**TCEQ DOCKET NO. 2007-1496-AGR**

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| **APPLICATION BY JEWELL ALT AND OENE KEUNING, dba O-KEE DAIRY, FOR MAJOR AMENDMENT TO TPDES PERMIT NO. WQ0004108000** | § § § § | **BEFORE THE TEXAS COMMISSION ON ENVIRONMENTAL QUALITY** |

**<u>REPLY BY THE CITY OF WACO TO EXECUTIVE DIRECTOR'S RESPONSE TO HEARING REQUEST</u>**

TO THE HONORABLE MEMBERS OF THE TEXAS COMMISSION ON ENVIRONMENTAL QUALITY:

The City of Waco ("City") files this reply to the Executive Director's response to its request for a contested case hearing on the application of Jewell Alt and Oene Keuning, dba O-Kee Dairy ("O-Kee Dairy"), for a major amendment of TPDES Permit No. WQ0004108000 and the draft permit that the Executive Director has issued to O-Kee Dairy based upon that application.

## I. THE CITY OF WACO IS AN "AFFECTED PERSON."

The Executive Director's recommendation that the Commission find that the City is not an affected person rests upon nine erroneous stated premises:

1. **The Executive Director asserts that "[n]one of the documentation submitted by Waco identifies the Applicant by name as a source of nutrients. Waco's issue in this case is not the potential contamination that could be caused by this particular dairy, but the cumulative affects [sic] of all CAFO dairy operations in the North Bosque watershed." E.D. Response, p. 4, last ¶.**

Contrary to the Executive Director's assertion, the City's Request for a Contested Case Hearing and the attached affidavits of its technical expert, Bruce Wiland, P.E., and its Director of the City's Water Utility, Richard Garrett, P.E., expressly state that, and describe how, under the terms of O-Kee Dairy's expansion application and the draft permit prepared by the Executive Director, the discharges and runoff of phosphorus and pathogens from the O-Kee Dairy that reach Lake Waco will increase and, therefore, cause increased harm to the City's drinking water supply and jeopardy to the health of its citizens who engage in water recreation in the Lake. *See* the City's Request for Contested Case Hearing, pp. 3 – 5; Affidavit of Bruce Wiland that is attached thereto as Exhibit A, ¶¶7 – 8; and Affidavit of Richard Garrett that is attached thereto as Exhibit E, ¶16.

In the Supplementary Affidavit of Bruce Wiland, P.E., that is attached hereto as Exhibit F, Mr. Wiland reiterates, and further explains, his opinion that the expansion of O-Kee Dairy will cause increased taste and odor problems in the City's drinking water and increased dangers to the health of its citizens if this dairy is managed no differently than described in its application and regulated no more stringently than the draft permit requires. *See* Supplementary Affidavit of Bruce Wiland, Exhibit F, ¶¶6 – 7. In further support of his opinion, Mr. Wiland has attached to his Supplementary Affidavit a document entitled *Opinions Regarding Nutrient Loading to Lake Waco and Resultant Impacts*, authored by Kenneth J. Wagner, Ph.D., CLM, as part of the comprehensive study of the factors adversely affecting Lake Waco that has been performed by the ENSR Environmental Consulting and Engineering Group. This Wagner report, which is hereby incorporated into the City's hearing request, provides additional explanation of the mechanisms by which the phosphorus and pathogens discharged from the O-Kee Dairy, like from any similarly managed dairy in the North Bosque River watershed, adversely affect Lake Waco, the City's water supply, and the health and welfare of its citizens.

**2. The Executive Director asserts that a dairy's contribution to cumulative effects that adversely impact the City is not enough to constitute an impact of the**

**regulated activity on the health, safety, and use of Lake Waco by the City [implicitly within the terms of 30 T.A.C. § 55.203(c)(4) and (5)]. E.D. Response, p. 4., last ¶.**

Even if the only harmful impacts on the City of the operation of O-Kee Dairy under this draft permit were due to the contributions of its phosphorus and pathogen discharges to the "cumulative" effects of *all* loadings of phosphorus and pathogens into the North Bosque River and Lake Waco, the City should have standing as an "affected person" to challenge O-Kee's draft permit or one being issued to any other contributing cause of harm to the City.

The proposition that, if one will be harmed only by a single permit applicant, he has standing to challenge the application, but not if he will be harmed by the "cumulative effects" of many, has no basis in law or common sense. Adoption of such a restricted principle in the context of wastewater discharge permits would mean that a protestant would have to model the quality of the water in the segment to which it was exposed as if there were no other sources of pollutants like those discharged by the permittee or of any other substances with which the permittee's discharges might interact to form harmful compounds. This would require a protestant to, in effect, first model the waterbody in a pristine, pure condition, absent all other point and nonpoint sources of pollution in order to establish that, standing alone, the permittee was the sole cause of any adverse effects attributed to it. Such a proposition would be illogical and contrary to the whole principle of granting standing to persons who have "personal justiciable interests" and a "stake in the outcome" of the Commission's decision.

Moreover, the scientific principle behind determination of the total maximum daily load ("TMDL") of an impaired waterbody, and the legal principle of limiting the combined contributions of all loadings of a pollutant of concern to the level necessary for attainment of specified water quality, and making each source responsible for staying at or below its allocated load, is based upon the premise that impairment (and, therefore, adverse effects on other persons) is usually only caused by combined loadings from all sources – i.e., cumulative effects. To deny a contested case hearing to the City, or to any other person adversely affected by the cumulative discharges of all CAFOs in the North Bosque River watershed, would fly in the face of both the science and the law underlying attainment of water quality standards under the Clean Water Act.

The attached report by Dr. Wagner explains the mechanism by which discharges and runoff of phosphorus from dairy CAFOs in the North Bosque River watershed foul Lake Waco, and the two affidavits by Bruce Wiland explain how the discharges and runoff from the O-Kee Dairy become part of this problem. If that is not enough, it would only be because of an arbitrary policy fashioned out of whole cloth to address some fear that the Commission's floodgates against a deluge of contested case hearings will be breached. There is no justification for such an imaginary fear.

**3. The Executive Director impliedly asserts that compliance with TCEQ's Subchapter B rules insulates a CAFO application from challenge for noncompliance with the federal Clean Water Act, EPA rules promulgated thereunder, and TMDLs approved by EPA. E.D. Response, pp. 4 – 5.**

In arguing that "many of the changes Waco wants in the permit go beyond TCEQ CAFO rules and challenge not this permit, but TCEQ rules," the Executive Director seems to be suggesting that it is enough for the permit drafted for O-Kee Dairy to require compliance with the best management practices ("BMPs") and other requirements specified on the face of Subchapter B, 30 T.A.C. §§ 321.31 – 321.47. Such a suggestion is not correct. As generally provided in Section 321.36(b), and as the TCEQ assured the City when responding to its comments on the proposed Subchapter B rules, the basic requirements of the Subchapter B rules were never intended alone to impose sufficient restrictions on the dairies in the North Bosque River watershed to comply with the TMDL for phosphorus in the River, assure attainment of the water quality standards for phosphorus and bacteria in the River, and comply with 40 C.F.R. §§ 122.4 and 122.44. Additional BMP requirements would have to be imposed on individual dairy CAFOs in the permitting process in order to ensure compliance with the TMDL and federal regulations and attain the state water quality standards. Unfortunately, the Executive Director seems to have forgotten this obligation in preparing the draft permit for O-Kee Dairy. Therefore, the Executive Director's suggestion that the City should seek a change in the Subchapter B rules or the Texas Water Code is misplaced. No change in the Subchapter B rules or the applicable state statutes is necessary in order for the Executive Director to comply with his obligation to prepare a permit that assures attainment of the TMDL for phosphorus in the River, the state water quality standards for phosphorus and bacteria, and comply with 40 C.F.R. §§ 122.4 and 122.44.

**4. The Executive Director suggests that the City has not challenged the permit for noncompliance with TCEQ's Subchapter B rules. E.D. Response, pp. 4 – 5.**

Besides contending that compliance with the basic BMP requirements specifically set out in the Subchapter B rules is not enough, the City also has pointed out many instances in which the draft permit does not satisfy the minimum requirements of the Subchapter B rules, for example:

A. (RTC 3E) The NMP for O-Kee Dairy allows application of phosphorus-laden waste far in excess of the agronomic needs of the crop. The Subchapter B rules require application in a beneficial manner which does not exceed the agronomic need or rate of the crop. 30 T.A.C. §§ 321.31(a), 321.32(6), 321.32(24), 321.40(b). The agronomic rate is defined as providing the crop with *needed* nutrients. 30 T.A.C. § 321.32(1). There is no way around the fact that the crops do not *need* more phosphorus when the soil exceeds 50 ppm phosphorus. Any application to soil with phosphorus levels above 50 ppm is in excess of the needs and is no longer beneficial use or application at agronomic rates.

B. (RTC 4) Draft permit provisions VII.A.8(e)(5)(i)(D) – (E) allow application of manure or sludge to third-party fields with soil test phosphorus (P) above 50 ppm. The Executive Director asserts only that the rules allow the use of third-party fields. However, the Subchapter B rules also require that application to third-party fields be beneficially applied and at an agronomic rate based on soil test phosphorus. 30 T.A.C. §§ 321.42(i), 321.42(j)(1). When soil test phosphorus exceeds 50 ppm, there is no need for additional phosphorus to obtain optimal growth of the crop. Therefore, the rule would be violated because no beneficial use exists for adding additional phosphorus.

C. (RTC 17) The Executive Director indicates that initial sludge volume accumulation/depth and annual monitoring of the sludge is not necessary because the Subchapter B rules prohibit sludge from exceeding the design capacity and that daily pond markers should assist in determining excessive sludge accumulation. The daily pond markers will do virtually nothing, since the water level is generally much higher than the maximum level of sludge accumulation. Section 321.39(c) of the Subchapter B rules requires that the sludge accumulation and depth be monitored *as necessary* to prevent the sludge from reaching the maximum level ahead of schedule. The term "as necessary" should mean that the sludge level must be measured initially, given the fact that the sludge levels in so many dairy CAFO RCSs in the watershed already exceed their design capacity. Additionally, since the TCEQ has not historically been able to determine compliance based solely on visual inspections, "as necessary" should mean that the sludge volume must be monitored on an annual basis by someone with the equipment and qualifications to do so.

These are but a few of many examples of contentions made by the City in its Request for Contested Case Hearing that the application and draft permit do not comply with the Subchapter B rules.

**5. The Executive Director asserts that the distance from O-Kee Dairy to Lake Waco and the City water supply intake is so great that "a discharge from this dairy is unlikely to impact the health and safety of persons who drink Waco's water or to impact the use of the waters of Lake Waco." E.D. Response, p. 5, ¶5.**

The Executive Director's unsubstantiated speculation that "[a]t 82 miles upstream of the point where the North Bosque enters Lake Waco, the distance is such that if there is a discharge from the facility, assimilation and dilution would occur long before the water reaches Lake Waco" flies in the face of all studies thus far of the impacts of CAFO loadings on the North Bosque River and Lake Waco (some of which are attached as Exhibits to the City's Request for Contested Case Hearing) and ignores completely the following conclusion by Mr. Wiland in his September 2007 Affidavit:

> The distance of O-Kee Dairy from Lake Waco does not eliminate these adverse effects because the primary mechanism for transport of these pollutants to Lake Waco is the very heavy rainstorms that occur in the North Bosque River watershed, and that wash the phosphorus and bacteria off the fields on which dairy waste and

> wastewater are applied, and that can transport these pollutants to Lake Waco in a matter of 3 to 5 days.

September 2007 Wiland Affidavit, Exhibit A, p. 3. The process by which stormwater runoff from CAFOs in the North Bosque River watershed transports phosphorus and other pollutants down river to Lake Waco before significant lessening of their detrimental properties is explained on page 12 of Dr. Wagner's report, as quoted by Mr. Wiland in paragraph 8 of his Supplementary Affidavit:

> It is important to note that the travel time in the NBR is short during many storms. Attenuation of loading by natural nutrient removal can be a potent force when a week or more of travel time is provided, but studies by TIAER and Baylor have indicated that loads from the upper NBR can arrive in Lake Waco in a matter of hours to several days after a storm. The largest loads and least natural attenuation are therefore associated with wet weather. The location of sources, most notably dairy farms, far up the NBR from Lake Waco is therefore not adequate protection for in-lake water quality.

Wiland Supplementary Affidavit, Exhibit F, p. 4, ¶8; Wagner Report, p. 12.

The Executive Director's further statement – "However, even if the discharge could somehow survive that 82 mile trip downstream, it would then mix with Lake Waco water and would have to survive further dilution to travel an additional 6.8 miles across Lake Waco to reach the point where Waco extracts drinking water from the lake" – only betrays his lack of understanding of the processes by which the dairy phosphorus loadings swept downstream to Lake Waco cause the growth of the cyanobacteria masses that produce the foul smelling and tasting geosmin that is drawn into the City water supply at its lake intake. To begin with, as explained and illustrated in the summary of the Lake Waco Comprehensive Management Program prepared by ENSR that is attached as Exhibit 7 to Mr. Wiland's September 2007 Affidavit, the "slosh" effect of heavy storm generated inflows to Lake Waco from the North Bosque River rapidly pushes water from the mouth of the North Bosque to the south arm of the

Lake and the location of the City's drinking water intake, before any appreciable assimilation of the phosphorus occurs (and also before any appreciable die-off of pathogenic bacteria occurs). Furthermore, as explained in that ENSR summary and on page 19 of the Wagner report that is attached to Mr. Wiland's Supplementary Affidavit, it is not the immediate presence of stormwater born nutrients from the dairies that causes the problem; it is the lowering of the Nitrogen:Phosphorus ("N:P") ratio throughout the Lake that occurs as summer progresses (but that depends on the heavy phosphorus loads from the North Bosque River earlier in the year) that causes the dominant growth of the cyanobacteria that produces the geosmin known to cause the City's taste and odor problems. Richard Garrett Affidavit, Exhibit E, ¶¶9 and 10.

**6. The Executive Director asserts that because "[t]he draft permit would only authorize a discharge from the RCSs in the event of a rainfall event that exceeds the 25-year, 10-day storm event for this area," this means that Lake Waco and the City will not be adversely affected by authorized discharges of wastewater from this CAFO. E.D. Response, p. 5, ¶3.**

In the first place, the Executive Director is incorrect in his assertion that discharges from O-Kee's RCSs are allowed only in the event of a rainfall event that exceeds the 25-year, 10-day storm event. The draft permit, in fact, authorizes discharges from O-Kee's RCSs whenever any series of rainfall events (not just a 10-day storm event) causes so much runoff from O-Kee's animal confinement area that its RCSs (if properly designed, constructed, operated, and maintained) cannot contain the runoff and other authorized wastewater. *See* Draft Permit §§ VII.A.2.(a), VII.A.5.(a)(4); 30 T.A.C. § 321.32(10). History shows that the Executive Director finds these "chronic" rainfall conditions to arise with considerable regularity and much more frequently than once every 25 years. Furthermore, as explained in response to point 5 above, it is these very heavy prolonged series of rainstorms that convey the phosphorus and pathogen-laden wastewater from the RCSs and waste application fields of the dairies down the North Bosque River to Lake Waco where the damage to the City is done.

**7. The Executive Director asserts that "runoff from LMUs and third party fields are considered non-point source runoff and exempt agricultural runoff, not regulated under the Clean Water Act as long as waste is land applied at agronomic rates and in compliance with TCEQ's CAFO rules." E.D. Response, p. 5, ¶3.**

Although this statement by the Executive Director may, on its face, be technically correct, it conveys a very misleading impression. This is because, under the draft permit, the waste applied by O-Kee Dairy to LMUs and third-party fields is *not* restricted to application at "agronomic rates." *See* definition of "agronomic rates" at 30 T.A.C. § 321.32(1); City of Waco's Public Comments at V.7, VI.4, VI.7; City of Waco's Request for Contested Case Hearing addressing Responses 15, 20, 22, and 25 of the Executive Director. Moreover, even if O-Kee's waste application were to be at "agronomic rates" and in compliance with Subchapter B, the draft permit issued to it could still violate the federal Clean Water Act by failing to comply with the TMDL for phosphorus in the North Bosque River approved by EPA and by failing to attain state water quality standards as required by Clean Water Act § 301(b)(1)(c) and 40 C.F.R. §§ 122.4 and 122.44.

**8. The Executive Director asserts that "[i]f Waco is affected in this case, any Texas city can challenge any permit upstream of their drinking water supply, without regard to distance, through the CCH process." E.D. Response, p. 5, ¶4.**

This alarmist statement by the Executive Director seems to be an attempt to provoke the Commissioners to overreact to the City's hearing request and deny it party status based on unfounded fears of a deluge of contested case hearing requests in the future. By finding that the City of Waco is an affected person in this case, the TCEQ would only be establishing precedent for another downstream city that demonstrates through credible evidence that its municipal water supply and/or a lake where it holds the rights to the impounded water would be adversely affected by discharges from an upstream source of pollution. The City suggests that such precedents *should* be clearly established by the Commission and that doing so will only affirm that those who demonstrate entitlement to contested case hearings can obtain them. If it is shown that the distance from the source of the pollution to a city's water intake does not eliminate the harm to the city's water supply, then there is no valid reason that a city whose water supply is so harmed should be denied a contested case hearing. If, on the other hand, no such injury can be shown, no hearing need be granted.

**9. The Executive Director asserts that "Waco's interest is common to members of the general public." E.D. Response, p. 5, ¶5.**

Such a statement by the Executive Director is nothing more than an attempt to apply a negative conclusory label, unsupported by the application of such a conclusion in any remotely similar reported case, and absolutely contrary to the facts of this case. Waco's status as the owner of all rights in Lake Waco and as wholly dependent on the Lake as a source of its water supply is in no way analogous to a "member of the general public" whose only concern is with "bad government" by the TCEQ in issuing this permit to a polluter.

In summary, the Executive Director is wrong on all of the assertions upon which his recommendation to find the City not to be an affected person is based. Most remarkably, his response reads as if he has not even read the City's request or the attached reports and affidavits from experts that demonstrate at length the adverse effects on the City of the permitted discharges from this expanding dairy. The Executive Director may believe that, as a matter of general policy, cities located downstream of dischargers to which they are not adjacent should not have party status to contest drafted permits, but – without any support in the law – such a policy position should not cause him to ignore a clear, unrebutted demonstration of adverse effects in an individual case.

## II. DISPUTED, RELEVANT, AND MATERIAL ISSUES OF FACT.

The City agrees with the Executive Director that the fact issues that he has numbered 1 – 9 in his Response to Hearing Request are disputed, relevant, and material issues of fact that were raised during the comment period and not withdrawn, and that they should be referred to SOAH for evidentiary hearing. This agreement with the Executive Director on these nine issues is based on the City's assumption that all of the subsidiary issues encompassed in the corresponding "factual bases of dispute" that the City identified in describing its disputes with the Executive Director's Responses to Comments numbered 1, 2, 3, 4, 9, 10, 12, 14, 28, 29, 6, and 15 will be encompassed by referral of these nine broad issues.

The City disagrees with the Executive Director's evaluations and recommendations regarding non-referral of other issues that the City specified in its Request for Contested Case Hearing. These additional disputed factual issues that should be referred to SOAH are listed below – numbered to begin with the number 10 (to pick up where the Executive Director leaves off) and also referring, in parenthesis, to the Executive Director's enumeration in his Response to Hearing Request and to the corresponding Response to Comment ("RTC") number.

10. **(ED #10; RTC #5) Has the Executive Director provided adequate technical justification that the measures required of O-Kee Dairy by the draft permit will, along with the requirements imposed on other permittees discharging into the North Bosque River, meet the water quality standards for phosphorus and attain the reductions in phosphorus loading set forth in the TMDL for the River?**

The Executive Director's response that this issue is "not relevant and material" is based on his legal arguments that the TMDL is but a "goal" and that "adaptive management" is all that the TMDL and its Implementation Plan require. The City maintains that, only after factfindings demonstrating how miserably the Executive Director is failing to comply with the TMDL and attain the water quality standards for phosphorus in the River, can the TCEQ meaningfully evaluate the Executive Director's contentions that the TMDL is but a goal and that his "adaptive management" approach is achieving that goal and the state water quality standards.

11. **(ED #13; RTC #13) Will solids from O-Kee Dairy's settling basin be applied to LMUs or third-party fields in the North Bosque River watershed and, if so, does not such application of these solids in the watershed have to be accounted for in the NMP?**

The Executive Director's position against referral of this fact issue to SOAH appears to be premised on his assumption that the solids will not be applied to O-Kee's LMUs, which is an assumption of a contested factual issue.

12. **(ED #15; RTC #17) Can O-Kee Dairy's compliance with the rule prohibition of allowing sludge accumulation to exceed the design volume in its existing RCSs be determined without an initial certification of existing sludge volume?**

Because O-Kee Dairy has been operating for many years without identifying the sludge levels in its RCSs, waiting three years after the permit is issued to measure sludge levels will not protect against non-compliance. Just saying, as the Executive Director does, that no rule expressly governs the frequency of measurement of sludge in lagoons does not foreclose a demonstration of need for such a permit requirement in this instance.

13. **(ED #16; RTC #18) Should the permit not require more frequent than single annual sampling of wastewater and manure because of the significant risk of underestimation of phosphorus concentrations in the wastewater and LMU soil that occurs with such limited sampling (and shouldn't the wastewater sampling be taken from the irrigation pipeline in order to be representative)?**

The fact that the current CAFO rules do not contain such requirements is no justification for refusal to obtain findings regarding the efficacy of such limited sampling as this permit requires. The rules are minimum requirements and do not preclude additional permit requirements if they are shown to be warranted.

14. **(ED #17; RTC #19) Can the phosphorus TMDL for the North Bosque River and the water quality standards for the River be attained by allowing 100% of the manure produced by a dairy CAFO to be applied within the watershed, as is allowed of the O-Kee Dairy?**

Again, the Executive Director would have referral of this fact issue denied based solely on his reading of the Texas Water Code and Subchapter B. However, his response ignores the legal principle that the federal Clean Water Act, EPA regulations implementing it, and the federally approved TMDL "trumps" state law under supremacy doctrine. Moreover, the Executive Director's response ignores the fact that Texas Water Code § 26.503(b)(2) and the implementing provision in Subchapter B merely provide the TCEQ with waste application *options* to pick from in the circumstances of individual CAFO permitting. When, as in this instance, a dairy's use of in-watershed waste application would conflict with the TMDL and water quality attainment, that option should be precluded.

15. **(ED #18; RTC #20) Does applying waste to fields with excesses of 200 ppm phosphorus ensure "beneficial use" as required by Subchapter B, when 200 ppm is over seven times the amount of phosphorus needed to achieve optimal growth of proposed crops, and does allowing this gross over application of phosphorus-laden waste conflict with the TMDL?**

Contrary to the Executive Director's response, the City does not concede that the TCEQ's CAFO rules allow this. Moreover, as the City has argued throughout this reply, the mere fact that the CAFO rules would allow such a practice by a CAFO in some locations in other instances does not mean that the Executive Director is free to be so lenient when it will conflict with the TMDL and interfere with attainment of the water quality standards for the River.

**Issues of Law.** Upon referral to SOAH of each of these 15 fact issues, the Commission should clarify that the SOAH Judge should also hear and decide, in his/her PFD, all related issues of law as described on pages 5 – 6 of the City's Request for a Contested Case Hearing and listed in the City's explanation of its "legal basis of dispute" with each of the Executive Director's enumerated Responses to Comments 1 – 10, 12 – 20, 22, and 24 – 30, in the City's Request.

## III. DURATION OF THE CONTESTED CASE HEARING.

Given the number and complexity of the issues that must be considered at the contested case hearing on this application, the City suggests that the maximum expected duration of the hearing should be specified as 10 months from the preliminary hearing to the date the proposal for decision is issued.

## IV. PRAYER.

For all of the reasons explained herein, the City of Waco prays that the Commission will determine that it is an "affected person," grant its request for a contested case hearing on each of the disputed issues of fact identified herein, and refer the case to SOAH for a hearing and proposal for decision on each of the identified fact issues, any other fact issues that arise in the course of the hearing, and on all applicable issues of law and policy.

Respectfully submitted,

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By ______________________
Jackson B. Battle

ATTORNEYS FOR THE CITY OF WACO

## CERTIFICATE OF SERVICE

I hereby certify that on this 18th day of January, 2008, true and correct copies of the foregoing Reply by the City of Waco to the Executive Director's Response to Hearing Request have been served on the following persons in the manner indicated:

FOR THE APPLICANT:
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Jackson B. Battle

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**SUPPLEMENTARY AFFIDAVIT OF BRUCE L. WILAND, P.E.**

STATE OF TEXAS §
§
COUNTY OF TRAVIS §

Before me, the undersigned notary public, on this day personally appeared Bruce L. Wiland, P.E., who being by me duly sworn upon his oath, did depose and say:

1. My name is Bruce L. Wiland. I am over the age of eighteen years, am competent to testify, and have personal knowledge of the facts set forth in this Affidavit.

2. I adopt, reiterate, and incorporate by reference all of the statements made in the prior Affidavit that I executed in September 2007 in support of the City of Waco's Request for Contested Case Hearing on the O-Kee Dairy draft permit. A true and correct copy of my prior affidavit is attached here as Exhibit 1.

3. I have reconsidered the statements that I made in that prior affidavit in light of my subsequent review of the *Opinions Regarding Nutrient Loading to Lake Waco and Resulting Impacts* by Kenneth J. Wagner, Ph.D., CLM, as part of the comprehensive study of the factors adversely affecting Lake Waco that has been performed by the ENSR Environmental Consulting and Engineering Group. A copy of that document, *Opinions Regarding Nutrient Loading to Lake Waco and Resulting Impacts* (the "Wagner Opinion") is attached here as Exhibit 2. I find that all of the statements that I made in paragraph 6 of my prior affidavit regarding the adverse effects on Lake Waco of dairy operations, like the O-Kee Dairy, in the watershed of the North Bosque River are supported by the Wagner Opinion.

4. Several of Dr. Wagner's statements merit repeating for emphasis:

> "Loads of phosphorus (P) and nitrogen (N) to Lake Waco from its watershed are excessive, resulting in the concentrations that are impairing the designated uses of that waterbody." (p. 5)
>
> "Among itemized source areas, the North Bosque River (NBR) contributes the most P and N to Lake Waco, at a long-term average of 72% of TP [total phosphorus] loading and 44% of TN [total nitrogen] loading." (p. 10)
>
> "Loading of P and N to Lake Waco is most strongly influenced by precipitation and runoff, with wet weather inputs routinely exceeding 90% of the TP load and 75% of the TN load." (p. 12)
>
> "Loading from dairy operations accounts for at least 30% of the TP load and 10% of the TN load to Lake Waco." (p. 13)
>
> "Wastewater inputs from permitted treatment facility discharges account for 6 – 10% of the TP and 3 – 4% of the TN load to Lake Waco before implementation of additional P removal." (p. 16)

> "Remaining sources of P and N are largely uncontrollable, making control of loading from dairy operations a necessary priority for loading reductions." (p. 18)
>
> "Loading from the NBR ("North Bosque River") in general, and most critically from dairy operations, results in a low N:P ratio in Lake Waco, favoring cyanobacterial growth that threatens water supply quality." (p. 19)
>
> "A P load reduction of 50% has been targeted through multiple studies and management planning, but lesser reductions could benefit water quality in Lake Waco. ... Therefore, while a P load reduction on the order of 50% is desirable, some benefit may result from lesser reductions, if P is reduced without any commensurate reduction in N load. It is not possible to achieve the desired conditions in Lake Waco without reducing inputs from dairy operations, but it may be possible to detectably improve conditions by addressing only dairy-related inputs. ... At about 30% of the total P load to Lake Waco, dairy inputs of P represent the single largest itemized source and one of the more controllable sources." (pp. 20 – 21)

5. Based upon my close scrutiny of dairy CAFO operations in the North Bosque River watershed over the course of the past seven years, I believe that the extent of the contribution of dairy CAFOs in the watershed to the pollution of the North Bosque River and Lake Waco, and the harm to the City of Waco's water supply, has not diminished since the time period, 1994 to 2002, that was analyzed by Dr. Wagner. Indeed, they have potentially increased. The number of "existing" cows in the North Bosque River watershed upon which the 2002 TMDL Implementation plan was based was 40,450. The number of actual cows currently in the North Bosque River watershed is 48,878 based on FY2007 TCEQ inspection reports. So, even if BMPs recommended by the 2002 TMDL Implementation Plan had been implemented (which they have not), the overall waste production upon which this TMDL was based has increased by 21%. Further, the requirements of the new Subchapter B CAFO rules have not yet been enforced and only marginally implemented. The new Subchapter B CAFO rules were adopted in 2004, and virtually all of the CAFO permits in the North Bosque River have been expired since 2004. After over three years, only four permits out of the 50 expired permits have been issued to include provisions from the new rules. The TCEQ has apparently chosen to enforce almost none of the new provisions in the new Subchapter B CAFO rules until new permits are issued. Of particular note is the allowance of the use of third-party fields which was prohibited under the old rules and is allowed under the new rules only when specifically authorized in a permit. TCEQ has allowed CAFOs to dispose of manure and wastewater on third-party fields without any permit authorization and without even the minimal reporting and application limitations required by the new rules for third-party fields. .

6. I was surprised that the Executive Director asserted in his Response to Hearing Request on the O-Kee Dairy permit that "None of the documentation submitted by Waco

identifies the Applicant by name as a source of nutrients." The Executive Director must not have read the following statements in Paragraph 8 in my September 2007 Affidavit:

> 8. Based on the knowledge that I have gained of the processes by which the runoff and discharges of pollutants from dairy CAFOs in the North Bosque River watershed are adversely impacting Lake Waco and my review of the O-Kee Dairy draft permit, "Fact Sheet," application, public comments, and the Executive Director's Response to Comments, I am of the following opinions:
>
> - If the problems with the draft permit and incorporated application for O-Kee Dairy that are identified in Waco's public comment letter are not addressed, corrected, and remedied to any greater extent than described in the Executive Director's Response to Comments, Lake Waco will be adversely affected by the issuance of the proposed permit to O'Kee Dairy and its authorized increase in herd size from 690 to 999 cows, in that the amounts of phosphorus and pathogens transported from O-Kee Dairy and its waste application fields (including third party fields) down the North Bosque River to Lake Waco will increase.
>
> - The increase in the amount of phosphorus transported to Lake Waco will likely cause increased algae blooms, resulting in higher levels of geosmin, and greater incidence of objectionable taste and odor problems in drinking water derived from Lake Waco.
>
> - Similarly, the failure of the draft permit and incorporated application by O-Kee Dairy to control bacteria loadings into the North Bosque River, as required by the federal Clean Water Act and EPA and TCEQ regulations, will increase the possibility of adverse health effects experienced by persons who engage in water recreation in Lake Waco and drink the water derived from it.
>
> - The distance of O-Kee Dairy from Lake Waco does not eliminate these adverse effects because the primary mechanism for transport of these pollutants to Lake Waco is the very heavy rainstorms that occur in the North Bosque River watershed, and that wash the phosphorus and bacteria off the fields on which dairy waste and wastewater are applied, and that can transport these pollutants to Lake Waco in a matter of 3 to 5 days.

7. I reiterate each of these points. Lake Waco and the City's drinking water are adversely affected by the cumulative effects of the wastewater discharges and contaminated

runoff from waste applications fields at all of the 50 currently permitted CAFO dairies and the additional unpermitted AFOs in the North Bosque River watershed. However, Lake Waco and the City's water supply also will be adversely affected by O-Kee Dairy's wastewater discharges and contaminated runoff from its waste application fields under the inadequate terms and conditions contained in the draft permit and the incorporated permit application filed by O-Kee Dairy. With no more effective waste management methods than are required by this permit and application, O-Kee's addition of 309 more confined dairy cows to its CAFO will increase the phosphorus loadings to Lake Waco that are causing the excess algae blooms and resulting taste and odor problems, and it will proportionately increase the risk of dairy associated pathogens adversely affecting Waco's citizens who utilize Lake Waco and drink municipal water.

8. The Executive Director appears to make much of the distance from O-Kee Dairy to Lake Waco (approximately 80 to 82 river miles) and to the City's Lake intake for drinking water (an additional 6 to 7 miles across the Lake) in his assertion that "assimilation and dilution would occur long before the water reaches Lake Waco." This assertion by the Executive Director is not supported by any scientific study that I have seen. To the contrary, as explained by Dr. Wagner on page 12 of the attached report:

> It is important to note that the travel time in the NBR is short during many storms. Attenuation of loading by natural nutrient removal can be a potent force when a week or more of travel time is provided, but studies by TIAER and Baylor have indicated that loads from the upper NBR can arrive in Lake Waco in a matter of hours to several days after a storm. The largest loads and least natural attenuation are therefore associated with wet weather. The location of sources, most notably dairy farms, far up the NBR from Lake Waco is therefore not adequate protection for in-lake water quality.

Therefore, based on Dr. Wagner's study, the phosphorus-laden runoff from the LMUs and third-party fields, to which this permit would allow O-Kee's wastewater and manure to be applied in excess of agronomic need, would reach Lake Waco and the City's water supply during recurring periods of heavy rainfall before significant attenuation occurs to the nutrient loadings contributed by O-Kee. This problem is compounded by the fact that the draft permit prepared for O-Kee Dairy allows O-Kee to apply its wastewater to saturated fields, from which it naturally runs off into the North Bosque River, during rain events that exceed the capacity of its RCSs.

9. The public comments submitted by the City of Waco, to the preparation of which I contributed, describe all of the many ways in which the permit prepared for O-Kee Dairy by the Executive Director adversely affects the water quality of the North Bosque River. Each of the enumerated permit and application deficiencies also adversely affects Lake Waco and, therefore, the City's water supply by causing heavy algae growth, especially blue-green algae, with resulting geosmin production, and by raising bacterial levels.

10. Under these circumstances, to say that Lake Waco and the City of Waco would not be adversely affected by the issuance of the drafted permit to O-Kee Dairy is simply misinformed and wrong.

Further, Affiant sayeth not.

Bruce L. Wiland, P.E.

SUBSCRIBED AND SWORN to before me by the said Bruce L. Wiland, P.E., on this the 16th day of January 2008, to certify which witness my hand and seal of office.

DOROTHY ROEBER
Notary Public, State of Texas
My Commission Expires
JAN. 25, 2009

Notary Public in and for the
State of Texas

4052043.1
30419.2

## AFFIDAVIT OF BRUCE L. WILAND, P.E.

STATE OF TEXAS §
§
COUNTY OF TRAVIS §

Before me, the undersigned notary public, on this day personally appeared Bruce L. Wiland, P.E., who being by me duly sworn upon his oath, did depose and say:

1. My name is Bruce L. Wiland. I am over the age of eighteen years, am competent to testify, and have personal knowledge of the facts set forth in this Affidavit.

2. I have been retained by the City of Waco as a consulting expert in the field of water quality analysis, including assessment of the impacts upon Lake Waco of waste and wastewater discharges and runoff from dairy concentrated animal feeding operations ("CAFOs") in the watershed of the North Bosque River. I believe that all of my education and experience that is detailed in my current resume that is attached hereto as Exhibit 1 qualifies me as an expert in this area.

3. Since 2001, I have served the City of Waco as its primary technical consultant in assessing the impacts of CAFOs on the water quality of Lake Waco, in attempting to persuade the Texas Commission on Environmental Quality ("TCEQ") and the CAFO owners and operators themselves to more effectively address the water quality problems caused by CAFOs, by participating in the process of preparing total maximum daily loads ("TMDLs") and Implementation Plans to control phosphorus loadings in the North Bosque River, by participation in stakeholder groups (such as the "White Paper" committees in 2003) addressing aspects of the problem, in reviewing many CAFO permit applications, and in participating in TCEQ and EPA rulemaking related to control of runoff and discharges from CAFOs.

4. During the course of this work for the City of Waco, I have reviewed many documents, prepared by experts in their fields, describing the adverse impacts on Lake Waco of discharges and runoff of waste and wastewater from fields in the North Bosque River watershed on which dairy manure, sludge, and wastewater has been applied. Copies of several of these reviewed documents are attached: A. McFarland & L. Hauck, *Existing Nutrient Sources and Contributions to the Bosque River Watershed* (TIAER, September 1999) [Exhibit 2]; A. McFarland, R. Kiesling, & C. Pearson, *Characterization of a Central Texas Reservoir with Emphasis on Factors Influencing Algal Growth* (TIAER, April 2001) [Exhibit 3]; White Paper, *Management of Dairy Waste Application Fields in the North Bosque Watershed* (Report of the "Waste Application Fields Subcommittee," September 2003) [Exhibit 4]; K. Huffman, *Water Quality Standards Violations Caused by Wet Weather CAFO Lagoon Overflows* (EPA Region 6 Memorandum, July 16, 2002) [Exhibit 5]; P. Johnsey, K. Huffman, & P. Kaspar, *Addendum to July 16, 2002, Water Quality Memo from Kenneth Huffman to Jack Ferguson – An Analysis of Discharge Frequency of CAFO Manure/Wastewater Pond Overflows Caused by Chronic Rainfall Events and Reasonable Potential Evaluation* (EPA Region 6, March 18, 2003) [Exhibit 6].

5. Most recently, I have reviewed a summary on the Lake Waco Comprehensive Management Program, prepared by ENSR, Inc., in February 2006 (a copy of which is attached hereto as Exhibit 7).

6. Based on my own professional experience, my review of the referenced studies and others performed by other experts, my review of the ENSR lake study summary report, I have the following opinions:

- The North Bosque River contributes approximately 64% of the total flow to Lake Waco.
- The North Bosque River contributes more than 72% of the total phosphorus loading to Lake Waco.
- Dairy operations in the watershed of the North Bosque River contribute at least 30 to 40% of the total phosphorus load to Lake Waco.
- Most of the phosphorus loading to Lake Waco from dairy CAFOs in the North Bosque River watershed occurs in periods of heavy rainstorms, when the travel time from the runoff from dairy waste application fields into the river and downstream to Lake Waco is short (typically less than 5 days).
- Such rainstorm events carry phosphorus and bacteria from reaches of the North Bosque River watershed as distant from Lake Waco as is the O-Kee Dairy.
- The primary cause of heavy algal biomass in Lake Waco is the phosphorus that is introduced into the Lake from runoff, particularly from dairy CAFO operations in the upper North Bosque River watershed.
- Source tracking studies indicate that dairy CAFO operations in the North Bosque River watershed are a source of Enterococcus and e-coli, which can possibly be accompanied by cryptosporidium, giardia, and other pathogens, entering Lake Waco.

7. I have reviewed the draft permit that the TCEQ Executive Director has prepared for O-Kee Dairy (TPDES Permit No. WQ0004108000), the Fact Sheet and Executive Director's Preliminary Decision accompanying the draft permit, and the entirety of O-Kee Dairy's application for a major amendment of its TPDES permit to authorize an expansion of its dairy facility. I participated in preparing the "Public Comment" that the City of Waco submitted on the O-Kee Dairy application and draft permit, and I reviewed and endorsed the final comment letter submitted by the City. Most recently, I have reviewed the Executive Director's Response to Public Comment on the Executive Director's preliminary decision and the revisions that the Executive Director has made to the draft permit for O-Kee Dairy.

8. Based on the knowledge that I have gained of the processes by which the runoff and discharges of pollutants from dairy CAFOs in the North Bosque River watershed are

adversely impacting Lake Waco and my review of the O-Kee Dairy draft permit, "Fact Sheet," application, public comments, and the Executive Director's Response to Comments, I am of the following opinions:

- If the problems with the draft permit and incorporated application for O-Kee Dairy that are identified in Waco's public comment letter are not addressed, corrected, and remedied to any greater extent than described in the Executive Director's Response to Comments, Lake Waco will be adversely affected by the issuance of the proposed permit to O'Kee Dairy and its authorized increase in herd size from 690 to 999 cows, in that the amounts of phosphorus and pathogens transported from O-Kee Dairy and its waste application fields (including third party fields) down the North Bosque River to Lake Waco will increase.

- The increase in the amount of phosphorus transported to Lake Waco will likely cause increased algae blooms, resulting in higher levels of geosmin, and greater incidence of objectionable taste and odor problems in drinking water derived from Lake Waco.

- Similarly, the failure of the draft permit and incorporated application by O-Kee Dairy to control bacteria loadings into the North Bosque River, as required by the federal Clean Water Act and EPA and TCEQ regulations, will increase the possibility of adverse health effects experienced by persons who engage in water recreation in Lake Waco and drink the water derived from it.

- The distance of O-Kee Dairy from Lake Waco does not eliminate these adverse effects because the primary mechanism for transport of these pollutants to Lake Waco is the very heavy rainstorms that occur in the North Bosque River watershed, and that wash the phosphorus and bacteria off the fields on which dairy waste and wastewater are applied, and that can transport these pollutants to Lake Waco in a matter of 3 to 5 days.

Further, Affiant sayeth not.

Bruce L. Wiland, P.E.

SUBSCRIBED AND SWORN to before me by the said Bruce L. Wiland, P.E., on this the ______ day of September 2007, to certify which witness my hand and seal of office.

DOROTHY ROEBER
Notary Public, State of Texas
My Commission Expires
JAN. 25, 2009

Notary Public in and for the
State of Texas

# Opinions Regarding Nutrient Loading to Lake Waco and Resultant Impacts

**Offered by Kenneth J. Wagner, Ph.D., CLM**
**ENSR, P.O. Box 506, Willington, CT 06279**
**860-429-5323 kwagner@ensr.com**

## Background

As of mid-2003, the surface area of Lake Waco (the reservoir) was approximately 7194 acres (29 $km^2$) with a volume of approximately 144,830 acre-feet (179 million $m^3$) (McFarland et al., 2001). The maximum water depth was 79 ft (24 m), and the mean depth was 20 ft (6 m); over 75% of the reservoir bottom occurred at a depth of 30 ft (9 m) or less (Abraham et al., 1999). After the pool elevation was raised approximately 7 ft (2 m) in fall of 2003, the new area was estimated at 8994 acres (36.3 $km^2$), 1800 acres more than before the rise, with a volume of approximately 165,600 acre-feet (204 million $m^3$), 20,770 acre-feet more than before the rise. The maximum water depth is now 86 ft (26 m), and the mean depth is now 23 ft (7 m). The reservoir outlet consists of a dam along the northeast edge of the reservoir that drains into the Bosque River. The Bosque River combines with the Brazos River shortly downstream of Lake Waco. This analysis, which applies mainly data from 1994—2002, treats the reservoir at its former configuration, as we have insufficient experience yet to make any claim of changed condition in Lake Waco since the rise in pool elevation.

The reservoir watershed (1,058,276 acres or 4267 $km^2$) is drained to the north arm of Lake Waco by the North Bosque River (NBR), and to the south arm by the Middle (MBR) and South (SBR) Bosque Rivers and Hog Creek (HC) (Abraham, 1999). Several smaller tributaries and a number of storm water systems drain directly into the reservoir. The NBR drains about 75% of the watershed, with the MBR draining just over 12%, the SBR and HC draining about 5% each, direct drainage accounting for slightly more than 2%, and the reservoir itself covering less than 1% of the total system area. The watershed is 147 times the area of the reservoir, a large watershed to lake area ratio.

Each of the tributaries and drainage systems carries a load of water and contaminants, including nutrients, sediment, possible pathogens and other substances both natural and human-derived. Direct precipitation on the reservoir adds water and nutrients, and waterfowl and recreational uses may also add measurable nutrients. Ground water inseepage and internal recycling (mainly release from bottom sediments) are also possible sources, although investigations of the latter indicate minimal contribution of dissolved substances from bottom sediment to overlying water in Lake Waco. This analysis focuses on measurement of loading to the reservoir over a decadal period leading up to the rise in pool elevation, providing the best available estimate of inputs from areas and defined sources. A detailed watershed and water quality model is being developed by researchers at Baylor and will be applied to possible management scenarios. This model relies on much of the same data, but will have predictive capability useful in evaluating management options. This analysis provides both a preliminary evaluation of loading and a comparison for model outputs.

### Available Data

Data have been collected from a number of sources, including monitoring efforts by the City of Waco, the Texas Institute of Applied Environmental Research, the Texas Commission on Environmental Quality (through its predecessor, the Texas Natural Resources Conservation Commission), the US Army Corps of Engineers, the US Geological Survey, the Brazos River Authority, and Baylor University. Almost half a million data points were entered and subjected to scrutiny under an EPA-approved QA/QC program. All data have been assimilated into a Microsoft Access Data Base available to interested parties for use in evaluating conditions throughout the watershed and lake. Almost all data collected under the recent (2002-present) City of Waco/Baylor University/ENSR study are excluded from this data base, but will be used for later comparison as part of the Lake Waco comprehensive management planning project.

### Assessed Time Period

This analysis addresses conditions from 1994 to 2002. The intent is to assess conditions over the most recent period that can supply an adequate quantity of data to ensure that aberrations due to sampling program variability will not unduly influence the resultant calculations. While land use is always changing to some extent, this period was viewed as representative of current conditions in the watershed. Additionally, the influence of wet weather on water resources is well known (Debo and Reese 1995), particularly in watersheds such as that of Lake Waco (TNRCC 2001). Precipitation drives the routing of water and pollutants to the reservoir, and is a major factor in loading. It is therefore critical to evaluate a period of time sufficient to capture enough of the wet weather variability to accurately appraise related loading. No one storm or period of dryness is likely to properly represent conditions in the watershed or lake; the chosen period is believed to capture sufficient variation to provide a representative picture of loading to Lake Waco.

### Assessed Water Quality Variables

Phosphorus (P) and nitrogen (N) are of primary interest to conditions in Lake Waco; phosphorus tends to control overall algal productivity, while nitrogen is a critical determinant of the types of algae present (Holdren et al. 2001). However, research still underway at Baylor (Davalos-Lind pers. comm.) indicates that nitrogen co-limits algal growth in Lake Waco at least some of the time. As neither P nor N appears to be released from sediment to a great extent in the reservoir (ENSR 2004), loading of both P and N from the watershed is critical to algal growth in the reservoir. As the load is the product of concentration and flow, the volume of water passing any point of interest per unit of time (i.e., the flow) is another critical variable in assessing loading to the reservoir. The amount and types of algae in the reservoir are largely a function of this loading, modified by light availability, trace nutrient levels, grazing by small aquatic animals, and competitive interactions among algae. Light is an important factor in Lake Waco and is affected by sediment loading and resuspension, based on current research by Baylor staff (Lind pers. comm.). Trace nutrient availability does not appear to be a major factor, based on lab assays (Davalos-Lind pers. comm.). Grazing also does not appear to be a strong influence in Lake Waco. There may be some allelopathic interactions among algae, particularly once certain blue-greens (cyanobacteria) have become dominant. Yet algal abundance remains high much of the year, and is controlled mainly by P and N inputs from the watershed over an extended period of time. Consequently, this analysis focuses on P, N and flow.

**Assessed Stations**

Over 200 stations have been sampled over the last decade as part of multiple monitoring and investigative sampling programs. Many were sampled for only a brief period of time, yielding potentially useful insights but not providing a strong enough data base to evaluate longer term conditions at corresponding stations. This analysis focuses on inputs to the reservoir and at key upstream stations for which an extensive data base is available. Few stations with less than 100 samplings are included, and most of those used in this analysis have more than 500 samplings. Many stations were sampled only during dry or wet weather, or not at a sufficient frequency of both general weather types to provide an accurate appraisal of loading. Stations used to characterize portions of the watershed in this analysis have an adequate data base for both wet and dry conditions, usually more than 50 samples from each weather type and often with more than 100 samples from each. Ultimately, 35 watershed stations were deemed to have sufficient data for drawing definitive conclusions about the contributory watershed. Additional stations were considered where data would otherwise be insufficient to calculate a load, yet where a load calculation was considered essential (e.g., direct drainage area).

**Opinions Based on Data Analysis:**

***Concentrations of phosphorus (P) and nitrogen (N) in Lake Waco are excessive, impairing the designated uses of that waterbody.***

The concentration of P in Lake Waco, based on data collected between 1994 and 2002, averages 0.087 to 0.130 mg/L at sampled stations (Appendix), with the highest concentrations near the inlets of the North Bosque River (NBR) in the north arm of the reservoir and combined South Bosque River (SBR) and Middle Bosque River (MBR) inlets in the south arm of the reservoir. The overall grand average for the reservoir is about 0.10 mg/L. The concentration of N in Lake Waco, established by the same approach as for P, averages 0.96 to 2.54 mg/L (Appendix), with the highest average value at the mouth of Hog Creek in the south arm of the reservoir. Other average values (away from Hog Creek) were no greater than 1.30 mg/L.

Although many factors can affect algal production, phosphorus is widely recognized as the most influential nutrient in freshwaters (Holdren et al. 2001, Kalff 2002), with elevated values fostering algal blooms and related water quality problems. Thresholds have long been recognized based on surveys of many lakes (McKee and Wolf 1963, NAS/NAE 1973, USEPA 1974, Wetzel 1975, OECD 1982), with most researchers in agreement that values <0.01 mg/L rarely sustain enough algae to impair uses, while values >0.10 mg/L almost invariably cause elevated productivity and related use impairment. Local and regional factors affect the progression from minimum to maximum impact, with most lakes showing signs of impairment at P levels >0.02 mg/L and only rare cases avoiding impairment with P levels >0.05 mg/L. More recent efforts to develop regional criteria have applied detailed statistical analyses of very large databases (ENSR 2000) and fine tuned thresholds for regional management purposes. While regional limits to P control have been recognized in these efforts, they have confirmed this range of P levels as relevant to eutrophication potential.

Elevated P concentrations are known to favor blue-green algae (cyanobacteria), which tend to become the dominant form of phytoplankton in lakes at phosphorus concentrations greater than about 0.05 mg/L (Watson et al. 1997). At phosphorus values above 0.10 mg/L cyanobacteria may represent nearly all of the phytoplankton biomass. As cyanobacteria are a major cause of use impairment in many lakes, these observations are consistent with the phosphorus-impairment relationship discussed above. At an in-lake average phosphorus level of 0.10 mg/L, Lake Waco can be expected to experience eutrophic conditons with use impairment from cyanobacteria.

Nitrogen has also been evaluated by many researchers over time, with a resulting transitional impact range of roughly 0.30 to 2.0 mg/L. The form of N is very important to its impact, and the ability of some cyanobacteria to fix dissolved nitrogen gas (Graham and Wilcox 2000) constrains the potential for N to limit overall algal production. However, the ratio of N to P remains very important in determining the types of algae that will be present. Given that many of the algae that are favored by low N:P ratios are also taste and odor and/or toxin producers (Rashash et al. 1996, Chorus and Bartram 1999, Carmichael 2001), there may be concern over low N as well as high N, depending upon P availability. Logically, the low N:P ratios of concern would be most prevalent when P levels are high, reinforcing the observation by Watson et al. (1997) that increasing P leads to increasing cyanobacterial dominance.

Regional nutrient criteria for Texas reservoirs are in development by the Texas Council on Environmental Quality (TCEQ) in cooperation with the USEPA. Work to date (TCEQ 2004) has focused on developing criteria based on Level III ecoregion categories, and should be completed in 2005. Phosphorus values under consideration for ecoregions that might include the Lake Waco watershed range from 0.026 to 0.060 mg/L. The criterion set for similar Oklahoma ecoregions is 0.037 mg/L (OKOSE 2004). Work on Lake Waco by TIAER (Kiesling et al. 2001) suggested target P concentrations from 0.015 to 0.050 mg/L as appropriate, and a Technical Work Group selected 0.030 mg/L as the most appropriate value. Nitrogen levels under consideration for appropriate Texas ecoregions range from 0.456 to 0.858 mg/L. It is apparent that the P and N concentrations in Lake Waco are excessive in comparison to these thresholds.

P and N can directly impair water uses, but only at very high levels not typically encountered in Lake Waco or most reservoirs. Impairment is usually indirect, through algal production and biomass accumulation, which is most often measured as chlorophyll-a, the green pigment essential to photosynthesis. Studies have suggested impairment of uses at chlorophyll-a levels as low as 4 ug/L (Welch 1989). Current work by Walker (2004) for Texas reservoirs indicates impairment of recreational uses occurs at chlorophyll-a levels of 10-20 ug/L. Impairment for water supply purposes is often observed at lower chlorophyll-a levels, simply as a function of filter clogging, and is exacerbated by pH fluctuations, disinfection byproduct precursors, taste and odor, and toxins at higher chlorophyll-a levels.

Lake Waco chlorophyll-a values exhibit a geometric average of about 13 ug/L near the intake and in the main body of the reservoir, indicating impairment of uses. The range is wide, however, with geometric means as high as 25 ug/L in the NBR inlet and north arm of the reservoir and individual values in excess of 100 ug/L. Additionally, the ratio of N to P in Lake Waco is low, promoting N-fixing blue-green algae (cyanobacteria) associated with taste and odor or even toxicity that can affect both recreation and drinking water supply (Rashash et al. 1996, Chorus and Bartram 1999, Carmichael 2001).

***Loads of phosphorus (P) and nitrogen (N) to Lake Waco from its watershed are excessive, resulting in the concentrations that are impairing the designated uses of that waterbody.***

Loads of P and N are considered excessive based on the resulting concentrations in Lake Waco and the effect of those concentrations on algal production, related water quality, and designated uses of the reservoir. The total loads of P and N to a waterbody determine its potential fertility, which relates to the amount of algae and related biological productivity that can occur. Water resource managers therefore take great interest in P and N levels in a lake and the sources that contribute to those levels. There are multiple ways to estimate nutrient loading, falling into three general classes:

1. Back-calculation from known in-lake levels and lake features, applying empirical models of nutrient processing based on studies of many lakes, resulting in an estimate of how much P or N would have to be delivered to the reservoir over time to create the observed conditions in the reservoir.
2. Calculation of loading based on land use, weather patterns, nutrient transport and attenuation en route to the reservoir, resulting in an estimate of the loads actually entering the reservoir. This approach is usually followed by an evaluation of how nutrients are processed in the reservoir to result in the observed concentrations of P and N.
3. Actual measurement of P and N concentrations in streams or other water delivery pathways near the reservoir, with summation over space and time to estimate actual loads. This approach depends upon intensive and extensive field surveys, and often involves some estimation of loading for areas that are difficult to sample and extrapolation for time periods not completely assessed. It must also take into account direct inputs from sediments already in the reservoir, birds and other wildlife, and atmospheric deposition in an itemized approach.

The first approach has been carried out by applying a series of empirical models (Kirchner and Dillon 1975, Vollenweider 1975, Reckhow 1977, Larsen and Mercier 1976, Jones and Bachmann 1976), the results of which indicate that Lake Waco behaves as though it receives an active average phosphorus load of 153,000 lbs per year, with a range for that annual average of 120,000 to 190,000 lbs (Table 1, and Appendix). The models overpredict chlorophyll-a, however, as they fail to consider the light limitation induced by so much suspended sediment in the reservoir. The models are also likely to underestimate the total phosphorus load, as a considerable amount of P may settle with sediment shortly after entering the reservoir. Nevertheless, the empirical models reflect how the reservoir responds to P loading.

The same empirical models can provide an estimate of the permissible load, which is the load below which the probability of algal blooms would be very low, and can also predict the critical load, the load above which algal blooms are expected to be frequent. For Lake Waco, the permissible load is calculated as 25,000 lb/yr and the critical load is estimated at 50,000 lb/yr. Because of the high

## Table 1. Nutrient Loads to Lake Waco Based on Empirical Models.

| Model | Estimated Load (lb/yr) |
|---|---|
| **Phosphorus** | |
| Mass Balance (no loss) | 97279 |
| Kirchner-Dillon 1975 | 150503 |
| Vollenweider 1975 | 120353 |
| Reckhow 1977 (General) | 190003 |
| Larsen-Mercier 1976 | 158863 |
| Jones-Bachmann 1976 | 145976 |
| | |
| Model Average (without mass balance) | 153139 |
| | |
| Permissible Load | 25037 |
| Critical Load | 50075 |
| | |
| **Nitrogen** | |
| Mass Balance (no loss) | 1021921 |
| Bachmann 1980 | 1492857 |

## Table 2. Export Coefficients for Land Uses (after Reckhow et al. 1980).

| | | PHOSPHORUS EXPORT (KG/HA/YR) | | | | NITROGEN EXPORT (KG/HA/YR) | | | |
|---|---|---|---|---|---|---|---|---|---|
| LAND USE | DESCRIPTION | MAXIMUM | MEAN | MEDIAN | MINIMUM | MAXIMUM | MEAN | MEDIAN | MINIMUM |
| Urban 1 (LDR) | Low density residential (>1 ac lots) | 6.23 | 1.91 | 1.10 | 0.19 | 38.47 | 9.97 | 5.50 | 1.48 |
| Urban 2 (MDR/Hwy) | Medium density residential (0.3-0.9 ac lots) + highway corridors | 6.23 | 1.91 | 1.10 | 0.19 | 38.47 | 9.97 | 5.50 | 1.48 |
| Urban 3 (HDR/Com) | High density residential (<0.3 ac lots) + commercial | 6.23 | 1.91 | 1.10 | 0.19 | 38.47 | 9.97 | 5.50 | 1.48 |
| Urban 4 (Ind) | Industrial | 6.23 | 1.91 | 1.10 | 0.19 | 38.47 | 9.97 | 5.50 | 1.48 |
| Urban 5 (P/I/R/C) | Park, Institutional, Recreational or Cemetery | 6.23 | 1.91 | 1.10 | 0.19 | 38.47 | 9.97 | 5.50 | 1.48 |
| Agric 1 (Cvr Crop) | Agricultural with cover crops (minimal bare soil) | 2.90 | 1.08 | 0.80 | 0.10 | 7.82 | 5.19 | 6.08 | 0.97 |
| Agric 2 (Row Crop) | Agricultural with row crops (some bare soil) | 18.60 | 4.46 | 2.20 | 0.26 | 79.60 | 16.09 | 9.00 | 2.10 |
| Agric 3 (Grazing) | Agricultural pasture with livestock | 4.90 | 1.50 | 0.80 | 0.14 | 30.85 | 8.65 | 5.19 | 1.48 |
| Agric 4 (Feedlot) | Concentrated livestock holding area, manure disposal | 795.20 | 300.70 | 224.00 | 21.28 | 7979.90 | 3110.70 | 2923.20 | 680.50 |
| Forest 1 (Upland) | Land with tree canopy over upland soils and vegetation | 0.83 | 0.24 | 0.20 | 0.02 | 6.26 | 2.86 | 2.46 | 1.38 |
| Forest 2 (Wetland) | Land with tree canopy over wetland soils and vegetation | 0.83 | 0.24 | 0.20 | 0.02 | 6.26 | 2.86 | 2.46 | 1.38 |
| Open 1 (Wetland/Lake) | Open wetland or lake area (no substantial canopy) | 0.83 | 0.24 | 0.20 | 0.02 | 6.26 | 2.86 | 2.46 | 1.38 |
| Open 2 (Meadow) | Open meadow area (no clearly wetland, but no canopy) | 0.83 | 0.24 | 0.20 | 0.02 | 6.26 | 2.86 | 2.46 | 1.38 |
| Open 3 (Barren) | Mining or construction areas, largely bare soils | 4.90 | 1.50 | 0.80 | 0.14 | 30.85 | 8.65 | 5.19 | 1.48 |

turbidity in Lake Waco, higher loads might actually be tolerated, if sediment loading was not reduced by the same methods used to reduce P loading.

For nitrogen, only Bachmann (1980) provides an empirical model for back-calculating N load from in-lake concentrations and hydraulic features. For Lake Waco, that model suggests that the reservoir behaves as though it receives an active N load of 1,500,000 lb/yr. As with P, this may be an underestimate of actual loading. This suggests an average N:P ratio of slightly less than 10:1, which is likely to favor N-fixing cyanobacteria at least part of the year.

The second load estimation approach is being carried out with a two stage process, one that links a watershed load generation model with an in-stream and in-lake processing model. Applying a land use based model employing the Soil and Water Assessment Tool (SWAT) to evaluate loading from watershed sources and addressing in-stream and in-lake processes with a two-dimensional model (CE-QUAL-W2), researchers at Baylor University are advancing the modeling effort conducted by the Texas Institute of Applied Environmental Research (TIAER) in the late 1990s. Actual data are used to calibrate and verify the model for the Lake Waco system. This model is not yet complete, but will provide a platform for both understanding current loading and predicting the results of potential management actions.

In the absence of the complete model, all that can be compared are export coefficient values for various land uses (Table 2). Export coefficients refer to the yield of water or any contaminant from a standardized area of a given land use. For example, residential land typically produces phosphorus at a rate of 0.2 to 6.2 kg/ha/yr (0.18 to 5.5 lb/ac/yr) with a mean value of 1.9 kg/ha/yr (1.7 lb/ac/yr) and a median value of 1.1 kg/ha/yr (1.0 lb/ac/yr) (Reckhow et al. 1980). Largely natural land will typically generate a phosphorus load between 0.1 and 0.3 kg/ha/yr (0.09-0.26 lb/ac/yr). Livestock feeding areas and manure disposal, which would include the waste application fields associated with dairy operations, have an output range of 21 to 795 kg/ha/yr (18 to 700 lb/ac/yr) with a mean over 300 kg/ha/yr (265 lb/ac/yr). The pattern among land uses is similar for N export coefficients, with feedlot and manure disposal exhibiting the highest values (mean of over 3100 kg/ha/yr, or 2700 lb/ac/yr). Clearly, feedlots and manure disposal represent a major potential source where such operations exist.

Loading models are very helpful in getting a reasonable impression of load generation and delivery, and when calibrated and verified with reliable site specific data, can provide a predictive tool for evaluating expected changes in response to possible management actions or other watershed events. Where enough data are collected, however, direct estimation of inputs based on those data is also possible. It is rare to get enough data to make truly reliable calculations based on actual data, and weather induced variability can be substantial, necessitating a very large collection effort for a system such as the Lake Waco watershed. Yet a very large body of data has been assembled by ENSR from a variety of sources working in the Lake Waco watershed over a roughly decadal period, and these data can be used to provide direct estimates of loading.

The relative areas contributing to each itemized source and the associated estimate of flow are provided in Table 3. Land areas are based on GIS data provided by Baylor University researchers constructing the coupled watershed-lake model, and flows are from USGS gage stations, precipitation

Table 3. Best Estimates of Basin Areas and Water Loads to Lake Waco from Itemized Sources.

| Source | Total Basin Area (Ha) | Total Basin Area (Ac) | % of Total Area | Flow (cfs) | % of Total Flow |
|---|---|---|---|---|---|
| NBR | 319149 | 791490 | 74.8 | 327.2 | 64.4 |
| MBR | 51613 | 128000 | 12.1 | 73.4 | 14.4 |
| SBR | 22570 | 55974 | 5.3 | 33.2 | 6.5 |
| HC | 21151 | 52454 | 5.0 | 31.8 | 6.2 |
| Direct Drainage | 9341 | 23166 | 2.2 | 15.1 | 3.0 |
| Atmosphere | 2900 | 7192 | 0.7 | 26.6 | 5.2 |
| Groundwater | 580 | 1438 | 0.1 | 1.2 | 0.2 |
| Recreation | 2900 | 7192 | 0.7 | 0.0 | 0.0 |
| Waterfowl | 2900 | 7192 | 0.7 | 0.0 | 0.0 |
| Internal | 2900 | 7192 | 0.7 | 0.0 | 0.0 |
| | | | | | |
| Total | 426724 | 1058276 | 100 | 508 | 100 |

Table 4. Best Estimates of Nutrient Loads to Lake Waco from Itemized Sources.

| Source | TP Load (lbs/yr) | % of Total P Load | TN Load (lbs/yr) | % of Total N Load | TN:TP Load Ratio |
|---|---|---|---|---|---|
| NBR | 206239 | 71.9 | 1123531 | 43.5 | 5.4 |
| MBR | 34579 | 12.0 | 809208 | 31.3 | 23.4 |
| SBR | 25367 | 8.8 | 293343 | 11.4 | 11.6 |
| HC | 8664 | 3.0 | 130386 | 5.0 | 15.0 |
| Direct Drainage | 6183 | 2.2 | 68978 | 2.7 | 11.2 |
| Atmosphere | 2616 | 0.9 | 26158 | 1.0 | 10.0 |
| Groundwater | 699 | 0.2 | 13972 | 0.5 | 20.0 |
| Recreation | 330 | 0.1 | 1014 | 0.0 | 3.1 |
| Waterfowl | 440 | 0.2 | 2090 | 0.1 | 4.8 |
| Internal | 1914 | 0.7 | 113912 | 4.4 | 59.5 |
| | | | | | |
| Total | 287030 | 100 | 2582592 | 100 | 9.0 |

records, and actual field measurements during the various sampling programs from which the data base was constructed. Using the data summarized in the Appendix, the loads from each major source to Lake Waco have been estimated in Table 4. Results appear very similar to estimates derived by TIAER (McFarland and Hauck 1999), in terms of percentages assigned to itemized sources. More data were used in this analysis, but both efforts had large data bases with which to work. Additionally, this analysis works with total P, whereas the TIAER effort focused on soluble P, or orthophosphorus. Actual active phosphorus load (i.e., the load to which algae and water quality respond), appears to be intermediate to the soluble and total loads, based on application of the empirical models described above.

In this analysis, event based loads were emphasized. That is, loads were based on the sum of loads from assessed events whenever possible, not on an average concentration multiplied by an average flow, which can induce considerable error when flow and concentration are linked (as they are in this precipitation/runoff driven system). With almost 10 years of data and multiple samplings for selected stations in each year, including wet and dry weather, these values are expected to be fairly reliable as long-term averages. However, considerable variation can be imparted by weather patterns, with dry years providing much smaller loads than wet years. It would not be surprising to see total load swings of $\pm$ 20% in response to annual variation in precipitation. However, the loads from all tributaries and atmospheric inputs would all be affected in much the same way, minimizing any changes in relative importance of itemized sources in response to weather pattern. Loads from other sources (e.g., wildlife, recreation, internal load) are relatively small and assume minimally greater importance during drier years.

The use of a mean daily load, based on the average of event based loads adjusted to match weather pattern (90% dry weather, 10% wet weather), was chosen as the most representative method for deriving an actual load for a given tributary station. Comparative calculations using median loads, mean concentration times mean flow, or median concentration times median flow changed the actual load estimates substantially, but had limited effect on the percentage of total load assigned to each source. The relative order of input quantities remains unchanged with changes in calculation method.

Stations for which terminal input loads were calculated were close to the reservoir, but did not include inputs from some small portion of each associated watershed (5.2% for NBR, 7.6% for MBR, 4.3% for SBR and 13% for HC). Extrapolating loads for these areas was not considered necessary, as possible shifts in loading would not have changed the relative contribution from any tributary substantially.

The resulting long-term, annual average, total P load to Lake Waco is estimated at just over 287,000 lb. With a water load averaging 508 cubic feet per second (cfs), this suggests an average input P concentration of 0.285 mg/L. Measured concentrations in the arms of the reservoir average slightly less than half this value, suggesting that much of the P is particulate and settles out rapidly. Yet in-lake sampling during storm events is uncommon, so measured levels may underestimate actual average concentrations. Actual P data for tributary stations close to the reservoir do indicate that the vast majority of P is particulate. Although resuspension in Lake Waco is substantial, it does appear that a lot of the load to the reservoir is never "active" in the production of planktonic algae. Even with half the load removed by initial settling, the total P load is almost three times the calculated critical load for Lake Waco.

The resulting long-term, annual average, total N load to Lake Waco is estimated at just under 2.6 million lb/yr. With the estimated average flow, this results in an input concentration of 2.56 mg/L. The average N level in the reservoir near the inlet of Hog Creek is similar to this value, but all other in-lake stations have average N concentrations not more than about half this level. As with P, much N enters in a particulate form, settles rapidly, and is apparently not active in algae production. Nevertheless, the total load is quite high, even halving the estimated input load. While the N load is nine times higher than the P load, the ratio of N to P by load is in the transition zone for N vs. P limitation of algal growth. Given variability over time and possibly space within the reservoir, N can be expected to limit algal production in some cases, and this situation is likely to favor N-fixing cyanobacteria, many of which are associated with taste, odor and toxins. Work by Doyle (pers. comm.) and colleagues at Baylor University indicates that N fixation by cyanobacteria increases over the summer as watershed inputs decline and available N in the reservoir is depleted.

***Among itemized source areas, the North Bosque River (NBR) contributes the most P and N to Lake Waco, at a long-term average of 72% of TP loading and 44% of TN loading.***

Based on the analysis summarized in Tables 3 and 4, NBR has the largest contributing area and is clearly the largest contributor of water and nutrients. The contribution of N is relatively lower than P, however, and is the primary factor in the low to moderate N:P ratios observed in the reservoir. N:P ratios in the NBR average 5.4, while values in other tributaries are all >10.

While the model being developed by Baylor University researchers will address the routing and attenuation of water and nutrients from each sub-watershed, it is apparent that loads must travel further in the NBR to reach Lake Waco and will be subject to greater attenuation by natural processes (Figure 1). It is therefore not surprising that the water and nutrient yield from the NBR sub-watershed, on a per acre basis, is lower than those for the MBR, SBR and HC sub-watersheds. That is, loads of water and nutrients are attenuated more in the NBR than in the other major tributaries; while the NBR is the biggest contributor, the actual load per unit of watershed area is smaller than for some other sub-watersheds.

For purposes of nutrient management, reduction in the loads of P and N from the NBR will be necessary if total loading is to be decreased. In the case of the NBR, it is especially important to control P, as the NBR P load is more than five times greater than the next largest contribution, that being from the MBR at 12% of the total P load to Lake Waco. The combined N load from the MBR and SBR is comparable to that of the NBR. While the NBR is still the largest N source, it is not as dominant a source of N as it is of P.

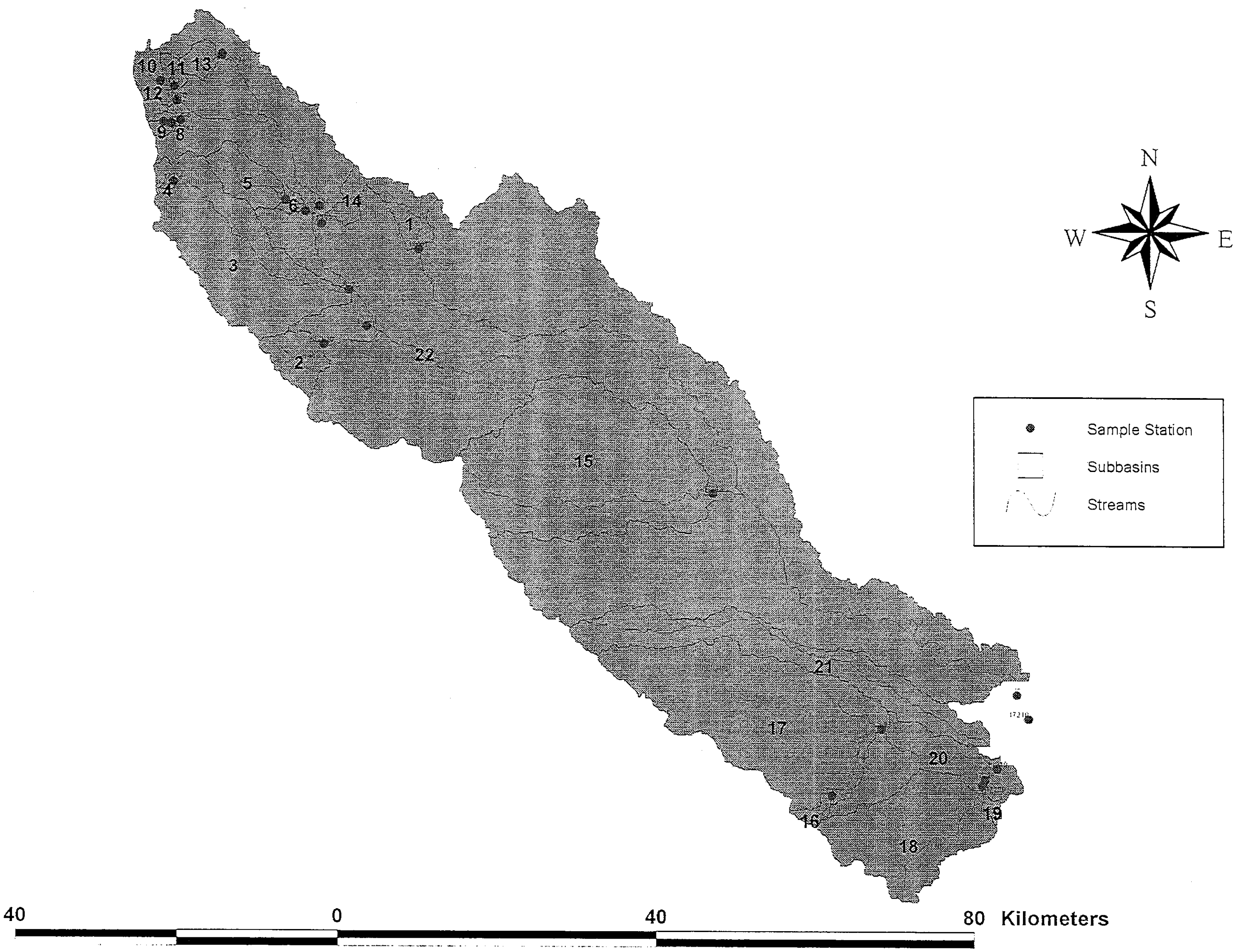


Figure 1. Lake Waco Watershed, Showing Sub-Watersheds Applied in Analysis.

***Loading of P and N to Lake Waco is most strongly influenced by precipitation and runoff, with wet weather inputs routinely exceeding 90% of the TP load and 75% of the TN load.***

Flows increase dramatically during wet weather, usually increasing by at least fivefold as an event average (wet period vs. dry period). Because most P sources in the Lake Waco watershed are non-point sources that have limited mobility in the absence of runoff, dry weather concentrations of phosphorus are much lower than wet weather concentrations. N is more mobile than P, and dry weather concentrations are not much different than wet weather levels, but the influence of elevated wet weather flow still makes the wet weather contribution of N much larger than the dry weather input. Although calculations in this analysis of loading are largely based on event loads (flow times concentration for each event, summed or averaged for all events), the disparity between dry and wet weather conditions is evident when viewing mean flows and concentrations for tributary stations slightly upstream of Lake Waco (Table 5).

Discharge quantity and quality for wastewater treatment facilities (WWTF) in the Lake Waco watershed do not vary widely with weather conditions, at least not relative to sub-watersheds with mainly non-point source inputs (Appendix). Infiltration from storm water into wastewater collection systems can occur in some systems, raising flow and limiting treatment effectiveness during storms, but WWTF inputs represent a relatively constant source in this watershed. Except just downstream of Stephenville, where the WWTF serving that municipality exerts a measurable influence on the NBR, point sources do not have a detectable effect on the relationship of flow and concentration in this watershed. Phosphorus levels increase markedly with precipitation and increased flow, yielding much higher loads during wet weather. Nitrogen levels change only nominally with precipitation, but the load increases with the increase in flow. Management to reduce nutrient loading to Lake Waco will have to address wet weather loading if a significant change in conditions is to be achieved.

It is important to note that the travel time in the NBR is short during many storms. Attenuation of loading by natural nutrient removal can be a potent force when a week or more of travel time is provided, but studies by TIAER and Baylor have indicated that loads from the upper NBR can arrive in Lake Waco in a matter of hours to several days after a storm. The largest loads and least natural attenuation are therefore associated with wet weather. The location of sources, most notably dairy farms, far up the NBR from Lake Waco is therefore not adequate protection for in-lake water quality. Water quality improvement measures should therefore focus on preventing nutrient loads from entering the NBR or its tributaries during wet weather. WWTF loads are not controllable in this regard, having relatively constant discharges, but wet weather controls are particularly applicable to dairy-related inputs.

**Table 5. Mean Dry and Wet Weather Flows and Nutrient Concentrations at Selected Stations.**

| | | Flow | | | TP | | TN | |
|---|---|---|---|---|---|---|---|---|
| Description | Station | Dry Mean (CFS) | Wet Mean (CFS) | USGS Mean (CFS) | Dry Mean (mg/L) | Wet Mean (mg/L) | Dry Mean (mg/L) | Wet Mean (mg/L) |
| North Bosque River downstream of Neils Ck confluence (aka BO100) | 17605 | 228.4 | 1218.1 | 285.6 | 0.104 | 0.310 | 1.14 | 1.99 |
| South Bosque River upstream of Church Road | 17229 | 7.3 | 249.4 | 64.1 | 0.086 | 0.365 | 5.85 | 6.67 |
| Middle Bosque River at FM 3047 | 17612 | 93.0 | 322.5 | 71.0 | 0.120 | 0.287 | 3.57 | 3.52 |
| Hog Creek at FM 185 | 17212 | 28.3 | 136.8 | 32.8 | 0.084 | 0.183 | 1.38 | 1.86 |

***Loading from dairy operations accounts for at least 30% of the TP load and 10% of the TN load to Lake Waco.***

Measurement of specific dairy operation inputs is complicated by the physical location of operations and management practices that include on-site lagoons, various manure storage options, and off-site waste application fields. Some sub-watersheds have many more dairy farms than others (Figure 2), and a few sub-watersheds have no dairy farms, thereby providing a reference condition. Using the data summarized in the Appendix, the background contribution for watersheds without dairy farms, waste application fields (WAF) and wastewater treatment facility (WWTF) discharges was determined. The typical annual export of P is 0.13 lb/ac/yr, while for N it is 1.02 lb/ac/yr, based largely on inputs from the Neils Creek and Meridian Creek sub-watersheds. These values are consistent with expectations from the literature (Reckhow et al. 1980, Clark et al. 2000). Subtracting this background load from total loads for sub-watersheds with dairy farms and/or WAFs but no WWTFs provides an indication of dairy operation inputs (Table 6).

Corrected export coefficients (with background and WWTF contributions removed) for P from sub-watersheds of the NBR that include dairy operations range from 0.12 to 11.1 lb/ac/yr. Comparable export coefficients for N range from 0.7 to 30.4 lb/ac/yr. The wide range of export coefficients attributed to dairy operations reflects several factors, including the area of the sub-watershed devoted to dairy operations, the proximity of those operations to watercourses, attenuation as the load moves downstream, and possible current management practices. The lowest corrected export coefficients come from Spring Creek, which has few dairy operations and none close to the stream, while the highest values are associated with the Scarborough Creek system and Goose Creek, having notably high concentrations of farms in small drainage areas (which places the sampling point closer to the actual sources) (Figure 2).

At the two downstream mainstem NBR stations for which non-dairy loads were subtracted, estimates of slightly more than 80,000 (Iredell) and 97,000 (Valley Mills) lb/yr are derived as the dairy-related P load component. The dairy-related load represents 65% and 52% of the total P load at those points, respectively. There may be some minor urban inputs not being subtracted from the load at these

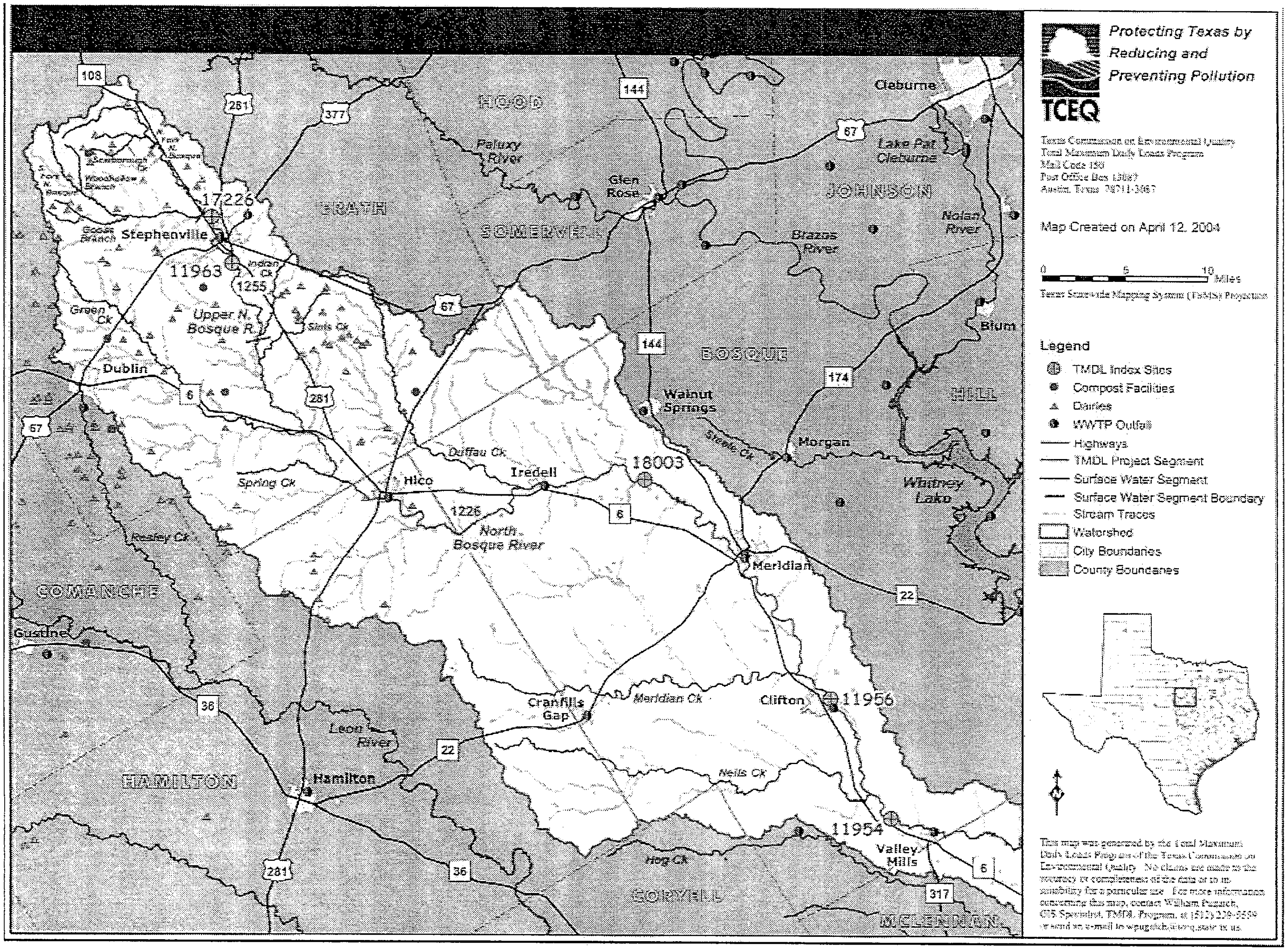


Figure 2. Location of Dairy Operations in the Lake Waco Watershed (after TCEQ 2005).

**Table 6. Nutrient Export Coefficients for Land in Sub-Watersheds Including Dairy Operations.**

| Sampling Site | Station # | Drainage Area (ac) | P Export Coefficient (lb/ac/yr) | P Export - Bkgrd (0.13 lb/ac/yr) | P Load Adjusted for Bkgrd and WWTF (lbs/yr) | N Export Coefficient (lb/ac/yr) | N Export - Bkgrd (1.02 lb/ac/yr) | N Load Adjusted for Bkgrd and WWTF (lbs/yr) |
|---|---|---|---|---|---|---|---|---|
| **North Bosque River** | **NBR** | | | | | | | |
| Scarborough Creek at CR 428 | 17221 | 2133 | 4.11 | 3.97 | 8472 | 10.27 | 9.25 | 19727 |
| Scarborough Creek at CR 423 | 17222 | 1314 | 11.20 | 11.07 | 14549 | 31.45 | 30.43 | 40001 |
| Unnamed Tributary of Scarborough Creek at CR423 | 17223 | 1168 | 4.47 | 4.34 | 5066 | 18.14 | 17.12 | 20002 |
| North Fork North Bosque River @ SH 108 | 17413 | 19418 | 0.65 | 0.52 | 10041 | 2.32 | 1.30 | 25335 |
| South Fork North Bosque River 1km upstream FM 219 | 17218 | 2026 | 0.42 | 0.29 | 587 | 2.91 | 1.89 | 3835 |
| Goose Branch downstream of FM8 | 17215 | 1503 | 2.91 | 2.78 | 4172 | 17.07 | 16.05 | 24119 |
| South Fork North Bosque River 2 KM Upstream of SH 108 in Stephenville | 14382 | 30752 | 0.61 | 0.47 | 14489 | 2.39 | 1.37 | 42268 |
| North Bosque River at Stephenville (FM 8), upstream of WWTF discharge | 17226 | 56296 | 0.56 | 0.42 | 23745 | 2.11 | 1.09 | 61363 |
| North Bosque River at Erath CR 454, 0.6 KM West of US 281 and 3.3 KM downstream of US 377/67 in Stephenville, downstream of WWTF discharge | 11963 | 73408 | 0.63 | 0.49 | 24071 | 2.51 | 1.49 | 77448 |
| Indian Creek near US 281 | 17235 | 1706 | 1.14 | 1.01 | 1717 | 3.37 | 2.35 | 4015 |
| Alarm Creek 2.7km east FM914 | 17237 | 13442 | 0.59 | 0.46 | 6171 | 1.75 | 0.73 | 9782 |
| Sims Creek Upstream of US 281 | 17240 | 4241 | 0.76 | 0.62 | 2634 | 4.08 | 3.06 | 12992 |
| Green Creek at unnamed road 1.8 KM upstream of the confluence with the North Bosque River | 13486 | 63984 | 0.33 | 0.20 | 12552 | 2.41 | 1.39 | 88927 |
| Spring Creek at CR271 | 17242 | 3348 | 0.25 | 0.12 | 403 | 1.69 | 0.67 | 2253 |
| North Bosque River at US 281 near Hico, upstream of Duffau Ck confluence | 11961 | 232872 | 0.46 | 0.33 | 63980 | 1.95 | 0.93 | 183773 |
| Duffau Creek at FM 927 West of Iredell | 11810 | 55552 | 0.35 | 0.22 | 12203 | 2.22 | 1.20 | 66595 |
| North Bosque River at FM 216 in Iredell, upst of Iredell WWTF | 11960 | 347696 | 0.37 | 0.24 | 80143 | 1.71 | 0.69 | 232765 |
| North Bosque River downstream of Neils Ck confluence (aka bo100) | 17605 | 750324 | 0.27 | 0.14 | 97111 | 1.49 | 0.47 | 317976 |

points, and there will be some additional attenuation of dairy loads between these points and the reservoir, but there will also be some downstream dairy-related additions not assessed in this analysis. Comparing the P loads attributed to dairy inputs in the NBR at Iredell and Valley Mills to the total P load to Lake Waco from the NBR, dairy operations are estimated to account for 39% to 47% of the NBR P load. Comparing the estimated dairy load to the total P load to the reservoir, dairy operations account for 28 to 34% of the total.

The same analysis for N reveals dairy-related loads at Iredell and Valley Mills of almost 233,000 and 318,000 lb/yr, respectively, representing 21% to 28% of the NBR N load to Lake Waco and 9% to 12% of the total N load to the reservoir. The relative contribution of N from dairy operations to the NBR and to Lake Waco is much smaller than that for P, resulting in low N:P ratios and favoring N-fixing cyanobacteria. Load ratios of N to P for the MBR, SBR and HC are much higher, consistent with expected ratios for lands dominated by crops (Uttormark et al. 1974).

The soluble portion of the P load from sub-watersheds dominated by dairy operations ranges from 0.44 to 0.75, with an average of 0.56 (56% of total P is soluble P). This is consistent with literature values for runoff and leachate from dairy operations (Sharpley et al. 1984), higher than any other known source in this watershed except for WWTF inputs. Additionally, much of the particulate P will be in a degradable organic form which may form soluble P as the load moves downstream. Background loads will be largely inorganic P bound to soil particles and considerably less available for algal uptake.

As a check on this whole approach to estimating loads from dairy operations, the general production of P and N by dairy cattle can be calculated for the existing herds. According to several older estimates of loading per cow (Uttormark et al. 1974, Omernik 1976), dairy cows can be expected to produce 20 to 25 kg P/1000 lb animal/yr. Dairy cows have gotten larger in the 30 years since this research was done, and feed mixes may elevate the P output, but this assessment assumes an output of 25 kg (55 lb) per animal per year. The CAFO permits for this watershed indicate a total of 68,334 dairy cows, but some herds may be slightly smaller than the permit allows. Assuming 60,000 cows at the 55 lb/yr P export rate, a total of almost 3.5 million pounds of P are generated in the Lake Waco watershed. This is more than 12 times the estimated total P load to the reservoir. Some of the manure is removed from the watershed, and the actual load to the NBR will undergo some attenuation, but an estimate of about 100,000 lb/yr of P entering the reservoir from dairy sources is quite possible and very probable.

The same analysis for N from dairy cows (84 lb/animal/yr) indicates that over 5 million pounds are generated in the watershed, a ratio of <2:1 for N:P, but N is more mobile than P and slightly higher ratios in runoff would be expected. Certainly the high N levels in dry weather samples from the NBR drainage area are consistent with a high N burden in groundwater induced by dairy-related loading.

***Wastewater inputs from permitted treatment facility discharges accounted for 6-10% of the TP load and 3-4% of the TN load to Lake Waco before implementation of additional P removal.***

Records for the WWTFs in the Lake Waco watershed are sufficient to make reliable estimates of total nutrient loads from those WWTFs (Table 7). Given limited variability over time and no expected correlation between flow and concentration, calculations were based on mean or median flows

## Table 7. Wastewater Inputs to the Lake Waco System.

| WWTF | Station | NPDES # | Design Flow (mgd) | Avg Flow (mgd) | Max Flow (mgd) | Mean TP Conc. (mg/L) | Median TP Conc. (mg/L) | Min. TP Conc. (mg/L) | Max. TP Conc. (mg/L) | TP Load (by means) (kg/yr) | TP Load (by median) (kg/yr) | Mean TN Conc. (mg/L) | Median TN Conc. (mg/L) | Min. TN Conc. (mg/L) | Max. TN Conc. (mg/L) | TN Load (by means) (kg/yr) | TN Load (by median) (kg/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hico | lb010 | TX0026590 | 0.20 | Unknown | Unknown | 4.10 | 3.67 | 0.53 | 39.50 | 1141 | 1021 | 13.20 | 12.25 | 0.84 | 155.13 | 3672 | 3407 |
| Iredell | lb020 | TX0024848 | 0.05 | 0.03 | 0.06 | 4.80 | 2.91 | 0.05 | 184.00 | 200 | 121 | 19.17 | 17.67 | 1.39 | 101.33 | 800 | 737 |
| Meridian | lb030 | TX0053678 | 0.45 | Unknown | Unknown | 3.55 | 3.43 | 1.02 | 21.50 | 2225 | 2146 | 20.89 | 21.25 | 1.87 | 36.58 | 13075 | 13296 |
| Clifton | lb040 | TX0033936 | 0.65 | 0.33 | 0.60 | 2.37 | 2.23 | 0.09 | 10.20 | 1088 | 1023 | 10.12 | 6.65 | 0.93 | 49.50 | 4642 | 3052 |
| Valley Mills | lb050 | TX0075647 | 0.36 | 0.05 | 0.10 | 3.14 | 3.16 | 0.17 | 6.39 | 219 | 220 | 18.85 | 18.90 | 0.61 | 29.99 | 1311 | 1314 |
| Crawford | lb060 | TX0054666 | 0.03 | 0.00 | 0.00 | 1.52 | 0.80 | 0.11 | 5.38 | 0 | 0 | 7.56 | 5.17 | 1.94 | 21.45 | 0 | 0 |
| McGregor | lb070 | TX0023914 | 1.10 | 0.67 | 2.81 | 2.20 | 1.72 | 0.42 | 19.80 | 2050 | 1603 | 11.44 | 10.89 | 1.42 | 23.70 | 10658 | 10146 |
| Stephenville | lb080/tp040 | TX0024228 | 1.85 | 1.53 | 4.76 | 2.65 | 2.59 | 0.11 | 15.00 | 5628 | 5500 | 6.99 | 5.96 | 1.50 | 20.00 | 14872 | 12681 |
| | Total | | 4.69 | 2.61 | | | | | | 12551 | 11634 | | | | | 49030 | 44634 |

multiplied by the corresponding mean or median concentration of P or N. The results are not appreciably different and appear quite reliable.

The Crawford WWTF has no measurable load, as all effluent is evaporated; there is no active discharge to the MBR. Actual discharge rates for the Hico and Meridian WWTFs were not available; design flows were applied, and are undoubtedly overestimates of actual discharge. P and N concentrations are typical of secondary treatment systems. The combined load for all WWTFs based on mean values for each WWTF is 12,551 kg/yr (27,612 lb/yr) for P and 49,030 kg/yr (107,866 lb/yr) for N.

Even assuming no attenuation after input to the rivers upstream of Lake Waco, the WWTF P load represents <10% of the total P load to the reservoir and the WWTF N load represents <5% of the total N load to the reservoir. Assuming attenuation similar to that expected for other inputs, based on the position of WWTFs in the watershed, the WWTF P load is expected to be closer to 6% of the total P load to the reservoir and the WWTF N load is expected to be no more than 3% of the total N load to Lake Waco.

With a goal of reducing WWTF inputs of P by 50%, in conformance with the TMDL prepared for the NBR, the Clifton WWTF has already instituted P reduction by chemical addition and the Stephenville WWTF is expected to have a similar treatment system in place in 2006. This will reduce the WWTF load of P to Lake Waco by over 6700 pounds, lowering the contribution of WWTFs to between 4% and 7% of the total P load. No change in N load is expected.

***Remaining sources of P and N are largely uncontrollable, making control of loading from dairy operations a necessary priority for loading reductions.***

Other sources of P and N, itemized in Table 4, have limited potential for control. Storm water from urbanized areas throughout the watershed and recreation-related inputs from activities on the reservoir could be controlled to some extent, although the cost to benefit ratio is high, given the magnitude of loads from those sources and their diffuse nature. Crop related agricultural inputs in the MBR, SBR and HC sub-watersheds could be controlled to some degree as well, but the sources are much more diffuse than dairy and wastewater sources, greatly complicating the technical aspects of achieving significant reductions and raising the associated cost. Additionally, the N:P ratios from those sub-watersheds are more favorably balanced; the NBR P load is by far the most desirable target for control. Atmospheric, groundwater and wildlife inputs are largely uncontrollable.

Internal load has been found to be minimal in two studies (McFarland et al. 2001, ENSR 2003). Some increase in the internal load may occur with the rise in pool elevation, as anoxia may be more severe and of a longer duration in deep waters. However, there is no clear evidence of such an increase over a year after pool rise. Even a substantial increase may be negligible compared to watershed inputs.

The OP:TP ratio for most other sources is quite low, indicating that much of the related loads may be unavailable for algal uptake anyway. About half of the total P load to the reservoir is potentially background loading, fròm naturally occurring or minimally controllable human-related sources, but the vast majority of this load enters the stream system as particulate inorganic phosphorus of minimal biological availability. P loads from Neils Creek and Meridian Creek, the most natural drainage areas for which sufficient data were available, exhibited OP:TP ratios of 0.12 and 0.07, respectively. Even if this background loading was curtailed, it is not clear that it would have any effect on algal production in Lake Waco. It is the more biologically active forms of P, added from dairy operations and WWTFs on the NBR, that are of greatest concern. Of those two general sources, dairy operations represent a much bigger source.

***Loading from the NBR in general, and most critically from dairy operations, results in a low N:P ratio in Lake Waco, favoring cyanobacterial growth that threatens water supply quality.***

The importance of nutrient ratios has been well studied for several decades (Tilman 1982). N-fixing cyanobacteria have a competitive advantage at N:P ratios less than about 7:1 on a mass basis (mg/L vs. mg/L), while green algae and diatoms are more prevalent at N:P ratios greater than about 12:1, with a transition zone in between these ratios (Rhee 1982, Smith 1983). N:P ratios for the major tributaries (Table 4) are 5.4:1 for the NBR and >10:1 for all other surface water sources. Overall nutrient loads to the southern arm of the reservoir, from the SBR, MBR and HC, exhibit an average N:P ratio of 18:1.

The overall N:P ratio for loads entering Lake Waco is 9:1, with the NBR N:P ratio as the primary factor lowering that ratio. Only a few other sources have low N:P ratios (recreation and wildlife), and the associated inputs to the reservoir from those sources are relatively low. As summer progresses and runoff generation declines, the NBR is left as the primary source of water and nutrients to Lake Waco, and the low N:P ratio becomes an even greater factor. The response of the phytoplankton community, evidenced by both algal data and N-fixation measurements done as part of the Lake Waco Comprehensive Study but not yet in report format, is a shift toward N-fixing cyanobacteria that include known taste and odor producers and potential toxin generators.

Problems with taste and odor are most prevalent during autumn and into winter after prolonged dominance by cyanobacteria. The build up of cyanobacteria and related compounds begins back in the summer, but reaches a critical point only after several months of N deficiency. The problem persists until sufficient precipitation brings N-laden runoff to the reservoir and relieves the N-deficiency. Weather therefore plays a pivotal if less predictable role in taste and odor in Lake Waco under the current loading scenario.

It has been noted previously that cyanobacteria tend to dominate at high P levels, without direct consideration of N:P ratio. However, low N:P ratios will occur most often when P concentrations are high, so this relationship is quite consistent with the role of the N:P ratio in favoring cyanbacteria. It should also be noted that taste and odor may be caused by bacteria other than cyanobacteria, most notably the Actinomycetes, but that growth of these other bacteria is most often triggered by nitrogen dynamics linked to N-fixation by cyanobacteria, so the cyanobacteria are a critical factor in the taste and odor problem, potentially directly and indirectly.

***A P load reduction of 50% has been targeted through multiple studies and management planning, but lesser reductions could benefit water quality in Lake Waco.***

The body of data and analysis compiled by TIAER (Kiesling et al. 2001, Flowers et al. 2001) made a compelling case for reducing the P load to the NBR by about 50%, and the TNRCC/TCEQ promulgated a TMDL (TNRCC 2001) and adopted an implementation plan (TCEQ 2002) based on that recommendation. It has been noted that even a 50% reduction in P loading to the upper NBR will not achieve a desirable P concentration in the upper NBR, but improvement would be expected and targets could be achieved in the lower NBR and in Lake Waco. This analysis suggests that the 50% reduction is a logical and appropriate initial target, to be revisited as progress is made and data are collected to evaluate system response.

The TIAER and TNRCC/TCEQ work was focused on soluble P, but the empirical models run as part of this analysis suggest that the reservoir responds as though it is getting an active P load equivalent to the soluble P load plus about one third of the remaining particulate load. Consequently, it may be necessary to reduce the total P load by more than 50% to achieve truly P limited conditions at an algal production level considered appropriate for a drinking water supply and major recreational resource. However, the current N:P ratio situation suggests that for every increment of P reduction achieved, there is the potential to shift that N:P ratio towards higher values and P limitation, potentially altering the composition of the phytoplankton before any appreciable decrease in actual productivity is attained. This could be beneficial to Lake Waco, as it is the dominance by cyanobacteria that appear to be causing the greatest problems for water supply and recreation. Therefore, while a P load reduction on the order of 50% is desirable, some benefit may result from lesser reductions, if P is reduced without any commensurate reduction in N load.

***It is not possible to achieve the desired conditions in Lake Waco without reducing inputs from dairy operations, but it may be possible to detectably improve conditions by addressing only dairy-related inputs.***

If a 50% reduction in P load is desired, a number of sources must be managed, but the choice of target sources is limited. Given the importance of N:P ratios as well as the actual loading of P, sources that are large contributors of P at low N:P ratios are the key targets of control. The two obvious source categories are dairy operations and WWTFs. WWTFs have attracted attention as both the regulatory framework and the technology to lower P outputs are in place and geared toward improved discharge quality. As facilities serving a rate-paying public, the economic means to affect P load reductions are also available, albeit potentially unpopular.

Dairy operations in this watershed, by contrast, are not owned by just a few entities or dependent on the local population for success. Inputs from dairy operations are varied and diffuse in many instances, although these inputs have been declared point sources under the Clean Water Act and are subject to regulatory controls. An economic analysis is to be conducted as part of the Lake Waco Comprehensive Management Program, and it is suspected that when actual costs are evaluated, managing dairy operations to improve downstream water quality will be found to be economically beneficial overall, although the potential drain of private dairy resources may create inertia for making desired improvements.

Nevertheless, while it may be necessary to manage more than dairy farms and WWTFs, it is clear that the current thrust of management of WWTFs is proceeding in the desired direction, and that failure to address dairy inputs may negate that and related pollution abatement efforts. At about 30% of the total P load to Lake Waco, dairy inputs of P represent the single largest itemized source and one of the more controllable sources. It is unrealistic to expect to eliminate dairy inputs, but if the load could be cut in half simply by taking 50% of the manure out of the watershed and then cut in half again by best management practices, the associated P load would decline by 75%. For a load that represents at least 30% of the total P load to the reservoir, this would be a 22.5% reduction in total P load and a 31% decrease in the load to the NBR, more than 60% of the targeted decrease under the TMDL developed by TCEQ. No other source in the NBR can provide that level of reduction, and without a management program for dairy operations, it is unlikely that the target reduction for the NBR under the TMDL can be reached.

While managing the dairy farms alone may not achieve the desired load reduction for P, the reduction outlined above would be expected to shift the N:P ratio in the NBR from 5.4:1 to about 7.8:1. Combined with other loads from the watershed, the average in-lake N:P ratio would be around 11:1, a definite improvement in terms of favoring more desirable algal forms over N-fixing cyanobacteria. If the dairy-related inputs represent a disproportionately large segment of the biologically available P entering the lake, as is the suspected case, the impact on effective N:P ratios may be even greater. For example, the TIAER studies that focused on soluble reactive P (the most available form) indicate that dairy-related P is a higher portion of the total soluble P load (35-44%); assuming the same level of soluble P reduction as for the TP analysis above, the resulting N:P ratio would be on the order of 15:1. This should be adequate to shift the algal community away from problematic blue-green forms linked to taste and odor problems.

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