's Index was developed to compare reservoirs using in-reservoir sampling data (Carlson, 1977; Carlson and Simpson, 1996). Secchi disk depths, chlorophyll *a* concentrations, and total phosphorus concentrations are three variables that are highly correlated and considered estimators of algal biomass. The Carlson Index uses regression analysis to relate these three parameters to determine trophic state. The TSI is determined from any of the three computational equations:

TSI (Secchi Disk) = 60 - 14.41 ln(SD), where SD is mean Secchi disk depth in meters.

TSI (Chlorophyll *a*) = 9.81 ln(Chl *a*) + 30.6, where Chl *a* is mean chlorophyll *a* in µg/L.

TSI (Total Phosphorus) = 14.42 ln(TP) + 4.15, where TP is mean total phosphorus in µg/L.

Although chlorophyll *a* is the most direct measure of algal biomass, the TSI uses 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 1-2). Since the relationships between Secchi disk and chlorophyll *a* was nonlinear a 10-unit TSI (Chl *a*) change does not correspond to a doubling of chlorophyll *a*. Instead, chlorophyll *a* approximately doubles for each 7-unit increase in TSI (Chl *a*).

Table 1 - 2. Carlson's Trophic State Index and Associated Parameters

Trophic State Index	Secchi Disc (m)	Total Phosphorus (µg/L)	Chlorophyll *a* (µg/L)
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	2.6
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

(Adapted from Carlson, 1977; and Carlson and Simpson, 1996)

Carlson's Index provides a useful tool for assessing a reservoir's condition and evaluating changes over time. For example, 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 restoration measures. The index provides useful information which explains possible causes of the water body condition. For example, if TSI (TP) > TSI (Chl *a*), phosphorus is probably not the limiting nutrient; TSI (SD) > TSI (Chl *a*) indicates the presence of non-algal turbidity.

Carlson's Index provides a simple model for evaluating condition which provides both advantages and disadvantages. The trophic state is developed on a continuous numeric scale and is useful for approximating the oligotrophic-hypereutrophic nomenclature required by the EPA. Secchi disk depths, total phosphorus, and chlorophyll *a* concentrations are routinely determined at fixed monitoring stations on reservoirs and lakes, so 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 by trophic state, priority ranking for restoration is difficult. Carlson's Index does not replace the need to use attainment determinations. Carlson (1977) points out that trophic state is not equivalent to an index of water quality. Assessment of reservoir water quality depends to a large degree on the assignment of beneficial uses and determinations to evaluate if the uses are being maintained and/or impaired. Texas reservoirs are ranked in Appendix A according to Carlson's TSI for chlorophyll *a* as an average calculated from 10 years of SWQM data (December 1, 2008 - November 30, 2018).
In order to maximize comparability among reservoirs, data from the monitoring station nearest

the dam, with the most available data, in the main pool of each reservoir were utilized if available. In some cases, multiple stations situated within close proximity of one another were also used. For many reservoirs, these are the only sites monitored by the TCEQ and Clean Rivers Program. Chlorophyll *a* was given priority as the primary trophic state indicator because it has proven to be most useful for estimating algal biomass in most reservoirs. A minimum of four chlorophyll *a* measurements, two total phosphorus, and two Secchi disk measurements were required for a reservoir to be included in the ranking. Of the 138 reservoirs surveyed, 134 had sufficient data to be included in the ranking. Based on this assessment, the 134 reservoirs show a range of eutrophication, from oligotrophic to hypereutrophic (Table 1 - 3). Rankings are also provided for total phosphorus (TP) and Secchi disk transparency (SD). Comparing TSI indicators between the reservoirs provides indications of the clearest reservoirs (low TSI SD) and identifies reservoirs with low and high total phosphorus concentrations.

Table 1 - 3. Number of Texas Reservoirs Assessed in Each Trophic Class

Trophic Class	TSI (Chl *a*) Index Range	Number of Texas Reservoirs
Oligotrophic	0 – 40	6
Mesotrophic	>40 – 50	24
Eutrophic	>50 – 70	99
Hypereutrophic	>70	5

Adapted from Carlson and Simpson (1996)

Reservoirs with the clearest water (highest mean Secchi disk transparency), listed in descending order are as follows: Canyon Lake (4.22 m), International Amistad Reservoir (4.20 m), Lake Travis (3.44 m), Lake Alan Henry (3.30 m) and Tyler State Park Lake (3.26 m). Reservoirs with the highest turbidity (poorest light transparency, lowest mean Secchi disk transparency), listed in ascending order are as follows: Rita Blanca Lake (0.08 m), Cox Lake (0.12 m), Palo Duro Reservoir (0.24 m), Lake Crook (0.28 m), Lake Springfield (0.30 m), and Lake Kickapoo (0.30 m).

Twenty-eight reservoirs share the lowest mean total phosphorus concentration of 0.02 mg/L. Reservoirs with the highest mean total phosphorus concentrations, listed in descending order are as follows: Rita Blanca Lake (3.24 mg/L), O. C. Fisher Lake (1.52 mg/L), Lake Tanglewood (1.02 mg/L), Lake Woodlands (0.92 mg/L), Palo Duro Reservoir (0.30 mg/L), and Lake Wichita (0.30 mg/L).

Water Quality Differences in Reservoirs

Carlson's TSI Chl *a* values for 92 reservoirs from the 2010 and 2020 reporting cycles were compared to indicate temporal differences (Appendix A). Differences could not be calculated for 42 reservoirs (31 %), due to the lack of comparable reporting information from 2010. The 2010 period of record was December 1, 1998 - November 30, 2008; for 2020, the period of record was December 1, 2008 - November 30, 2018.

TSI Chl *a* values, which estimate the amount of algal biomass, can indicate water quality improvement when values decrease. There were decreases in TSI Chl *a* values in 20 (22 %) of the comparable reservoirs between 2010 and 2020. Reservoirs with largest decrease in mean TSI Chl *a* values, listed in descending order are as follows: Lake Alan Henry (-16.12), Canyon Lake (-10.92), Twin Buttes Reservoir (-8.28), Medina Lake (-7.38), and Oak Creek Reservoir (-6.52). Increases in algal biomass (increase in TSI Chl *a* values) are indicated in 72 (78 %) of the comparable reservoirs, which may be indicative of natural or cultural eutrophication. Reservoirs with the largest differences for increasing algal content (substantial positive TSI Chl *a* values), listed in descending order are as follows: O. C. Fisher Reservoir (+23.32), Wright Patman Lake (+18.52), Lake Meredith (+14.86), Lake Georgetown (+13.62), and Lake Bob Sandlin (+11.74).

It should be noted that a reservoir's trophic rank may differ from that in the last assessment due to improvements in data reporting and analytical capabilities or a change in monitoring station(s) rather than changes in water quality. Many individual values in the SWQMIS water quality database are reported as less than analytical reporting limits (non-detects or censored data). There is no generalized way to determine the true value for an individual result in the range between zero and the reporting limit. For the trophic classification assessment of Texas reservoirs, 50 percent of an analytical reporting limit is computed for censored results. This is done to maximize the amount of data used in this analysis and to indicate the level of monitoring effort. For more information please contact the Surface Water Quality Monitoring Team at swqm@tceq.texas.gov.

Reservoir Control Programs

Texas implements several reservoir pollution control procedures to ensure high-quality water for recreational, aquatic life, domestic, and industrial uses. Surface water quality standards have been adopted for significant reservoirs throughout the state in Title 30, Texas Administrative Code (TAC), Chapter 307 the Texas Surface Water Quality Standards (TSWQS). The TSWQS establish uses for classified segments and unclassified waterbodies, 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. The TCEQ issues permits that include limits designed to protect these uses. Each major reservoir is routinely monitored to assess the overall condition of the water body in comparison to the criteria and determine short- or long-term water quality trends. Reservoirs with non-supported uses are placed on the State of Texas 303(d) List. When a water body is identified as impaired and in need of remedial efforts, in some cases a Total Maximum Daily Load (TMDL) is conducted to determine the assimilative capacity of the segment and to determine discharge treatment levels and nonpoint source loads necessary to meet the criteria. Compliance with wastewater permits is monitored through on-site inspections by TCEQ 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.

The TCEQ has several specific rules that prescribe permit limitations for discharges of domestic wastewater into reservoirs. The rules in 30 TAC, Chapter 309 Domestic Wastewater Effluent Limitation and Plant Siting, require discharges located within five river miles upstream of certain reservoirs to achieve a minimum effluent quality for 5-day biological oxygen demand (BOD_5) of 10 mg/L, and total suspended solids (TSS) of 15 mg/L; both expressed as a 30-day average. This rule applies to reservoirs that are subject to on-site/private sewage facility regulation or that may be used as a source for a public drinking water supply. Currently, 95 reservoirs are designated for the public water supply use in Section (§) 307.10, Appendices A and B of the TSWQS. Additional rules under 30 TAC, Chapter 311 Watershed Protection, have been promulgated that protect specific reservoirs:

Subchapter A, B and F: §§311.1-.6, 311.11-.16 and 311.51-.56.
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, meaning 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. Allowable storm water runoff and certain non-storm water discharges that may be authorized by a Texas Pollution Discharge Elimination System (TPDES) or National Pollution Discharge Elimination System (NPDES) permit are also included in these watershed rules.

Subchapter D: §§311.31- .36.
This rule requires all domestic and industrial permittees in the entire Lake Houston (Segment 1002) watershed to meet effluent limitations equal to or commensurate with 10 mg/L of $BOD_{5,}$ 15 mg/L of TSS, and 3 mg/L of ammonia-nitrogen (NH3-N); all expressed as a 30-day average. All wastewater effluents disposed of on land shall meet an effluent quality of 20 mg/L of BOD_5 and 20 mg/L of 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 G: §§311.61.-311.67.
This rule applies to Lakes Worth (Segment 0807), Eagle Mountain (Segment 0809), Bridgeport (Segment 0811), Cedar Creek (Segment 0818), Arlington (Segment 0828), Benbrook (Segment 0830), and Richland-Chambers (Segment 0836). 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 for BOD_5 of 10 mg/L, and filtration is required to supplement suspended solids removal by January 1, 1993. Section 311.67 specifies effluent limitations to control nutrients from new domestic wastewater facilities discharging to the Benbrook Lake watershed and Benbrook Lake water quality area. Based on location within the watershed and size of discharge, permittees must meet a daily effluent limit for TP of 1.0 mg/L, based on a 30-day average.

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 TCEQ is currently not administering any grant funding under this program. There are several lakes and reservoirs throughout the State where restoration efforts are currently under way to improve water quality. In addition to TMDLs, WPPs and Watershed Characterizations may be developed to protect high-quality waters, to address threatened waters before they become impaired, or to restore water bodies for which TMDLs are not practical. The lakes and reservoirs with ongoing restoration efforts include the following:

Lake O' the Pines – TMDL Implementation Plan
E.V. Spence Reservoir – TMDL Implementation Plan
Lake Austin – TMDL Implementation Plan
Lake Worth – TMDL Implementation Plan
Lake Houston – TMDL Implementation Plan
Aquilla Reservoir – TMDL Implementation Plan
Mountain Creek Lake – TMDL Implementation Plan
Lake Como – TMDL Implementation Plan
Fosdic Lake – TMDL Implementation Plan
Echo Lake – TMDL Implementation Plan
Donna Reservoir – TMDL Implementation Plan
Lake Arlington/Village Creek – Watershed Protection Plan
Lake Granbury – Watershed Protection Plan
Lake Lavon – Watershed Protection Plan
Joe Pool Lake – Watershed Protection Plan

High and Low pH in Texas Water Bodies

The trophic status of a water body can impact a number of water quality parameters, including pH. Photosynthesis, respiration, and decomposition all contribute to pH fluctuations due to their influences on available carbon dioxide levels in the water column. Elevations in pH are typically highest in mid-afternoon, and lowest just before sunrise. Section 314 of the CWA requires states to include methods and procedures to evaluate and mitigate pH as part of the trophic classification.

Instantaneous and diel pH data collected as part of routine water quality monitoring and special studies are evaluated to determine attainment with site-specific water quality standards for high and low pH as part of the Integrated Report. If impaired, TCEQ considers this information when developing restoration strategies such as TMDLs and Watershed Protection Plans (WPPs), to determine if the pH impairment is related to excessive enrichment.

Low pH in Texas Water Bodies

Data from one reservoir, freshwater stream, and tidal stream (Table 1-4) have indicated low pH (high acidity) in at least one assessment location resulting in the water bodies being included in the Index of Water Quality Impairments. During respiration, dissolved carbon dioxide reacts with water to form carbonic acid, which may lower pH. Most of these water bodies are located in the eastern portion of the state, where natural geologic buffering capacity is limited.

Table 1 - 4. Texas Water Bodies with Low pH

Segment Number	Water Body Name
0510	Lake Cherokee
0511	Cow Bayou Tidal
1407A	Clear Creek

High pH in Texas Water Bodies

Data from nine reservoirs and three freshwater streams (Table 1-5) have indicated elevated pH (high basicity) in at least one assessment location. A likely cause of elevated pH is consumption of dissolved carbon dioxide by photosynthetic processes. Excessive amounts of photosynthetically active algae and macrophytes can increase consumption of carbon dioxide during the day, increasing pH in the water column. Many of these water bodies are located in the eastern portion of the state, where natural geologic buffering capacity is limited.

Table 1 - 5. Texas Water Bodies with High pH

Segment Number	Water Body Name	Trophic Class
0105	Rita Blanca Lake	Hypereutrophic
0229	Upper Prairie Dog Town Fork Red River	Unknown
0302	Wright Patman Lake	Eutrophic
0306	Upper South Sulphur River	Unknown
0403	Lake O’ the Pines	Eutrophic
0405	Lake Cypress Springs	Eutrophic
0514	Big Sandy Creek	Unknown
0605	Lake Palestine	Eutrophic
0818	Cedar Creek Reservoir	Eutrophic
0826	Grapevine Lake	Eutrophic
1212	Somerville Lake	Eutrophic
1252	Lake Limestone	Eutrophic

Appendix A. Carlson's Trophic State Index (TSI)

Segment	Station ID	Reservoir	Chl *a* Rank [a]	Chl *a* Records	Chl *a* Mean (µg/L)	Chl *a* TSI	Chl *a* TSI (2010)	10 Year Change [c]	Secchi Rank	Secchi Records	Secchi Mean (m)	Secchi TSI	TP Rank	TP Records	TP Mean (mg/L) [b]	TP TSI
1805	12597	CANYON LAKE	1	35	1.82	36.44	47.36	-10.92	1	34	4.22	39.22	1	33	0.02	40.5
1904	12826 12825	MEDINA LAKE	2	10	1.9	36.94	44.32	-7.38	7	29	3.08	43.76	2	27	0.02	42.5
1241B	18414	LAKE ALAN HENRY	3	18	1.94	37.08	53.2	-16.12	4	20	3.3	42.8	108	19	0.08	68.3
2305	13835	INTERNATIONAL AMISTAD RESERVOIR	4	31	1.98	37.28			2	32	4.2	39.34	4	30	0.02	43.8
1909	18407	MEDINA DIVERSION LAKE	5	16	2.12	37.96			27	18	1.48	54.26	11	18	0.02	46.7
0302G	20813	TP LAKE	6	18	2.36	39			24	26	1.54	53.7	84	19	0.06	62
0404N	17337	LAKE DAINGERFIELD	7	7	2.88	40.96			8	9	2.82	45.04	92	9	0.06	63.2
0506M	21823	TYLER STATE PARK LAKE	8	9	2.9	41.02			5	10	3.26	42.98	10	9	0.02	46.5
0611R	17824	LAKE STRIKER	9	33	3.06	41.6	45.18	-3.58	59	38	1	60.08	34	34	0.04	54
0614	10639	LAKE JACKSONVILLE	10	33	3.08	41.62	45.52	-3.9	9	39	2.54	46.62	5	29	0.02	44.3
1404	12302	LAKE TRAVIS	11	67	3.34	42.46	41.28	1.18	3	67	3.44	42.18	3	67	0.02	43.3
1216	11894	STILLHOUSE HOLLOW LAKE	12	70	3.5	42.9	44.2	-1.3	10	69	2.52	46.64	36	70	0.04	54.1
1234	12005	LAKE CISCO	13	14	3.96	44.08			90	15	0.74	64.5	71	14	0.04	59.2
1604	15377	LAKE TEXANA	14	40	4	44.18			129	111	0.34	75.9	125	40	0.18	78.6
0506I	14422	LAKE HAWKINS	15	35	5.32	46.98			11	36	2.42	47.32	12	30	0.02	47
0202Q	16945	PICKENS LAKE	16	21	5.42	47.18			16	22	1.88	50.92	73	21	0.04	59.6
1220	11921	BELTON LAKE	17	40	5.54	47.38	46.74	0.64	14	42	1.94	50.48	23	40	0.02	51
0505E	13703	BRANDY BRANCH RESERVOIR	18	32	5.7	47.68			6	37	3.2	43.2	17	31	0.02	49
0610	14906	SAM RAYBURN RESERVOIR	19	36	5.88	47.96	48.06	-0.1	17	39	1.78	51.64	76	32	0.04	60.5
0611Q	15801	LAKE NACOGDOCHES	20	38	5.94	48.06	43.28	4.78	22	38	1.66	52.74	64	38	0.04	57.9
1249	12111	LAKE GEORGETOWN	21	67	6.02	48.2	34.58	13.62	23	67	1.62	52.98	38	67	0.04	54.2
0840	14039 17834	RAY ROBERTS LAKE	22	47	6.18	48.46	45.92	2.54	49	33	1.12	58.28	19	45	0.02	50.2
0504	10404	TOLEDO BEND RESERVOIR	23	108	6.4	48.8	47.6	1.2	15	107	1.9	50.82	43	111	0.04	55.1

Segment	Station ID	Reservoir	Chl *a* Rank [a]	Chl *a* Records	Chl *a* Mean (µg/L)	Chl *a* TSI	Chl *a* TSI (2010)	10 Year Change [c]	Secchi Rank	Secchi Records	Secchi Mean (m)	Secchi TSI	TP Rank	TP Records	TP Mean (mg/L) [b]	TP TSI
0204B	15447	MOSS LAKE	24	19	6.46	48.9	47.12	1.78	42	19	1.26	56.6	29	19	0.02	52.3
1233	12002	HUBBARD CREEK RESERVOIR	25	17	6.54	49.02	47.44	1.58	55	21	1.06	59.18	21	16	0.02	50.9
1426A	12180	OAK CREEK RESERVOIR	26	21	6.58	49.06	55.58	-6.52	37	19	1.38	55.36	20	17	0.02	50.7
0228	10188	MACKENZIE RESERVOIR	27	25	6.76	49.34	53.2	-3.86	52	26	1.1	58.58	14	22	0.02	48.1
0811	10970	BRIDGEPORT RESERVOIR	28	45	6.78	49.38	42.6	6.78	56	47	1.02	59.62	30	41	0.04	53.3
0213	10143	LAKE KICKAPOO	29	26	6.9	49.56			133	27	0.3	77.28	101	27	0.08	65.6
1403	12294	LAKE AUSTIN	30	60	7.06	49.76	42.92	6.84	21	60	1.66	52.66	9	59	0.02	45.7
0203	15440 20545	LAKE TEXOMA	31	89	8.26	51.32			44	65	1.22	57.24	64	89	0.04	57.9
0605F	17575	LAKE ATHENS	32	37	8.46	51.54	49.54	2	13	40	2.04	49.8	6	32	0.02	45.2
1433	12511	O. H. IVIE RESERVOIR	33	20	8.52	51.62	47.26	4.36	18	24	1.76	51.84	23	24	0.02	51
1419	12398	LAKE COLEMAN	34	19	8.56	51.66	45.56	6.1	75	22	0.86	62.32	39	21	0.04	54.6
1418	12395	LAKE BROWNWOOD	35	15	9.12	52.28	46.78	5.5	61	20	0.96	60.44	51	17	0.04	56.7
0408	17059	LAKE BOB SANDLIN	36	29	9.76	52.96	41.22	11.74	20	31	1.7	52.44	8	26	0.02	45.4
1231	11979	LAKE GRAHAM	37	21	10.2	53.38	47.44	5.94	82	22	0.8	63.3	49	18	0.04	56.6
0223	10173	GREENBELT LAKE	38	33	10.28	53.46	44.3	9.16	72	35	0.9	61.68	45	34	0.04	55.6
1423	12422	TWIN BUTTES RESERVOIR	39	24	10.3	53.48	61.76	-8.28	94	26	0.68	65.7	53	23	0.04	56.8
0603	10582	B A. STEINHAGEN LAKE	40	37	10.42	53.58	50.74	2.84	122	38	0.38	73.84	96	33	0.06	64.4
0217	10159	LAKE KEMP	41	29	10.6	53.76	49.96	3.8	45	31	1.16	57.88	40	31	0.04	54.7
0834	11063	LAKE AMON G. CARTER	42	18	10.78	53.94	46.38	7.56	38	19	1.38	55.4	36	15	0.04	54.1
1408	12344	LAKE BUCHANAN	43	67	10.82	53.96	51.6	2.36	26	67	1.5	54.08	25	67	0.02	51.3
1207	11865	POSSUM KINGDOM LAKE	44	118	11.04	54.16	50.36	3.8	12	117	2.22	48.46	32	117	0.04	53.6
0208	10137	LAKE CROOK	45	27	11.18	54.28			134	29	0.28	78.84	124	27	0.16	77.8
0836	15168	RICHLAND-CHAMBERS RESERVOIR	46	43	11.7	54.72	51.26	3.46	58	42	1	60.02	67	42	0.04	58.6
0613	10637	LAKE TYLER	47	35	11.72	54.74			32	38	1.46	54.64	15	30	0.02	48.2
1012	11342	LAKE CONROE	48	31	11.92	54.9	58.9	-4	69	97	0.9	61.4	99	71	0.06	65

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0613	10638	LAKE TYLER EAST	49	35	12.1	55.06	50.98	4.08	35	38	1.42	54.86	16	30	0.02	48.9
0612G	21435	LAKE NACONICHE	50	17	12.32	55.22			34	19	1.44	54.72	7	19	0.02	45.3
0214H	20162	NORTH FORK BUFFALO CREEK RESERVOIR	51	7	12.5	55.38			111	7	0.5	70.16	118	6	0.12	73.2
1429	12476	LADY BIRD LAKE (FORMERLY TOWN LAKE)	52	43	12.64	55.48	49.58	5.9	29	41	1.46	54.54	93	32	0.06	63.6
0212	10142	LAKE ARROWHEAD	53	32	12.72	55.54	51.06	4.48	105	33	0.54	68.78	122	31	0.16	77.1
0512	10458	LAKE FORK RESERVOIR	54	107	12.98	55.76	55.42	0.34	40	112	1.36	55.6	62	111	0.04	57.8
0303A	16856	BIG CREEK LAKE	55	32	13.24	55.94			118	32	0.4	73.12	110	29	0.08	68.6
0506L	18847	LAKE HOLBROOK	56	25	13.36	56.02			31	28	1.46	54.62	18	25	0.02	49.7
0604T	17339	LAKE RATCLIFF	57	35	13.78	56.34			88	32	0.76	64.06	71	33	0.04	59.2
1406	12324	LAKE LYNDON B JOHNSON	58	66	13.88	56.4	52.68	3.72	33	67	1.44	54.68	27	67	0.02	51.7
2454A	12514	COX LAKE	59	34	14.14	56.6	55.24	1.36	136	33	0.12	91.54	130	28	0.26	84.4
1247	12095	GRANGER LAKE	60	70	14.5	56.82	48.46	8.36	113	69	0.42	72.22	59	70	0.04	57.6
0813	10973	HOUSTON COUNTY LAKE	61	37	14.58	56.9	53.58	3.32	39	40	1.38	55.46	44	32	0.04	55.5
1225	11942	WACO LAKE	62	39	14.8	57.04	54.02	3.02	81	39	0.8	63.24	62	34	0.04	57.8
1203	11851	WHITNEY LAKE	63	32	14.9	57.1	57.48	-0.38	25	44	1.52	53.98	27	33	0.02	51.7
1422	12418	LAKE NASWORTHY	64	29	15.06	57.2	54.74	2.46	100	31	0.58	67.76	72	28	0.04	59.5
1254	12127	AQUILLA RESERVOIR	65	39	15.5	57.5	51.64	5.86	101	39	0.58	67.84	65	35	0.04	58.3
0307	13855	JIM L. CHAPMAN LAKE (FORMERLY COOPER LAKE)		29	15.54	57.5			96	31	0.66	66	106	28	0.08	67.2
0826	17827 11035	GRAPEVINE LAKE	67	48	15.98	57.78			76	35	0.82	62.72	56	44	0.04	57.4
1236	12010	FORT PHANTOM HILL RESERVOIR	68	19	16	57.8			104	19	0.56	68.54	102	15	0.08	65.7
1407	12336	INKS LAKE		65	16	57.8	57.08	0.72	41	65	1.34	55.84	28	65	0.02	52.2
1405	12319	MARBLE FALLS LAKE	70	66	16.1	57.86	51.26	6.6	30	66	1.46	54.6	81	66	0.06	61.3
0506H	17062	LAKE GLADEWATER	71	37	16.32	58	57.4	0.6	66	41	0.92	61.22	60	34	0.04	57.7
2116	13020	CHOKE CANYON RESERVOIR	72	40	16.42	58.06			125	40	0.36	74.72	81	40	0.06	61.3

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0817	10981	NAVARRO MILLS LAKE	73	31	16.48	58.08	52.96	5.12	109	32	0.5	69.88	97	28	0.06	64.5
0816	10980	LAKE WAXAHACHIE	74	32	16.68	58.22	54.18	4.04	108	41	0.52	69.38	53	36	0.04	56.8
0209	16343	PAT MAYSE LAKE	75	38	16.82	58.28			53	40	1.1	58.68	42	33	0.04	55
0830	15151	BENBROOK LAKE	76	49	16.82	58.3	58.28	0.02	78	49	0.82	62.88	75	47	0.04	60.3
0401	10283	CADDO LAKE	77	38	17.12	58.46	53.24	5.22	91	142	0.72	64.56	114	34	0.1	70.6
0409D	17478	LAKE GILMER	78	36	17.16	58.48	56.58	1.9	28	37	1.46	54.5	48	29	0.04	56
0215	10157	DIVERSION LAKE	79	23	17.42	58.64	53.78	4.86	93	25	0.7	65.34	47	26	0.04	55.9
0809	10945 10944	EAGLE MOUNTAIN RESERVOIR	80	42	17.52	58.7	61.96	-3.26	71	44	0.9	61.62	82	43	0.06	61.9
1224	11939	LEON RESERVOIR	81	16	18.14	59.04	50.82	8.22	57	19	1.02	59.84	51	13	0.04	56.7
0818	16749 16748	CEDAR CREEK RESERVOIR	82	91	18.24	59.08			68	78	0.9	61.36	79	90	0.06	60.8
2103	12967	LAKE CORPUS CHRISTI	83	40	18.5	59.22	60.74	-1.52	131	45	0.32	76.76	129	40	0.22	82
0102	10036	LAKE MEREDITH	84	37	18.64	59.3	44.44	14.86	73	39	0.88	61.9	42	32	0.04	55
2312	13267	RED BLUFF RESERVOIR	85	17	19	59.48	61.58	-2.1	78	18	0.82	62.88	25	15	0.02	51.3
0210	10139	FARMERS CREEK RESERVOIR (ALSO KNOWN AS LAKE NOCONA)	86	30	19.08	59.52	48.66	10.86	79	30	0.82	62.96	68	30	0.04	58.9
1008F	16482	LAKE WOODLANDS		32	19.06	59.52	62.74	-3.22	116	100	0.42	72.6	133	33	0.92	102.5
1242H	18457	TRADINGHOUSE RESERVOIR	88	39	19.58	59.78	59.36	0.42	74	39	0.88	61.98	66	38	0.04	58.5
1411	13863	E. V. SPENCE RESERVOIR	89	16	19.82	59.9	60.38	-0.48	54	15	1.08	58.82	89	16	0.06	63
0214G	17947	LAKE IOWA PARK	90	7	19.88	59.94			119	7	0.4	73.2	117	6	0.12	72.4
0815	10979	BARDWELL RESERVOIR	91	32	20.02	60	58.34	1.66	121	40	0.4	73.56	79	35	0.06	60.8
1228	11974	LAKE PAT CLEBURNE	92	35	20.3	60.14			98	39	0.64	66.6	69	34	0.04	59.1
0505F	13601	MARTIN CREEK RESERVOIR	93	30	21.16	60.54			51	34	1.12	58.38	47	29	0.04	55.9
2303	13189	INTERNATIONAL FALCON RESERVOIR	94	30	21.28	60.6	52.22	8.38	47	24	1.12	58.24	87	29	0.06	62.5
0405	10312	LAKE CYPRESS SPRINGS	95	35	21.34	60.62	52.82	7.8	46	39	1.14	58.04	32	34	0.04	53.6
1428K	20161	WALTER E. LONG LAKE	96	24	21.44	60.66			36	24	1.4	55.24	59	14	0.04	57.6
0828	13904	LAKE ARLINGTON	97	45	22.22	61.02			89	46	0.74	64.24	95	45	0.06	64.2

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0820	10998	LAKE RAY HUBBARD	98	51	22.68	61.22	61.06	0.16	67	39	0.92	61.3	56	52	0.04	57.4
1413	21614	LAKE J. B. THOMAS	99	16	22.98	61.34	51.1	10.24	92	16	0.72	64.78	94	16	0.06	63.8
0807	10942	LAKE WORTH	100	44	23.08	61.4	55.78	5.62	95	45	0.66	65.88	86	43	0.06	62.3
0821	15685	LAKE LAVON	101	35	23.22	61.46			103	39	0.56	68.38	92	39	0.06	63.2
0803	10899	LAKE LIVINGSTON	102	38	23.78	61.68	57.54	4.14	114	39	0.42	72.3	113	39	0.1	70.2
1232D	17941	LAKE DANIEL	103	14	23.94	61.76			121	17	0.4	73.56	116	14	0.12	71.9
1205	11860	LAKE GRANBURY	104	120	24.32	61.9			65	120	0.94	61.02	54	119	0.04	57.1
0403	10296	LAKE O' THE PINES	105	33	25.08	62.22	54.44	7.78	70	38	0.9	61.5	36	35	0.04	54.1
0605	16159	LAKE PALESTINE	106	37	26.1	62.6	61.46	1.14	60	39	1	60.12	57	29	0.04	57.5
1434C	17020	LAKE BASTROP	107	59	26.7	62.82	58.2	4.62	50	59	1.12	58.36	90	58	0.06	63.1
1237	12021	LAKE SWEETWATER	108	13	28.06	63.3			127	15	0.34	75.34	100	13	0.06	65.4
1252	12123	LAKE LIMESTONE	109	62	28.84	63.58			87	64	0.76	63.98	77	62	0.06	60.7
1240	12027	WHITE RIVER LAKE	110	31	29.62	63.84	52.44	11.4	130	37	0.32	76.44	98	30	0.06	64.8
0199A	10005	PALO DURO RESEVOIR	111	20	30.52	64.14			135	21	0.24	80.42	131	19	0.3	86.4
0832	11061	LAKE WEATHERFORD	112	36	30.74	64.2	55.26	8.94	106	36	0.54	68.82	74	35	0.04	59.9
1002	11204	LAKE HOUSTON	113	35	30.88	64.24	56.12	8.12	117	35	0.4	72.86	127	35	0.22	81.7
1235	12006	LAKE STAMFORD	114	22	31.58	64.48	55.78	8.7	112	25	0.44	71.56	107	20	0.08	67.9
1416B	12179	BRADY CREEK RESERVOIR	115	24	31.94	64.58	58.84	5.74	85	26	0.78	63.76	88	23	0.06	62.9
0507	10434	LAKE TAWAKONI	116	104	32.3	64.68	64.38	0.3	63	109	0.96	60.62	85	108	0.06	62.1
0827	11038	WHITE ROCK LAKE	117	32	33	64.9			107	37	0.52	69.16	103	34	0.08	66.1
0509	10444	MURVAUL LAKE	118	35	34.2	65.26	66.36	-1.1	86	39	0.76	63.82	84	33	0.06	62
0515A	17948	LAKE QUITMAN	119	36	34.84	65.44			84	34	0.78	63.48	104	25	0.08	66.3
0302	14097 10213	WRIGHT PATMAN LAKE	120	68	36.56	65.9	47.38	18.52	97	152	0.64	66.36	110	52	0.08	68.6
1210	17586	LAKE MEXIA	121	40	36.94	66			123	45	0.36	74.56	123	38	0.16	77.7
0803G	16953	LAKE MADISONVILLE	122	12	38.66	66.46			115	11	0.42	72.32	120	12	0.12	74.1

Segment	Station ID	Reservoir	Chl *a* Rank [a]	Chl *a* Records	Chl *a* Mean (µg/L)	Chl *a* TSI	Chl *a* TSI (2010)	10 Year Change [c]	Secchi Rank	Secchi Records	Secchi Mean (m)	Secchi TSI	TP Rank	TP Records	TP Mean (mg/L) [b]	TP TSI
1402G	17017	CEDAR CREEK RESERVOIR/LAKE FAYETTE	123	59	39.24	66.6	62.12	4.48	62	59	0.96	60.56	112	59	0.1	70
1222	11935	PROCTOR LAKE	124	19	40.08	66.8	58.68	8.12	110	20	0.5	70.14	119	19	0.12	73.3
1241C	11529	BUFFALO SPRINGS LAKE	125	19	41.18	67.08	69.92	-2.84	80	20	0.8	63.04	105	19	0.08	66.4
1212	11881	SOMERVILLE LAKE	126	34	42.66	67.42	67.3	0.12	99	37	0.62	66.8	115	30	0.1	71.8
0804J	17951	FAIRFIELD LAKE	127	38	49.62	68.9			84	41	0.78	63.48	121	35	0.14	75.9
0202M	21032	LAKE BONHAM (BONHAM CITY LAKE)	128	67	50.58	69.08			124	61	0.36	74.66	110	68	0.08	68.6
1242A	16781	NEW MARLIN CITY LAKE	129	40	50.84	69.14	67.48	1.66	128	39	0.34	75.78	126	35	0.2	80.9
0229A	10192	LAKE TANGLEWOOD	130	33	68.88	72.12	63.46	8.66	64	38	0.94	60.76	134	27	1.02	104.1
1253A	16247	SPRINGFIELD LAKE	131	39	71.98	72.56	64.18	8.38	132	42	0.3	77.14	128	37	0.22	81.8
0219	10163	LAKE WICHITA	132	28	96.74	75.46	76.44	-0.98	126	25	0.34	75.16	132	33	0.3	86.8
1425	12429	O. C. FISHER LAKE	133	17	323.94	87.3	63.98	23.32	102	19	0.58	67.9	135	17	1.52	109.7
0105	10060	RITA BLANCA LAKE	134	21	817.02	96.38	88.52	7.86	137	25	0.08	96.04	136	20	3.24	120.7

Chl *a* – chlorophyll *a*; TP – total phosphorus

The Carlson's TSI (Chl a), (TP), and (Secchi) 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 a), (TP), and (Secchi) values may vary slightly from a ranking based on the arithmetic average of chlorophyll a, total phosphorus, and Secchi disk values.

[a] Reservoirs are ranked in priority by TSI (Chl *a*). A true rank was used which can result in a tied rank for reservoirs with the same TSI (Chl *a*). Therefore, some ranking assignments are skipped by the computational data model. The rank resumes with subsequent rank value.

[b] Total phosphorus concentrations converted from µg/L to mg/L.

[c] A positive value indicates increased algal content; A negative value indicates decreased algal content; missing values indicate a comparison cannot be made due to absence of comparable data.

Citations:

Carlson, R.E. (1977) A trophic state index for lakes. Limnology and Oceanography. *22:2 361—369*

Carlson, R.E. and J. Simpson. 1996. *A Coordinator's Guide to Volunteer Lake Monitoring Methods*. North American Lake Management Society. 96 pp.

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