Nutrient Screening—Revised

Handout for April 27, 2009 workgroup meeting.

DRAFT

Nutrients

Introduction

The TCEQ has included numerical criteria for nutrients in major reservoirs in the Standards. The criteria are based on historical chlorophyll *a* data from the main body of selected reservoirs. The TCEQ also plans to develop nutrient criteria for streams and rivers, estuaries, and wetlands and evaluate them for inclusion in a future revision of the Standards.

In addition to numerical criteria for reservoirs, the following rules also address the issue of controlling nutrients in wastewater discharges:

- General narrative criteria for nutrients in the Standards (section 307.4)
- Antidegradation provisions of the Standards (section 307.5)
- Watershed rules (30 TAC Chapter 311)
- Edwards Aquifer rules (30 TAC Chapter 213)

General Screening Approach for Nutrient Impacts

Applicability

The TCEQ evaluates applications for new or expanding domestic discharges to reservoirs and to streams and rivers to determine if an effluent limit is needed for total phosphorus (TP) or, in appropriate situations, total nitrogen (TN) to prevent violation of numerical nutrient criteria and/or preclude excessive growth of aquatic vegetation. Permit renewals and industrial discharges may be evaluated for potentially significant concentrations of TP (and if appropriate, TN) on a case-by-case basis.

General Procedure

Discharges into or near a reservoir that has been assigned numerical nutrient criteria in the Standards are first screened to evaluate main pool effects. Additional screening is performed, if applicable, to evaluate local effects in the reservoir and in the tributary stream or river under the narrative provisions of the Standards.

Assessing Numerical Nutrient Criteria—Main Pool Effects

For discharges to reservoirs that have numerical nutrient criteria, a detailed evaluation is performed using a completely-mixed, steady-state

reservoir model to assess the effect of a proposed discharge on phosphorus levels in the main pool of the reservoir. Screening procedures are provided to evaluate model results and to determine if an effluent limit on TP is needed. The procedures for this evaluation are in the section entitled "Nutrient Screening for Main Pool Effects in Reservoirs with Numerical Nutrient Criteria" on page 5.

Assessing Narrative Nutrient Provisions—Local Effects

To assess the local effects of discharges under the narrative nutrient provisions of the Standards, the TCEQ evaluates site-specific screening factors to assess eutrophication potential rated in terms of low, moderate, or high. Qualitative and quantitative guidelines are provided; screening factors may have one or the other or both. In some situations only some of the suggested factors may be needed for the evaluation, and sufficient data may not always be available to address every factor. The procedures for this evaluation are in the sections entitled "Nutrient Screening for Local Effects in Reservoirs" on page 11 and "Nutrient Screening in Streams and Rivers" on page 18.

Assessing the Results of Site-Specific Screening Factors

The individual screening factors establish the basis for an overall "weight-of-evidence" assessment to identify the need for a nutrient effluent limit. An effluent limit for TP is typically indicated when a significant number of screening factors are rated as moderate and high. However, the importance and weight of individual screening factors can vary from one site to another. If an effluent limit for TP is indicated, then screening factors and levels of concern can also be applied to determine the specific concentration limit for TP.

Initial assessments can be improved and reconsidered in light of additional site-specific data and/or more extensive models and evaluations.

Effluent Limits for Total Phosphorus

When evaluations indicate that a reduction of effluent TP is needed, an effluent limit is recommended based on reasonably achievable technology-based limits, with consideration of the sensitivity of the site. Typical effluent limits for TP, as a daily average concentration, generally fall into the following ranges:

Permitted Flow (MGD)	Typical TP Limit (mg/L)
< 0.5	1.0
0.5 – 3.0	1.0 to 0.5
> 3.0	0.5

Higher or lower limits may be recommended based on site-specific mitigating factors.

Regulatory Factors that Prescribe Nutrient Controls in Discharge Permits

Additional screening is unnecessary when site-specific regulatory factors explicitly establish an effluent limit for TP or other requirements:

- A TP limit, or a prohibition on wastewater discharges, is established in a watershed rule (30 TAC Chapter 311) or in the Edwards Aquifer rule (30 TAC Chapter 213)

- A water body is listed as impaired in the current Texas 303(d) List due to excessive nutrients such as TP, making the provisions in the section of this document entitled "Protecting Impaired Water Under Tier 1" applicable (see page x).

- A TMDL or TMDL Implementation Plan specifies TP limits for wastewater discharges.

Focus on Phosphorus Instead of Nitrogen

Considerations for nutrient impacts focus on TP rather than nitrogen for the following reasons:

- substantially less data on total nitrogen have been collected in Texas reservoirs, streams, and rivers

- phosphorus is a primary nutrient in freshwaters, although nitrogen can be limiting during parts of the year

- nitrogen can be fixed directly from the atmosphere by most of the noxious forms of blue-green algae

- available waste treatment technologies make reducing phosphorus more effective than reducing nitrogen as a means of limiting algal production.

Effluent limits for total nitrogen can be considered in extraordinary situations when existing or projected nitrogen levels would result in:

- growth of nuisance aquatic vegetation
- a substantial increase in nitrate-nitrogen that could adversely affect public drinking water supplies (with a nitrate-nitrogen criterion of 10 mg/L).
- potential eutrophication of unusually sensitive tidal waters, such as around seagrass beds.

Nutrient Screening for Main Pool Effects in Reservoirs with Numerical Nutrient Criteria

General Approach

Numerical nutrient criteria in the Standards are expressed as the long-term average concentration of chlorophyll *a* in the main pool of a reservoir. These criteria are based on historical data to ensure that existing reservoir water quality is maintained. Screening levels for total phosphorus (TP) in reservoirs have been similarly established (see Table F-1 in Appendix F).

Discharges of domestic (and in some cases industrial) wastewater into the watersheds of reservoirs with numerical nutrient criteria are evaluated to ensure compliance with water quality standards for chlorophyll *a* and with screening criteria for nutrients.

Applicability

Evaluations are conducted for permit applications that propose to increase permitted discharge flow of greater than 0.5 MGD into the watersheds of reservoirs with numerical nutrient criteria. Evaluations are conducted for the following discharge sizes within the listed distance from the reservoir:

Permitted flow (MGD)	Distance from reservoir (stream miles)
< 1	≤ 5
1 – 3	≤ 10
> 3	≤ 20*

* Very large discharges at greater distances may be evaluated.

Screening Model for TP

The primary screening is based on the relative change in TP concentration in the main pool of the reservoir that would occur solely from the proposed discharge. (The screening could also be applied to TN.) The change in TP is estimated by applying a steady-state, completely-mixed model to the reservoir using long-term estimates of reservoir retention time and reservoir volume at the normal operating pool elevation. The equations used in the screening procedure represent one example of an appropriate steady-state model.[1]

The TCEQ will consider more sophisticated models if they are submitted for review. If a more sophisticated model is used, predicted changes in chlorophyll *a* may be evaluated directly rather than evaluating predicted changes in TP.

The screening procedure consists of six steps as follows.

(1) For discharges that are over one mile from the normal operation pool elevation of the reservoir, estimate the loss of TP in the tributary stream or river as follows:

Equation 1:

$$f_{TP,x} = \exp\{-k_P[x/(11318 Q_T^{0.5})]\}$$

where:

$f_{TP,x}$ = fraction of TP **remaining** at a distance x downstream of the discharge

x = distance along the stream to the normal pool elevation of the reservoir (m)

Q_T = permitted discharge flow **plus** harmonic mean flow upstream of the discharge (m^3/s)

k_P = TP decay rate at an assumed annual mean temperature of 20ºC. Assume to be 0.08/day unless an alternative rate is shown to be more appropriate.

For discharge points that are less than or equal to one mile from the normal operating pool elevation of the reservoir, assume no loss of TP in the tributary stream or river (that is, set $f_{TP,x} = 1$).

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[1] For a discussion of model formulations and settling velocity, see Kenneth Reckow. 1979. Empirical Lake Models for Phosphorus: Development, Applications, Limitations and Uncertainty. In: *Perspectives in Lake Ecosystem Modeling.* Donald Scavia and Andrew Robertson (eds.). Ann Arbor Science.

(2) Estimate the concentration of TP from the discharge that is delivered to the reservoir using Equation 2:

Equation 2:

$$TP_d = f_{TP,x} \times TP_e$$

where:

TP_d = concentration of TP from the discharge delivered to the reservoir (mg/L)

$f_{TP,x}$ = fraction of TP **remaining** at a distance x downstream of the discharge, calculated using Equation 1

TP_e = concentration of TP in the effluent (mg/L), assumed to be 3.5 mg/L (or levels required by local impacts screening) if no effluent data are available.

(3) Estimate the annual average loading of TP in the entire reservoir due to the discharge using Equation 3:

Equation 3:

$$TP_L = 1{,}381{,}525 \times Q_P \times TP_d$$

where:

TP_L = annual average loading of TP in the entire reservoir due to the discharge (g/yr)

Q_P = permitted discharge flow (MGD)

TP_d = concentration of TP from the discharge delivered to the reservoir (mg/L), calculated using Equation 2

(4) Estimate the areal loading rate to the reservoir using Equation 4:

Equation 4:

$$w' = \frac{TP_L}{A_R}$$

where:

w' = TP areal loading rate (g/m^2·yr)

TP_L = annual average loading of TP in the entire reservoir due to the discharge (g/yr), calculated using Equation 3

A_R = surface area of reservoir (m^2) from Table F-2 in Appendix F (multiply acres by 4,047 to get m^2)

(5) Estimate the annual average concentration of TP in the entire reservoir due to the discharge using Equation 5:

Equation 5:

$$TP_R = \frac{w'}{v_s + z/\tau}$$

where:

TP_R = annual average TP in the entire reservoir due to the discharge (mg/L)

w' = TP areal loading rate (g/m^2·yr), calculated using Equation 4

v_s = settling velocity (m/yr). For TP, assume 13 m/yr

z = mean depth (m), see Appendix F, Table F-2 (multiply feet by 0.3048 to get m)

τ = retention time (yrs), see Appendix F, Table F-2

(6) Finally, compare the change in TP in the main body of the reservoir to the reservoir's mean TP concentration using Equation 6:

Equation 6:

$$\%\ change = \frac{100 \times TP_R}{TP_A}$$

where:

$\%\ change$ = percent change in TP relative to the mean TP of the reservoir

TP_R = annual average TP in the entire reservoir due to the discharge (mg/L), calculated using Equation 5

TP_A = mean TP concentration of the reservoir (see Appendix F, Table F-1; these are long-term means of TP in the main pool of each reservoir)

Assessing the Results of Main Pool Screening

If TP is estimated to change by less than 5 percent, a TP limit is probably not needed. If TP is estimated to change by more than 10 percent, then a TP limit is probably needed. If TP is estimated to change by 5-10 percent, either TP monitoring or a TP limit is possible, depending on the specifics of the case.

Use the typical effluent limit for TP based on permitted flow (see the table on page 4) in the screening procedure to estimate how much TP in the reservoir will change due to the discharge. The limit may need to be adjusted if the estimated change in reservoir TP is greater than 10%.

Example Calculation:
An applicant proposes to locate a new 0.75 MGD discharge 3 miles upstream of Lake Houston, Seg. 1002. Would a TP limit likely be recommended?

(1) Estimate the fraction of TP from the discharge that reaches Lake Houston using Equation 1. Assume the stream has a harmonic mean flow of 1 cfs. Watch out for unit conversions!

$$f_{TP,x} = \exp\{-0.08[4827/(11318\times(0.032865+0.02832)^{0.5})]\} = 0.87$$

(2) Estimate the concentration of TP from the discharge that reaches Lake Houston using Equation 2. Assume an effluent TP concentration of 3.5 mg/L.

$$TP_d = 0.87\times 3.5 = 3.045\,\text{mg/L}$$

(3) Estimate the annual average loading of TP from the discharge to Lake Houston in its entirety using Equation 3.

$$TP_L = 1{,}381{,}525\times 0.75\times 3.045 = 3{,}155{,}058\,\text{g/yr}$$

(4) Estimate the areal loading rate from the discharge to Lake Houston using Equation 4. (Reservoir characteristics are in Table F-2 in App. F.)

$$w' = \frac{3{,}155{,}038}{11{,}854\times 4{,}047} = 0.066\,\text{g/m}^2\cdot\text{yr}$$

(5) Estimate the annual average TP concentration from the discharge in Lake Houston using Equation 5.

$$TP_R = \frac{0.066}{13+0.3048\times(128{,}863/11{,}854)/0.11} = 0.0015\,\text{mg/L}$$

(6) Compare the change in TP due to the discharge to the mean TP concentration in Lake Houston using Equation 6.

$$\%\,change = \frac{100\times 0.0015}{0.189} = 0.81\%$$

A limit on TP is unlikely to be recommended.
Monitoring of TP is also unlikely to be recommended.

Chlorophyll a Considerations

The primary focus of the analysis to this point is TP screening levels. As a secondary screening, the relative potential increase in chlorophyll *a* that might result from the estimated increase in TP can be considered, although the TCEQ is not performing such an estimate at this time. The potential increase in chlorophyll *a* can be estimated from the projected increase in TP by the following generic regression equation[2] for Texas reservoirs:

Equation 7: $\ln[Chl\ a\ (\mu g/L)] = 0.8497 \ln[TP\ (mg/L)] + 4.7447$

As a rough guideline, the potential change in chlorophyll *a* in the entire reservoir can be evaluated using the following procedure:

First use Equation 7 to calculate the chlorophyll *a* value in the reservoir using the mean TP concentration and the median TSS concentration in Table F-1 in Appendix F:

$$\ln[Chl_{AP}\ (\mu g/L)] = 0.8497 \ln[TP_A\ (mg/L)] + 4.7447$$

Then use Equation 7 to calculate the chlorophyll *a* value in the reservoir using the sum of the mean TP concentration (from Table F-1) and the annual average TP in the entire reservoir due to the discharge (TP_R, from Equation 5):

$$\ln[Chl_{AR}\ (\mu g/L)] = 0.8497 \ln[TP_A + TP_R\ (mg/L)] + 4.7447$$

Finally, the predicted change in chlorophyll *a* in the reservoir due to the discharge is estimated using Equation 8:

Equation 8: $Chl_R = Chl_{AR} - Chl_{AP}$

where:

Chl_R = chlorophyll *a* added by the discharge (µg/L)

Chl_{AR} = chlorophyll *a* (µg/L) predicted in the reservoir due to the discharge at permitted flow, calculated using Equation 7

Chl_{AP} = chlorophyll *a* (µg/L) predicted in the reservoir at ambient TP concentration (see Appendix F, Table F-1), calculated using Equation 7

Once the predicted change in chlorophyll *a* in the reservoir due to the

[2] Larry Hauck. Texas Institute for Applied Environmental Research. Letter to TCEQ dated January 23, 2009 and email dated March 9, 2009.

discharge has been estimated, it is compared to the assimilative capacity of the reservoir using Equation 9.

Equation 9: $$\%\ change = \frac{100\,[Chl_R]}{Chl_C - Chl_A}$$

where:

$\%\ change$ = percent change in chlorophyll *a* relative to the assimilative capacity of the reservoir

Chl_R = annual average chlorophyll *a* in the entire reservoir due to the discharge (mg/L), calculated using Equation 8

Chl_C = Chlorophyll *a* criterion for the reservoir from Appendix F of the Standards.

Chl_A = mean chlorophyll *a* concentration of the reservoir (see Appendix F, Table F-1; these are long-term means of chlorophyll *a* in the main pool of each reservoir)

The difference between the chlorophyll *a* screening level and the mean chlorophyll *a* concentration is considered to be the assimilative capacity of the reservoir. The percent change in assimilative capacity for chlorophyll *a* should probably be less than 10%, otherwise, a limit on TP is probably needed.

Nutrient Screening for Local Effects in Reservoirs

General Approach

To assess local effects in reservoirs from a discharge under the narrative nutrient provisions of the Standards, the TCEQ first evaluates the discharge using general guidelines. If the general guidelines indicate that a TP limit should be considered, then the TCEQ conducts a more comprehensive review using site-specific screening factors. Eutrophication potential is rated as a low, moderate, or high level of concern for each factor. Some screening factors can be rated on either qualitative or quantitative information, depending on data availability. Not every factor is appropriate or definable at a particular site.

Applicability

These site-specific screening procedures focus on larger reservoirs, such as those used for public water supplies. They can also be applied to smaller perennial impoundments (no smaller than about 10 surface acres in size), but some of the site-specific screening factors might not apply. Smaller impoundments, ponds, and perennial pools are addressed in the

nutrient screening procedures for streams and rivers (see page 18). Evaluations are conducted for the following discharge sizes within the listed distance from the reservoir:

Permitted flow (MGD)	Evaluation Distance (stream miles)
< 0.25	< 5
0.25 to < 1.0	< 10
≥ 1.0*	< 20

* Very large discharges may be evaluated on a case-by-case basis.

A separate analysis is conducted to compare the potential impact of the discharge with numerical criteria for nutrients in the main pool of the reservoir (see the previous section of this document entitled "Nutrient Screening for Main Pool Effects in Reservoirs with Numerical Nutrient Criteria" on page 5).

General Guideline for Considering TP Limits

TP limits are potentially indicated in the following situations:

- for new or expanding major discharges (≥ 1 MGD) into or near reservoirs
- for new or expanding discharges > 0.25 MGD into or near shallow, restricted coves of reservoirs
- where explicitly required by watershed rules or other specific regulatory requirements.

Smaller proposed discharges (such as those between 0.1 to 0.25 MGD) can also be of concern and evaluated for TP limits if the discharge location is into a sensitive area with very low dispersion.

Site-Specific Screening Factors

For cases where the general guidelines indicate that a limit on TP should be considered further, site-specific screening factors are applied to assess the potential need for a TP limit to control eutrophication. These screening factors include the following:

A. size of discharge
B. distance from reservoir
C. sensitivity to nutrient enrichment—water clarity

D. sensitivity to growth of aquatic vegetation—observations
E. sensitivity to growth of aquatic vegetation—shading and sunlight in narrow backwaters and small coves
F. sensitivity to nutrient enrichment—chlorophyll *a* to TP ratio
G. consistency with similar permits
H. local dispersion and mixing
I. impact on the main pool of the reservoir

The level of concern (low, moderate, or high) for each of these factors is described in the following sections.

A. SIZE OF DISCHARGE

The size of a discharge into or near a reservoir affects phosphorus loading and the concern for potential impacts, as indicated in the following table. A higher level of concern may be assigned to discharges into sensitive areas.

Level of Concern	Permitted Flow (MGD)
Low	< 0.25
Moderate	0.25 to < 1.0
High	≥ 1.0

B. DISTANCE FROM RESERVOIR

The level of concern is based on the size of the discharge and its distance from the normal operating pool of the reservoir.

Size of Discharge (MGD)	Level of Concern (stream miles)		
	Low	Moderate	High
< 0.25	> 3	3 to > 1	≤ 1
0.25 to < 1.0	> 7	7 to > 3	≤ 3
≥ 1.0*	> 15	15 to > 7	≤ 7

* Very large discharges may be evaluated on a case-by-case basis.

C. SENSITIVITY TO NUTRIENT ENRICHMENT – WATER CLARITY

Reservoirs with higher transparency allow more light to penetrate, which increases the tendency for algal growth. In addition, the aesthetic impact of phytoplankton algal blooms tends to be greater in reservoirs that generally have low turbidity. A qualitative screening approach is used when other data are not readily available. A quantitative screening

approach that uses average total suspended solids (TSS) as an estimate of transparency may be used if adequate TSS data are available.

Option 1: Qualitative analysis: Relative clarity is assessed using general observations and knowledge by individuals who are familiar with the reservoir or similar reservoirs in the area.

Level of Concern	Discharge Environment
Low	Turbid from suspended particles or color (tannins)
Moderate	Some visible turbidity but without heavy murkiness
High	A "clear water" reservoir with high transparency

Option 2: Quantitative analysis: Relative clarity is assessed using the median of long-term TSS data (if available) in the main pool of the reservoir or at sampling sites near the proposed discharge. Levels of concern based on clarity are as follows:

Level of Concern	TSS (mg/L)*
Low	≥ 12
Moderate	6 to < 12
High	0 to < 6

* TSS ranges for each impact level are derived by dividing the long-term database on TSS for Texas reservoirs into thirds.

D. Sensitivity to Growth of Aquatic Vegetation—Observations

When site-specific observations are available with respect to aquatic vegetation in areas of the water body with existing wastewater discharges, the applicable category of nutrient impacts are as follows:

Level of Concern	Observed Aquatic Vegetation
Low	Little attached, floating, or suspended aquatic vegetation
Moderate	Limited patches of attached, floating, or suspended vegetation
High	Heavy patches of vegetation in areas with nutrient input

E. Sensitivity to Growth of Aquatic Vegetation—Shading and Sunlight in Narrow Backwaters and Small Coves

The sensitivity of narrow backwaters and small coves to various kinds of aquatic vegetation can be affected by the extent to which sunlight reaches

the water's surface. The amount of available sunlight is related to the amount of tree canopy cover during warm seasons.

Level of Concern	Canopy Cover and Shading During Warm Months
Low	Extensive canopy cover shades most of water surface
Moderate	Substantial canopy cover, but shading is only partial and not equivalent to "deep woods"
High	Canopy cover diffuses light to some extent, but substantial light reaches water surface

F. SENSITIVITY TO NUTRIENT ENRICHMENT – CHLOROPHYLL *A* TO TP RATIO

The relative effect of TP on algal growth in a reservoir is estimated by the ratio of chlorophyll *a* to TP. Higher ratios indicate a potentially higher sensitivity to TP additions. Long-term median concentrations of chlorophyll *a* and TP in the main pool of the reservoir (both in mg/L) are used to calculate the ratio of chlorophyll *a* to TP. The following transformation is used to adjust the ratio for Texas reservoirs[3]:

$$\text{Adjusted ratio} = \frac{-0.01 \ln[\text{Chl } a \text{ (mg/L)}]}{\text{TP (mg/L)}}$$

Levels of concern based on this adjusted ratio are as follows:

Level of Concern	-0.01[ln Chl *a* (mg/L)]:TP
Low	< 1
Moderate	1 to 1.5
High	> 1.5

G. CONSISTENCY WITH OTHER PERMITS

An assessment is conducted to determine whether TP limits have been required for other wastewater permits with similar characteristics and locations in this area.

Level of Concern	TP Limits in Other Permits in the Area?
Low	Similar permits usually do not have effluent limits for TP
Moderate	There are some similar permits with TP limits, but applicability is site-specific and not "across-the-board"

[3] Glenn C. Clingenpeel. Trinity River Authority of Texas. Letter to the TCEQ dated January 21, 2009.

Level of Concern	TP Limits in Other Permits in the Area?
High	Discharges with similar characteristics usually have a TP limit

H. LOCAL DISPERSION AND MIXING

The local impacts of a discharge to a reservoir depend greatly on the extent to which the discharge is dispersed and mixed at the discharge site. Both qualitative and quantitative options for this analysis are described below. The qualitative option is based on the general physical characteristics of the discharge site. The quantitative option uses either a completely-mixed model or a QUAL-TX stream model to determine the extent to which phosphorus concentrations are potentially elevated by the discharge (ΔTP).

Option 1: Qualitative analysis: Discharges to the main body of the reservoir or to large, deep open coves are of low potential concern with respect to dispersion and mixing. Discharges into smaller coves, shallow areas, inundated creeks, and canals are of moderate concern. Discharges into narrow, slow moving areas of a reservoir, whether riverine transition zones or wetlands, are of high concern.

Level of Concern	Discharge Environment
Low	Large, open coves or main body of reservoirs
Moderate	Coves with restricted circulation
High	Narrow, backwater transition zones

Option 2: Quantitative analysis:

A: Discharges to the main body of the reservoir or to large deep open coves (relative to the size of the discharge) are assessed as having a low level of concern with respect to dispersion and mixing. For this scenario, the assessment is still qualitative, and no quantitative analysis is performed.

B: Discharges into coves with restricted circulation are evaluated to assess the projected increase in **local** TP concentration (ΔTP) that will be added by the discharge at permitted flow. A steady-state, completely-mixed model is used to determine ΔTP as described in the section entitled "Nutrient Screening for Main Pool Effects in Reservoirs with Numerical Nutrient Criteria" on page 5.

Default cell size for the model is 10 acres, although smaller cell sizes may be used to address physical barriers at smaller distances. Surface area and average depth are determined from best available map information. Tributary inflows at 7Q2 are used in the calculation of detention time for the cell volume. (Note: if a completely-mixed, steady-state model for dissolved oxygen is also used at a site, the morphometry for the TP model will correspond to the DO model.)

C: Discharges into narrow, backwater transition zones that are within the normal operating pool of the reservoir are screened using the same QUAL-TX model that is used for dissolved oxygen (if available for that site). The QUAL-TX results are evaluated by assessing the instream proportion of effluent at a distance of 300 feet from the point where the discharge enters the transition zone within the normal operating pool.

The ΔTP is calculated by first either assuming an effluent concentration of 3.5 mg/L TP or by using effluent TP data (if available) and then multiplying the effluent TP by the instream proportion of effluent. For discharges that are greater than one stream mile from the normal operating pool, the loss of phosphorus over stream distance can be calculated as described in the section entitled "Nutrient Screening for Main Pool Effects in Reservoirs with Numerical Nutrient Criteria" on page 5.

For discharges to both restricted coves and backwater transition zones (cases B and C above), levels of concern for the predicted ΔTP are as follows:

Level of Concern	Predicted ΔTP (mg/L)
Low	< 0.05
Moderate	0.05 to < 0.25
High	≥ 0.25

I. IMPACT ON THE MAIN POOL OF THE RESERVOIR

Although this screening factor is not a local effect, it is useful for evaluating discharge impacts to reservoirs with no numeric nutrient criteria when:

- the reservoirs are larger than 100 surface acres
- there are major discharges that are large enough to potentially cause a significant change to phosphorus concentrations in the main pool of the reservoir.

A steady-state, completely-mixed model is used to determine ΔTP in the main pool, as described in the section entitled "Nutrient Screening for Main Pool Effects in Reservoirs with Numerical Nutrient Criteria" on page 5. Using the results of that modeling procedure, the following levels of concern are assigned to various predicted changes in TP concentration:

Level of Concern	Predicted ΔTP (mg/L)
Low	< 0.0001
Moderate	0.0001 to < 0.001
High	≥ 0.001

Assessing the Results of Site-Specific Screening Factors

Once the individual screening factors have been rated, they provide the basis for a "weight-of-evidence" assessment to identify the need for a nutrient effluent limit. An effluent limit for TP is probably needed when a substantial number of screening factors are rated moderate and high.

Alternatively, numeric values can be assigned to each level of concern (for example, Low=1, Moderate=3, High=5) and the values averaged. If the average is <2, a TP limit is probably not needed. If the average is > 4, a TP limit is probably needed. If the average is 2-4, either TP monitoring or a TP limit is possible, depending on the specifics of the case. The importance and weight of the individual screening factors can vary from one site to another.

If an effluent limit for TP is indicated, the screening factors and levels of concern are used to help determine the specific effluent limit for TP. Initial assessments can be improved and reconsidered in light of additional site-specific data and more extensive models and evaluations.

Nutrient Screening for Streams and Rivers

General Approach

To assess local effects in streams and rivers from discharges under the narrative nutrient provisions of the Standards, the TCEQ first evaluates the discharge using general guidelines. If the general guidelines indicate that a TP limit should be considered, then the TCEQ conducts a more comprehensive review using site-specific screening factors. Eutrophication potential is rated as a low, moderate, or high level of concern for each factor. Some screening factors can be rated on either qualitative or quantitative information, depending on data availability. Not

every factor is always appropriate or definable at a particular site.

Applicability

These screening procedures are primarily intended for freshwater streams and rivers. Perennial impoundments greater than 10 surface acres along streams can be individually evaluated using screening factors for reservoirs, as described in previous sections.

If a stream or river changes characteristics downstream of the discharge such that eutrophication impacts might be greater in downstream areas, then screening procedures are also applicable to those downstream reaches. As a rough guide, nutrient screening procedures are typically applied for the following discharge sizes within the following distance of the discharge point:

Permitted flow (MGD)	Evaluation Distance (stream miles)
< 0.25	< 3
0.25 to < 1.0	< 7
≥ 1.0*	< 15

* Very large discharges may be evaluated on a case-by-case basis.

General Guideline for Assigning TP Limits

Typically, TP limits are potentially indicated in the following situations:

- for new or expanding discharges > 0.25 MGD to perennial, shallow, relatively clear streams with rocky bottoms or other substrates that promote the growth of attached vegetation
- for new or expanding discharges > 0.25 MGD to streams with long, shallow, relatively clear perennial impoundments
- where explicitly required by watershed rules or other specific regulatory requirements.

Other situations where receiving streams appear to be especially sensitive to nutrient increases can also be considered. Smaller proposed discharges (such as those between 0.1 to 0.25 MGD) can also be of concern and evaluated for TP limits if the discharge location is into a sensitive area with very low dispersion/dilution.

Site-Specific Screening Factors

For cases where a limit on TP should be considered further, site-specific screening factors are applied to assess the potential need for a TP limit to control instream vegetation growth. These screening factors include the following:

A. size of discharge
B. instream dilution
C. sensitivity to growth of attached algae—type of bottom
D. sensitivity to growth of attached vegatation—depth
E. sensitivity to nutrient enrichment—water clarity
F. sensitivity to growth of aquatic vegetation—observations
G. sensitivity to growth of aquatic vegetation—shading and sunlight
H. streamflow sustainability
I. impoundments and pools
J. consistency with other permits

The level of concern (low, moderate, or high) for each of these factors is described in the following sections. Calculations are based on 7Q2 stream flows unless otherwise indicated.

A. SIZE OF DISCHARGE

The permitted size of the discharge affects the downstream extent of impact and the amount of nutrient loading to deeper, slower moving areas such as pools and small impoundments.

Level of Concern	Permitted Flow (MGD)
Low	< 0.25
Moderate	0.25 to < 1.0
High	≥ 1.0

B. INSTREAM DILUTION

The potential impact of nutrients from discharges to streams and rivers is substantially affected by the dilution and resulting instream concentration during dry-weather flows. The percent effluent instream at the discharge and at downstream points is calculated at permitted discharge flow and 7Q2 streamflow.

Level of Concern	Percent Effluent
Low	< 10
Moderate	10 to < 25

Level of Concern	Percent Effluent
High	≥ 25

The percent of effluent instream can be obtained either from dilutions calculated for critical conditions or from modeling results for dissolved oxygen.

C. SENSITIVITY TO GROWTH OF ATTACHED ALGAE – TYPE OF BOTTOM

In shallow, clear streams, the tendency for the stream to have nuisance levels of attached algae depends in part upon a stable stream bottom upon which attached algae may grow.

Level of Concern	Bottom Substrate
Low	Mud or sand
Moderate	Rocky cobble, gravel, usually with riffle areas
High	Larger rocks and boulders, rock slabs

D. SENSITIVITY TO GROWTH OF ATTACHED VEGETATION – DEPTH

The growth of attached vegetation tends to be facilitated by the extent of shallow areas. Levels of concern associated with the potential for eutrophication are as follows:

Level of Concern	Depth Characteristics
Low	Relatively steep banks and deep channels across stream
Moderate	Gently sloping sides with some shallow areas
High	Substantial shallow areas near banks and in stream channel

E. SENSITIVITY TO NUTRIENT ENRICHMENT—WATER CLARITY

Relative clarity is assessed using general observations and knowledge by individuals who are familiar with the stream or river.

Level of Concern	Discharge Environment
Low	Turbid from suspended particles or color (tannins), bottom may not be visible
Moderate	Some visible turbidity but without heavy murkiness, bottom sometimes visible
High	Relatively clear water, bottom usually visible

F. Sensitivity to growth of aquatic vegetation—observations

When site-specific observations are available with respect to aquatic vegetation in areas of the water body with existing wastewater discharges, the levels of concern for nutrient impacts are as follows:

Level of Concern	Observed Aquatic Vegetation
Low	Little attached, floating, or suspended aquatic vegetation
Moderate	Limited patches of attached, floating, or suspended vegetation
High	Heavy patches of vegetation in areas with nutrient input

G. Sensitivity to Growth of Aquatic Vegetation—Shading and Sunlight

The sensitivity of streams to various kinds of aquatic vegetation can be affected by the extent to which sunlight can reach the water's surface. The amount of available sunlight is related to the amount of tree canopy cover during warm seasons.

Level of Concern	Canopy Cover and Shading During Warm Months
Low	Extensive canopy cover shades most of stream surface
Moderate	Substantial canopy cover, but shading is only partial and not equivalent to "deep woods"
High	Canopy cover diffuses light to some extent, but substantial light reaches stream surface

H. Streamflow Sustainability

Growth of aquatic vegetation and the potential impact of nutrients are enhanced by flow characteristics that sustain permanent aquatic environments.

Level of Concern	Stream Type
Low	Intermittent
Moderate	Intermittent with perennial pools
High	Perennial

I. Impoundments and Pools

Perennial impoundments that are greater than 10 surface acres can be individually evaluated with screening factors that are applied to reservoirs (see previous section that starts on page 11). The presence of smaller riverine impoundments and perennial pools can also increase the level of

concern for eutrophication impacts.

Level of Concern	Extent of Pools and Impoundments
Low	No impoundments > 300 feet in length and no reach with extensive smaller pools
Moderate	No impoundments > 300 feet in length, but substantial smaller pools over > 20% of affected reach
High	At least one impoundment > 300 feet in length

J. CONSISTENCY WITH OTHER PERMITS

An assessment is conducted to determine whether TP limits have been required for other wastewater permits with similar characteristics and locations in this area.

Level of Concern	TP Limits in Other Permits in the Area?
Low	Similar permits usually do not have effluent limits for TP
Moderate	There are some similar permits with TP limits, but applicability is site-specific and not "across-the-board"
High	Discharges with similar characteristics usually have a TP limit

Assessing the Results of Site-Specific Screening Factors

Once the individual screening factors have been rated, they provide the basis for a "weight-of-evidence" assessment to identify the need for a nutrient effluent limit. An effluent limit for TP is typically indicated when a substantial number of screening factors are rated moderate and high.

Alternatively, numeric values can be assigned to each level of concern (for example, Low=1, Moderate=3, High=5) and the values averaged. If the average is <2, a TP limit is probably not needed. If the average is > 4, a TP limit is probably needed. If the average is 2-4, either TP monitoring or a TP limit is possible, depending on the specifics of the case. The importance and weight of the individual screening factors can vary from one site to another.

If an effluent limit for TP is indicated, the screening factors and levels of concern are used to help determine the specific effluent limit for TP. Initial assessments can be improved and reconsidered in light of additional site-specific data and more extensive models and evaluations.

Nutrient Screening Procedure for Discharges into Estuaries

Limits for total phosphorus are generally not considered for discharges to

tidal rivers or estuaries because vegetation growth in tidal waters is typically controlled by nitrogen rather than by phosphorus. At sensitive sites such as those with seagrasses nearby, limits on nutrients are considered for new or increased discharges. For more information, see the subsection of this chapter entitled "Seagrasses" on page x.

Other Applicable Rules

In addition to effluent limits based on dissolved oxygen, bacteria, nutrients, and other appropriate criteria, the draft permit also includes all treatment requirements of applicable rules such as:

- 30 TAC Chapter 309—"Domestic Wastewater Effluent Limitation and Plant Siting"
- 30 TAC Chapter 311—"Watershed Protection"
- 30 TAC Chapter 213—"Edwards Aquifer"
- 30 TAC Chapter 319—"General Regulations Incorporated Into Permits."

These rules are available on the agency's Web site (www.tceq.state.tx.us); follow the link for "Rules."

Appendix F. Nutrient Screening Parameters for Reservoirs with Nutrient Criteria.

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Table F-1: Total Phosphorus Screening Values for Reservoir Standards Attainment

Notes on table:

1) Segment numbers in parentheses refer to the segment in whose watershed the lake is located.

2) The TP screening values are applicable to the SWQM monitoring site(s) listed in the Site ID column for each reservoir. The sites listed and used for calculating and assessing standards attainment are those also used to assess trophic state for the reservoirs. Additional or alternate site IDs were used where appropriate and are listed.

3) Screening values were calculated using the formula in Moore & McCabe, Pooled two-sample *t* procedures. pp 542-549, in *Introduction to the Practice of Statistics*. W. H. Freeman and Company, New York. Degrees of freedom are $(n_1+n_2 -2)$, where n_1 is the count of the baseline data and n_2 is always 10.

4) The mean values for TP are geometric means.

5) The mean values for chlorophyll *a* are geometric means.

6) Median TSS values were calculated using the same data sets used to develop the ambient segment values in Appendix D of this document.

Segment No.	Lake/Reservoir Name	Site ID	TP Screening Value (mg/L)	TP Mean (mg/L)	Chloro-phyll *a* Mean (µg/L)	TSS Median (mg/L)
0102	Lake Meredith	10036	0.028	0.019	2.46	5.0
0203	Lake Texoma	10128	0.072	0.044	6.54	6.0
0208	Lake Crook	10137	0.241	0.170	4.77	28
0209	Pat Mayse Lake	10138	0.043	0.029	7.64	5.0
0210	Farmers Creek Reservoir/ Lake Nocona	10139	0.036	0.024	3.17	5.0
0212	Lake Arrowhead	10142	0.179	0.119	5.39	7.0
0213	Lake Kickapoo	10143	0.112	0.067	3.68	13
0215	Diversion Lake	10157	0.050	0.031	5.34	7.4
0217	Lake Kemp	10159	0.043	0.027	5.17	7.5
0219	Lake Wichita	10163	0.238	0.164	33.23	38
0223	Greenbelt Lake	10173	0.024	0.017	2.59	5.0
0228	Mackenzie Reservoir	10188	0.027	0.019	2.64	5.0
0229	Lake Tanglewood	10192	1.599	1.081	19.94	12
0302	Wright Patman Lake	10213	0.123	0.087	12.51	14
0401	Caddo Lake	10283	0.058	0.042	6.82	6.0
0403	Lake O' the Pines	10296	0.038	0.027	6.64	5.0

Segment No.	Lake/Reservoir Name	Site ID	TP Screening Value (mg/L)	TP Mean (mg/L)	Chloro-phyll *a* Mean (µg/L)	TSS Median (mg/L)
0405	Lake Cypress Springs	10312	0.036	0.026	7.41	6.0
0504	Toledo Bend Reservoir	10402	0.048	0.033	6.21	4.0
0507	Lake Tawakoni	10434	0.050	0.039	12.60	11
0509	Murvaul Lake	10444	0.069	0.047	19.72	8.0
0510	Lake Cherokee	10445	0.099	0.048	5.69	4.0
0512	Lake Fork Reservoir	10458	0.043	0.033	8.38	4.0
0603	B. A. Steinhagen Lake	10582	0.091	0.065	6.75	15
0605	Lake Palestine	16159	0.041	0.029	9.14	7.0
0610	Sam Rayburn Reservoir	14906	0.033	0.024	4.36	5.0
0613	Lake Tyler	10637	0.025	0.018	5.02	4.0
0613	Lake Tyler East	10638	0.031	0.022	7.72	5.0
0614	Lake Jacksonville	10639	0.023	0.017	3.02	2.0
0803	Lake Livingston	10899	0.210	0.156	17.04	19
0807	Lake Worth	10942	0.052	0.030	6.38	12
0809	Eagle Mountain Reservoir	10944 10945	0.066	0.022	11.32	11
0811	Bridgeport Reservoir	10970	0.046	0.031	3.57	5.0
0813	Houston County Lake	10973	0.028	0.022	5.02	3.0
0815	Bardwell Reservoir	10979	0.064	0.046	10.46	12
0816	Lake Waxahachie	10980	0.054	0.032	4.73	6.0
0817	Navarro Mills Lake	10981	0.061	0.042	8.00	16
0818	Cedar Creek Reservoir	10982 16749	0.076	0.057	16.39	10
0823	Lewisville Lake	11027	0.069	0.047	10.77	12
0826	Grapevine Lake	11035 16113	0.062	0.034	7.53	8.4
0827	White Rock Lake	11038	0.121	0.086	20.55	14
0828	Lake Arlington	11040 13904	0.052	0.024	15.99	10
0830	Benbrook Lake	11046 15151	0.070	0.055	16.04	10
0832	Lake Weatherford	11061	0.058	0.038	5.86	7.5
0834	Lake Amon G. Carter	11063	0.058	0.035	4.16	5.0
0836	Richland-Chambers Reservoir	15168	0.044	0.033	10.30	5.9

Segment No.	Lake/Reservoir Name	Site ID	TP Screening Value (mg/L)	TP Mean (mg/L)	Chloro-phyll *a* Mean (µg/L)	TSS Median (mg/L)
1002	Lake Houston	11204	0.246	0.189	6.28	20
1012	Lake Conroe	11342	0.047	0.032	9.22	7.0
1203	Whitney Lake	11851	0.025	0.018	4.73	7.0
1205	Lake Granbury	11860	0.058	0.035	13.76	7.0
1207	Possum Kingdom Lake	11865	0.051	0.029	6.28	4.0
(1208)	Millers Creek Reservoir	11679	0.089	0.062	10.34	20
1212	Somerville Lake	11881	0.072	0.053	20.73	14
1216	Stillhouse Hollow Lake	11894	0.023	0.015	1.50	2.0
1220	Belton Lake	11921	0.025	0.016	3.47	5.0
1222	Proctor Lake	11935	0.069	0.048	18.00	20
1224	Leon Reservoir	11939	0.030	0.021	5.04	7.5
1225	Waco Lake	11942	0.107	0.064	6.34	9.0
1228	Lake Pat Cleburne	11974	0.091	0.060	10.49	14
1230	Lake Palo Pinto	11977	0.078	0.050	3.37	7.0
1231	Lake Graham	11979	0.060	0.034	3.90	7.0
1233	Hubbard Creek Reservoir	12002	0.044	0.029	3.68	5.0
1234	Lake Cisco	12005	0.022	0.016	1.75	4.0
1235	Lake Stamford	12006	0.080	0.057	10.43	20
1236	Fort Phantom Hill Reservoir	12010	0.062	0.044	5.32	10
1237	Lake Sweetwater	12021	0.041	0.031	8.49	8.0
1240	White River Lake	12027	0.027	0.019	2.65	6.0
(1241)	Buffalo Springs Lake	11529	0.242	0.122	35.49	13
1247	Granger Lake	12095	0.050	0.036	6.65	16
1249	Lake Georgetown	12111	0.021	0.014	2.63	3.0
1252	Lake Limestone	12123	0.043	0.033	11.65	9.0
1254	Aquilla Reservoir	12127	0.050	0.034	8.36	9.0
1403	Lake Austin	12294	0.021	0.014	2.37	3.0
1404	Lake Travis	12302	0.018	0.012	2.06	3.0
1405	Marble Falls Lake	12319	0.032	0.021	4.96	5.0
1406	Lake Lyndon B. Johnson	12324	0.029	0.019	4.43	6.0
1407	Inks Lake	12336	0.028	0.019	6.64	5.0

Segment No.	Lake/Reservoir Name	Site ID	TP Screening Value (mg/L)	TP Mean (mg/L)	Chloro-phyll *a* Mean (µg/L)	TSS Median (mg/L)
1408	Lake Buchanan	12344	0.020	0.014	4.21	5.5
1411	E. V. Spence Reservoir	12359	0.027	0.023	6.81	11
(1412)	Lake Colorado City	12167	0.052	0.035	10.21	10
(1416)	Brady Reservoir	12179	0.039	0.030	14.62	7.5
1418	Lake Brownwood	12395	0.023	0.017	2.63	9.0
1419	Lake Coleman	12398	0.023	0.016	3.64	5.0
1422	Lake Nasworthy	12418	0.061	0.045	11.69	15
1423	Twin Buttes Reservoir	12422	0.035	0.024	5.77	12
1425	O.C. Fisher Lake	12429	0.071	0.051	10.25	15
(1426)	Oak Creek Reservoir	12180	0.037	0.023	4.36	6.0
1429	Town Lake/ Lady Bird Lake	12476	0.049	0.028	2.74	4.0
1433	O. H. Ivie Reservoir	12511	0.027	0.022	4.45	6.0
1805	Canyon Lake	12598	0.061	0.038	1.91	4.0
1904	Medina Lake	12826	0.023	0.016	2.04	5.0
2103	Lake Corpus Christi	12967	0.190	0.151	8.16	15
2116	Choke Canyon Reservoir	13019	0.063	0.044	7.77	9.0
2303	International Falcon Reservoir	13189	0.059	0.038	9.43	10
2305	International Amistad Reservoir	13211	0.020	0.014	1.44	4.0
2312	Red Bluff Reservoir	13267	0.046	0.034	11.97	14
(2454)	Cox Creek Lake	12514	0.303	0.265	7.85	83

Table F-2: Size Characteristics and Retention Times for Reservoir Standards Attainment

Notes on table:

1) Segment numbers in parentheses refer to the segment in whose watershed the lake is located.

2) Surface areas are at normal pool elevation as defined in Appendix C of the Standards. Surface areas were obtained from the Texas Water Development Board unless noted otherwise.

3) Volumes are at normal pool elevation as defined in Appendix C of the Standards. Volumes include the dead pool and were obtained from the Texas Water Development Board (TWDB) unless noted otherwise.

4) Retention times are calculated as noted in the source documentation but may be recalculated as reservoir capacities or flows are updated or as the TCEQ becomes aware of significant water transfers in or out of these reservoirs.

Segment No.	Lake/Reservoir Name	Surface Area (acres)	Volume (acre-ft.)	Retention Time (yrs)	Retention Time Source*
0102	Lake Meredith	16,411	817,970	15.1	Ground
0203	Lake Texoma	74,686	2,516,232	0.79	Ground
0208	Lake Crook	1,060	9,210	0.22	Ground
0209	Pat Mayse Lake	5,940	118,100	1.3	Ground
0210	Farmers Creek Reservoir/ Lake Nocona	1,362	21,749	3.0	Ground
0212	Lake Arrowhead	14,969	235,997	4.7	TCEQ
0213	Lake Kickapoo	6,028	85,825	2.2	TCEQ
0215	Diversion Lake	3,133	33,420	0.36	TCEQ
0217	Lake Kemp	15,357	245,434	3.0	Ground
0219	Lake Wichita	2,200	14,000	1.5	Ground
0223	Greenbelt Lake	2,025	60,400	6.4	Ground
0228	Mackenzie Reservoir	896	46,454	38.1	Ground
0229	Lake Tanglewood	258 [(a)]			
0302	Wright Patman Lake	24,438	167,300	0.06	Ground
0401	Caddo Lake	26,800	129,000	0.03	TCEQ
0403	Lake O' the Pines	16,919	241,081	0.56	Ground
0405	Lake Cypress Springs	3,461	67,690	1.7	Ground
0504	Toledo Bend Reservoir	181,600	4,477,000	1.1	Ground
0507	Lake Tawakoni	37,879	888,140	2.5	Ground
0509	Murvaul Lake	3,529	38,284	0.85	Ground
0510	Lake Cherokee	3,467	43,737	0.68	Ground

Segment No.	Lake/Reservoir Name	Surface Area (acres)	Volume (acre-ft.)	Retention Time (yrs)	Retention Time Source*
0512	Lake Fork Reservoir	27,264	636,133	3.9	Ground
0603	B. A. Steinhagen Lake	10,687	66,972	0.03	Ground
0605	Lake Palestine	22,656	373,202	1.2	Ground
0610	Sam Rayburn Reservoir	112,590	2,876,033	1.8	Ground
0613	Lake Tyler	2,224 [(b)]	43,500 [(c)]		
0613	Lake Tyler East	2,276 [(b)]	36,698 P[(d)]	0.84	Ground
0614	Lake Jacksonville	1,165	25,732	1.8	Ground
0803	Lake Livingston	83,277	1,741,867	0.35	Ground
0807	Lake Worth	3,458	33,495		
0809	Eagle Mountain Reservoir	8,702	182,505	0.95	Ground
0811	Bridgeport Reservoir	11,954	366,236	3.1	Ground
0813	Houston County Lake	1,330	17,665	1.3	Ground
0815	Bardwell Reservoir	3,138	46,472	1.0	Ground
0816	Lake Waxahachie	656	11,386		
0817	Navarro Mills Lake	5,061	56,963	0.64	Ground
0818	Cedar Creek Reservoir	32,873	644,785	1.7	Ground
0823	Lewisville Lake	29,170	571,926	0.99	Ground
0826	Grapevine Lake	6,893	164,703	1.5	Ground
0827	White Rock Lake	1,088	9,004		
0828	Lake Arlington	1,926	40,188	2.4	Ground
0830	Benbrook Lake	3,635	85,648	1.7	Ground
0832	Lake Weatherford	1,158	18,714	1.3	TCEQ
0834	Lake Amon G. Carter	1,540	20,050		
0836	Richland-Chambers Reservoir	41,356	1,136,600	1.8	TCEQ
1002	Lake Houston	11,854	133,990	0.11	Ground
1012	Lake Conroe	20,118	416,228	2.7	Ground
1203	Whitney Lake	23,220	554,203	0.61	Ground
1205	Lake Granbury	7,945	129,011	0.21	Ground
1207	Possum Kingdom Lake	16,716	540,340	1.1	Ground
(1208)	Millers Creek Reservoir	2,268	29,171		
1212	Somerville Lake	11,555	147,104	0.65	TCEQ
1216	Stillhouse Hollow Lake	6,484	227,825	1.5	Ground

Segment No.	Lake/Reservoir Name	Surface Area (acres)	Volume (acre-ft.)	Retention Time (yrs)	Retention Time Source*
1220	Belton Lake	12,135	435,225	1.3	Ground
1222	Proctor Lake	4,537	55,457	0.86	Ground
1224	Leon Reservoir	1,590	27,290	1.2	Ground
1225	Waco Lake	8,437	199,277	0.73	Ground
1228	Lake Pat Cleburne	1,558	25,730		
1230	Lake Palo Pinto	2,498	27,650	0.98	Ground
1231	Lake Graham	2,444	45,302	1.9	Ground
1233	Hubbard Creek Reservoir	14,922	324,983	4.1	Ground
1234	Lake Cisco	10,450	26,000		
1235	Lake Stamford	5,124	51,573		
1236	Fort Phantom Hill Reservoir	4,213	70,036		
1237	Lake Sweetwater	630	11,900	3.8	Ground
1240	White River Lake	1,642	31,846	16.3	Ground
(1241)	Buffalo Springs Lake	200	4,200		
1247	Granger Lake	4,064	52,525	0.42	Ground
1249	Lake Georgetown	1,287	36,904	0.76	Ground
1252	Lake Limestone	12,553	208,017	0.93	Ground
1254	Aquilla Reservoir	3,020	45,319	1.3	Ground
1403	Lake Austin	1,599	21,804	0.02	Ground
1404	Lake Travis	18,622	1,132,172	1.1	Ground
1405	Marble Falls Lake	608	7,486	0.01	Ground
1406	Lake Lyndon B. Johnson	6,534	134,353	0.14	Ground
1407	Inks Lake	788	14,074	0.02	Ground
1408	Lake Buchanan	22,019	875,610	1.2	Ground
1411	E. V. Spence Reservoir	14,640	517,272	33.3	Ground
(1412)	Lake Colorado City	1,612	31,805	1.3	Ground
(1416)	Brady Reservoir	2,020	30,430	2.3	Ground
1418	Lake Brownwood	6,587	131,429	1.2	Ground
1419	Lake Coleman	1,811	38,094	2.1	Ground
1422	Lake Nasworthy	1,380	10,108	1.2	Ground
1423	Twin Buttes Reservoir	9,080	186,200	18.7	Ground
1425	O. C. Fisher Lake	5,440	115,743	6.2	Ground

Segment No.	Lake/Reservoir Name	Surface Area (acres)	Volume (acre-ft.)	Retention Time (yrs)	Retention Time Source*
(1426)	Oak Creek Reservoir	2,375	39,360	2.1	Ground
1429	Town Lake/Lady Bird Lake	468	6,409	0.01	Ground
1433	O. H. Ivie Reservoir	19,149	554,340	11.9	TCEQ
1805	Canyon Lake	8,308	378,852	1.3	Ground
1904	Medina Lake	6,066	254,823	1.6	Ground
2103	Lake Corpus Christi	18,256	257,260	0.53	Ground
2116	Choke Canyon Reservoir	25,989	695,271	3.7	Ground
2303	International Falcon Reservoir	85,195	2,646,817	1.2	Ground
2305	International Amistad Reservoir	65,597	3,275,532	2.1	Ground
2312	Red Bluff Reservoir	11,193	289,670	2.8	Ground
(2454)	Cox Creek Lake	541	5,034		

P[(a)] Dimensions obtained from http://findlakes.com

[(b)] Surface area from http://www.tpwd.state.tx.us

[(c)] Capacity from http://www.cityoftyler.org

[(d)] Calculated as the difference between the TWDB total capacity for both lakes (80,198 acre-ft) and the City of Tyler's capacity for Lake Tyler (http://www.cityof tyler.org).

* Ground: Ground, T. A. 1992. Relationships of Watershed Climate and Geochemical Processes to Trophic Characteristics in Texas Reservoirs. Master of Science thesis. Retention time was calculated using the mean annual discharge from the nearest downstream USGS gage and the mean annual reservoir volume as published by USGS.

TCEQ: Calculated using capacity at conservation pool from TWDB and annual average flow calculated either from the nearest downstream USGS gage or from US Army Corps of Engineers gated flow data.