Trophic Classification of Texas Reservoirs

2016 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, 2004 - November 30, 2014).
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 140 reservoirs surveyed, 136 had sufficient data to be included in the ranking. Based on this assessment, the 136 reservoirs show a range of eutrophication, from mesotrophic 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	23
Eutrophic	>50 – 70	99
Hypereutrophic	>70	8

Adapted from Carlson and Simpson (1996)

Reservoirs with the clearest water (highest mean Secchi disk transparency), listed in descending order: International Amistad Reservoir (4.18 m), Brandy Branch Reservoir (3.58 m), Canyon Lake (3.38 m), Lake Alan Henry (3.38 m), and Lake Travis (3.08 m). Reservoirs with the highest turbidity (poorest light transparency, lowest mean Secchi disk transparency), listed in ascending order: Rita Blanca Lake (0.06 m), Cox Lake (0.16 m), Lake Crook (0.18 m), Lake Kickapoo (0.22 m), and Palo Duro Reservoir (0.26 m).

Thirty-four 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: Rita Blanca Lake (4.22 mg/L), O. C. Fisher Lake (1.04 mg/L), Lake Tanglewood (1.02 mg/L), Lake Woodlands (0.92 mg/L), and Scarborough Creek Reservoir (0.68 mg/L).

Water Quality Differences in Reservoirs

Carlson’s TSI Chl *a* values for 89 reservoirs from the 2006 and 2016 reporting cycles were compared to indicate temporal differences (Appendix A). Differences could not be calculated for 47 reservoirs (34 %), due to the lack of comparable reporting information from 2006. The 2006 period of record was December 1, 1994 - November 30, 2004; for 2016, the period of record was December 1, 2004 - November 30, 2014.

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 26 % of the comparable reservoirs between 2006 and 2016. Reservoirs with largest decrease in mean TSI Chl *a* values, listed in descending order: Canyon Lake (-15.36), Oak Creek Reservoir (-10.38), Medina Lake (-8.96), Lake Jacksonville (-8.26), and Stillhouse Hollow Lake (-7.3). Increases in algal biomass (increase in TSI Chl *a* values) are indicated in 65 (73 %) 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: Joe Pool Lake (+23.54), O. C. Fisher Reservoir (+21.72), Wright Patman Lake (+18.66), Pat Mayse Lake (+18.62), and Rita Blanca Lake (+16.48). One reservoir, Lake Nasworthy had no change in TSI Chl *a* scores.

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 (specific numeric criteria were proposed as part of the 2014 revisions to the water quality standards). The Texas Surface Water Quality Standards establish uses for classified (designated uses) and unclassified (presumed uses) 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. 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. Chapter 309 of the effluent standards portion of the TCEQ rules requires discharges located within five river miles upstream of certain reservoirs to achieve a minimum effluent quality of 10 mg/L BOD5 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, 96 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- .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 BOD5, 15 mg/L TSS, and 3 mg/L NH3-N as a 30-day average. All wastewater effluents disposed of on land shall meet an effluent quality of 20 mg/L BOD5 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, 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.

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 of 10 mg/L BOD5, 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 of 1.0 mg/L TP as 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, Watershed Protection Plans (WPP) and Watershed Characterizations (WC) 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 Characterization

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 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 twelve reservoirs and two 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.

Since five new waterbodies were impaired for high pH during the 2016IR, changes in environmental conditions due to drought have contributed to the increased number of impairments. TCEQ will continue to evaluate the impact of drought on water quality results.

Table 1 - 5. Texas Water Bodies with High pH

Segment Number	Water Body Name	Trophic Class
0105	Rita Blanca Lake	Hypereutrophic
0302	Wright Patman Lake	Eutrophic
0306	Upper South Sulphur River	Unknown
0307	Jim L. Chapman Lake (formerly Cooper Lake)	Eutrophic
0403	Lake O' the Pines	Eutrophic
0405	Lake Cypress Springs	Eutrophic
0512	Lake Fork Reservoir	Eutrophic
0605	Lake Palestine	Eutrophic
0818	Cedar Creek Reservoir	Eutrophic
0826	Grapevine Lake	Eutrophic
1002	Lake Houston	Eutrophic
1212	Somerville Lake	Eutrophic
1232	Clear Fork Brazos River	Unknown
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 (2006)	10 Year Change [c]	Secchi Rank	Secchi Records	Secchi Mean (m)	Secchi TSI	TP Rank	TP Records	TP Mean (mg/L) [b]	TP TSI
2305	13835	INTERNATIONAL AMISTAD RESERVOIR	1	30	1.96	37.18			1	34	4.18	39.42	7	30	0.02	48.9
1805	12597	CANYON LAKE	2	38	2.14	38.1	53.46	-15.36	3	37	3.38	42.46	4	34	0.02	48.2
0302G	20813	TP LAKE	3	15	2.2	38.34			19	19	1.74	51.96	87	16	0.06	62.3
1909	18407	MEDINA DIVERSION LAKE	4	22	2.26	38.64			20	22	1.7	52.44	13	21	0.02	49.6
1241B	18414	LAKE ALAN HENRY	5	19	2.34	38.94			4	19	3.38	42.48	5	19	0.02	48.3
1904	12825 12826	MEDINA LAKE	6	21	2.48	39.5	48.46	-8.96	7	27	2.66	45.96	19	24	0.02	51.4
1404	12302	LAKE TRAVIS	7	59	3.06	41.56	41.7	-0.14	5	60	3.08	43.8	9	60	0.02	49.3
1234	12005 18510	LAKE CISCO	8	17	3.16	41.9			27	20	1.48	54.34	8	17	0.02	49.1
0505E	13703	BRANDY BRANCH RESERVOIR	9	18	3.3	42.28			2	21	3.58	41.64	3	17	0.02	45.8
0611R	17824	LAKE STRIKER	10	35	3.3	42.32	49.4	-7.08	51	40	1.12	58.4	88	36	0.06	62.5
1216	11894	STILLHOUSE HOLLOW LAKE	11	88	3.32	42.36	49.66	-7.3	6	89	2.9	44.64	52	86	0.04	55.4
1604	15377	LAKE TEXANA	12	40	3.66	43.32			132	112	0.32	76.58	126	40	0.18	78.6
0614	10639	LAKE JACKSONVILLE	13	39	3.78	43.62	51.88	-8.26	9	37	2.34	47.78	11	33	0.02	49.4
1403	12294	LAKE AUSTIN	14	59	4.34	45.02	44.3	0.72	14	60	1.88	50.9	14	59	0.02	50.2
0611Q	15801	LAKE NACOGDOCHES	15	38	5.2	46.76	49.7	-2.94	23	40	1.62	53.1	95	40	0.06	64
1220	11921	BELTON LAKE	16	47	5.32	47	47.3	-0.3	12	49	2	49.98	34	46	0.02	53.1
0610	14906	SAM RAYBURN RESERVOIR	17	55	5.38	47.12			16	58	1.84	51.22	56	54	0.04	56.2
0506I	14422	LAKE HAWKINS	18	33	5.4	47.14			8	35	2.56	46.46	16	28	0.02	50.5
1233	12002	HUBBARD CREEK RESERVOIR	19	25	5.6	47.5	51.22	-3.72	43	26	1.26	56.7	21	21	0.02	51.9
0504	10404	TOLEDO BEND RESERVOIR	20	111	5.74	47.74	48.44	-0.7	13	110	1.96	50.28	35	73	0.04	53.2
1249	12111	LAKE GEORGETOWN	21	81	5.82	47.88	40.24	7.64	22	81	1.66	52.72	59	76	0.04	56.3
0208	10137	LAKE CROOK	23	13	5.96	48.12			137	13	0.18	84.96	130	12	0.22	82.4
0840	14039 17834	RAY ROBERTS LAKE		34	5.96	48.12	48.6	-0.48	55	27	1.08	58.76	16	31	0.02	50.5
0612G	21435	LAKE NACONICHE	24	5	6.02	48.22			17	5	1.8	51.52	1	5	0.02	40

Segment	Station ID	Reservoir	Chl *a* Rank [a]	Chl *a* Records	Chl *a* Mean (µg/L)	Chl *a* TSI	Chl *a* TSI (2006)	10 Year Change [c]	Secchi Rank	Secchi Records	Secchi Mean (m)	Secchi TSI	TP Rank	TP Records	TP Mean (mg/L) [b]	TP TSI
1230	11977	LAKE PALO PINTO	25	12	6.04	48.24	54.12	-5.88	89	12	0.76	63.94	69	12	0.04	58.4
1433	12511	O. H. IVIE RESERVOIR	26	27	6.06	48.26	50.76	-2.5	10	32	2.18	48.72	26	30	0.02	52.6
0204B	15447	MOSS LAKE	27	17	6.14	48.4	52.54	-4.14	29	16	1.46	54.64	34	17	0.02	53.1
1426A	12180	OAK CREEK RESERVOIR	28	20	6.42	48.84	59.22	-10.38	36	19	1.36	55.64	21	17	0.02	51.9
0834	11063	LAKE AMON G. CARTER	29	17	6.76	49.36	47.3	2.06	18	18	1.78	51.7	31	15	0.02	53
0213	10143	LAKE KICKAPOO	30	12	7.3	50.08	49.84	0.24	136	13	0.22	81.42	102	13	0.06	64.8
1419	12398	LAKE COLEMAN	31	21	7.38	50.22	49.7	0.52	71	23	0.92	61.24	45	20	0.04	54.7
0811	10970	BRIDGEPORT RESERVOIR	32	46	7.58	50.48	42.58	7.9	56	46	1.08	58.84	59	41	0.04	56.3
0228	10188	MACKENZIE RESERVOIR	33	20	7.92	50.9	51.96	-1.06	53	20	1.1	58.52	37	17	0.04	53.3
1418	12395	LAKE BROWNWOOD	34	16	7.96	50.94	49.5	1.44	54	20	1.1	58.7	63	18	0.04	56.9
1418C	12178	HORDS CREEK RESERVOIR	35	6	7.98	50.98	54.38	-3.4	41	6	1.28	56.4	28	5	0.02	52.7
1231	11979	LAKE GRAHAM	36	26	8.02	51.04	51.1	-0.06	81	26	0.84	62.36	63	23	0.04	56.9
0223	10173	GREENBELT LAKE	37	37	8.34	51.4	46.8	4.6	30	38	1.44	54.82	47	37	0.04	55.1
0605F	17575	LAKE ATHENS	38	38	8.46	51.54	53.28	-1.74	15	41	1.88	50.92	11	34	0.02	49.4
0408	17059	LAKE BOB SANDLIN	39	29	8.8	51.94	45.76	6.18	21	33	1.68	52.58	11	32	0.02	49.4
0510	10445 15514	LAKE CHEROKEE	40	50	9.08	52.24			40	72	1.3	56.24	21	4	0.02	51.9
0203	15440 20545	LAKE TEXOMA	41	72	9.96	53.16			35	38	1.36	55.48	77	73	0.04	60
1429	12476	LADY BIRD LAKE (FORMERLY TOWN LAKE)	42	35	10.72	53.86	49.7	4.16	24	34	1.58	53.32	37	25	0.04	53.3
1408	12344	LAKE BUCHANAN	43	59	10.86	54	49.18	4.82	26	60	1.48	54.28	24	60	0.02	52.4
0613	10638	LAKE TYLER EAST	44	32	11.52	54.58			42	35	1.28	56.56	18	29	0.02	51.2
0217	10159	LAKE KEMP	46	23	11.72	54.74	48.9	5.84	31	24	1.42	54.94	31	25	0.02	53
0603	10582	B A. STEINHAGEN LAKE		38	11.7	54.74	53.42	1.32	113	38	0.44	71.72	104	35	0.08	65.5
0823	11027 17830	LEWISVILLE LAKE	47	34	12.04	55			70	16	0.94	61.04	38	34	0.04	53.6
1207	11865	POSSUM KINGDOM LAKE	48	101	12.1	55.06			11	102	2.08	49.52	47	94	0.04	55.1
1406	12324	LAKE LYNDON B JOHNSON	49	58	12.2	55.14	51.22	3.92	37	60	1.34	55.76	56	60	0.04	56.2

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0512	10458	LAKE FORK RESERVOIR	50	111	12.36	55.28	54.6	0.68	28	115	1.48	54.36	43	74	0.04	54.2
0613	10637	LAKE TYLER	51	33	12.54	55.42	53.24	2.18	46	35	1.22	57.1	18	29	0.02	51.2
1422	12418	LAKE NASWORTHY	52	41	12.62	55.46	55.46	0	105	46	0.58	68.1	74	43	0.04	59.2
0506L	18847	LAKE HOLBROOK	53	17	12.64	55.48			34	18	1.4	55.2	6	17	0.02	48.8
1247	12095	GRANGER LAKE	54	84	13.12	55.86	41.78	14.08	119	83	0.42	72.44	78	79	0.04	60.1
0212	10142	LAKE ARROWHEAD	55	26	13.18	55.9	49.84	6.06	96	26	0.66	65.88	118	25	0.14	75.6
0813	10973	HOUSTON COUNTY LAKE	56	38	13.3	55.98	53.24	2.74	25	38	1.52	54.04	28	32	0.02	52.7
1224	11939	LEON RESERVOIR	57	16	13.32	56	51.1	4.9	45	20	1.24	56.98	39	14	0.04	53.7
0836	15168	RICHLAND-CHAMBERS RESERVOIR	58	38	13.98	56.48	51.24	5.24	64	35	1	60.06	72	37	0.04	59
1012	11342	LAKE CONROE	59	38	14.02	56.5	57.5	-1	69	88	0.94	60.98	85	66	0.06	61.7
2454A	12514	COX LAKE	60	37	14.36	56.74			138	34	0.16	85.74	131	31	0.28	85.2
0604T	17339	LAKE RATCLIFF	61	21	14.38	56.76			85	18	0.8	63.16	65	20	0.04	57.7
0210	10139	FARMERS CREEK RESERVOIR (ALSO KNOWN AS LAKE NOCONA)	62	24	14.6	56.9	49.56	7.34	62	24	1.02	59.68	53	24	0.04	55.5
2116	13019 13020	CHOKE CANYON RESERVOIR	63	40	14.64	56.92			91	56	0.74	64.48	71	40	0.04	58.9
0215	10157	DIVERSION LAKE	65	20	14.84	57.06	51.26	5.8	75	22	0.9	61.5	51	23	0.04	55.3
1405	12319	MARBLE FALLS LAKE		58	14.84	57.06	49.94	7.12	32	59	1.4	55.06	24	59	0.02	52.4
1254	12127	AQUILLA RESERVOIR	66	42	14.88	57.08	52.44	4.64	98	40	0.66	66.2	66	37	0.04	58.1
0409D	17478	LAKE GILMER	67	37	14.88	57.1	58.66	-1.56	38	37	1.34	55.88	41	30	0.04	54
2303	13189	INTERNATIONAL FALCON RESERVOIR	68	32	15.16	57.28			76	22	0.9	61.6	108	29	0.08	67.7
0307	13855	JIM L. CHAPMAN LAKE (FORMERLY COOPER LAKE)	69	14	15.52	57.5			95	15	0.7	65.34	102	13	0.06	64.8
1407	12336	INKS LAKE	70	58	15.62	57.56	54.74	2.82	40	59	1.3	56.24	29	59	0.02	52.9
1225	11942	WACO LAKE	71	36	15.68	57.6	51.08	6.52	83	36	0.82	62.76	54	34	0.04	56
0826	11035 16113 17827	GRAPEVINE LAKE	72	35	16	57.8	54.3	3.5	84	28	0.82	62.84	70	30	0.04	58.6
0303A	16856	BIG CREEK LAKE	73	20	16.24	57.94			114	19	0.44	71.78	105	20	0.08	65.8
0817	10981	NAVARRO MILLS LAKE	74	28	16.66	58.2	54.88	3.32	116	28	0.44	72.02	100	25	0.06	64.6

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1236	12010	FORT PHANTOM HILL RESERVOIR	75	11	17.82	58.86			109	11	0.52	69.2	97	9	0.06	64.2
0816	10980	LAKE WAXAHACHIE	76	29	18.02	58.96	55.7	3.26	104	37	0.58	68.08	61	34	0.04	56.6
0102	10036	LAKE MEREDITH	78	36	18.42	59.18	47.34	11.84	63	37	1.02	59.72	64	29	0.04	57.6
1228	11974	LAKE PAT CLEBURNE		42	18.44	59.18			101	42	0.62	67.02	85	37	0.06	61.7
0401	10283	CADDO LAKE	79	36	18.84	59.4			90	144	0.74	64.32	117	30	0.14	74.4
0405	10312	LAKE CYPRESS SPRINGS	80	32	19	59.48	54.16	5.32	50	34	1.12	58.34	31	31	0.02	53
1203	11851	WHITNEY LAKE	81	37	19.1	59.54	50.5	9.04	44	45	1.24	56.92	26	35	0.02	52.6
0815	10979	BARDWELL RESERVOIR	83	29	19.42	59.7	57.72	1.98	112	36	0.44	71.64	79	32	0.04	60.3
1423	12422	TWIN BUTTES RESERVOIR		29	19.4	59.7	55.12	4.58	74	33	0.9	61.42	81	30	0.06	61.1
0209	10138 16343	PAT MAYSE LAKE		36	19.4	59.7	41.08	18.62	58	36	1.04	59.34	49	32	0.04	55.2
1242H	18457	TRADINGHOUSE RESERVOIR	85	39	19.54	59.76			82	39	0.84	62.62	56	39	0.04	56.2
2103	12967	LAKE CORPUS CHRISTI	87	40	20.04	60			121	56	0.42	72.56	123	40	0.16	77.6
0505F	13601	MARTIN CREEK RESERVOIR		27	20.02	60			59	31	1.04	59.44	40	25	0.04	53.9
0838	13891	JOE POOL LAKE	88	4	20.16	60.06	36.52	23.54	52	6	1.12	58.46	2	6	0.02	44.7
0506H	17062	LAKE GLADEWATER	89	38	21.48	60.68	53.54	7.14	78	40	0.86	62.02	47	36	0.04	55.1
1413	21614	LAKE J. B. THOMAS	90	16	21.76	60.82	50.82	10	128	16	0.34	75.76	103	16	0.06	65.2
1411	13863	E. V. SPENCE RESERVOIR	91	16	21.86	60.86	59.94	0.92	61	16	1.02	59.62	60	16	0.04	56.4
0809	10944 10945	EAGLE MOUNTAIN RESERVOIR	92	46	22.26	61.04	61.94	-0.9	57	44	1.08	58.9	90	46	0.06	63.1
1008F	16482	LAKE WOODLANDS	93	39	22.38	61.1			122	116	0.4	72.94	135	39	0.92	102.5
1232D	17941	LAKE DANIEL	94	4	22.56	61.16			133	5	0.28	78.24	119	3	0.14	76.1
0820	10998	LAKE RAY HUBBARD	95	37	22.92	61.32	61.02	0.3	72	35	0.92	61.32	69	37	0.04	58.4
0830	11046 15151	BENBROOK LAKE	96	51	23.96	61.76	58.24	3.52	79	51	0.86	62.1	89	51	0.06	62.9
1416B	12179	BRADY CREEK RESERVOIR	97	34	24.16	61.84	57.64	4.2	99	37	0.64	66.62	74	34	0.04	59.2
0803	10899	LAKE LIVINGSTON	98	42	24.2	61.86	56.96	4.9	103	41	0.58	67.68	115	42	0.12	73.9
0403	10296	LAKE O' THE PINES	99	35	24.52	61.98	52.52	9.46	67	36	0.94	60.8	45	36	0.04	54.7
0832	11061	LAKE WEATHERFORD	100	29	24.68	62.06	56.04	6.02	107	30	0.54	68.86	75	28	0.04	59.5

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0701D	10642	SHALLOW PRONG LAKE	101	31	24.78	62.1			111	45	0.52	69.52	113	32	0.1	71
1428K	20161	WALTER E. LONG LAKE	102	14	24.88	62.12			47	15	1.22	57.22	67	4	0.04	58.2
2312	13267	RED BLUFF RESERVOIR	103	15	25.46	62.36	56.12	6.24	77	21	0.88	61.94	51	13	0.04	55.3
0605	16159	LAKE PALESTINE	104	35	25.92	62.54	60.5	2.04	68	37	0.94	60.94	43	29	0.04	54.2
0818	16748 16749	CEDAR CREEK RESERVOIR	105	81	26.18	62.62			80	65	0.86	62.26	99	82	0.06	64.4
1205	11860	LAKE GRANBURY	106	105	26.94	62.9			65	109	0.96	60.46	77	101	0.04	60
1235	12006	LAKE STAMFORD	107	20	27.82	63.22	54.32	8.9	108	20	0.54	69.02	106	17	0.08	66.8
1002	11204	LAKE HOUSTON	108	47	28.3	63.4	52.3	11.1	127	34	0.36	75.12	127	67	0.18	79.5
1434C	17020	LAKE BASTROP	109	58	28.58	63.5			49	59	1.14	58.16	86	58	0.06	61.9
1402G	17017	CEDAR CREEK RESERVOIR/LAKE FAYETTE	110	58	29.32	63.74			60	59	1.04	59.52	92	59	0.06	63.7
1252	12123	LAKE LIMESTONE	111	48	29.36	63.76	52.88	10.88	87	50	0.8	63.24	91	44	0.06	63.3
0807	10942	LAKE WORTH	112	32	29.78	63.9	57.04	6.86	92	32	0.72	64.78	93	31	0.06	63.9
0199A	10005	PALO DURO RESEVOIR	113	20	31.22	64.36			135	20	0.26	79.16	132	19	0.3	86.4
1240	12027	WHITE RIVER LAKE	114	32	32.54	64.76	54.46	10.3	115	37	0.44	71.96	95	32	0.06	64
0828	13904	LAKE ARLINGTON	115	40	33.64	65.1			86	40	0.8	63.22	97	40	0.06	64.2
0515A	17948	LAKE QUITMAN	116	21	35.88	65.72			94	18	0.72	64.92	107	13	0.08	67.1
0507	10434	LAKE TAWAKONI	117	108	35.96	65.74	61.68	4.06	66	123	0.94	60.74	80	72	0.06	60.9
0827	11038	WHITE ROCK LAKE	118	20	36.3	65.84			110	22	0.52	69.28	98	19	0.06	64.3
1210	17586	LAKE MEXIA	119	40	37.68	66.2	58.34	7.86	125	39	0.38	74.28	124	38	0.16	77.9
0803G	16953	LAKE MADISONVILLE	120	12	38.66	66.46			118	11	0.42	72.32	116	12	0.12	74.1
1237	12021	LAKE SWEETWATER	121	4	39.88	66.76			134	4	0.28	78.86	113	3	0.1	71
0302	10213 14097	WRIGHT PATMAN LAKE	122	42	42.94	67.48	48.82	18.66	100	96	0.62	66.86	111	30	0.1	70.9
0509	10444	MURVAUL LAKE	123	36	44.48	67.82	63.2	4.62	97	39	0.66	65.94	83	35	0.06	61.6
1241C	11529	BUFFALO SPRINGS LAKE	124	20	44.56	67.84	69.24	-1.4	73	18	0.9	61.38	82	19	0.06	61.3
1222	11935	PROCTOR LAKE	125	21	46.06	68.18	56.18	12	106	22	0.56	68.5	114	18	0.1	71.1
1212	11881	SOMERVILLE LAKE	126	34	47.32	68.44	63.8	4.64	102	39	0.6	67.46	109	33	0.08	68.5

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0202M	21032	LAKE BONHAM (BONHAM CITY LAKE)	127	37	50.52	69.08			124	31	0.4	73.06	110	38	0.1	69.3
1242A	16783	OLD MARLIN CITY LAKE	128	5	50.88	69.14	68.94	0.2	123	5	0.4	72.98	121	5	0.16	76.8
0804J	17951	FAIRFIELD LAKE	129	36	59.66	70.7			93	37	0.72	64.8	125	34	0.18	78.4
1242A	16781	NEW MARLIN CITY LAKE	130	38	64.98	71.54			130	37	0.32	76.26	122	35	0.16	77.3
1253A	16247	SPRINGFIELD LAKE	131	39	65.72	71.66	62.6	9.06	131	39	0.32	76.48	128	37	0.2	81.2
0229A	10192	LAKE TANGLEWOOD	132	35	66.18	71.72	60.92	10.8	48	39	1.18	57.6	136	29	1.02	104.1
1255K	17224	SCARBOROUGH CREEK RESERVOIR	133	26	103.92	76.16			129	26	0.32	76.04	134	26	0.68	98.2
0219	10163	LAKE WICHITA	134	21	128.64	78.24	75.72	2.52	126	18	0.36	74.86	133	26	0.32	87.7
1425	12429	O. C. FISHER LAKE	135	24	242.82	84.48	62.76	21.72	120	27	0.42	72.52	137	26	1.04	104.3
0105	10060	RITA BLANCA LAKE	136	22	1061.5	98.96	82.48	16.48	139	24	0.06	100.6	138	19	4.22	124.5

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 increased 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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